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Patterned Exceptions in Phonology

A dissertation submitted in partial satisfaction of the

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in Linguistics

by

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ABSTRACT OF THE DISSERTATION

Patterned Exceptions in Phonology

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Standard Optimality-Theoretic grammars contain only the information necessary to transform inputs into outputs; regularities among inputs are not accounted for. Using the example of Tagalog nasal substitution, this dissertation presents a model of how lexical regularities could be learned, represented in the grammar, used by speakers and listeners, and perpetuated over time.

Lexical regularities are represented as low-ranking constraints, their rankings learned through exposure to the lexicon using Boersma's Gradual Learning Algorithm. High-ranked constraints ensure the primacy of listed pronunciations; but when a speaker produces a novel word, these high-ranking constraints are irrelevant and the constraints that encode lexical regularities take over. The subterranean constraints are stochastically ranked; speakers' behavior on novel words probabilistically reflect the lexical regularities. The listener uses the same grammar to produce well-formedness judgments for novel words and to reconstruct inputs from an interlocutors' outputs. The model's

well-formedness judgments reproduce the experimental result that although the productivity of nasal substitution on novel words is low, nasal-substituted novel words are judged more acceptable than non-substituted words in certain cases.

Bayesian reasoning by the listener favors novel nasal-substituted words—they are disproportionately likely to become listed. A computer simulation of the speech community confirms that although nasal substitution is the minority pronunciation for novel words, a word may eventually enter the lexicon as nasal-substituted.

Tagalog vowel raising under suffixation is close to exceptionless in the native vocabulary but quite exceptionful among loanwords. A loan stem's probability of resisting raising is highly influenced by its degree of internal similarity. I propose that internal similarity encourages speakers to construe a word as reduplicated, even without morphosyntactic motivation; raising is blocked because it would disrupt base-reduplicant identity.

Alternatives to encoding lexical regularities in the grammar are considered. It is argued that the vowel raising facts are not amenable to an associative memory account. The qualitative difference between "regulars" and "exceptions" cited by proponents of the Dual-Mechanism model as evidence for leaving lexical regularities out of the grammar reduces to a difference between listed words and synthesized words; this difference can arise through listener reasoning, without a prior qualitative difference.

1. Introduction

This dissertation presents a model of how phonological patterns in the lexicon could be learned and used by speakers and hearers, and perpetuated over time. This chapter introduces the phenomenon of lexical patterns, discusses why they are problematic in current phonological thinking, and gives a preview of the model.

1.1. Lexical regularities

I will use the terms *lexical regularity* and *phonological pattern* to refer to generalizations about the phonological properties of the set of words in a language. Regularities can be observed that apply within morphemes, within morphologically complex words, and across sets of words.

1.1.1. Regularities within morphemes

In English roots of the form *sCVC*, the two Cs generally cannot be both labial, both velar, both nasal, or both [l].[1] The generalization is quite strong (see Berkley 1994 for statistical findings on this and related phenomena in the English lexicon), and hypothetical exceptions, though pronounceable, sound somewhat ill-formed (?[slɪl], ?[skæŋ]).[2] Generalizations like this one are often attributed to morpheme structure constraints

[1] Although such sequences are common across word or morpheme boundaries: *It's Lily!* or *Ask Angry Joe*.

[2] A search of the online *Oxford English Dictionary* for *sCVC* words only (i.e., not the full set of sC(C)VC(C) words, which follow similar restrictions) found, collapsing variant spellings and pronunciations, just 3 words with two labials (*Spam, spume, spoom*), 9 words with two velars (*skoke, skeck, skowke, skeg, skig, scak, scoke, scag, scug*), 3 words with two nasals (*smon, snam, snum*), and no words with two *l*s. Most of these words were unfamiliar to me.

(introduced by Halle 1959 as "morpheme structure rules")[3]—language-specific conditions that rule out some set of possible morphemes as ill formed.

Morpheme structure constraints are static in the sense that they can be observed only as a property of existing words; they do not drive alternations. Although *slill* sounds strange, it is pronounceable and does not require any "repair".

Morpheme structure constraints are rarely exceptionless. For example, English words like *[spʘm]* 'Spam (brand name of processed meat product)' and *[skɛg]* 'skeg (oat species; part of ship's keel; fin of surfboard; plum species; nail; stump of a branch; tear in cloth)' violate the *sCVC* restriction described above. There needs to be some mechanism that allows these words to escape the constraint.

1.1.1.1. Zimmer's conundrum

What is the role of morpheme structure constraints in the grammar, since they do not drive alternations? In Optimality Theory (OT; see §1.5), often include a proof that the correct surface forms result no matter what the input (Richness of the Base: Prince & Smolensky 1993, Smolensky 1996a). For example, if a language lacks morphemes of the form C_iVC_i, the analysis includes a demonstration that the input */pop/* is repaired to (say) *[pot]*. A problem with this type of demonstration, of course, is that the analyst generally does not know what the correct surface form for the input */pop/* should be (*[pok]*, *[kop]*, *[po]*...)—it might even be *[pop]*.

In the case of morpheme structure constraints at least, it is doubtful that such proofs are necessary, because the learner has no reason to posit underlying forms that are significantly different from the surface forms. For example, by Lexicon Optimization (Prince & Smolensky 1993; Itô, Mester, & Padgett 1995), the learner would construct the

[3] although *root structure constraint* would be more apt in most cases.

underlying form */pok/* for a morpheme that is always pronounced *[pok]*; similarly, she would construct */kop/* for *[kop]*, and so on. If she never hears *[pop]*, she will not construct */pop/*, and so there is no need for the grammar to repair */pop/*, because no such lexical entries exist. If the constraint against morphemes of the form C_iVC_i plays no role except to repair inputs that may not exist anyway, then perhaps it does not belong in the grammar.

Inkelas, Orgun, and Zoll 1997 make a similar argument for Labial Attraction, a constraint on vowels in Turkish roots.[4] Inkelas et al. propose a overspecification as a mechanism for tagging words as exceptions to constraints. Nonexceptional segments in morphemes are underspecified, and their feature values can be filled in by markedness constraints at no faithfulness cost. In different morphological contexts, different values will be filled in, resulting in alternation. Exceptional segments, on the other hand, are fully specified, and high-ranked faithfulness constraints prevent tampering with those underlying specifications. The tableau in (1) illustrates the analysis for Turkish final devoicing: underspecified */kitaB/* (*B* stands for a bilabial stop unspecified for voicing) undergoes final devoicing, but overspecified */etyd/* does not.

[4] Labial Attraction is a systematic exception to Round Harmony: normally, a high vowel must agree in [round] with a preceding vowel (e.g., **atu*), but if the preceding vowel is [*a*] and the intervening consonant is labial, then a high, back vowel will be [+round] instead of [-round] as expected. Round Harmony drives alternations, applying across a suffix boundary, but Labial Attraction holds only within morphemes (and even within morphemes, there are exceptions).

(1) Under- and overspecification

	/kitaB/+/a/ ‘book-dative’	IDENT-IO[HIGH]	C/__# = [-VOICE]	C =[+VOICE]
a	☞ kitaba			*!
b	kitapa			
	/kitaB/ ‘book-nominative’	IDENT-IO[HIGH]	C/__# = [-VOICE]	C =[+VOICE]
c	kitab		*!	
d	☞ kitap			*
	/etyd/ ‘etude’	IDENT-IO[HIGH]	C/__# = [-VOICE]	C =[+VOICE]
e	☞ etyd		*	
f	etyt	*!		*

Inkelas et al. conclude, however, that for a static pattern such as Labial Attraction, special tagging is not necessary. Without alternations, nothing drives the learner to construct underspecified lexical entries. Therefore, faithfulness constraints do all the “work”, and there is no role in the grammar for constraints like Labial Attraction.

Zimmer (1969) attempted to find psychological evidence for Labial Attraction and two other Turkish morpheme structure constraints, and found that many speakers had internalized a different version of Labial Attraction than the one linguists had formulated.[5] Zimmer speculates on why this should be so:

> The question of course arises as to how speakers of a language can get away with such erroneous notions [the “wrong” version of Labial Attraction]. This, however, is not really very mysterious. The mistaken generalizations we have attributed to speakers of Turkish do not involve productive phonological rules. Both groups presumably learn lexical items in their fully specified form and then simply repeat them; the MSC’s [morpheme structure constraints] in question do not fill in values for incompletely specified segments. […] Since these generalizations [that speakers make about vowel cooccurrences], and those made in this area by other speakers, have no observable consequences in the course of the normal use of the language, they are not subject to correction in the same way in which a wrongly learned productive rule would be.

[5] The linguists’ constraint: [u] is required after [ɑ] followed by a labial consonant. The constraint exhibited by some of the speakers: [u] is required after [ɑ] followed by any consonant.

The conundrum is, if Labial Attraction does no "work" in the grammar of Turkish, why had speakers internalized any version of it at all?

1.1.2. Regularities within morphologically complex words

Regularities are also to be found in morphologically complex words. For example, English words suffixed with *-ic* generally have penultimate stress, regardless of the stress pattern in the base.

(2) Stress in English words with -ic

artíst-ic	*cf.*	ártist
laparoscóp-ic	*cf.*	láparoscope
cholerá-ic	*cf.*	chólera

There are a few exceptions to this generalization, such as *chóler-ic* (cf. *chóler*) and *Árab-ic* (cf. *Árab*).

Regularities in polymorphemic words are "productive" in the sense that if a speaker knows only the related base, it is up to her to create a word that follows or does not follow the generalization. (By contrast, if a speaker knows the word *slill*, she has no choice but to pronounce it *slill*.) For example, should the *-ic* form of *carob* be *carób-ic* or *cárob-ic* (or something else)? Compared to morpheme structure constraints, regularities in polymorphemic words thus have more opportunity to make themselves felt in the language, as new affixed forms are coined much more frequently than new morphemes.

Regularities in morphologically complex words might seem at first glance to naturally belong in the grammar (and so Zimmer's conundrum would not arise), but when there is evidence that the words are listed as separate lexical entries (see §2.2.3), the situation is the same as with morpheme structure constraints: speakers would not need to

learn the regularity in order to produce existing words correctly. But if speakers do apply the regularity to novel affixed words, this fact must be accounted for somehow.

1.1.3. Regularities across words

Regularities also exist in the mappings among related words. For example, many English verb roots ending in [… ɪŋ(C)] form their past tense by changing [ɪ] to [æ], although there are several competing patterns:

(3) English present-past mappings

present	*past*
sing	sang
ring	rang
sink	sank
drink	drank

but

fling	flung
bring	brought
blink	blinked

This is not a generalization about the shape of past-tense forms, but rather a generalization about the mappings between present- and past-tense forms. Like regularities within morphologically complex words, regularities in the mappings between words have the property of productivity: when a speaker forms the past tense of novel *spling*, for example, she must decide whether it should be *splang*, *splung*, *splinged*, or perhaps something else.[6] Thus, mapping regularities also have opportunity to make their presence known. And like regularities in morphologically complex words, regularities in mappings do not need to be learned in order to produce existing words correctly.

[6] Bybee & Moder 1983 performed an experiment that required speakers to do just this task. See §5.3.1 for a discussion.

1.2. Exceptions to lexical patterns

It was mentioned above that lexical regularities tend to have exceptions (*Spam, Árabic, blinked*), but the distribution of exceptions often is not random. In the two cases discussed in this dissertation (Chapters 2 and 4), the exceptions themselves are highly patterned: although it is not predictable whether any given word will be an exception, words with certain phonological properties are more likely than others to be exceptions. There are not enough exceptions to the *sCVC* morpheme structure constraint or to the generalization that *-ic* carries penultimate stress to look for patterns within the exceptions, but we can see many such patterns in English past tense. For example, a verb is more likely to follow the [ɪ]-[æ] mapping if it has a velar nasal in the coda than if it has an alveolar or bilabial nasal (*begin, began*; *swim, swam*) (see Bybee & Slobin 1992 for a discussion of regularities in the distribution of English past-tense mappings).

Frisch, Broe, and Pierrehumbert (1996), expanding on Pierrehumbert 1993, examined the distribution of exceptions to an Arabic morpheme structure constraint that forbids consonants of the same place of articulation within a root. They showed that far from being random, exceptions to the constraint are distributed such that the more similar two consonants are, the less likely they are to cooccur. For example, /t...d...k/ and /t...z...k/ both violate the constraint against homorganic consonants within a root, but because *t* and *d* are more similar than *t* and *z* (they share membership in more natural classes), roots of the form /t...d...X/ are more common than roots of the form /t...z...X/. Frisch et al.'s account of the Arabic facts is discussed in the following section. See Frisch and Zawaydeh (to appear) for evidence on the psychological reality of this constraint.

1.2.1. Regularities in a separate system: the Stochastic Constraint Model

The Stochastic Constraint Model (Frisch, Broe, & Pierrehumbert 1996, Frisch 1996) is an attempt to model lexical regularities. Frisch et al. propose constraints that are functions from phonological characteristics to acceptability values, which should predict experimental well-formedness judgments and lexical frequency.[7] The functions are of the form $acceptability = 1/(1+e^{K+Sx})$, where x is the numerical value of the phonological characteristic, and *K* and *S* are parameters that determine the location and sharpness of the boundary between acceptable and unacceptable.

To account for the Arabic constraint, a function is proposed that takes as its *x* the similarity between two consonants and returns an acceptability value between 0 and 1.[8] The acceptability value was compared against lexical frequency, and the match was found to be good. Frisch 1996 compared this model to several others and found that it was a better fit to the Arabic lexicon.

The Stochastic Constraint Model models knowledge of well-formedness, and explains patterns in the distribution of exceptions to morpheme structure constraints. But constraints in this model play a very different role from that of constraints in OT. To quote Frisch 1996, "[the stochastic constraint] does not influence what the output is for

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[7] The mechanism relating well-formedness and lexical frequency in unclear, but we can say there is a two-way relationship. On the one hand, lexical frequency shapes acceptability values by determining what values the learner assigns to the parameters of the stochastic constraint. On the other hand, acceptability values could shape lexical frequency by influencing how rare words or loans are "repaired" (low-acceptability words would tend to drift towards repairs that enhance their acceptability), and influencing the shape of newly coined words.

[8] This is somewhat of a simplification. First, the function is $acceptability = A/(1+e^{K+Sx})$, where *A* need not be 1. In directly modeling lexical frequency (observed number of occurrences/expected number of occurrences) without the mediating step of acceptability, Frisch 1996 uses other values of A to get a better fit. Second, Frisch 1996 actually multiplies together three different constraints to get a total acceptability value: one constraint is a function on the similarity of the first two consonants in a triliteral, one is on the similarity between the second and third, and one is on the similarity between the first and third.

any particular input, but rather it constrains the space of possible inputs and outputs in a probabilistic manner." (p. 92) The mental system represented by the Stochastic Constraint Model would have to exist alongside the system for mapping inputs to outputs. This dissertation proposes a model in which the same system that maps inputs to outputs can encode lexical regularities and patterns in the distribution of exceptions to those regularities.

1.3. Preview of the proposal

It is conceivable that knowledge of lexical regularities resides outside the grammar—or even that no discrete knowledge of the regularities exists at all. Speaker behavior that appears to reflect such knowledge could merely be the result of some on-line procedure such as consultation of a sample of the lexicon or matching to associative memory. These two strategies are discussed at greater length in Chapter 6 and shown to be ill suited to the regularities discussed in this dissertation. As argued there, the speaker must possess knowledge that is abstracted away from the lexicon itself. The only linguistic subsystem commonly proposed that contains such knowledge is the grammar. Therefore, the approach taken here will be to incorporate knowledge of lexical regularities directly into the grammar.

To accomplish that goal, this dissertation proposes a model of grammar that allows the primacy of listed information to coexist with knowledge of lexical regularities. Existing words' behavior is encoded in their lexical entries; that information is preserved through high-ranking faithfulness constraints and constraints that force listed information to be used if available. Lexical regularities are encoded through low- and variably ranked constraints, which are irrelevant for existing words, but determine the pronunciation of novel words.

The ranking tendencies of these subterranean constraints are learned through exposure to the lexicon, using Boersma's (1998) Gradual Learning Algorithm, which is shown to be capable of learning rates of lexical variation: constraints that are violated by many words become low-ranked, and constraints that are violated by few words become high-ranked, even if none of those constraints are relevant for existing words once the grammar reaches its adult state (in this case, because high-ranking faithfulness constraints determine the optimal candidate).

Chapter 2 presents Tagalog nasal substitution, a sporadic morphophonemic phenomenon. A statistical examination of the lexicon reveals that the distribution of exceptions to nasal substitution is patterned. Experimental evidence is presented for the psychological reality of nasal substitution and its subregularities. The chapter implements the model for the case of nasal substitution, showing how the subterranean constraints governing nasal substitution and its patterns produce rates of substitution on novel words and acceptability ratings for novel words that are similar to the experimental results. In particular, the paradoxical result that speakers perform nasal substitution at a low rate on novel words, but rate certain types of nasal-substituted novel words as highly acceptable is explained in terms of the listener's probabilistic reasoning about her interlocutor's underlying form (in rating a novel word, the listener must entertain the possibility that for her interlocutor, the word is not novel).

Chapter 3 shows how probabilistic interactions between speakers and listeners perpetuate lexical patterns as new words enter the language. Bayesian reasoning on the part of the listener results in a bias in favor of nasal-substituted pronunciations: although they are the minority pronunciation for a novel word, listeners disproportionately tend to add them to their lexicons (whereas unsubstituted pronunciations tend to be ignored). The chapter presents the results of introducing novel words into a computer-simulated speech

community, attempting to replicate the rates of substitution for various stem types that can be observed in Spanish loans.

Chapter 4 applies the model to vowel height alternations in Tagalog. Although vowel raising under suffixation is nearly universal in native words, many loanwords from Spanish and English have resisted raising. The chapter argues that the main predictor of whether a word will resist raising is how amenable it is to being construed as reduplicated (raising is then prevented, because it would disrupt reduplicative identity). It is argued that a purely phonological mechanism (Aggressive Reduplication) drives such morphosyntactically unmotivated reduplicated construals. This second case is of interest because the subregularity involved is quite abstract, and does not emerge straightforwardly from associative memory.

1.4. Tagalog

Because nearly all the data discussed in the body of this dissertation are from Tagalog, this section covers some essential facts about the language, and gives details on how lexical data were obtained. Although this dissertation's main goal is to present a model of lexical regularities, I hope that it will also be useful as a source of detailed information on several aspects of Tagalog phonology.

Tagalog (Austronesian, Malayo-Polynesian, Western Malayo-Polynesian, Meso Philippine, Central Philippine, Tagalog) is the national language of the Philippines (in this role, it is sometimes called Pilipino). It has over 15 million first-language speakers worldwide (*Ethnologue* 1996), and is used to some degree by 39 million Pilipinos. First-language speakers are mainly in Luzon and Mindoro.

The language has long had contact to varying degrees with Chinese, Malay, and languages of Indonesia and India; a moderate number of loanwords from these languages

are still in use. During the time of the Spanish occupation of the Philippines (mid sixteenth through nineteenth centuries), there was extensive contact with Spanish; starting with the U.S. occupation (first half of the twentieth century) and continuing to today there has been extensive contact with English. There are now large numbers of loanwords from Spanish and English.

1.4.1. Phonology sketch

The phoneme inventory of Tagalog is given in (4).

(4) Tagalog phoneme inventory

p	t	k	ʔ		i	u
b	d	g			e	o
	s		h			a
m	n	ŋ				
	l					
	ɾ					
w	j					

The phonemes /d/ and /ɾ/ were probably once allophones of the same phoneme (and were represented identically in the pre-Hispanic syllabary): within native roots, they are in complementary distribution, with [ɾ] intervocalically and [d] elsewhere. Root-final /d/ always alternates between [d] when word-final and [ɾ] when intervocalic because of suffixation. Root-initial /d/ is always [d] when word-initial, and may be either [d] or [ɾ] when intervocalic because of prefixation. Spanish loans, however, introduced many [d]s and [ɾ]s in other positions.

The situations of /i/, /e/ and /u/, /o/ are similar: the high/mid distinction was probably once purely allophonic (only two heights are distinguished in the syllabary), with mid vowels restricted to final syllables, and high vowels elsewhere. For extensive discussion of the situation today, see Chapter 4.

Other sounds are frequently used in loanwords, such as [ʃ], [tʃ], [dʒ], [ɔʷ] and sometimes [f].

The basic syllable structure is CV(C), although onset clusters are commonly found in loanwords, and coda clusters occasionally. Most roots are disyllabic. Either stress or length is contrastive.[9] I will not take a position on which (for two opposing views, see e.g. Schachter & Otanes 1972 and French 1988), and both are marked in all examples (long vowels with no marked stress are secondary-stressed).

Tagalog is rich in morphology. There are many derivational prefixes, which are often stacked several deep. There are two inflectional (and sometimes derivational) infixes, *-in-* and *-um-*, which are inserted between the first C and V of the stem (the result may be a verb, noun, or adjective depending on the construction).[10] There are two suffixes, *-in* and *-an*, which also play a variety of roles. When a vowel-final word is suffixed, the allomorphs *-hin* and *-han* are used. There is also reduplication: the first C and V can be copied (usually inflectional; I refer to this as RED_{CV}), or the first two syllables (derivational). Some examples of Tagalog affixes are shown in (5).

[9] There are two types of word: those with a long, stressed penult, and those with a short penult and a stressed ultima. There are a few loans that some speakers pronounce with antepenultimate stress and length. In native words, a long/stressed penult must be open, but in some loans, it is closed. In derived words, there may be length and secondary stress on the antepenult or earlier syllables.

[10] In loans with complex onsets, the position of the infix varies (between the two onset consonants or between the onset and nucleus). See Ross 1996.

(5) Examples of Tagalog affixes

bare stem:	lakí	‘size, bulk’
prefixation:	ma-lakí	‘big’
	ma-pag-ma-lakí	‘smug’
infixation:	l-um-akí	‘to grow big’
suffixation:	laki-hán[11]	‘to enlarge (object focus[12])’
reduplication:	laː-lakí	‘will grow big’
	ma-lakí-lakí	‘fairly large’

1.4.2. Notes on the data

Tagalog data of three types are presented: experimental data, lexical statistics, and examples. The experimental data are discussed in detail in §2.3. The lexical statistics are based on English (1986), a two-volume Tagalog-English, English-Tagalog dictionary. The dictionary was compiled by Leo English, a (non-native speaker of Tagalog) priest who lived in the Philippines for 30 years, and Teresita Castillo, a native speaker of Tagalog. The exact methods for determining which pronunciations to include are not known, and probably involved consensus among Castillo and the several other Tagalog speakers who assisted. Because of the large size of the corpus and the frequent disagreement among speakers as to the correct pronunciation of individual words, the dictionary was used as the sole source of lexical statistics, producing a large, consistent

[11] also *lak-hán*. See §4.7.2 for a discussion of syncope.

[12] Every Tagalog sentence (with a few exceptions) has what may loosely be called the focus: a noun phrase that bears the enclitic *si* (for proper names of people) or *ʔaŋ* (for all other noun phrases); the other noun phrases in the sentence bear the enclitic *kaj*/*sa* (if indirect object, goal, etc.) or *ni*/*naŋ* (if direct object or subject). There are also corresponding focus and nonfocus pronouns. The verbal morphology indicates the thematic role of the focused noun phrase. For example, in a sentence with the verb *laki-hán*, the object being enlarged would be marked with *ʔaŋ*, the person enlarging it with *ni*, and the instrument being used to enlarge with *sa*. See Schachter & Otanes 1972 for a thorough description of Tagalog syntax.

source of pronunciations. Thus, although an individual word discussed in Chapter 2 might be pronounced with nasal substitution (see §2.2.1) by some speakers and without by others, the overall statistics should be representative of the speech community.

Examples given in the text are drawn from English's dictionary, from reference sources such as Schachter and Otanes 1972 and Ramos and Bautista 1986, and from my own observations of spoken and written Tagalog. I am not a native (or even fluent) speaker of Tagalog, but have studied the language both as a linguist and in the classroom.

Transcriptions are IPA (*Handbook of the International Phonetic Association* 1999), with the exception that an acute accent is used to indicate stress. In some tables and charts, where phonetic fonts were not available, "N" is used for [ŋ], "?" for [ʔ], and "r" for [ɾ]. Tagalog orthography is also used in some tables and charts; it is identical to IPA except that "ng" is used for [ŋ], "r" for [ɾ], and "y" for [j], and [ʔ] is not written.

1.5. Appendix: OT basics

The analytical framework used here is Optimality Theory (OT: Prince & Smolensky 1993). The machinery of Correspondence Theory (McCarthy & Prince 1995) is also employed extensively. It is not possible of course to give a complete explanation of Optimality Theory here, but a brief overview is possible. See Archangeli and Langendoen 1997 or Kager 1999 for a full introduction to OT.

OT employs two functions, *Gen* and *Eval*. *Gen* takes an underlying representation ("input") and returns a (possibly infinite) set of possible surface forms ("output candidates"). Some output candidates might be identical to the input, others slightly modified (for example by deleting one segment), others unrecognizable. *Eval* chooses the candidate that best satisfies a set of ranked constraints; this optimal candidate becomes

the surface representation. The ranked constraints are violable, in the sense that the optimal candidate may still violate some constraints.

The constraints are of two types: *Markedness* constraints enforce well-formedness of the output itself, for example by forbidding consonant clusters. *Faithfulness* constraints enforce similarity between the input and the output, for example by requiring all input segments to appear in the output.

In standard OT, the constraint set is strictly ranked: a candidate that violates a high-ranking constraint more than other candidates do can never redeem itself by satisfying lower-ranked constraints. *Eval* can be thought of as choosing the subset of candidates that violates the top-ranked constraint the fewest times, then of this subset, selecting the sub-subset that violates the second-ranked constraints the fewest times, and so on until only one candidate remains.

The "tableau" (a standard expositional device in OT) in (6) illustrates this procedure for the input */ilp/* (upper left corner) in a hypothetical mini-language. Each of the output candidates *a*, *b*, and *c* is flawed in some way: *c*, the candidate that looks most like the input, has a consonant cluster; this violates the constraint against consonant clusters, *CC, as indicated by the asterisk in the cell at the intersection of *CC's column and candidate *c*'s row. *CC is a Markedness constraint. Candidate *b* has deleted a segment, and candidate *a* has inserted a segment; these candidates violate the Faithfulness constraints DON'TDELETE and DON'TINSERT, respectively.[13]

In this language, *CC is the highest-ranked constraint (ranking is indicated by left-to-right ordering of the constraints' columns—we can also write *CC>>DON'TDELETE>>DON'TINSERT). *Eval* first eliminates candidate *c* from the

[13] These two constraint names are shorthands. See §2.4.3 for some standard constraint names and definitions.

competition because it alone violates *CC. The elimination is represented by the exclamation mark; the shading in the cells to the right represents the fact that candidate *c*'s violations of lower-ranked constraints are now irrelevant. *Eval* next eliminates candidate *b*, because of its violation of DON'TDELETE; now just one candidate remains (*a*), so it is optimal, as indicated by the pointing finger. All of DON'TINSERT's cells are shaded, because it is now irrelevant. In this language, then, an input string /ilp/ is pronounced [ilip]; in another language, the constraint ranking might be different and would choose a different candidate.

(6) Sample OT tableau

	/ilp/	*CC	DON'TDELETE	DON'TINSERT
a	☞ [ilip]			*
b	[il]		*!	
c	[ilp]	*!		

OT was chosen as the analytical framework here because it allows straightforward expression of the idea that when the lexicon cannot determine some aspect of a word's pronunciation, the likelihood that a particular option will be chosen depends on that option's well-formedness along a variety of conflicting dimensions (see §2.7).

2. The model as applied to nasal substitution

2.1. Chapter overview

This chapter presents a model of lexical regularities through the example of nasal substitution in Tagalog. Section 2.2 describes the phenomenon of nasal substitution and its distribution in the lexicon. Section 2.3 presents the results of an experiment aimed at assessing the psychological reality of nasal substitution in production and judgment of well-formedness. Section 2.4 gives a grammar for nasal substitution, with constraints that encode the regularities in its distribution. Section 2.5 considers several possibilities for how potentially nasal-substituting words are represented in the lexicon. Section 2.6 shows how the grammar in §2.4 could be learned from exposure to the lexicon, using Boersma's (1998) Gradual Learning Algorithm. Section 2.7 describes the speaker's probabilistic use of the grammar for novel and existing words. Finally, §2.8 describes how the listener uses the grammar to determine her interlocutor's underlying form and to arrive at acceptability judgments.

2.2. Nasal Substitution

2.2.1. The phenomenon

Nasal substitution is a phenomenon that occurs somewhat sporadically in the Tagalog lexicon. When certain prefixes are attached to a stem beginning in a sonorant, they appear as *paŋ-*, *maŋ-*, or, less often, *naŋ-*, which is derived morphologically from *maŋ-*.[14] (e.g., ***h****ukbó* 'army', *paŋ-**h****ukbó* 'military'). But when these same prefixes attach to an obstruent-initial stem, either they appear with place assimilation to the obstruent, as *pam-/pan-/paŋ-*, *mam-/man-/maŋ-*, *nam-/nan-/naŋ-* (e.g., ***p****oʔók* 'district', *pa**m**-**p****oʔók* 'local'), or the final nasal of the prefix and the obstruent appear to combine into a nasal that is homorganic to the original obstruent (e.g., *mag-**b**igáj* 'give', *ma-**m**igáj* 'distribute'). It is the second case that is known as nasal substitution. In (7) are shown examples, for every consonant in the Tagalog inventory, of substitution and

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[14] There are a variety of productive morphological constructions that participate in nasal substitution, but in all of them, the prefix complex ends in *paŋ-*, *maŋ-*, or *naŋ-* (even though, morphosyntactically, it may be preferable to think of the affixes as a whole, since the meaning of the prefix complex is often not compositional). There are also some unproductive constructions that can trigger nasal substitution, whose prefix complexes end in, *taŋ-*, *tuŋ- siŋ-*, *hiŋ-* (the only common one), *kaŋ-*, and *kuŋ-* (e.g., *bĕ́laŋ* 'number', *tam-biláŋ* 'digit'; *balîk* 'upside-down', *tum-balîk* 'return'; *púːnoʔ* 'leader', *si-múːnoʔ* 'grammatical subject'; *kúːto* 'louse', *hi-ŋutúː-hin* 'to pick out lice'; *patáj* 'corpse', *ka-maːtá-jan* 'death'; *babáʔ* 'descent', *mag-pa-kum-babáʔ* 'humble'). The fairly productive construction *mag-kaŋ-*R_{CV}, for verbs of accidental result (*dapáʔ* 'face down', *mag-kan-da-ráːpaʔ* 'to fall on one's face'), never produces substitution.

This set exhausts the prefixes that end in *ŋ*, except for a group that I do not consider real prefixes, because they seem more like members of a compound: *waláŋ-*, *(ʔi)sáŋ-*, *(ka)siŋ-*, *pagîŋ-* and *magîŋ-* (e.g., *báːjad* 'payment' *waláŋ-báːjad* 'free'; *dáːliʔ* 'finger-width' *san-dáːliʔ* 'one finger width'; *ʔitîm* 'black', *kasîŋ-ʔitîm* 'as black as'; *búːŋa* 'fruit' *pagigîŋ-búːŋa* 'conversion into a fruit'; *súːkaʔ* 'vinegar' *magîŋ-súːkaʔ* 'to become vinegar'). These are all two syllables long (except for optionally shortened *(ʔi)sáŋ-* and *(ka)siŋ-*), can bear their own stress, produce semantically transparent words, never induce nasal substitution, and often fail to undergo nasal assimilation. In addition, *waláʔ* 'does not have/exist' and *ʔisáʔ* 'one' also occur as free-standing words, which require the "linker" *-ŋ-* under certain circumstances.

nonsubstitution, using a variety of common morphological constructions that can trigger substitution.

(7) Nasal-substituting prefixes with various stems

p	**p**ighatíʔ	‘grief’	pa-**m**i-**m**ighatíʔ	‘being in grief’
	poʔók	‘district’	pa**m**-poʔók	‘local’
t	paq̣-**t**úːloj	‘staying as guest’	kaː-pa-**n**ulúːj-an	‘fellow lodger’
	tabój	‘driving forward’	pa**n**-tabój	‘to goad’
k	**k**amkám	‘usurpation’	ma-pa-**ŋ**amkám	‘rapacious’
	kaliskís	‘scales’	pa**ŋ**-kaliskís	‘tool for removing scales’
ʔ	**ʔ**isdaʔ	‘fish’	maː-**ŋ**i-**ŋ**isdáʔ	‘fisher’
	ʔulól	‘silly’	ma**ŋ**-**ʔ**ulól	‘to fool someone’
b	mag-**b**igáj	‘to give’	ma-**m**igáj	‘to distribute’
	bigkás	‘pronouncing’	mam-**b**i-**b**igkás	‘reciter’
d	**d**alá:ŋin	‘prayer’	ʔi-pa-**n**aláŋ-in	‘to pray’
	diníg	‘audible’	pa**n**-diníg	‘sense of hearing’
g	**g**indáj[15]	‘unsteadiness on feet’	pa-**ŋ**i-**ŋ**indáj	‘unsteadiness on feet’
	gáːwaj	‘witchcraft’	ma**ŋ**-**g**a-**g**áwaj	‘witch’
s	**s**úːlat	‘writing’	maː-**n**u-**n**ulát	‘writer’
			pa**n**-**s**úːlat	‘writing instrument’
h	**h**ukbó	‘army’	pa**ŋ**-**h**ukbó	‘military’
m	**m**arká	‘mark’	pa**ŋ**-**m**arká	‘marker’
(no examples of *n*[16])				
ŋ	**ŋ**álit	‘grinding of teeth’	pa**ŋ**-**ŋ**a-**ŋ**álit	‘grinding of teeth’
ɾ	**ɾ**asjón	‘ration’	pa**ŋ**-**ɾ**asjón, pa**n**-**ɾ**asjón	‘for rationing’
l	**l**ágom	‘assimilation’	ma-pa**n**-**l**ágom	‘monopolistic’
w	mag-**w**isík	‘to sprinkle’	pa**ŋ**-**w**isík	‘sprinkler’
j	**j**amót	‘annoyance’	ma**ŋ**-**j**amót	‘to annoy’

A few remarks on the examples in (7): First, when nasal substitution occurs in conjunction with reduplication, both base and reduplicant are substituted (*pa-**m**i-**m**ighatîʔ* rather than **pa-**m**i-**b**ighatîʔ* or **pa-**m**i-**mb**ighatîʔ*); when no nasal substitution occurs, the assimilated nasal precedes only the reduplicant (*mam-**b**i-**b**igkás* rather than **mam-**b**i-m**b**igkás*). I adopt Wilbur’s (1973) and McCarthy and Prince’s (1995)

[15] One of only 2 instances of substitution of *g* that I found.

[16] Nasal-initial roots are few in Tagalog. The absence of any *n*-initial roots that have potentially nasal-substituting derivatives is probably accidental.

proposal that "overapplication" of nasal substitution in *pa-**m**i-**m**ighatîʔ* results from reduplicative correspondence. Note that the overapplication shows that a nasal resulting from substitution belongs to the stem (although it may also belong to the prefix in some sense; see the discussion of coalescence in §2.4), whereas a prefix nasal that merely assimilates is not part of the stem.

Second, it is not clear whether nasal substitution is possible on nasal-initial stems: nasal-initial stems are rare to begin with, and among those that do exist, it is not always possible to tell what the prefix is. For example, in *ma-manhîd* 'to become numb', from *manhîd* 'numb', it is not clear whether the prefix is simply *ma-* (which can also form verbs, with similar semantics), or *maŋ-* with nasal substitution.[17] There do exist unambiguous constructions (such as *maŋ+REDUPLICATION*—there is no potentially confusable *ma+REDUP*), but no cases of nasal-initial stems in these constructions.

Third, glottal stop is problematic. Many researchers have assumed that initial glottal stop in Tagalog is simply predictably inserted in vowel-initial words (since there are no strictly vowel-initial words); the preservation of initial glottal stop in prefixed words like *mag-ʔáːwaj* 'to fight' (or *maŋ**ʔ**ulól*) would then be regarded as the effect of a tendency to align morpheme boundaries with syllable boundaries (for a formal theory of alignment, see McCarthy & Prince 1993, Cohn & McCarthy 1998). And a word like

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[17] Schachter and Otanes (1972) argue that these verbs are *maŋ*-prefixed, because their gerunds are formed by changing *m* to *p* and reduplicating, as are the gerunds of uncontroversially *maŋ*-prefixed verbs (*taːkot* 'fear', *ma-náːkot* 'to intimidate', *pa-na-náːkot* 'intimidating'). In contrast, *ma-* verbs' gerunds are formed by replacing *ma-* with *pagka-* (*maː-bujó* 'to get involved', *pagka-bujó* 'getting involved'). But Carrier (1979) points out that some $m \rightarrow p$ & R_{CV} gerunds do come from *ma-* verbs (*pa-li-líːgoʔ* 'bathing' from *ma-líːgoʔ* 'to take a bath').

Carrier (1979) argues against the *maŋ*-with-substitution analysis for nasal-initial stems, because some of the nasal-initial stems that take *ma-*/*maŋ-* do not substitute when combined with *paŋ-*, and so should not substitute with *maŋ-* (*paŋ-noʔód* 'for watching'). But, I have found many stems that substitute with *maŋ-* but not with *paŋ-* (*buntót* 'tail end', *ma-muntót* 'to finish last', *pam-buntót* 'tailpiece').

maːŋiŋisdáʔ would be failure of alignment rather than true nasal substitution, either with the nasal of the prefix becoming associated to the stem, or with reduplicative correspondence causing the second *ŋ* to be inserted.[18] Since glottal stop is phonemic word-finally, I prefer to regard word-initial glottal stop as phonemic rather than epenthetic (why pick glottal stop as the epenthetic segment rather than something else?), and I view *maːŋiŋisdáʔ* as nasal-substituted, although, as will be seen below, the distribution of "substituted" glottal stops in the lexicon is puzzling.

2.2.2. Distribution of exceptions

I collected all 1,736 words from English (1986) that had an obstruent-initial stem and a potentially nasal-substituting prefix, and found two trends. First, substitution is most likely with a front stem-initial consonant (*p* or *b*) and least likely with a back consonant (*k* or *g*). Second, substitution is more likely if the stem-initial consonant is voiceless than if voiced. Both trends can be seen in (8), which combines data from all constructions (*t* and *s* are also combined, to better illustrate the two trends; *t* and *s* are separated in the more detailed charts that follow).[19]

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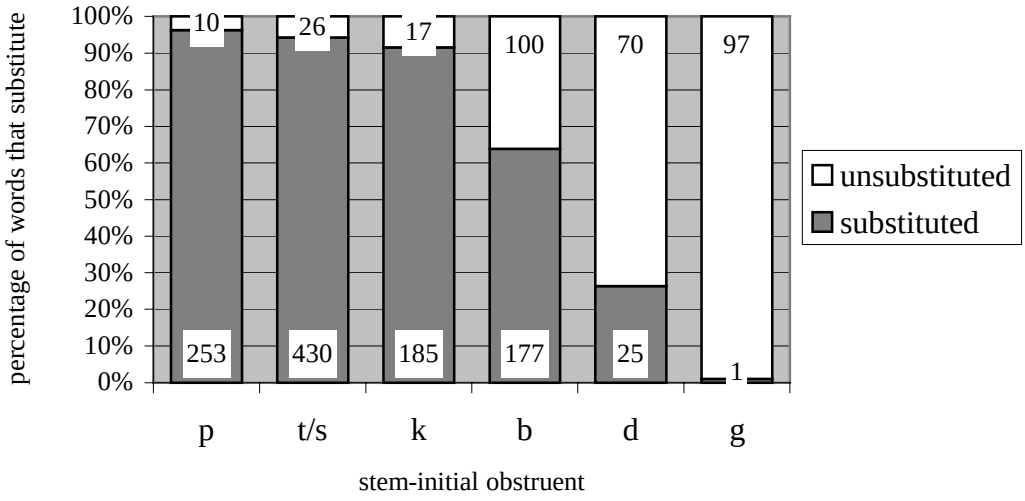
[18] A similar proposal, considered and rejected by Carrier (1979), is that there is a phonemic difference between truly glottal-stop-initial and truly vowel-initial stems, which determines whether or not nasal substitution will appear to occur. Thus *ʔisdáʔ* would be underlyingly */isdáʔ/*, and *ʔulól* underlyingly */ʔulól/*. There are some glottal/vowel-initial stems whose derivatives vary in whether or not they substitute, but this does not refute Carrier's idea: such stems would be underlyingly vowel-initial, but in some derivatives morpheme-specific alignment constraints would force an epenthetic glottal stop.

[19] Previous accounts of the lexical distribution of nasal substitution have noted (not quite correctly) that *g* never substitutes (Bloomfield 1917, Schachter & Otanes 1972); that *d* and *g* rarely substitute (Blake 1925); that voiceless consonants substitute more than voiced ones (De Guzman 1978, but see fn. 20); and that morphology matters (Schachter & Otanes 1972, De Guzman 1978).

(8) Rates of nasal substitution for entire lexicon



Different constructions have different overall substitution rates. The bar charts in (9) show rates of substitution for each stem-initial obstruent in the most common affix patterns. The breakdown by affix is suggested in part by De Guzman (1978), who distinguished adversative from nonadversative verbs,[20] and instrumental adjectives (*tîtik* 'writing', *pa-nîtik* 'used for writing') from reservative adjectives (*baŋkéte* 'banquet', *pam-baŋkéte* 'for a banquet (said of clothes, food, etc.)').[21]

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[20] Adversative verbs are hostile or harmful to the patient (e.g., *bató* 'stone', *ma-mató* or *mam-bató* 'to throw stones at'). Nonadversative verbs include inchoatives (*paját* 'thin', *ma-maját* 'to become thin'), statives (*butiktîk* 'teeming with', *ma-mutiktîk* 'to teem with'), professional verbs (*gamót* 'medicine', *maŋ-gamót* 'to practice medicine'), habitual verbs (*sigarîljo* 'cigarette', *ma-nigarîljo* 'to be a smoker'), distributives (*k-um-úːha* 'get', *ma-ŋúːha* 'to gather things'), and repetitives (*bintáːna* 'window', *ma-mintáːna* 'to keep looking out a window').

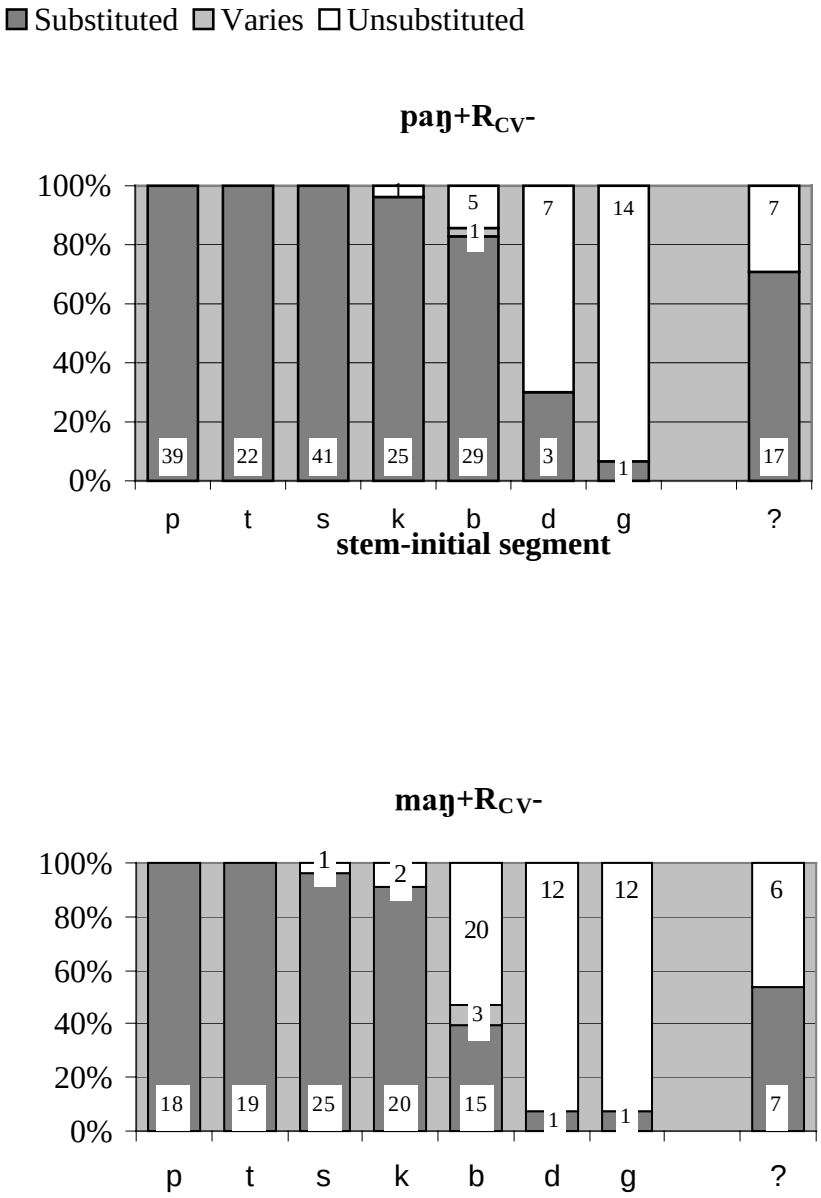
[21] De Guzman claimed that in non-adversative verbs, substitution is obligatory for all obstruents and that in adversative verbs, substitution is obligatory for voiceless Cs but optional for voiced Cs and glottal stop. (9) shows that there are some counterexamples to the first clause of the claim; although the classification of some verbs could be argued over, there are some nonsubstituting verbs that are definitely nonadversative

The constructions illustrated in (9) are adversative-verb-forming *maŋ-*; nonadversative-verb-forming *maŋ-*; *paŋ+R_{CV}-*, which forms mainly gerunds, but also some less predictable nominalizations (*tahîʔ* 'stitch', *pa-na-nahîʔ* 'sewing'); *maŋ+R_{CV}-*, which forms professional or habitual nouns (*báːtas* 'law', *mam-ba-báːtas* 'legislator'); noun-forming *paŋ-* (instrumentals, gerunds, and unpredictable nominalizations, e.g., *gúːgol* 'expense', *paŋ-gúːgol* 'spending money'); and reservative-adjective-forming *paŋ-* (no other constructions had enough examples with each segment to make a chart meaningful).

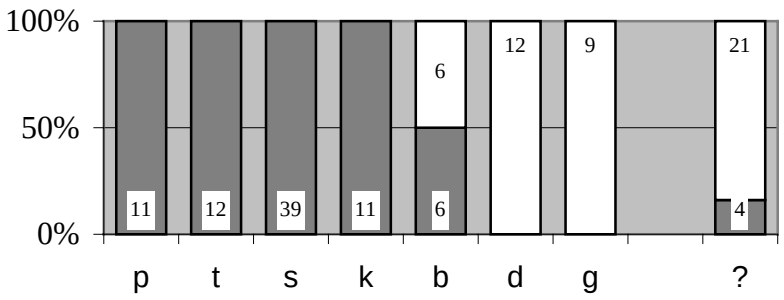
Within each chart, each obstruent is scaled for comparison. For example, the first column in the first graph says that there are a total of 39 *p*-initial stems listed in English (1986) that took the *paŋ-R_{CV}-* construction, and of those, all are substituted. The fifth column shows that there are 35 *b*-initial stems, of which 29 substitute, 1 varies, and 5 do not substitute.

(*gîːgil* 'tremble, thrill', *maŋ-gîːgil* 'to tremble, thrill'). There are no counterexamples to the second clause of the claim. De Guzman further claims that in instrumental adjectives, substitution is optional for voiceless Cs and impossible for voiced Cs and glottal stop. Instrumental adjectives are not included in (9) because there were too few tokens; there were indeed no substituted voiced Cs, but there were only 5 tokens of *b*, none of *d*, and 2 of *g*.

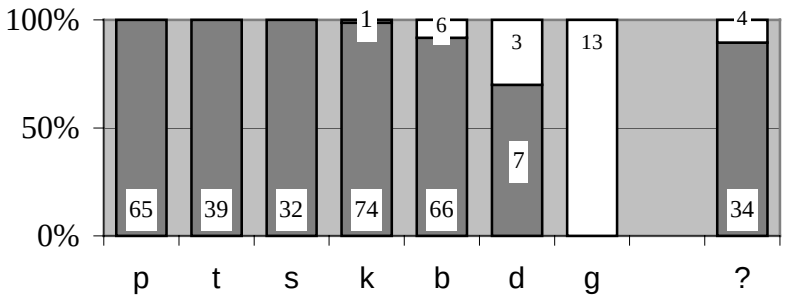
(9) Rates of substitution for various prefixes



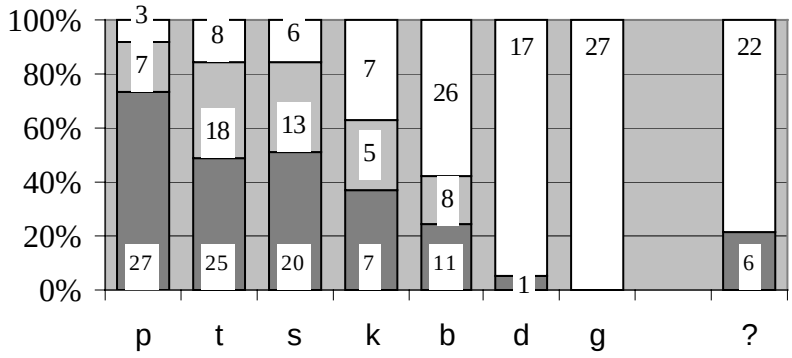
maŋ- (adversative)



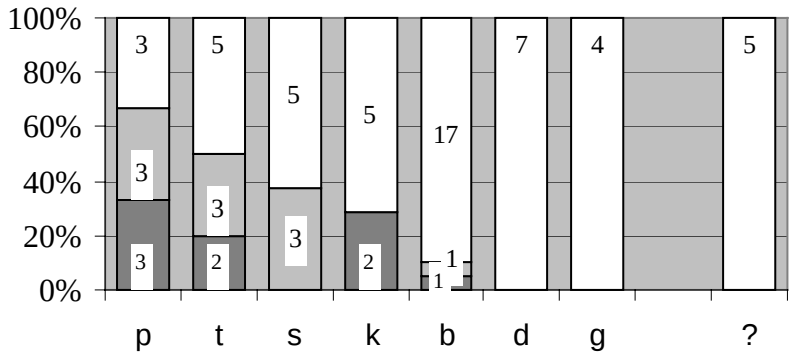
maŋ- (other)



paŋ- (noun)



paŋ- (reservative adjective)



To determine the statistical significance of the voicing and place-of-articulation effects, I used contingency table analysis, a way of determining whether two nominal variables are independent of each other. Glottal stop is omitted from the statistical results, because although it mostly patterns as the most posterior voiceless stop (substituting a bit less often than *k*), in adversative *maŋ-* verbs, *ʔ* inexplicably substitutes less than 20% of the time, whereas the other voiceless stops always substitute. As noted above, it is unclear whether *ʔ* actually undergoes nasal substitution (rather than simple deletion) at all.

To test whether the voicing effect was significant, we can construct a table with the observed number of voiced and voiceless consonants[22] that were unsubstituted or substituted,[23] as in (10) and a similar table with the "expected" values—the values that we would see if voicing and substitution were independent of each other—as in (11).

(10) Voicing and nasal substitution: observed frequencies

	unsubstituted	substituted	total
voiceless	**46**	**578**	624
voiced	**217**	**142**	359
total	263	720	983

(11) Voicing and nasal substitution: expected frequencies

	unsubstituted	substituted	total
voiceless	**166.950**	**457.050**	624.000
voiced	**96.050**	**262.950**	359.000
total	263.000	720.000	983.000

[22] Using just the 6 most common constructions. All other constructions account for only an additional 66 words.

[23] Varying cases are omitted, because a smaller table yields more-conservative significance results.

The table of expected frequencies uses the same totals as the table of observed frequencies, and fills in the other (boldface) values proportionally: since in total, 624/983 = 63.48% of the words are voiceless-initial, 63.48%, or 166.950, of the 263 unsubstituted words should be voiceless-initial. Conversely, since 263/983 = 26.75% of the words were unsubstituted, 26.75%, or 166.950, of the 624 voiceless-initial words should be unsubstituted.

Inspecting the two tables visually, it is clear that the observed and expected values are quite different. It was expected that about 457 voiceless-initial stems would substitute, but 578 did; it was expected that about 96 voiced-initial stems would fail to substitute, but 217 did. In other words, substitution is more common than expected among voiceless-initial stems, and less common than expected among voiced-initial stems.

To test the significance of the differences between the observed and expected values, χ^2, which is the sum, for all table cells (excluding the totals), of

(observed-expected)^2*/expected*.

In this case, $\chi^2 = 327.572$. If two nominal variables like substitution and voicing are known, given the number of rows and columns in the table, the probability *p* that any given value of χ^2 or a higher value would be obtained by chance is known. In this case, $p < 0.0001$.

It would be ideal to test for the voicing effect within each place of articulation and within each morphological construction, since it might be that, for instance, a disproportionately large number of voiceless-initial stems in a construction that has a high independent rate of substitution is skewing the results. The numbers are too small to do this kind of breakdown, but it should be apparent from inspection of the charts in (9) that the voiceless-initial stems are not concentrated in the highly-substituting

constructions, and that within every construction, the voiceless-initial stems substitute more frequently.

Similar contingency tables can be constructed for nasal substitution and place of articulation. Here, we must break the data into voiceless and voiced cases, since we already know that voicing has a strong effect, and the proportion of voiced- vs. voiceless-initial stems is not steady across place of articulation. Observed and expected frequencies are given in (12) and (13).

(12) Place of articulation and nasal substitution: observed frequencies

voiceless	unsubstituted	substituted	total
labial	**6**	**163**	169
dental	**25**	**276**	301
velar	**15**	**139**	154
total	46	578	624

voiced	unsubstituted	substituted	total
labial	**80**	**128**	208
dental	**58**	**12**	70
velar	**79**	**2**	81
total	217	142	359

(13) Place of articulation and nasal substitution: expected frequencies

voiceless	unsubstituted	substituted	total
labial	**12.458**	**156.542**	169.000
dental	**22.189**	**278.811**	301.000
velar	**11.353**	**142.647**	154.000
total	46.000	578.000	624.000

voiced	unsubstituted	substituted	total
labial	**125.727**	**82.273**	208.000
dental	**42.312**	**27.688**	70.000
velar	**48.961**	**32.039**	81.000
total	217.000	142.000	359.000

In (12) and (13), there are more rows, so trends are harder to spot. To make them more apparent, (14) lists *(observed-expected)/expected* for each cell. A large negative value means that the observed value was much lower than expected, and a large positive value means that it was much higher than expected.

(14) Place of articulation and nasal substitution: (observed-expected)/expected values

voiceless	unsubstituted	substituted
labial	-0.518	0.041
dental	0.127	-0.010
velar	0.321	-0.026

voiced	unsubstituted	substituted
labial	-0.364	0.556
dental	0.371	-0.567
velar	0.614	-0.938

Recall that the place effect predicts that labials should be substituted more often than expected (positive value in the top-right cell of (14)) and unsubstituted less often than expected (negative value in the top-left cell), velars should be the opposite, and dentals should fall somewhere in between. The tables in (14) show that in both the voiceless and voiced cases, labials are substituted more often than expected (although the effect is weak for voiceless *p*) and are unsubstituted less often than expected; velars are substituted at about the expected rate when voiceless and much less often when voiced, and are unsubstituted more often than expected in both cases. Dentals and velars can be compared by noting that the tendency to be unsubstituted more often than expected is greater than expected in velars than in dentals in both the voiceless (0.321 vs. 0.127) and voiced (0.614 vs. 0.371) cases. In the voiced case, the tendency to be unsubstituted less often that expected is much stronger among velars than among dentals (-0.935 vs. -0.551); in the voiceless case, the difference between velars and dentals is tiny (although in the right direction: -0.026 vs. -0.010)

We can perform a χ^2 test for the place-of-articulation effect too, but the results are less meaningful, because they tell us only that (12) and (13) are significantly different, not whether the front-to-back trend is significant. The χ^2 value for voiceless consonants is 5.264; for a table this size, the a probability of obtaining such a large χ^2 by chance if place of articulation and substitution were independent is p= 0.07. The χ^2 value for voiced consonants is 103.345, $p < 0.0001$. It is not surprising that the place differences are small among the voiceless consonants, because in four of the six morphological constructions included there is a ceiling effect—nearly all the voiceless consonants of any place of articulation are substituted.

Finally, (15) summarizes the results of performing pairwise contingency-table analyses between pairs of consonants. The test used was Fisher's Exact Test,[24] which enumerates all tables having the same row and column totals as the table of observed values. Each such table's probability of occurring, assuming no association between the variables (initial obstruent and nasal substitution), can be calculated. The probabilities for the tables that are skewed in the same direction as the observed table, to the same degree or more extremely, are added to find the probability p that such a skewed table could have arisen by chance if the two variables were independent.

(15) Pairwise differences in rate of substitution

expected difference		*Fisher's Exact Test*
voicing effect	p>b	$p < 0.0001$
	t,s>d	$p < 0.0001$
	k>g	$p < 0.0001$
place effect	p>t	$p = 0.0528$
	t,s>k	$p = 0.6038$
	b>d	$p < 0.0001$
	d>g	$p = 0.0034$

[24] All statistical results were calculated in Statview.

2.2.3. Productivity of nasal substitution

There are several ways in which nasal substitution appears unproductive. First, despite the lexical trends described above, it is of course not completely predictable which words will undergo substitution—substitution is not even predictable among derivatives of the same stem, as illustrated in (16). Note the lack of a strict implicational hierarchy for substitution among the constructions *paŋ-*, *paŋ+RED$_{CV}$-*, *maŋ+RED$_{CV}$-*, and *maŋ-*.

(16) Differing behavior among derivatives of the same stem

bigáj	*'gift'*
pa**m-b**igáj	'gifts to be distributed'
pa-**m**i-**m**igáj	'act of giving away'
má:-**m**i-**m**îgaj	'distributor'
ma-**m**igáj	'to distribute (actor focus)'
bugbóg	*'wallop'*
pa-**m**ugbóg	'wooden club used to pound clothes during washing'
pa**m-b**u-**b**ugbóg	'act of clubbing or pounding; assault'
ma**m-b**ugbóg	'to wallop'
búlos	*'harpoon'*
pa-**m**úlos	'harpoon'
ma**m-b**u-**b**úlos	'harpooner'
buʔóʔ	*'whole'*
pa**m-b**uʔóʔ	'something used to produce a whole'
pa-**m**u-**m**uʔóʔ	'becoming whole; coagulation'
ma-**m**uʔóʔ	'to solidify; to clot'

Second, although the semantic connection between stem and derivative is always apparent, exact meanings are sometimes unpredictable, especially with certain prefixes, such as verbal *maŋ-*. Note that semantic idiosyncrasy is found in both substituted and unsubstituted words:

(17) Semantic unpredictability with nasal-substituting affixes

ʔabáŋ	‘watcher’
maŋ-ʔabáŋ	‘to wait near people who are eating, hoping to get some food’
babáːʔe	‘woman’
mam-babáːʔe	‘to have a mistress’
siʔíl	‘oppressed by a ruler’
ma-niʔíl	‘to strangle to death’
ʔibáːbaw	‘surface’
paːŋ-ʔibáːbaw	‘veneer’
kíːta	‘visible’
paː-ŋitáːʔ-in, paː-ŋitaʔ-ín[25]	‘apparition, omen’
túːbig	‘water’
ma-nubíg	‘to urinate’
balík	‘return’
pa-malík	‘hand rudder’
gántʃo	‘hook’
maŋ-ga-gáːntʃo	‘con man’

Third, certain affixes can cause unpredictable stress/length shifts. Note that this idiosyncrasy too occurs in both substituted and unsubstituted words (but see (62)):

(18) Unpredictable stress/length shifts associated with nasal-substituting affixes

tahíʔ		‘sewing’
maː-na-náːhiʔ		‘seamstress’
cf.	puná	‘remark’
	maː-mu-muná	‘critic’
ʔáːmak		‘town’
maŋ-ʔa-ʔamák		‘resident of town’
cf.	káːɾit	‘sickle’
	maː-ŋa-ŋáːɾit	‘person whose job it is to cut grass with a sickle’

[25] This stem is exceptional: it has a final glottal stop only when suffixed.

tú:big		‘water’
ma-nubíg		‘to urinate’
cf.	kí:kil	‘carpenter’s file’
	ma-ŋí:kil	‘to chisel; to ask for money’
sí:pit		‘claws’
pan-sipít		‘(type of) rat-trap’
cf.	gá:mas	‘weeding’
	paŋ-gá:mas	‘tool for weeding’

The result is that for many words with nasal-substituting affixes, a speaker must know a number of facts not predictable from other words containing the same stem—whether or not the word undergoes substitution, the meaning of the word, and the stress of the word—and thus must maintain a separate lexical entry for that word (for a discussion of other ways to encode the unpredictable information, see §2.5).

If most or all words with nasal substitution are fully listed, there is no need to represent nasal substitution in the grammar: each word is simply pronounced the way it is listed (see §1.1.1.1). The sticking point here is whether or not nasal substitution is part of speakers’ competence. If it is, it should be accounted for (somehow). The following section addresses this question experimentally.

2.3. An experiment

2.3.1. Introduction

I conducted an experiment aimed at answering two questions: (i) Is nasal substitution productive? (ii) Are speakers aware of the lexical patterns within nasal substitution? If the answer to either of these questions is yes, then perhaps nasal substitution belongs in the grammar—certainly it must be accounted for somewhere in the system that governs linguistic behavior, whether in the grammar or in some other subsystem. As discussed in §1.3, this dissertation takes the approach that absent a clear understanding of how other subsystems could account for a particular linguistic behavior, the behavior should be accounted for by the grammar wherever plausible.

Nine native speakers of Tagalog living in Los Angeles participated. As shown in (19), they ranged in age from 18 to 69, and had emigrated from the Philippines 3 to 20 years earlier (age at emigration did not correlate with productivity of nasal substitution).

(19) Personal characteristics of experiment participants

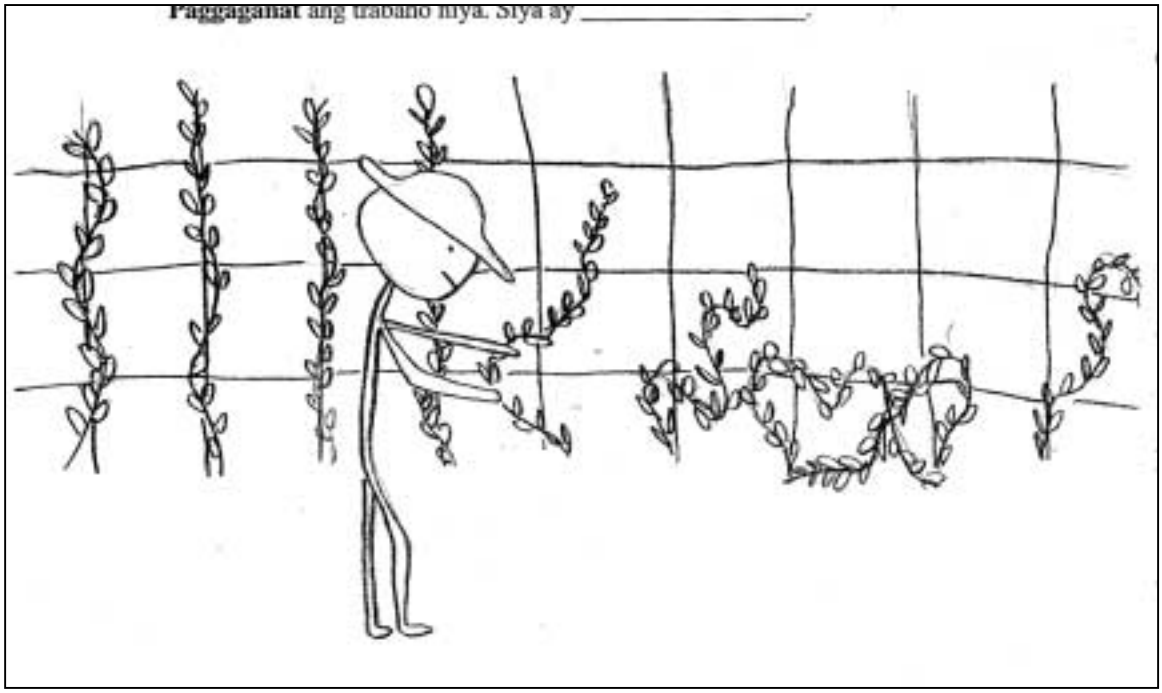
Participant #	Age	Age at emigration from Philippines
1	27	7
2	46	35
3	43	40
4	69	66
5	43	34
6	56	50
7	40	30
8	18	8
9	37	25

2.3.2. Task I: productivity

In the first task, participants were shown a series of cards, each of which had a crude illustration of a person performing a farming or craft activity, with two sentences

(in regular Tagalog orthography, with accent marks[26]) printed at the top. A sample card is shown in (20).

(20) Sample card for Task I



The sentences were designed as a "wug" test (Berko 1958) for the *maŋ+R_{CV}-* construction, which forms professional and habitual nouns (similarly to English *-er*): participants had to produce the *maŋ+R_{CV}-* form of a novel stem, which involved deciding whether or not to perform nasal substitution. For example, in the sentence shown in (21), the novel root is *bugnát*, presented in a construction (*pag+R_{CV}-*) that does not permit substitution. To fill in the blank, the participant would probably choose one of *maŋ-bu-*

[26] Accent marks—which are optional and not commonly used—indicate nonpenultimate stress and the presence or absence of final glottal stop. I used accent marks in this standard way, but also placed accent marks over penultimate stressed syllables, to ensure that the intended stress was always clear.

bugnát (no substitution, no assimilation), *mam-bu-bugnát* (assimilation only), or *ma-mu-mugnát* (substitution).

(21) Sample sentence pair for Task I

> Pagbubugnát ang trabaho niya. Siya ay _____.
> to-bugnat (topic) job his/her He/she (inversion)
> His/her job is to *bugnat*. He/she is a _____.

The experiment was carried out in individual sessions. Starting with two real-word examples (blanks filled in) and then two real-word training items, the participant took each card and read the sentences aloud, filling in the blank. Participants in Group A (4 participants) were given some real words mixed in with novel words, and were told that many of the words were rare and that if they didn't know a word or its *maŋ+*R_{CV}- form, they should just guess. Participants in Group B (5 participants), were given only novel words after the training items, and were told that the words were invented and there were no right or wrong answers. (See §0 for a complete list of stimuli).

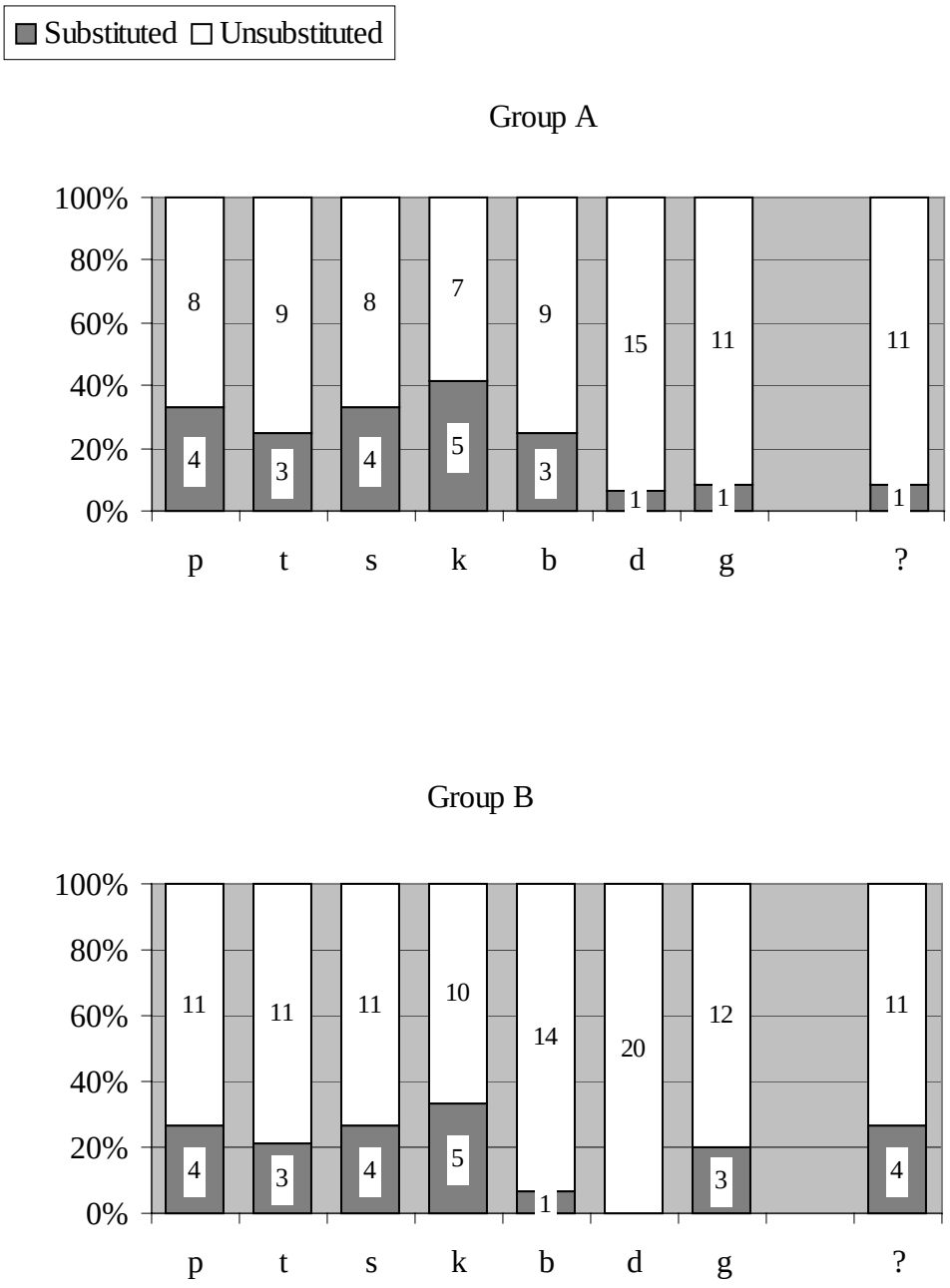
The purpose of the illustrations was to encourage participants to think of the words as real. Since none of the participants grew up in a rural environment, it was plausible that they would not be familiar with farming and craft terms. There is a large part of the Tagalog vocabulary known as "deep Tagalog"—affixed words which have been largely replaced by Spanish and English loanwords—so the idea that an unfamiliar word could still be real and native should not seem too implausible to Tagalog speakers. When Group A participants were told at the end of the experiment that most of the words were in fact novel, three of the four expressed mild surprise; one said that he had so suspected.

2.3.2.1. Results of Task I

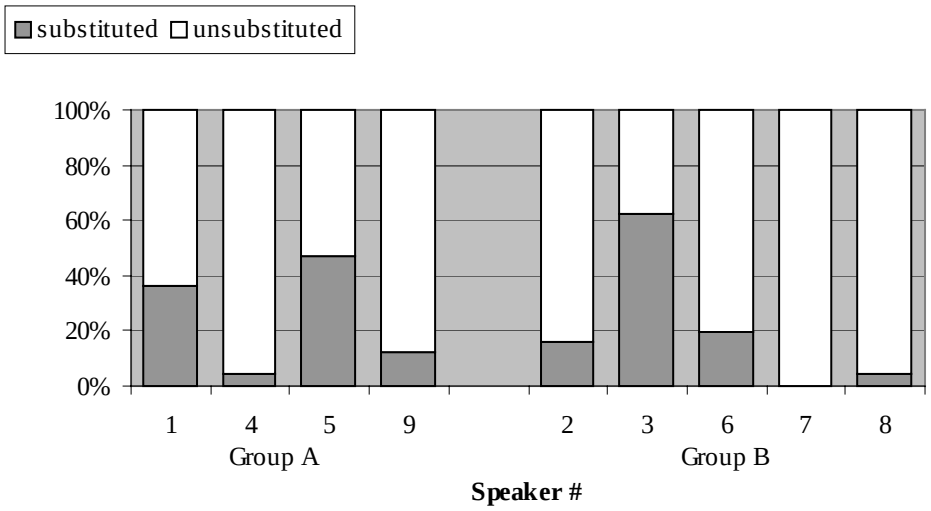
The main result from Task I, shown in (22),[27] was that substitution rates were much lower than the rates found in the lexicon for *maŋ+R_{CV}-*, but were higher than zero. In other words, nasal substitution is neither very productive nor completely unproductive. Note that Group B included one participant (#3, a Tagalog instructor at a university), who had a very high rate of substitution. If she is omitted, the rate of substitution for Group B is much lower. The difference between Groups A and B (A has a slightly higher substitution rate) is not significant. To give some idea of the amount of inter-speaker variation, (23) gives overall substitution rates for each participant; the four columns on the left are speakers from Group A, and the five columns on the right are speakers from Group B.

[27] Token counts shown in (22) are for all speakers combined. Because Group A has one few speaker than Group B, token counts are not the same between the two groups. One token was omitted (from Speaker #3) because it could not be clearly classified as substituted or unsubstituted (*ma:ŋaŋathál* for *tahál*—perhaps interference from *kathá?* 'literary work', *ma:ŋaŋathá?* 'author'?)

(22) Rates of substitution on novel words



(23) Overall rates of substitution on novel words, broken down by participant



Group B's low rate of substitution (compared to the proportion of existing words that substitute) is not surprising. This group was told they were dealing with novel words, and it makes sense not to perform nasal substitution in coining a novel derived word, in order to promote recoverability of the stem for the listener (especially since nasal substitution neutralizes voicing and continuancy distinctions in the stem). With an established word that would be familiar to the listener, recoverability is less of a concern.

The low rate of substitution for Group A might seem puzzling, though, because this group was told they were dealing with real words, and so should be making guesses that would match rates of substitution in the lexicon. But Group A was told they were dealing with *rare* real words, and so they may still have been matching lexical frequencies—the lexical frequencies found in rare words. Bloomfield (1917) asserted that nasal substitution was more frequent among common words, and although I have no

lexical-frequency data against which to test this assertion systematically, it seems plausible.[28]

2.3.3. Task II: acceptability

The second experimental task was designed to determine whether or not participants' grammars include the patterns of voicing and place of articulation seen in nasal substitution. Substitution rates in the first task were too low to probe for effects of voicing and place. Task II was administered immediately after Task I: starting with four novel-word practice items (substituted and unsubstituted for each of two stems) each participant (whether from Group A or Group B) was given cards with the same illustrations and the same sentences as in Task I, but this time with the blanks filled in, as shown in (24). Each root was presented twice (but not consecutively; order was randomized), once substituted and once unsubstituted.

(24) Example stimuli for Task II

> Kung pagbubugnát ang trabaho niya, siya ay mamumugnát.
> Kung pagbubugnát ang trabaho niya, siya ay mambubugnát.
> 'If her/his job is to *bugnat*, she/he is a *bugnat*-er'

The participant read the sentences aloud, then stated his or her rating of the sentence pair, on a scale from 1 (bad) to 10 (good).

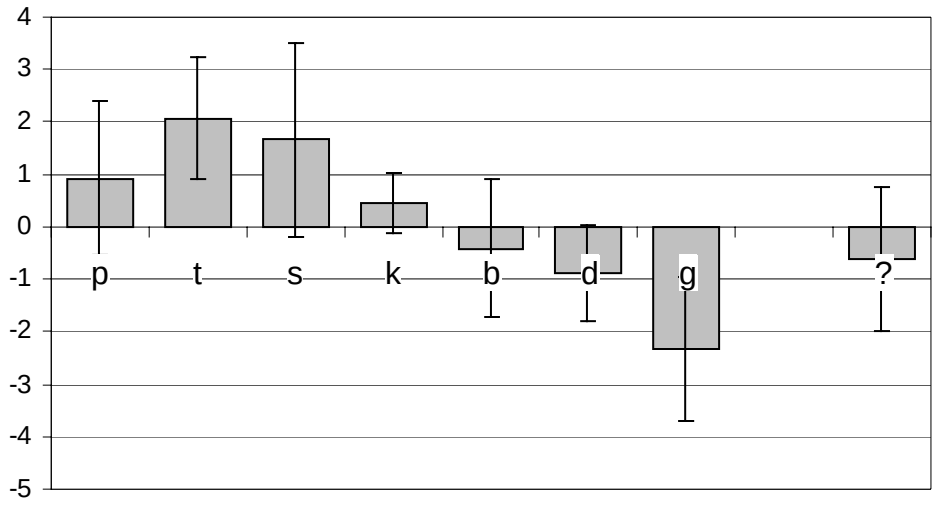
2.3.3.1. Results of Task II

Participants' acceptability judgments generally reflected lexical frequencies. (25) shows the combined average for each segment of the rating given to a substituted stimulus

[28] Cf. English verbs: irregulars tend to have higher frequency than regulars, in part because low-frequency irregulars are more likely to regularize over time (Bybee 1985).

minus the rating given to the corresponding unsubstituted stimulus. A positive number means that over all, participants rated the substituted stimulus higher; a negative number means that over all, participants rated the unsubstituted stimulus higher.

(25) Acceptability judgments: substituted - unsubstituted; error bars indicate 95% confidence interval



The positive numbers for voiceless-initial roots and negative numbers for voiced-initial roots mean that over all, participants tended to prefer the substituted stimuli for voiceless-initial roots and tended to prefer the unsubstituted stimuli for the voiced-initial roots, reflecting the voicing effect. And, except for the unexpectedly low ratings for *p*,[29] acceptability judgments also reflected the place effect. The voiceless/voiced difference is

[29] The *p-t* and *p-s* differences are not significant. I investigated the possibility that the low ratings for substituted *p* were the result of a neighborhood effect, but they do not appear to be: for each stimulus word, I counted the number of substituting and nonsubstituting words in its phonological neighborhood. The neighborhood was defined as the set of words sharing 5 segments, in the right positions (with empty codas counting as segments), with the target word. The average number of substituting words in the neighborhoods of the *p* stimuli was 2 (average number of unsubstituted = 0), and the average number of substituting words in the neighborhoods of the *s* and *t* stimuli was also 2 (average number of unsubstituted = 0.33).

highly significant—$p < 0.0001$ by Scheffé's F.[30] The place effect is not very significant: because of the low values for *p*-initial stems, the overall difference between bilabials and dentals is not even in the right direction. The difference between bilabials and velars is in the right direction, but is not significant ($p < 0.0736$ by Scheffé's F). The difference between dentals and velars is in the right direction and significant ($p = 0.0168$ by Scheffé's F).

An ANOVA on voicing, place, and speaker shows that there was no significant interaction between voicing and place, meaning that the magnitude of the voicing effect does not vary significantly by place of articulation, and the magnitude of the place effect, such as it is, does not vary significantly by voicing. There were, however, significant interactions between voicing and speaker ($F = 3.088$, $p = 0.0056$) and between place and speaker ($F = 3.402$, $p = 0.0002$), meaning that the voicing and place effects had different strengths for different speakers. There was no significant difference in acceptability ratings between Group A and Group B.

[30] For the ANOVA and Scheffé's results, some data had to be omitted into order to balance cells. Data for *s*-initial stems were omitted (to avoid having twice as many data points for voiceless dentals as for other categories); data for one of the *da*-initial stems was omitted (to avoid have 25% more data points for *d* than for other segments); and data were excluded for participant #6, who made several errors in reading aloud the stimuli (not applying substitution, although the stimulus was substituted; the errors were all on velar-initial stems, which can be confusing to read because the digraph *"ng"* is used to represent *ŋ*).

2.4. The grammar

2.4.1. Desiderata for an analysis

The experimental results described above suggest that nasal substitution and its patterns must be modeled in the grammar, in a way that accounts for the following facts: existing words with nasal-substituting affixes are listed; speakers rarely perform nasal substitution on novel words or rare words; and listeners prefer nasal substitution on voiceless obstruents over voiced, and front over back.

The basic model that I will propose involves high-ranking input-output correspondence constraints that cause established words to be pronounced as listed, with lower-ranked markedness constraints that come into play when no listed form is available (as with a novel word). This section presents the constraints involved in nasal substitution, and shows how they interact to produce novel utterances and to produce utterances based on listed words. Subsequent sections show that the grammar proposed is learnable from the lexical data, that the grammar predicts appropriate behavior by both speakers and listeners, and that the interaction of speakers and listeners maintains lexical patterns.

2.4.2. Paradigm Uniformity

Paradigm Uniformity, also known as Output-Output Correspondence, enforces similarity among related words (Crosswhite 1996 and 1998, Steriade 1996, Kenstowicz 1997, Benua 1998). For any word, there are potentially many other words to which it could be seen as related: *ma-migáj* is clearly related to the bare-stem word *bigáj*, perhaps related to other derivatives of the stem *bigáj*, and perhaps even related to other words with the prefix *maŋ-*. It is clear that nasal substitution reduces similarity between the nasal-

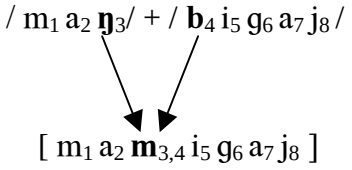
substituted word and unsubstituted derivatives of the same stem, including the bare stem, violating Output-Output Correspondence constraints. I will use *PU* as a shorthand for those correspondence constraints that enforce similarity between an unsubstituted stem like *bigáj* and the substituted form of that stem found in *ma-migáj* and are violated by nasal substitution (e.g., IDENT-OO[SONORANT], IDENT-OO[VOICE] for voiceless-initial stems). Candidates with nasal substitution violate PU once, and candidates without nasal substitution do not violate PU.

2.4.3. Input-Output Correspondence

PU is one of the forces that discourage substitution in novel words. Input-Output Correspondence is part of the force that allows substitution in words that are listed as substituted (USELISTED, discussed below, is the other crucial part).

Input-Output Correspondence enforces similarity between an input and an output, and thus encourages substitution if the input is a substituted word, but discourages substitution if the input is an unsubstituted word or a prefix+stem combination. Adopting the view of Lapoliwa (1981), Newman (1984), and Pater (1996), nasal substitution is a coalescence of two segments, as illustrated in (26).

(26) Nasal substitution as coalescence



Matching subscripts indicate that a segment in the output is the correspondent of a segment in the input, so */maŋ3/+/b4igaj/* → *[mam3,4igaj]* means that the surface segment *[m3,4]* corresponds to both the input segment */ŋ3/* and the input segment */b4/*. The

coalescence analysis allows output *[$m_{3,4}$]* to straightforwardly inherit some of the features of */$ŋ_3$/* (manner features) and some of the features of */b_4/* (place features). If one of the input segments were actually deleted, the analysis would be more complicated, requiring constraints that preserve the features of an input segment even if that segment is not present in the output.

Coalescence can produce featural misidentity between the prefix nasal and the coalesced nasal—*/$ŋ_3$/* is [dorsal], but *[$m_{3,4}$]* is [labial]—and between the underlying stem-initial obstruent and the coalesced nasal—*/b_4/* is [-sonorant], but *[$m_{3,4}$]* is [+sonorant]; thus, nasal substitution violates IDENT-IO constraints. Coalescence also alters the precedence relations between segments in the underlying string: in the input, segment 3 strictly precedes segment 4, but in the output, it does not.

There is a difference, though, between substitution of a synthesized prefix+stem combination and substitution of an unsubstituted listed word (if that listed word is a phoneme string—see §2.5 for consideration of other possibilities). In */ma$ŋ_3$/+/$b_4$igaj/ → [ma$m_{3,4}$igaj]*, the precedence relation that is interrupted is between segments that do not belong to the same lexical entry (*/$ŋ_3$/* and */b_4/*); within the prefix and within the stem, all precedence relations are preserved. If coalescence applies to a single listed word, however, as in */ma$m_3$$b_4$igaj/ → [ma$m_{3,4}$igaj]*, however, the precedence relation that is disturbed is between two members of the same lexical entry. Pater (1996) differentiates between LINEARITY, which is violated by any coalescence, and ROOTLINEARITY, which is violated only by coalescence within a root. I will instead make the distinction between MORPHORDER, which is violated by disturbing the linear order of morphemes (such as by coalescing members of two different morphemes) and ENTRYLINEARITY, which is violated by disturbing the linear order of segments (as by coalescence) within a lexical entry coalescence:

(27) Constraints against coalescence

MORPHORDER

> If morpheme μ_1 precedes μ_2 in the input, then all the segments of μ_1 must precede all the segments of μ_2 in the output.

ENTRYLINEARITY

> If segment *X* precedes segment *Y* within a lexical entry, *A* is the output correspondent of *X*, and *B* is the output correspondent of *Y*, then *A* must precede *B*.

Pater justifies ROOTLINEARITY by the fact that roots often contain a richer contrast set than affixes, but it could also be seen as justified by work such as Cho (to appear), which suggests that timing relations between gestures belonging to different morphemes are much more variable than timing relations between gestures belonging to the same morpheme, implying that violating timing relations such as precedence within a lexical entry is more strongly avoided than violating timing relations across lexical entries.

The table in (28) summarizes the role of Input-Output Correspondence in nasal substitution by showing the CORR-IO[31] violations of a variety of input-output pairs.

[31] "CORR-XY" stands for any constraint affecting correspondence between X and Y (IDENT[F]-XY, MAX-XY, DEP-XY, etc.)

(28) Corr-IO constraints: sample violations

'to *bigáj*'	IDENT [PLACE]	IDENT [SON]	DEP	MAX	MORPH ORDER	ENTRY LINEARITY
/maŋ$_3$/+/b$_4$igaj/ → [mam$_{3,4}$igaj]	*	*			*	
/maŋ$_3$/+/b$_4$igaj/ → [mam$_3$igaj]	*			*		
/maŋ$_3$/+/b$_4$igaj/ → [mam$_4$igaj]		*		*		
/maŋ$_3$/+/b$_4$igaj/ → [mam$_3$b$_4$igaj]	*					
/mam$_3$i$_4$gaj/ → [mam$_3$i$_4$gaj]						
/mam$_3$i$_4$gaj/ → [mam$_3$bi$_4$gaj]			*			
/mam$_3$i$_4$gaj/ → [mam$_3$b$_3$i$_4$gaj]		*				*[32]
/mam$_3$b$_4$igaj/ → [mam$_{3,4}$igaj]		*				*
/mam$_3$b$_4$igaj/ → [mam$_3$igaj]				*		
/mam$_3$b$_4$igaj/ → [mam$_4$igaj]		*		*		
/mam$_3$b$_4$igaj/ → [mam$_3$b$_4$igaj]						

2.4.4. Listedness

This section introduces a constraint USELISTED, which requires that a single lexical entry be used as input (rather than a prefix+stem combination). If no such entry is available, USELISTED is irrelevant, because it is violated by all candidates, but if such an entry is available, USELISTED requires that it be used.

It is usually assumed that the input to a tableau is a particular lexical entry or combination of lexical entries; CORR-IO constraints evaluate each output candidate's faithfulness to that one input. I will assume instead (as in (28)) that each candidate is an input-output pair—different candidates can have different inputs—and CORR-IO constraints evaluate correspondence within each pair. The real "input" to a tableau that is shared by all candidates is the morphosyntactic and semantic features that the speaker wishes to express, which I will call the *intent*; there may be more than one lexical item or combination of lexical items that could express that intent. This means that *Gen*, the component of the grammar that generates the candidate set, must generate a complete set

[32] "Splitting" a segment can be thought of as a violation of ENTRYLINEARITY, because in the input, segment 3 does not precede itself, but in the output, it does.

of outputs for each input that is available in a given tableau. As in (28), two distinct candidates may share the same[33] output, but have different inputs.

USELISTED enforces a preference for candidates whose inputs consist of a single lexical entry, rather than a string of morphemes:

(29) USELISTED

The input portion of a candidate must be a single lexical entry.

(1 violation if not true)[34]

The tableaux in (30) illustrate the operation of USELISTED. I assume that high-ranked constraints enforce morphosyntactic and semantic identity between intent and output, preventing some unrelated lexical entry or prefix+stem combination from being used.[35] In (30), these constraints are included in the shorthand constraint MEANING, which I omit from subsequent tableaux. In the first tableau, candidate *a*, which uses a single lexical entry, satisfies both MEANING and USELISTED. Candidate *b* satisfies MEANING,[36] but violates USELISTED, because it uses a combination of two lexical entries. Candidate *c*

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[33] The outputs are not exactly the same, because their segments are in correspondence with the segments of different inputs.

[34] It might be desirable to make USELISTED sensitive to the number of lexical entries beyond a binary one/many opposition (i.e., preferring a candidate that uses a lexicalized prefix-stem combination plus a suffix over a candidate that concatenates prefix+root+suffix afresh), but the constraint as defined will suffice for present purposes.

[35] Or perhaps the restriction is in GEN (the function that generates the set of candidates) itself. Using high-ranking constraints instead is attractive, though, because it allows speech errors in which the wrong input is (e.g., *deviant* for *devious*) to be described as the result of very rare rankings (see §2.4.7).

[36] A prefix+stem combination does not completely satisfy MEANING when the meaning of the existing single lexical entry is idiosyncratic but it satisfies what would presumably be the highest-ranking MEANING constraints. For example, if a speaker wants to talk about a rudder (for which there is a listed word,, */pamalik/* 'rudder'), her linguistic intent is not perfectly satisfied if she synthesizes */paŋ/+/balik/* (however she decides to pronounce it), which should mean just 'tool for returning'. But */paŋ/+/balik/* would satisfy her intent better than an input that lacked the meaning 'tool', or was not a noun, or meant 'tool for digging'.

uses a single lexical entry, but it violates MEANING, because it is not Actor-Focus (it is Patient-Focus). Candidate *d* violates MEANING because it is [-distributive] (it would simply mean 'to give'). In the second tableau, *bugnat* is a novel stem, and so there is no lexical entry */mamugnat/* available, and all possible candidates violate USELISTED.

(30) Violations of USELISTED

	Intent: V, Actor-Focus 'to distribute'	MEANING	USELISTED
(a)	/mamigaj/ → [mamigaj]		
(b)	/maŋ/+/bigaj/ → [mamigaj]		*
(c)	/ʔipamigaj/ → [ʔipamigaj]	*	
(d)	/mag/+/bigaj/ → [magbigaj]	*	*

	Intent: V, Actor-Focus 'to bugnat'	MEANING	USELISTED
(e)	/maŋ/+/bugnat/ → [mamugnat]		*
(f)	/mag/+/bugnat/ → [magbugnat]	*	*

Are all lexical entries equally available? Surely the leap during word-learning from unknown word to fully available lexical entry is not instantaneous. More-frequent words seem to have stronger lexical entries—they are, for example, faster to recognize (Rubenstein, Garfield, & Millikan 1970; Forster & Chambers 1973). Frisch (to appear) reports experimental results in which subjects who were exposed to a novel word twice rated it more "word-like" than subjects who were exposed to a novel word just once, suggesting that a word is not immediately accepted the first time it is heard. The model here assumes that rather than simply being listed in the mental lexicon or not, lexical entries range in strength from 0 (not at all listed) to 1 (always available for use). Strength of a lexical entry in this model is a function of the number of times a speaker has heard the word, although in real life there are probably other factors, such as who the speaker has heard the word from and in what context.

There are two ways of implementing "gradient listedness" in the grammar. One is to replace USELISTED with a family of inherently ranked constraints such as

USE100%LISTED >> USE90%LISTED >> ... >> USE10%LISTED >> USELISTED

where USEX%LISTED is satisfied by a candidate whose input lexical entry is X% listed or more. Other constraints could be inserted into this hierarchy. For example, if

USE40%LISTED >> PU >> USE30%LISTED

a nasal-substituted derivative with 30% listedness (i.e., of whose listedness the speaker is 30% certain, or whose lexical entry's strength is 30% of the maximum possible strength) or lower will not be used because Paradigm Uniformity to the base forbids nasal substitution. But a nasal-substituted derivative with 40% listedness (or higher) would override PU and be used. This is illustrated schematically in (31): Candidate *a*, the faithful parse of the single lexical entry, fails because it violates PU; candidate *b* satisfies PU, but violates CORR-IO. Candidate *d* is the optimal candidate because, although it violates USE30%LISTED, it satisfies PU, which is more highly ranked. But in the second half of the tableau, candidates are available that satisfy USE40%LISTED, and so candidate (e) is optimal despite its violation of PU.

(31) Interaction of a family of USEX%LISTED constraints and Paradigm Uniformity

		ENTRY LINEARITY	USE40% LISTED	PU	USE30% LISTED
(a)	/manala/ (30% listed) → [manala]		*	*!	
(b)	/manala/ (30% listed) → [mantala]	*!	*		
(c)	/maŋ/+/tala/ → [manala]		*	*!	*
(d)	☞ /maŋ/+/tala/ → [mantala]		*		*
(e)	☞ /manili/ (40% listed) → [manili]			*	
(f)	/manili/ (40% listed) → [mansili]	*!			
(g)	/maŋ/+/sili/ → [manili]		*!	*	*
(h)	/maŋ/+/sili/ → [mansili]		*!		*

The other way to approach gradient listedness is to have a single constraint, USELISTED, with the availability of a given lexical entry in any utterance equal to the listedness of the entry. For example, a word that is 30% listed has a 30% probability of being available in any given tableau. The ranking CORR-IO, USELISTED >> PU produces the result */manala/ → [manala]* 30% of the time (upper tableau in (32)—listed */manala/* is available as an input), and the result */maŋ/+/tala/ → [mantala]* 70% of the time (lower tableau in (32)—synthesized candidates only).

(32) Interaction of a unitary USELISTED constraint and Paradigm Uniformity

		ENTRY LINEARITY	USE LISTED	PU
(a)	☞ /manala/ → [manala]			*
(b)	/manala/ → [mantala]	*!		
(c)	/maŋ/+/tala/ → [manala]		*!	*
(d)	/maŋ/+/tala/ → [mantala]		*!	
(g)	/maŋ/+/tala/ → [manala]		*	*!
(h)	☞ /maŋ/+/tala/ → [mantala]		*	

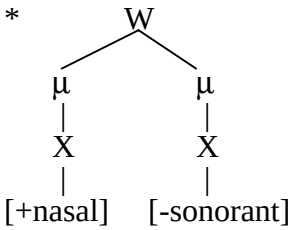
In contrast, we would see */manili/ → [manili]* 40% of the time, and */maŋ/+/tili/ → [mantili]* 60% of the time. This may seem like an obvious empirical difference between the unitary-USELISTED approach and the USEX%LISTED approach, which produced uniformly */manala/ → [manala]* and uniformly */manili/ → [manili]* in (31), but under the stochastic constraint ranking scheme introduced below, the difference is not so clear. For that reason, I will use unitary USELISTED.

2.4.5. Constraints specific to nasal substitution

Nasal substitution is some 5000 years old (see fn. 83). The original phonetic motivation might have been consonant-cluster avoidance, as suggested in Archangeli, Moll, and Ohno 1998; post-nasal lenition; or an attempt to avoid a non-crisp edge (prefix nasal and stem-initial consonant sharing place of articulation, as required by nasal assimilation), as

suggested in Pater 1999b. I suspect that modern Tagalog nasal substitution is divorced from any phonetic or prosodic motivations, and simply exists as an arbitrary alternation.[37] Accordingly, I will propose a constraint, NASSUB (short for "nasal-substitute") that simply requires nasal substitution:

(33) NASSUB[38]



A morpheme-final nasal must not be immediately followed by an obstruent within the same word.[39]

I will assume that NASSUB penalizes failure to substitute in both synthesized prefix+stem candidates, and in candidates whose input is a single listed word.[40] This is because even although a morphologically complex lexical entry like */mamiŋaj/* contains no morpheme boundaries, its segments are coindexed to related lexical entries: the first

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[37] Note that the prefixes *mag-* and *pag-* also produce consonant clusters—and, with velar-initial stems, non-crisp edges (e.g., *mag-kilatí:s-an* 'to appraise each other' from *kilá:tes*, *kilá:tis* 'carat'), unless some mechanism requires the *g* and *k* to have separate-but-identical features. But these prefixes do not induce coalescence, even though the identity violations would be no worse those incurred in nasal substitution.

[38] Representations in constraint definitions should be interpreted as nonexhaustive at the edge of each tier. For example, in (33), other morphemes may come before or after the two shown, but not between. When tiers are missing, the information on those tiers should be considered irrelevant. For example, in (34), the two segments may belong to different morphemes or to the same morpheme.

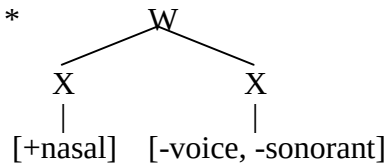
[39] Where "word" must be defined so as to exclude the compounding-like prefixes discussed in fn. 14, which never trigger nasal substitution.

[40] Although this assumption is not crucial to the model proposed here—once a word is listed as unsubstituted, ENTRYLINEARITY almost always prevent NASSUB from having any effect.

three segments (*mam*) are coindexed with the segments of the lexical entry for the prefix */maŋ-/*, and the last five segments (*migaj*) are coindexed to the segments of the lexical entry for the word */bigaj/*. The candidate */mamigaj/ → [mamigaj]* satisfies NASSUB, because there is no sequence of a distinct nasal and obstruent coindexed to two different morphemes.

Turning to the constraints that produce the patterns in the lexical distribution of nasal substitution,[41] I attribute the higher rate of substitution on voiceless-initial stems to a constraint *NC̥, a constraint forbidding a sequence of a nasal and a voiceless obstruent:

*(34) *NC̥*



A [+nasal] segment must not be immediately followed by a [-voice, -sonorant] segment within the same word.

Hayes and Stivers (1996) give a phonetic motivation for *NC̥: the raising of the velum during the nasal-to-oral transition expands the oral cavity, slowing the buildup of the supraglottal air pressure that would otherwise "turn off" voicing. An *NC̥* sequence thus requires extra effort (such as glottal abduction) to keep the obstruent voiceless.

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[41] This is a form of Emergence of the Unmarked (McCarthy & Prince 1994): although nasal substitution itself is not motivated by pure markedness, the patterns in its distribution seem to reflect considerations of markedness.

Newman (1984) finds an implicational hierarchy reflecting similar effects in related languages in which nasal substitution is predictable if the stem-initial obstruent is known: If the language substitutes *g*, it also substitutes *d*, and if a language substitutes *d*, it substitutes *b*; similarly, substitution on *k* implies

Hayes and Stivers propose that the articulatory difficulty of *NÇ* clusters drives postnasal voicing. Pater (1996) discusses *NÇ as the motivation for postnasal voicing, Indonesian nasal substitution (which applies only to voiceless obstruents), nasal deletion, and denasalization.[42]

*NÇ favors substitution in voiceless-initial stems. A word like *mantukad*, without substitution, violates *NÇ, but *manukad*, with substitution, does not. *NÇ is irrelevant for voiced-initial stems, since it is violated by neither substitution (*mandukad*) nor nonsubstitution (*manukad*).

If *NÇ is ranked high enough to produce an effect in nasal substitution, why is *NÇ violated so freely word-internally? One answer is the distinction made above between MORPHORDER and ENTRYLINEARITY:

(35) Coalescence within vs. across listed items

/maŋ$_1$/+/p$_2$ili/	ENTRY LINEARITY	*NÇ	MORPH ORDER
☞ mam$_{1,2}$ili			*
mam$_1$p$_2$ili		*!	
/ban$_1$t$_2$á:j/			
ban$_{1,2}$á:j	*!		
☞ ban$_1$t$_2$á:j		*	

substitution on *t,s* and *p*. In addition, substitution on *b* implies substitution on *p*, *d* on *t,s*, and *g* on *k*. Thanks to Joe Pater for pointing out this interesting finding.

[42] Pater 1999b proposes instead that Alignment is the driving force behind Indonesian nasal substitution, and that IDENT-IO for pharyngeal expansion (see Steriade 1995) is what restricts nasal substitution to voiceless obstruents: voiced obstruents require pharyngeal expansion to maintain transglottal airflow despite a vocal tract obstruction, and so are [+pharyngeal expansion], but voiceless obstruents—which lack transglottal airflow—and nasals—which lack a vocal-tract obstruction—are [-pharyngeal expansion]. So, fusing a voiced obstruent and a nasal violates IDENT[PHARYNGEAL EXPANSION], but fusing a voiceless obstruent and a nasal does not. This approach might work for Tagalog as well (with stochastic constraint ranking).

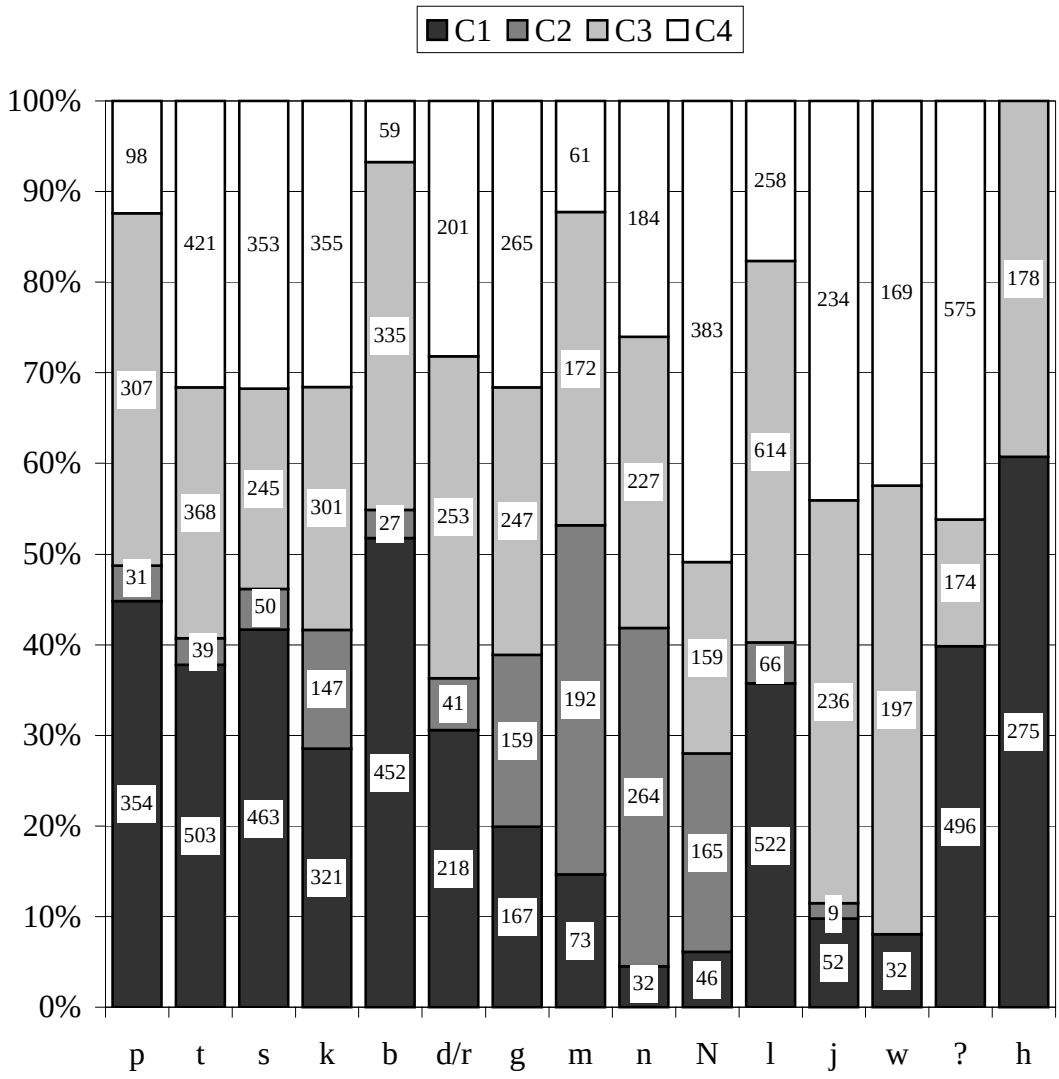
If ENTRYLINEARITY is very highly ranked, *NC̥ will not be able to shape the lexicon root-internally the way it seems to have done for nasal substitution (by a mechanism proposed below).[43]

To introduce the constraints that produce the place-of-articulation effect, consider the chart in (36), showing the distribution of various consonants in various positions within the root in Tagalog. The numbers are from a database of about 4,600 disyllabic Tagalog roots,[44] with reduplicated roots excluded.

[43] But see fn. 42: adopting Pater's (1999b) approach to Indonesian, the voicing effect would be driven by a difference in faithfulness (rather than a difference in markedness), in which case there is no drive to coalesce nasal-obstruent clusters word-internally. Under the learning mechanism discussed below, though, there is no way to prevent *NC̥ from being learned with a fairly high ranking, so we would still have to rely on ENTRYLINEARITY to prevent root-internal coalescence.

[44] All the native, disyllabic roots in English 1986 were recorded. The count shown is by type—each root is counted just once, no matter how many affixed forms it has. The restriction to disyllabic roots is necessary because monosyllables are clitics (pronominal and discourse), which may not obey the same morpheme structure constraints as lexical roots, and roots of more than two syllables are—at least historically—polymorphemic. Because of evidence that speakers may treat words that appear polymorphemic as polymorphemic, even without morphosyntactic motivation (see Baroni 1998, Hammond 1999, and Chapter 4 of this dissertation), words with more than two syllables might therefore also escape root structure constraints.

(36) Distribution of consonants in roots of the form $C_1V(C_2)C_3V(C_4)$



Note that in general, fronter consonants are better represented root-initially.[45] For example, about 45% of *p*s are root-initial (C_1), but only about 28% of *k*s are root-initial. Note further that obstruents are better represented initially than are sonorants. There are very few root-initial nasals, both over all and as a proportion of nasals in all positions; among the nasals, *m* is better represented root-initially than *n* or *ŋ*. This consonantal distribution suggests that (and would provide evidence to the learner that) root-initial nasals are disfavored, but that among the root-initial nasals, the fronter ones are less disfavored.

I propose the following family of constraints against root-initial nasals: *[$_{root}$ŋ, *[$_{root}$n, *[$_{root}$m (abbreviated *[ŋ, *[n, *[m).

*(37) *[ŋ, *[n, *[m*

* [$_{root}$ X (|) [+nasal, +dorsal] [$_{root}$ X (|) [+nasal, +coronal] [$_{root}$ X (|) [+nasal, +labial]

A root must not begin with [ŋ] ([n], [m]).

This family of constraints disfavors substitution.[46] For example, *ma-nukad*, with substitution, violates *[n, because the *n* that results from substitution is root-initial (as well as prefix-final). But *man-tukad*, without substitution, does not violate *[n], because the *n* belongs to the prefix only. The ranking *[ŋ >> *[n >> *[m (which could be inherent

[45] Ingram (1974) proposes "fronting" as an acquisition strategy: a front-to-back order is preferred for both consonants and vowels within a word (i.e., *...p...t...*, *...p...k...*, and *...t...k...* are preferred to *...t...p...*, *...k...p...*, or *...k...t...*; *...i...u...* is preferred to *...u...i...*).

[46] in synthetic candidates as well as in candidates with single-lexical-entry inputs, because the *n* in a lexical entry */manukad/* would be coindexed to the *t* of the related word */tukad/*. This assumption does not materially affect the model presented here, however (see fn. 40).

or learned) would disfavor substitution most on posterior places of articulation.[47] For example, if *[ŋ >> *[n >> NASSUB >> *[m, then all else being equal, substitution would occur on a labial-initial root, but not on a coronal- or velar- initial root:

*(38) *[ŋ >> *[n >> *[m*

	/maŋ/+/bala/	*[ŋ	*[n	NASSUB	*[m
(a)	☞ mamala				*
(b)	mambala			*!	
	/maŋ/+/dala/				
(c)	☞ mandala		*!		
(d)	manala			*	
	/maŋ/+/gala/				
(e)	☞ maNgala	*!			
(f)	maNala			*	

Is there any functional motivation for dispreferring root-initial nasals, or for especially dispreferring root-initial back nasals? Among voiceless obstruents, the place effect could be seen as a fine-tuned version of *NC̥. Recall that the phonetic motivation proposed by Hayes and Stivers (1996) for *NC̥ is that the expansion of the oral cavity during velum-raising encourages voicing. Their model also found that frontness of the obstruent encourages voicing, because there is a greater expanse of flexible cheek wall that can expand outward and reduce supralaryngeal pressure. This would explain why *p* substitutes more often than *k*. But it does not explain why *b* substitutes more often than *d*, since turning off voicing is not necessary in *mb*, *nd*, and *ŋg* clusters—indeed, the frontness of *b* would make voicing easier to maintain,[48] and thus the cluster *mb* would be less marked (and so less subject to repair by coalescence) than *nd* or *ŋg*.

[47] Cf. English, in which root-initial *ŋ* is not permitted at all.

[48] See Ohala & Riordan (1980), who found that passive cavity expansion maintained voicing longer for *b* than for *d* or *g*.

Another possibility, expanding on Pater 1999b (see fn. 42), is that IDENT-IO violations are greater when substituting a fronter consonant. Pater proposes that the reason voiced obstruents do not substitute in Indonesian is that if they did, it would violate IDENT-IO[PHARYNGEAL EXPANSION]: voiced obstruents are [+pharyngeal expansion]—they require active expansion of the pharynx, or some other exertion, to maintain voicing—but nasals are [-pharyngeal expansion], because voicing is maintained by venting air out the nose. Fronter consonants should require less pharyngeal expansion, because more cheek area is available for passive expansion, and so coalescing a *b* with a nasal is less of a violation of (some gradient version of) IDENT-IO[PHARYNGEAL EXPANSION]. The place effect among voiceless consonants is then a puzzle, though, because no voiceless consonants require any pharyngeal expansion.

Whatever the reason, the Tagalog lexicon manifests a dispreference for root-initial nasals, so I will simply assume the *[NASAL constraint family. Although there may be a reason for the family to be inherently ranked *[ŋ >> *[n >> *[m, this ranking is learnable from the lexicon (see §2.6), so it need not be assumed.

2.4.6. Summary of constraints

The table in (39) summarizes the constraints relevant to determining whether a word is pronounced with nasal substitution.

(39) Constraints affecting nasal substitution

Constraint	*Effect*
PARADIGM UNIFORMITY	discourages N.S. (nasal substitution)
NASSUB	encourages N.S.
*NC̥	encourages N.S. for voiceless-initial stems
*[ŋ̊	discourages N.S. for velar-initial stems
*[n	discourages N.S. for coronal-initial stems
*[m	discourages N.S. for bilabial-initial stems
MORPHORDER	discourages N.S. in prefix+stem concatenations
ENTRYLINEARITY	encourages N.S. if word is listed with substitution discourages N.S. if word is listed without substitution.

As noted above, if a word has a listed form, and it is available, and ENTRYLINEARITY is ranked high, the word will be pronounced as listed:[49]

(40) Input-Output Correspondence requires use of listed form

	ENTRY LIN	USE LISTED	*[ŋ	*NC̥	*[n	NAS SUB	PU	MORPH ORDER	*[m
(a) ☞ /mambú:laʔ/ → mambú:laʔ						*			
(b) /mambú:laʔ/ → mamú:laʔ	*!						*		*
(c) /maŋ/+/bú:laʔ/ → mambú:laʔ		*!				*			
(d) /maŋ/+/bú:laʔ/ → mamú:laʔ		*!					*	*	*

	ENTRY LIN	USE LISTED	*[ŋ	*NC̥	*[n	NAS SUB	PU	MORPH ORDER	*[m
(e) ☞ /mamalsá/ → mamalsá							*		*
(f) /mamalsá/ → mambalsá	*!					*			
(g) /maŋ/+/balsá/ → mamalsa		*!					*	*	*
(h) /maŋ/+/balsá/ → mambalsá		*!				*			

[49] Candidate *f* in (40) results from splitting underlying *m* into *m* and *b*. Epenthesizing the *b* instead would produce a homophonous candidate (not shown) that satisfies ENTRYLINEARITY but violates high-ranking DEP.

But when no listed form is available, as in a novel word, ENTRYLINEARITY is satisfied by all candidates, and USELISTED cannot be satisfied by any candidate, so both are irrelevant; the lower-ranked constraints decide. The tableau in (41) illustrates how the constraint ranking in (40) would treat a novel root beginning with each obstruent.

(41) Coining of novel words, using the ranking in (40)

	maŋ- form of /pala/	ENTRY LIN	USE LISTED	*[ŋ	*NC̥	*[n	NAS SUB	PU	MORPH ORDER	*[m
(a)	☞ /maŋ/+/pala/ → mamala		*					*	*	*
(b)	/maŋ/+/pala/ → mampala		*		*!		*			
(c)	☞ /maŋ/+/tala/ → manala		*			*		*	*	
(d)	/maŋ/+/tala/ → mantala		*		*!		*			
(e)	☞ /maŋ/+/sala/ → manala		*			*		*	*	
(f)	/maŋ/+/sala/ → mansala		*		*!		*			
(g)	☞ /maŋ/+/kala/ → maŋkala		*		*		*			
(h)	/maŋ/+/kala/ → maŋala		*	*!				*	*	
(i)	☞ /maŋ/+/bala/ → mamala		*					*	*	*
(j)	/maŋ/+/bala/ → mambala		*				*!			
(k)	☞ /maŋ/+/dala/ → mandala		*				*			
(l)	/maŋ/+/dala/ → manala		*			*!		*	*	
(m)	☞ /maŋ/+/gala/ → maŋgala		*				*			
(n)	/maŋ/+/gala/ → maŋala		*	*!				*	*	

Under this ranking, in which PU is fairly low, the ranking of *NC̥ with respect to the three anti-root-initial-nasal constraints (*[ŋ, *[n, *[m) creates a place-of-articulation cutoff among the voiceless obstruents; in this case, labials and coronals substitute, and

dorsals do not. The ranking of NASSUB with respect to the three nasal constraints places a cutoff among the voiced obstruents; in this case, only labials substitute.

2.4.7. Stochastic constraint ranking

Of course, this cannot be the constraint ranking for the language, because not all novel *b*-initial stems (for example) were substituted in the experiment. There is no one ranking that would be compatible with the experimental results above on novel stems, because for every consonant tested, there were some tokens in which speakers substituted it, and some in which they did not.

For this reason, I will adopt stochastic constraint ranking, as proposed in Hayes and MacEachern 1998, Boersma 1998, Boersma and Hayes 1999, and Hayes (to appear). Stochastic constraint ranking is similar to variable constraint ranking (as in Anttila 1997). In Anttila's system, certain ranking pairs within a hierarchy are fixed, and all ranking permutations of the constraints that respect those fixed pairs are equally possible. For example, with constraints C_1, C_2, C_3, and C_4 and the ranking $C_1 >> \{C_2, C_3\} >> C_4$, there is a 50% probability of speaker's using the ranking $C_1 >> C_2 >> C_3 >> C_4$ in any given utterance, and a 50% probability of using $C_1 >> C_3 >> C_2 >> C_4$.

Stochastic constraint ranking differs from variable constraint ranking in that rather than having only two types of ranking between any two constraints (completely fixed and completely free), any ranking is possible, but some are more probable than others. This is implemented by assigning each constraint a probability distribution centered on a particular ranking value. In any given utterance, an actual value is generated for each constraint, at random but in accordance with the constraint's probability distribution.[50]

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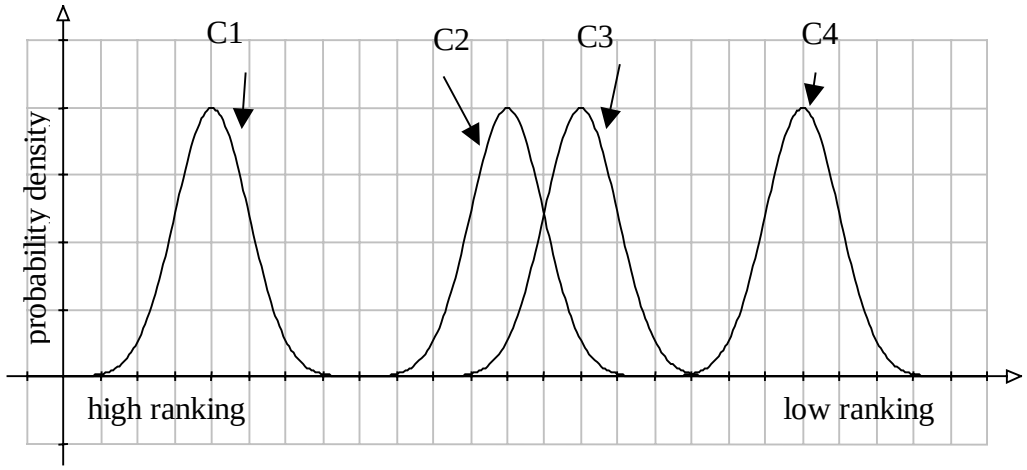
[50] And, in Boersma's system, using a quantity called "ranking spread". Full details are given below, in "The Speaker".

The dominance relations in the constraint hierarchy are determined by these actual values. For example, consider the hypothetical constraint system in (42). C_1 has a fairly high ranking value, C_2 and C_3 are somewhat lower, and C_4 is quite a bit lower.

(42) Hypothetical constraint system



In nearly all of the linear rankings that would be produced by this system on various occasions, C_1 outranks the other three constraints, because its distribution is centered on a much higher ranking value. This means that it would be possible, but vanishingly unlikely,[51] for C_1 to be ranked low enough, and/or any other constraint to be ranked high enough, for C_1 to be dominated. Similarly, it is very improbable that C_4 will outrank any other constraint. But C_2 and C_3 overlap considerably, which means that their ranking with respect to each other varies quite a bit. This system is different, however, from an Anttila-style $C_1 >> \{C_2, C_3\} >> C_4$ system in that it encodes a weak tendency for C_2 to outrank C_3 rather than completely free ranking between the two.

Stochastic constraint ranking allows us to model a situation in which nasal substitution rarely occurs in any novel word, but it is more likely to occur on a voiceless-

[51] See §2.7 for calculations of probability.

or front-initial stem: PU and MORPHORDER will tend to prevent substitution, but substitution will occur on a voiced-initial segment whenever NASSUB outranks PU and the relevant *[NASAL constraint, and on a voiceless-initial segment whenever either NASSUB *or* *NC̥ outranks PU and the relevant *[NASAL constraint. This means that there are more rankings under which, say *p* would substitute than *b*, making it more likely that *p* will substitute. As for the place effect, if *[ŋ tends to outrank *[n, which in turn tends to outrank *[m, it is more likely that NASSUB (or *NC̥, if relevant) will outrank *[m, allowing substitution, than that it will outrank *[n or *[ŋ. The following sections show how such a constraint system would be learned and used.

2.5. Representations: encoding exceptionality

It was argued in §2.2.3 that potentially nasal-substituting words must have their own lexical entries, both to ensure that the word is reliably substituted or unsubstituted, as the case may be, and to list additional unpredictable information, such as stress shifts and opaque meanings.[52] An equivalent[53] approach would be for every stem to list the unpredictable information about its derivatives, as in (43).

(43) Sample lexical entry for stem-listing approach (cf. (16))

[bugbóg], Noun, 'wallop'

derivative		*phonological notes*	*semantic notes*
paŋ-	(tool for doing X)	[+nasal subst.]	when washing clothes
paŋ+RED_{CV}-	(act of doing X)	[-nasal subst.]	
maŋ-	(to perform an X)	[-nasal subst.]	

This section considers some other alternatives to full listing: substitution diacritics, underspecification, and allomorph listing. All three will be discussed in terms of separate lexical entries for each derivative of a stem, but could also be combined with the stem-listing approach (for example, (43) lists substitution diacritics in the stem's subentries).

[52] The only exception would be variably pronounced words with no other unpredictable semantic or phonological characteristics. Section 0 takes up the question of whether a three-way distinction can be captured without listing all existing words.

[53] equivalent for present purposes, that is. This stem-listing approach and full listing might make different predictions about behavior in lexical access tasks.

2.5.1. Substitution diacritics

Rather than a full string of phonemes, a derived word's lexical entry could consist of a string of morphemes, plus diacritics indicating additional unpredictable information, such as nasal substitution (see the discussion of diacritic-based exceptionality in §1.1.1.1).[54] This approach shares properties of full listing (each word has its own lexical entry) and stem-listing (only unpredictable information is listed). We could assign the special diacritic to nonsubstituting words, to substituting words, or to both. If the diacritic is applied only to substituting words, we need some mechanism to distinguish between listed, nonsubstituting words and novel words—that is, we must ensure that a listed, diacritic-less word (almost) never undergoes substitution, whereas a novel word (also diacritic-less) may well undergo it. Similarly, if only nonsubstituting words bear the diacritic, we need a mechanism to distinguish the behavior of a diacritic-less listed word (which must undergo substitution) and a novel word (also diacritic-less, which may or may not substitute).

Absent such a mechanism, every word that is consistently substituted or consistently unsubstituted must bear the diacritic [+NasSub] or [-NasSub]. To make the grammar sensitive to the difference, the constraint NASSUB could be split into two constraints (high-ranked $\text{NASSUB}_{[+]}$ and low-ranked $\text{NASSUB}_{[-]}$), or its definition could be modified so that it does not apply to [-NasSub] words.[55]

---

[54] The presence of the diacritic would make a word subject to special constraints or to a special constraint ranking.

[55] Restricting NASSUB to only [+NasSub] words would not work, because NASSUB must be able to apply to newly coined words, which would not have any diacritic. Variable words might be words that lacked a diacritic.

The diacritics approach is equivalent, for present purposes, to full listing: novel words' behavior is variable and depends solely on the grammar; the lexicon determines the behavior of established words.

2.5.2. Underspecification

The underspecification approach of Inkelas, Orgun, and Zoll 1997 (see §1.1.1.1) assigns a fully specified feature matrix to a segment that resists an alternation (Faithfulness constraints preserve the underlying feature values no matter what), and an underspecified feature matrix to a segment that does alternate (Markedness constraints fill in context-appropriate feature values).

Underspecification might work well if all the derivatives of a single stem behaved uniformly: representations for a hypothetical nonsubstituting stem *palid* (with full specification) and a hypothetical substituting stem *pilad* (with underspecification) are shown in (44). Faithfulness constraints would prevent [-nasal] segments from merging with prefix-final *ŋ*, but [0nasal] segments would be free to merge.

(44) Partial lexical entries for underspecification approach

p a l i d	P i l a d
|	|
[-nasal]	[0nasal]

Because multiple features are involved, the underspecification approach would also need to ensure that when the *P* in */Pilad/* becomes [+nasal], it also becomes [+voice], [+sonorant], and so on, and that a [-voice] specification does not prevent coalescence into a nasal.[56]

---

[56] Nasal-initial stems (which would be [+nasal]) are also a problem. As discussed in §2.2.1, it is unclear whether or not they can undergo substitution, but it is clear that sometimes they do not (e.g., pa**ŋ**-**m**arká 'marker'). Because IDENT-IO[NASAL] could not prevent substitution on a [+nasal] segment, MORPHORDER

But in any case, as discussed in §2.2.3, a stem's derivatives do not behave uniformly. The underspecified/fully specified contrast, then, would be implemented in the derived words themselves, which buys little, since an underspecified segment like the *P* in */maŋPilad/* would always be in the same context (nasal-substituting).

Another use of underspecification would be for novel words: the initial obstruents of stems themselves could be underspecified ([0nasal]), so that when stems were combined for the first time with a substitution-inducing prefix, it would be up to the grammar to determine whether or not nasal substitution would apply: MORPHORDER and the *[NASAL constraints would discourage substitution; NASSUB and *NC̥ would encourage it. The stem-initial segments of existing derived words, on the other hand, would be fully specified as [-nasal] if unsubstituted and [+nasal] if substituted, and high-ranking IDENT-IO[NASAL] would preserve the underlying feature values. Again, this version of underspecification would be largely equivalent to full listing.

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would have to somehow be formulated or parametrized so as to prevent substitution on [+nasal] segments but not on [0nasal] segments.

2.5.3. Allomorph listing

The final approach to be considered is allomorph listing. If the derivatives of a stem behaved uniformly, we might say that a nonsubstituting stem had just one allomorph—continuing the example from (44), */palid/*—whereas a substituting stem had two—*/pilad/* and */milad/*.[57] For stems with two allomorphs, the best one would be selected according to context (*ŋ*-final prefix or not—the prefix would also have to have two allomorphs).

Adapting the allomorphs approach to the unpredictable behavior of a stem's derivatives, we could let each derivative's lexical entry specify which allomorph it selects. In this case, the only empirical difference between a stem with no nasal-substituted allomorph and a stem with a substituted allomorph that no derivatives happen to select would be that novel derivatives of the first kind of stem would most likely be unsubstituted at first—a substituted allomorph might later develop—because a substituted pronunciation could arise only from the grammar. Novel derivatives of the second kind of stem would be more likely to substitute, since a substituted pronunciation could arise either from the grammar or from selecting the existing, substituted allomorph.[58] Aside from this difference between classes of stems, the allomorphs approach is equivalent in effect to diacritics for derivatives.

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[57] Actually, several allomorphs would be necessary in order to deal with other phonology that a derived word (including potentially nasal-substituted words) might undergo, such as vowel raising with suffixation (see Chapter 4), syncope (see §4.7.2), and stress shifts.

[58] See Steriade 1999 for evidence that the pronunciation of a new derived word depends on the available allomorphs for the word's stem

2.6. The Learner

Section 2.4.7 proposed that constraints are stochastically ranked. But "stochastic" does not mean "freely variable": the learner must determine *ranking values* for each constraint, which will then determine the probability of any particular total ranking of constraints. This section gives a brief explanation of Boersma's (1998) Gradual Learning Algorithm, and then shows what kind of grammar is learned using the constraints introduced and a mini-lexicon. In particular, I will show how the Gradual Learning Algorithm can rank constraints even when their presence is unnecessary in tableaux for existing words; subsequent sections exploit this result.

Boersma's Gradual Learning Algorithm was designed to learn a stochastic grammar (see §2.4.7) from variable data. The algorithm is error-driven: it generates hypothetical outputs, in proportion to the frequencies generated by the constraint ranking achieved so far. Schematically, a grammar consisting only of the constraints PU and NASSUB would begin with the two constraints equally ranked. For the input */mamigaj/*, outputs *[mamigaj]* (correct) and *[mambigaj]* (incorrect) would each be produced 50% of the time:

(45) Learning, starting with two equally-ranked constraints

NASSUB >> PU (probability .5)

	/mamigaj/	NASSUB	PU
☞	mamigaj		*
	mambigaj	*!	

PU >> NASSUB (probability .5)

	/mamigaj/	PU	NASSUB
☜	mambigaj		*
☞	mamigaj	*!	

Learning occurs when an output is incorrect, as in the second tableau (incorrectly selected candidate indicated by ☜; "real" winner, not selected under this ranking, indicated by ☞). The constraint violations of the incorrect winner (*mambili*) are compared to those of the correct output (*mamili*) and constraint rankings are adjusted accordingly: all constraints on which the incorrect output does better than the correct output are demoted, and all constraints on which the correct output does better than the incorrect output are promoted. Note that only two candidates are relevant to adjusting the constraint ranking: the incorrect winner and the correct output. The adjustment does not take into account the constraint violations of the other candidates, since they were correctly ruled out by the ranking used. Note also that each candidate is an input-output pair: the learner does not have to, for example, consider all possible inputs that could have generated the correct or incorrect output.

In this case, if *mambili* is incorrectly chosen as the winner, PU is demoted—since *mambili* has fewer violations of it than *mamili* does—and NASSUB is promoted—since *mambili* has more violations of it than *mamili* does. Adjustments are initially large, and become smaller and smaller as learning progresses, so that as the learner approaches its "adult" state, the grammar is not very susceptible to change.

I applied the Gradual Learning Algorithm (using Hayes 1999) to a set of substituted and unsubstituted words, composed of hypothetical stems each with a nasal-substituting prefix, assuming that each was fully listed as a whole word. The corpus reflected the numbers of substituted and unsubstituted words in the lexicon[59] for all constructions combined. The table in (46) summarizes the composition of the mini-lexicon used for learning.

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[59] Only type frequencies were used, because token frequencies were not available.

(46) Mini-lexicon for learning

initial segment	*number of words*	
	substituted	unsubstituted
p	21	1
t & s	36	3
k	15	1
b	15	8
d	2	6
g	0	8

Along with the correct candidate (the faithful rendering of the lexical entry), each tableau had three incorrect candidates: the unfaithful rendering of the lexical entry (e.g., */pamuntol/ → [pampuntol]*, or */paŋkundol/ → [paŋundol]*), the unsubstituted prefix+stem (*/paŋ/+/puntol/→ [pampuntol]*), and the substituted prefix+stem (*/paŋ/+/puntol/→ [pamuntol]*). The constraints used were those given in §2.4.

Since all the words were fully listed, ENTRYLINEARITY and USELISTED together suffice to select the correct output. On every learning trial in which an incorrect output is produced, ENTRYLINEARITY or USELISTED is promoted, but adjustment of other constraints also occurs. For example, if the ranking in (47) is generated, the incorrect candidate ☟*/pamuntol/ → [pampuntol]* is selected instead of the correct candidate ☜*/pamuntol/ → [pamuntol]*. So, NASSUB, *NC̥, and ENTRYLIN must be promoted; PU and *[m must be demoted.

(47) Sample learning trial

	PU	NAS SUB	*[ŋ	*NC̥	*[m	*[n	USE LISTED	MORPH ORDER	ENTRY LIN
☟ /pamuntol/ → pampuntol		←*		←*					←*
☜ /pamuntol/ → pamuntol	*!→				*→				
/paŋ/+/puntol/ → pampuntol		*		*			*!		
/paŋ/+/puntol/ → pamuntol	*!				*		*	*	

If the lexical entry in question had instead been */panuntol/*, the *[NASAL constraint to be demoted would have been *[n, and if the lexical entry had been */paŋuntol/*, *[ŋ would have been demoted. The proportion of words that are substituted in the mini-lexicon is higher for labials (36 out of 45 are substituted) and coronals (38 out of 47) than for velars (15 out of 24). Since *[NASAL constraints are demoted only when the correct output is substituted (and the grammar instead selects an unsubstituted output), *[m and *[n are demoted more often than *[ŋ. In other words, even though in the target grammar the *[NASAL constraints play no role in determining the optimal output, their relative ranking is learned because the Gradual Learning Algorithm adjusts the rankings of all constraints on which the correct and incorrect candidates differ.[60]

When ENTRYLINEARITY and USELISTED climb high enough in grammar that no more incorrect outputs are generated, learning stops. Therefore, the initial constraint adjustment increment must be small enough that there is opportunity to learn about the lower-ranked, seemingly irrelevant constraints before ENTRYLINEARITY and USELISTED take over.[61]

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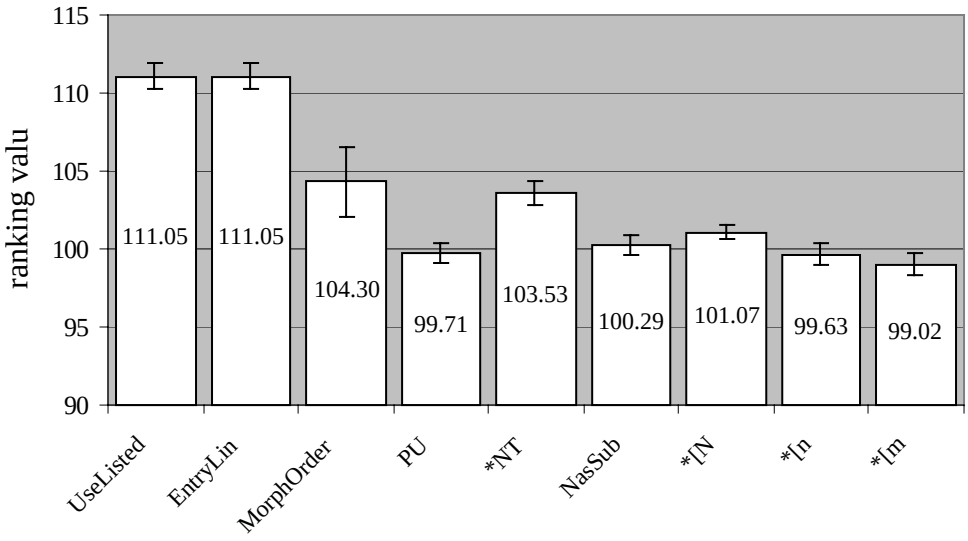
[60] Although it is clear among voiced obstruents that there is a much higher rate of substitution for [b] than for [d], the large number of substituted voiceless coronals (the [t]s *and* the [s]s) obliterates the labial/coronal distinction. If the mini-lexicon is devised so that each obstruent type is equally represented (e.g., 10 [p]s, 10 [t]s and [s]s, etc.) and the rate of substitution within each type is reflected, rather than absolute numbers of substituted words, a sharp ranking difference emerges between *[m and *[n as well as between those two and *[ŋ.

Evidence for the ranking of the *[NASAL constraints could also come from the distribution of roots in the lexicon (see (36)), although these were not included in the learning procedure. For example, there are few roots beginning in /ŋ/, and so there would be few instances in which the learner had to demote *[ŋ because a candidate that obeyed it (e.g., /ŋata/ → [kata]) had mistakenly won; there are more roots beginning in /m/, and so more instances in which *[m would be similarly be demoted.

[61] This seeming inefficiency is not troubling if we consider that in the early stages of learning, the child may be ill-equipped to guess which words as really listed for adults and which are synthesized, and may not have enough evidence about the underlying form to know whether ENTRYLINEARITY is ever violated. So learning that involves USELISTED, ENTRYLINEARITY, and other non-phonotactic constraints should proceed cautiously.

Using an initial learning increment of 0.1 and a final increment of 0.0001 over 2000 trials produced satisfactory results (in each trial, one output is generated for each word in the mini-lexicon). The average constraint rankings over twelve such runs are shown in (48); error bars indicate standard deviations.[62]

(48) Ranking values arrived at by Gradual Learning Algorithm



The following section shows what kind of production behavior occurs with this grammar.

Note that in the case of nasal substitution, the high ranking of ENTRYLINEARITY is essential to assuring that listed words are pronounced faithfully. This high ranking is assured because although different words give conflicting evidence to the learner about the ranking of most constraints (PU, NASSUB, *[m, etc.), every word gives evidence in the same direction for ENTRYLINEARITY—the correct candidate always obeys

[62] The standard deviation, that is, of the ranking values arrived at over the twelve runs, which could be imagined as twelve different learners' exposures to the same data.

ENTRYLINEARITY. This result generalizes to other cases of exceptionality: if existing words' stable behavior is encoded in some property of their lexical entries, then the constraint(s) requiring faithfulness to that property will always become high ranked, because correct candidates always obey them.

2.7. The Speaker

Section 2.6 presented the typical ranking values that a learner arrives at after exposure to the lexicon. The ranking values determine the probability that a given candidate will be optimal in a particular tableau, but there is a certain amount of calculation involved. This section goes through the steps that yield the frequencies at which the grammar predicts various outcomes for both listed and novel words.

2.7.1. Probability of a candidate's being optimal

As described in §2.4.7, in the Boersmian model, a constraint ranking is chosen probabilistically for each utterance, in accordance with the ranking values in the grammar. Once the ranking is chosen, the optimal output for a given input is fully determinate. But, in my model, the availability of inputs in a given utterance is also decided probabilistically (on the basis of Listedness values). Therefore, the probability of occurrence for any output, given the speaker's linguistic intentions, depends probabilistically on both the grammar and the lexicon.

Before giving actual numbers for nasal substitution, some explanation of the method for calculating these probabilities: The probability of a lexical entry's being available is straightforward. As discussed in §2.4.4, it is a function of how many times the word has been heard, (as well as, ideally, from whom and in what context). §3.4 discusses the function further.

(49) Availability as a function of listedness

P(Available(Entry)) = Listedness(Entry)

If the set of available inputs is known, the probability that a particular input-output pair will be chosen as optimal is just the probability that a constraint ranking under

which that pair is optimal will be generated. The set of such rankings can be determined by inspecting a tableau. For example, in the schematic tableau in (50), in order for candidate *a* to be optimal, it must be superior to both *b* and *c*. For *a* to be superior to *b*, *a*'s violations of C_2 and C_4 must be outweighed by *b*'s violations of C_1 and/or C_3. In other words, either C_1 or C_3 must outrank C_2, and either C_1 or C_3 must outrank C_4. Similarly, for *a* to be superior to *c*, C_1 must outrank C_4.

(50) Hypothetical tableau

	C_1	C_2	C_3	C_4
(a)		*		*
(b)	*		*	
(c)	*	*		

Any ranking that meets the condition in (51) will produce *a* as the optimal candidate.

(51) Ranking requirements for candidate a *in (50) to be optimal*

(C_1 >> C_2 OR C_3 >> C_2) AND C_1 >> C_4

Before showing how to calculate the probability of obtaining a ranking consistent with complex requirements like those in (51), let us first consider the simplest case, with only two candidates and two constraints:

(52) Simple hypothetical tableau

	C_1	C_2
(a)		*
(b)	*	

Computing the probability of C_1>>C_2 is fairly simple and is described in §2.11. In brief, in a given utterance, each constraint is assigned a "selection point", or actual value, based on the constraint's ranking value in the grammar and a certain degree of random noise. Therefore, $P(C_i>>C_j)$ depends only on the difference in ranking value between C_i and C_j.

Probabilities of $C_i>>C_j$ for integer differences in ranking value from -10 to 10 are given in (53).

(53) Probability of C_i's outranking C_j in a given utterance

$rV(C_i) - rV(C_j)$	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1
$P(C_i>>C_j)$	.0002	.0007	.002	.007	.02	.04	.08	.14	.24	.36

0	1	2	3	4	5	6	7	8	9	10
.50	.64	.76	.86	.92	.96	.98	.993	.998	.9993	.9998

The situation is more complicated if we want to calculate $P(C_1>>C_2$ *AND* $C_1>>C_3)$. We cannot simply multiply ($P(C_1>>C_2) * P(C_1>>C_3)$), because $P(C_1>>C_2)$ and $P(C_1>>C_3)$ are not independent. A method for calculating probabilities of complex ranking requirements is given in §2.11, with a sample calculation in *Mathematica* given in §2.12.

We can now begin to calculate actual probabilities of outcomes from the grammar learned in §2.6.

2.7.2. Generating a listed form

When a listed word exists, the probability that it will be faithfully used is very high, but never quite 1. The probability at which unfaithful outcomes occur—or at which the listed form is ignored in favor of forming the word afresh—is quite low given the grammar learned in §2.6, low enough to be in the realm of speech errors.

For a listed, substituted form of a *p*-initial stem with the *maŋ+R_{CV}-* prefix complex (/mamumuntol/), the four outcomes I will consider here are faithful */mamumuntol/ → [mamumuntol]*; unfaithful */mamumuntol/ → [mampupuntol]*; unsubstituted, newly formed */maŋ/+/R_{CV}/+/puntol/ → [mampupuntol]*; and substituted, newly formed */maŋ/+/R_{CV} /+/puntol/ → [mamumuntol]*:

(54) Four candidates for a listed, substituted word

	USE LISTED	ENTRY LIN	MORPH ORDER	*NC̥	NASSUB	PU-maŋ +R_{CV}-	*[ŋ	*[n	*[m
/mamumuntol/ → [mamumuntol]						*			*
/mamumuntol/ → [mampupuntol]		*		*	*				
/maŋ/+/R_{CV}/+/puntol/ → [mampupuntol]	*			*	*				
/maŋ/+/R_{CV} /+/puntol/ → [mamumuntol]	*		*			*			*

For the faithful output */mamumuntol/ -> [mamumuntol]* to occur, (i) the input */mamumuntol/* must be available; (ii) PU must be outranked by *NC̥, or NASSUB, or USELISTED and ENTRYLINEARITY; and (iii) *[m must be outranked by *NC̥, or NASSUB, or USELISTED and ENTRYLINEARITY. If */mamumuntol/*'s listedness is 0.953, for example, the probability of (i) is 0.953. The joint probability of (ii) and (iii) is 0.9999,[63] so the probability of */mamumuntol/ → [mamumuntol]*'s being the optimal output given that */mamumuntol/* is 95.3% listed is 0.953 * 0.9999 = 0.953.

We can similarly calculate the probability that */mamumuntol/ → [mampupuntol]* will be the optimal candidate:

P(*/mamumuntol/* is available) = 0.953
P((PU or *[m >> ENTRYLIN) and (PU or *[m >> *NC̥) and (PU or *[m >> NASSUB) and (USELISTED >> ENTRYLIN)) = 0.00003

P(*/mamumuntol/ → [mampupuntol]*) = 0.00003

Thus, */mamumuntol/ → [mampupuntol]* is possible, but extremely unlikely.

We can also calculate P(*/maŋ/+/R_{CV}/+/puntol/ → [mampupuntol]*) and P(*/maŋ/+/R_{CV}/+/puntol/ → [mamumuntol]*), both small but not minuscule:

[63] Using the method in §2.11, this is the result of integrating pdf($z_{*NC̥}$, z_{NasSub}, $z_{UseListed}$, $z_{EntryLin}$, $z_{*[m}$) over the region where the requirements in (ii) and (iii) are met.

P(*/maŋ/+/R_{CV}/+/puntol/ → [mampupuntol]*)

= P(*/maŋ/+/R_{CV}/+/puntol/ → [mampupuntol]*| */mamumuntol/* is not available) *
P(*/mamumuntol/* is not available)
+ P(*/maŋ/+/R_{CV}/+/puntol/ → [mampupuntol]*| */mamumuntol/* is available) *
P(*/mamumuntol/* is available)

= 0.600 * 0.047 + 0.00003 * 0.953
= 0.029

P(*/maŋ/+/R_{CV}/+/puntol/ → [mamumuntol]*) =

= P(*/maŋ/+/R_{CV}/+/puntol/ → [mamumuntol]*| */mamumuntol/* is not available) *
P(*/mamumuntol/* is not available)
+ P(*/maŋ/+/R_{CV}/+/puntol/ → [mamumuntol]*| */mamumuntol/* is available) *
P(*/mamumuntol/* is available)

= 0.399 * 0.047 + 0 * 0.953
= 0.019

(P(*/maŋ/+/R_{CV}/+/puntol/ → [mamumuntol]*| */mamumuntol/* is available) = 0 because candidate */maŋ/+/R_{CV}/+/puntol/ → [mamumuntol]*'s constraint violations are a superset of candidate /*mamumuntol/ → [mamumuntol]*'s.)

We can perform the same calculations to determine the likelihood of each outcome if the 95.3% listed input */mampupuntol/* exists (assuming there is no listed input */mamumuntol/*[64]):

[64] If there are two listed entries for the word, the calculations are still straightforward, but there are six candidates in the tableau (two for the first entry, two for the second entry, and two for the prefix+stem combination). But the model given in 3 of how the listener updates her lexicon prevents two competing entries from becoming fully listed, so this case is not considered here.

(55) Candidate probabilities if /mampupuntol/ exists

	USE LISTED	ENTRY LIN	MORPH ORDER	*NC̥	NASSUB	PU-maŋ +R_{CV}-	*[ŋ	*[n	*[m
/mampupuntol/ → [mampupuntol]				*	*				
/mampupuntol/ → [mamumuntol]		*				*			*
/maŋ/+/R_{CV}/+/puntol/ → [mampupuntol]	*			*	*				
/maŋ/+/R_{CV}/+/puntol/ → [mamumuntol]	*		*			*			*

P(/mampupuntol/ → [mampupuntol]) = 0.953
P(/mampupuntol/ → [mamumuntol]) = 0.00003
P(/maŋ/+/R_{CV}/+/puntol/ → [mampupuntol]) = 0.029
P(/maŋ/+/R_{CV}/+/puntol/ → [mamumuntol]) = 0.019

The following table summarizes the same results for all six types of initial obstruent, to five decimal places:

(56) P(input|output) for various stem-initial obstruents

	p	*t/s*	*k*	*b*	*d*	*g*
/substituted/						
P(/*substituted*/ → [*substituted*])	.95251	.95249	.95219	.95250	.95247	.95213
P(/*substituted*/ → [*unsubstituted*])	.00003	.00004	.00019	.00004	.00005	.00022
P(/maŋ/+/R_{CV}/+/X/ → [*unsubstituted*])	.02852	.02868	.02969	.04429	.04441	.04500
P(/maŋ/+/R_{CV}/+/X/ → [*substituted*])	.01894	.01879	.01793	.00317	.00307	.00265
/unsubstituted/						
P(/*unsubstituted*/ → [*unsubstituted*])	.94566	.94566	.94568	.95246	.95246	.95246
P(/*unsubstituted*/ → [*substituted*])	.00363	.00363	.00361	.00007	.00007	.00006
P(/maŋ/+/R_{CV}/+/X/ → [*unsubstituted*])	.02849	.02864	.02950	.04426	.04436	.04478
P(/maŋ/+/R_{CV}/+/X/ → [*substituted*])	.02223	.02208	.02121	.00322	.00312	.00270

The high ranking values of USELISTED and ENTRYLINEARITY tend to swamp differences among stem-initial segments and between the two constructions, but as we will now see, the differences become greater when there is no listed form.

2.7.3. Generating a novel form

When there is no listed form, the only possible candidates are */maŋ/+/R_{CV}/+/X/ → [unsubstituted]* and */maŋ/+/R_{CV}/+/X/ → [substituted]*. The probabilities of the two outcomes for each stem-initial obstruent are given in (57), which shows that the overall rate of substitution on novel words will be fairly low. There are slight differences in probability of substitution among the three places of articulation, and there is a sharp difference between voiced and voiceless segments.

(57) Probabilities of outcomes when no listed form exists

	p	*t/s*	*k*	*b*	*d*	*g*
P(/maŋ/+/R_{CV}/+/X/ → [*unsubstituted*]	.60066	.60385	.62198	.93314	.93527	.94413
P(/maŋ/+/R_{CV}/+/X/ → [*substituted*]	.39934	.39615	.37802	.06686	.06473	.05587

We can see, then, that the grammar produces the desired result for speakers: very high faithfulness to listed words, and low but nonzero substitution on novel words. Chapter 3 shows how the probabilistic interaction of speakers and listeners shapes the establishment of new words in the lexicon.

2.8. The Listener

2.8.1. Introduction

In addition to the behavior of the learner and the speaker, the model must also account for the behavior of the listener. Most work on perception/comprehension in OT has focussed on how the listener retrieves the underlying form given the utterance she hears (Smolensky 1996b, Tesar 1998, Boersma 1998, Pater 1999a). The meat of that problem here is not calculating the segmental content of the input, but rather deciding whether the input was a single listed word or a concatenation of morphemes. This section discusses how the listener makes this decision, which is crucial to determining the probability that a new polymorphemic word will eventually be assimilated into the lexicon as substituted or as unsubstituted. This section also discusses how the listener arrives at a judgment of how acceptable an utterance is; in particular, I will show how the model produces acceptability judgments similar to those seen in the experiment.

2.8.2. Reconstructing the underlying form

The idea of *lexicon optimization* was introduced Prince and Smolensky (1993) and elaborated by Itô, Mester, and Padgett (1995) and Smolensky (1996b): given an output produced by another speaker, the listener chooses the input such that the input-output pair is maximally harmonic. A schematic example is shown in (58).

(58) Choosing the optimal input

[bak]	NoCoda	Dep-C
☞ /bak/ → [bak]	*	
/ba/ → [bak]	*	*!

Because the output is held constant, violations of pure markedness constraints (in this case NOCODA) and of correspondence constraints not involving the input (e.g., CORR-BR) are the same for every input. Therefore, CORR-IO constraints alone (here, DEP-C) determines the optimal input, and the optimal input is the one that is most similar to the actual output. Differences between input and output then exist only when driven by alternations.[65] For example, in Hale and Reiss's (1998) model of grammar- and lexicon-learning, when different outputs are recognized as containing the (semantically and morphosyntactically) same morpheme, in order to avoid synonymy they are learned as having the same input, which must then violate Input-Output Correspondence at least sometimes.

Without adopting the details of any particular version of input recognition in Optimality Theory, I will assume that the adult listener is capable of recognizing that hypothetical *[mamumuntol]*—uttered in a context that supplies morphosyntactic and semantic information—may be composed of the familiar morphemes *maŋ*, R_{CV}, and *puntol*.[66]

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[65] Or, as in Prince and Smolensky 1993 (p. 196), by violations of *SPEC, which prohibits underlying material. The tension between *SPEC and Input-Output Correspondence is the tension between storing as little information as possible in the lexicon and changing the input as little as possible when uttering it.

[66] An interesting question is what the listener does if the stem *puntol* is not familiar. The listener must then decide whether the stem is *puntol*, *buntol*, or *muntol* (*tuntol*, etc. are easily ruled out by faithfulness constraints on obstruent place of articulation).

The model predicts that the probability that the listener would select a particular stem—*P(/puntol/|[mamumuntol])*—is proportional to two other probabilities: first, the prior probability of that stem's existence—*P(/puntol/)*—which can be calculated from lexical statistics on the frequency of word-initial *p*, the frequency of cooccurrence of *p* and *l* within a word, etc.; and second, the probability that *[mamumuntol]* would be produced given the stem under consideration—*P([mamumuntol]|/puntol/)*—which is straightforwardly calculable from the constraint ranking.

In the experiments described above in §2.3.3, though, the listener knows the segmental content of the stem, because it is presented in the prompt, so stem selection is not part of the task.

But the listener also must consider the possibility that *[mamumuntol]* was generated from a single listed form, such as */mamumuntol/* or */mampupuntol/*. Assuming that decisions about underlying forms are made stochastically, the listener must compare the three probabilities in (59).

(59) Three possibilities on hearing [mamumuntol]

P(/maŋ/+/R_{CV}/+/puntol/|[mamumuntol])	"the probability that the speaker's input was */maŋ/+/R_{CV}/+/puntol/*, given that the output heard was *[mamumuntol]*"
P(/mamumuntol/|[mamumuntol])	"the probability that the speaker's input was */mamumuntol/*, given that the output heard was *[mamumuntol]*"
and	
P(/mampupuntol/|[mamumuntol])	"the probability that the speaker's input was */mampupuntol/*, given that the output heard was *[mamumuntol]*"

As shown in (60), we can rewrite these using Bayes' Theorem. The theorem states:

> P(A|B) = P(B|A)*P(A)/P(B)
> "The probability of A given B is equal to the probability of B given A, times the prior probability of A (i.e. the probability of A when nothing is known about B), divided by the prior probability of B."

(60) Bayesian inversion of probabilities compared by listener

P(/maŋ/+/R_{CV}/+/puntol/ | [mamumuntol])
= P([mamumuntol] | /maŋ+R_{CV}+puntol/) * P(/maŋ/+/R_{CV}/+/puntol/) / P([mamumuntol])

P(/mamumuntol/ | [mamumuntol])
= P([mamumuntol] | /mamumuntol/) * P(/mamumuntol/) / P([mamumuntol])

P(/mampupuntol/ | [mamumuntol])
= *P([mamumuntol] | /mampupuntol/) * P(/mampupuntol/) / P([mamumuntol])

Since the denominators are the same in all three expressions, the numerators determine the differences in probability. The probabilities *P([mamumuntol]| /maŋ/+/R_{CV}/+/puntol/)*, *P([mamumuntol]| /mamumuntol/)*, and *P([mamumuntol]| /mampupuntol/)* are calculated by the grammar. Given the grammar learned in §2.6, they are equal to 0.39934, 0.99936, and 0.00003, respectively. But we still need to know the prior probabilities *P(/maŋ/+/R_{CV}/+/puntol/)*, *P(/mamumuntol/)*, and *P(/mampupuntol/)*. In other words, the listener must decide how likely it is that the speaker's lexicon contains this word as a single, pre-packaged entity (and that this lexical entry was used) versus how likely it was that the speaker formed the word on the fly by concatenating a prefix and a stem.

How does the listener make this decision? One possibility is that she relies solely on the listedness of */mamumuntol/* or */mampupuntol/* in her own lexicon, taking each word's listedness as the probability that it was used by the speaker.

But a more cautious listener, capable of learning new words from interlocutors, would also take into account the overall productivity of the *maŋ+R_{CV}-* construction. *P(/maŋ/+/R_{CV}/+/puntol/)* should decrease as the listedness of a whole word (*/mamumuntol/* or */mampupuntol/*) increases, and should increase as the productivity of *maŋ+R_{CV}-* increases. In other words, the more listed a whole word is for the listener, the less likely that the speaker would have composed */maŋ/+/R_{CV}/+/puntol/* on the fly—since the speaker and listener belong to the same speech community, the listener can assume that their lexicons will tend to be similar—and, the more productive the construction is, the more easily the speaker could have employed it to generate a new word. Additionally, *P(/maŋ/+/R_{CV}/+/puntol/)* should be close to 0 if a whole word is 100% listed, regardless of the productivity of *maŋ+R_{CV}-* (no matter how productive the construction is, if the word is already listed it will probably not be formed anew), and it should also be close to

0 if the productivity of *maŋ+R_{CV}-* is zero, regardless of the listedness of any whole word (even if the word is isn't listed for the listener, if the construction is not productive, it must have been listed for the speaker). The function shown in (61) has the desired properties; the constants 3 and 6 were chosen (somewhat arbitrarily) because they produce endpoints that are close to zero and one, and a gentle slope (rather than a strict cutoff) centered on 0.5 on each axis.[67]

(61) P(/maŋ/+/R_{CV}/+/puntol/) = $1/((1+e^{-3+6*Listedness(whole\ word)})*(1+e^{3-6*Productivity(maŋ+Rcv)}))$

[67] In a function of the form $y = 1/(1+e^{a-bx})$ (a logistic function), *b* determines how steep the function is (large absolute value for *b* means steep slope; positive *b* means *y* increases as *x* increases; negative *b* means *y* decreases as *x* increases)and *b/a* is the location of the "half-way point"—the value of x for which y = 0.5. Similarly, in multi-dimensional functions with multiple $(1+e^{\wedge}(a_i - b_i x_i))$ multiplied together in the denominator, each b_i determines the steepness of the function along the dimension x_i, and a_i/b_i determines where on the x_i axis the function is centered.

where *Listedness(whole word)* is the listedness of whichever appropriate word is more listed (*max(Listedness(/mamumuntol/), Listedness(/mampupuntol/))*).

How does the listener assess the productivity of the construction *maŋ-R_{cv}*? There are several cues available. One cue is the proportion of stems of the appropriate morphosyntactic and semantic category that the listener has experienced as occurring in the construction. For example, if *maŋ-R_{cv}-* is highly productive, the listener will have heard the *maŋ-R_{cv}-* form of many stems; gaps would be accidental (and should tend to be for rare stems). But if it is not very productive, only (or mostly[68]) those stems that have a listed *maŋ-R_{cv}-* form can ever occur with *maŋ-R_{cv}-*, and so there will be many stems that the listener has never heard with *maŋ-R_{cv}-*. If we can use dictionary entries as a rough guide,[69] sampling just the first stem on every tenth page[70] with any nonstative verbal derivative (as a rough diagnostic of suitability for the *maŋ-R_{cv}-* construction), 12 out of 152 have a *maŋ-R_{cv}-* derivative, yielding a productivity index of 0.079. Ideally, this index would be weighted for frequency—the absence of a *maŋ-R_{cv}-* form for a low-frequency stem should not count against productivity as much it would for a high-frequency stem.

A second cue is the correlation between the token frequency of each *maŋ-R_{cv}-* word and the token frequency of its stem. If the construction is very unproductive, there will be many separately listed *maŋ-R_{cv}-* words, whose frequencies are not affected by the

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[68] Speakers might occasionally use an unproductive construction to create a nonce form.

[69] There is an obvious flaw in relying on the dictionary, of course, rather than a text or speech corpus, because, depending on the lexicographer's methods, a very productive construction may be less likely to have its products listed in the dictionary (for example, in English 1986, only the infinitive of each verb is listed, not the various aspects). In addition, for any construction, there are probably some missing derived forms, causing all productivity indices to be artificially low.

[70] Excluding nasal-initial stems.

frequencies of their stem, weakening the correlation. Since frequency data are not available, though, we cannot calculate a productivity index based on this cue.

A third cue is the proportion of *maŋ-R_{cv}-* words that are phonologically or semantically idiosyncratic. These words must have their own lexical entries to contain the idiosyncratic information. Phonological idiosyncrasy in this case could include nasal substitution and stress shifts. The behavior of *maŋ-R_{cv}-* words with respect to stress and nasal substitution is summarized in (62). The cells in boldface are those that could be considered idiosyncratic (either a stress change or nasal substitution), and they make up 119/195 = 61% of the total. Put another way, 39% of the *maŋ-R_{cv}-* words listed in the dictionary lack idiosyncratic phonological characteristics, and thus a maximum of 39% could lack their own lexical entries and be formed on the fly.

(62) Idiosyncrasies in maŋ-R_{cv}- *words*

		stress change				
		none	varies	penultimate → final	final → penultimate	total
nasal substitution	does not substitute	50	**1**	**1**	**1**	53
	varies	**3**	**0**	**0**	**0**	3
	substitutes	**80**	**14**	**6**	**5**	105
	sonorant-initial (cannot substitute)	26	**2**	**6**	**0**	34
	total	159	17	13	6	195

If we took into account semantic idiosyncrasy, the figure might fall further. I will not develop a formal metric of semantic idiosyncrasy here, but it is clear from casual inspection of the various nasal-substituting constructions that some produce more semantic idiosyncrasy than others do. For example, the meaning of a *paŋ-* (instrumental

adjective)[71] word is almost completely predictable: *paŋ-X* means "used as a tool for *X*". In contrast, the meaning of a *maŋ+R_{cv}-* word can be considerably less predictable. *Manlulustaj* 'embezzler' from *lustaj* 'embezzle' is straightforward enough, but *manliliŋkis* 'boa constrictor' from *liŋkis* 'tightly bound' surely must have its own lexical entry.

The productivity index for *maŋ+R_{cv}-* is, then, roughly somewhere between 0.08 and 0.39. For the sake of argument, let us assume it is 0.2, which the listener combines with her listedness for this particular word, using the function in (61), to arrive at the prior probability *P(/maŋ/+/R_{CV}/+/puntol/)*. If no whole word is listed at all for the listener, *P(/maŋ/+/R_{CV}/+/puntol/)* = $1/((1+e^{-3+6*0})(1+e^{3-6*0.2})) = 0.135$.

Because the only alternatives to synthesized *P(/maŋ/+/R_{CV}/+/puntol/)* that are remotely probable are listed */mamumuntol/* and listed */mampupuntol/*, the prior probabilities *P(/mamumuntol/)* and *P(/mampupuntol/)* must add up to about 1 - 0.135 = 0.865 (still in the case that the listener has nothing listed). We want a function such that *P(/mamumuntol/)*'s share of the 0.865 (i) is greater the more listed */mamumuntol/* is for the listener, (ii) is smaller the more listed competing */mampupuntol/* is for the listener, and (iii) is greater the larger the proportion of existing potentially-substituting words with *p*-initial stems that undergo nasal substitution. Condition (iii) is necessary because in the

[71] This raises the question of whether it makes sense to treat the various adjectival *paŋ*-s as separate constructions (likewise nominal *paŋ-*, verbal *maŋ-*). It may be that adjectival *paŋ-* is really just one construction, part of whose semantic function depends on the nature of the stem, so that the primary meaning for a stem that denotes an action is instrumental, the primary meaning for a stem that denotes a situation or class of people is reservative, and any other meaning can be considered idiosyncratic.

event that neither */mamumuntol/* nor */mampupuntol/* is listed at all for the listener, she must rely on substitution rates in her lexicon[72] to decide which would be more likely.

Consider the following function (again, constants are somewhat arbitrary—see fn. 67):

$$F(/\text{mamumuntol}/) = 1/((1+e^{2-6*\text{Listedness}(/\text{mamumuntol}/)})(1+e^{-4+6*\text{Listedness}(/\text{mampupuntol}/)})(1+e^{3-6*\text{SubstProp}(p)}))$$

F increases with *Listedness(/mamumuntol/),* decreases with *Listedness(/mampupuntol),* and increases with *SubstProp(p),* the proportion of potentially nasal-substituting words based on *p*-initial stems that substitute (*SubstProp(p)* is 1, but the proportion for other segments is lower). Similarly,

$$F(/\text{mampupuntol}/) = 1/((1+e^{2-6*\text{Listedness}(/\text{mampupuntol}/)})(1+e^{-4+6*\text{Listedness}(/\text{mamumuntol}/)})(1+e^{3-6*\text{UnsubstProp}(p)}))$$

The units of *F* are arbitrary, since the purpose of *F* is to compute */mamumuntol/*'s and */mampupuntol/*'s respective shares of *1- P(/maŋ/+/R$_{cv}$/+/puntol/).* We can now use *F* to calculate *P(/mamumuntol/)* and *P(/mampupuntol/)* by dividing up *1- P(/maŋ/+/R$_{cv}$/+/puntol/)* proportionally:

(63) Prior probabilities of /mamumuntol/ *and* /mampupuntol/

$$P(/\text{mamumuntol}/) = (1-P(/\text{maŋ}/+/R_{cv}/+/\text{puntol}/)) * \frac{F(/\text{mamumuntol}/)}{F(/\text{mamumuntol}/)+F(/\text{mampupuntol}/)}$$

$$P(/\text{mampupuntol}/) = (1-P(/\text{maŋ}/+/R_{cv}/+/\text{puntol}/)) * \frac{F(/\text{mampupuntol}/)}{F(/\text{mamumuntol}/)+F(/\text{mampupuntol}/)}$$

[72] In a richer model, the listener could rely not just on substitution rates for *p*-initial stems, but also on substitution rates for classes of stems related in other ways (other segments in the stem, number of syllables).

For example, if *Listedness(/mamumuntol/) = Listedness(/mampupuntol/) = 0*,

F(/mamumuntol/)
= $1/((1+e^{2-6*\text{Listdnss(/mamumuntol/)}})(1+e^{-4+6*\text{Listdnss(/mampupuntol/)}})(1+e^{3-6*\text{SubstProp(p)}}))$
= $1/((1+e^{2-6*0})(1+e^{-4+6*0})(1+e^{3-6*1}))$
= 0.112

F(/mampupuntol/)
= $1/((1+e^{2-6*\text{Listdnss(/mampupuntol/)}})(1+e^{-4+6*\text{Listdnss(/mamumuntol/)}})(1+e^{3-6*\text{UnsubstProp(p)}}))$
= $1/((1+e^{2-6*0})(1+e^{-4+6*0})(1+e^{3-6*0}))$
= 0.006

so P(/mamumuntol/) = 0.865 * 0.112 / (0.112 + 0.006) = 0.824
and P(/mampupuntol/) = 0.865 * 0.006 / (0.112 + 0.006) = 0.041

It is now possible to begin calculating the probabilities in (60), which was the use of Bayes' Law by the listener to calculate the probability that the speaker was using a particular input. In (64), the numerators are calculated using the figures arrived at above.

(64) Calculating (60) when listener has no listed form

P(/maŋ/+/puntol/|[mamumuntol]) = 0.399 * 0.135 / P([mamumuntol])
P(/mamumuntol /|[mamumuntol]) = 0.999 * 0.824 / P([mamumuntol])
P(/mampupuntol/|[mamumuntol]) = 0.00003 * 0.041 / P([mamumuntol])

The denominator can now be calculated also, by adding together the probability of deriving *[mamumuntol]* from each possible source:

(65) Prior probability of the output

P([mamumuntol])
= P([mamumuntol]|/maŋ/+/R_{cv}/+/puntol/) * P(/maŋ/+/R_{cv}/+/puntol/) +
P([mamumuntol]|/mamumuntol/) * P(/mamumuntol/) +
P([mamumuntol]|/mampupuntol/) * P(/mampupuntol)

≈ 0.399 * 0.135 + 0.999 * 0.824 + 0.00003 * 0.041 = 0.878

Plugging this denominator into the equations in (65), we get:

(66) Final result for (64)

P(/maŋ/+/R_{cv}/+/puntol/|[mamumuntol]) ≈ 0.399 * 0.135 / 0.878 = 0.062
P(/mamumuntol/|[mamumuntol]) ≈ 0.999 * 0.824 / 0.878 = 0.939
P(/mampupuntol/|[mamumuntol]) ≈ 0.00003 * 0.041 / 0.878 = 0.000002

So, given an output *[mamumuntol]*, a listener with neither */mamumuntol/* nor */mampupuntol/* will still be most likely to identify */mamumuntol/* as the input, because the construction is not very productive, and because *P([mamumuntol]|/mamumuntol/)* is much larger than *P([mamumuntol]| /maŋ/+/R_{cv}/+/puntol/).* Still, it is not outlandish to guess that *[mamumuntol]* was synthesized (i.e., came from */maŋ/+/R_{cv}/+/puntol/*)—the listener will choose that possibility 6% of the time. She will almost never (1 time out of every 500,000) guess that the input was */mampupuntol/*.[73]

We can perform the same calculations for cases in which the listener hears *[mampupuntol]*:

(67) Determining the input given output [mampupuntol]

P(/maŋ/+/R_{cv}/+/puntol/|[mampupuntol]) =
P([mampupuntol]|/maŋ/+/R_{cv}/+/puntol/) * P(/maŋ/+/R_{cv}/+/puntol/)
/ P([mampupuntol])
= 0.601 * 0.135 / 0.125 = 0.649

P(/mamumuntol/|[mampupuntol])
= P(/mamumuntol/) * P([mampupuntol]|/mamumuntol/) / P([mampupuntol])
= 0.004 * 0.824 / 0.125 = 0.025

P(/mampupuntol/|[mampupuntol])
= P(/mampupuntol/) * P([mampupuntol]|/mampupuntol /) / P([mampupuntol])
= 0.993 * 0.041 / 0.125 = 0.326

[73] The reason *P(/mampupuntol/|[mamumuntol])* is not quite zero is that (i) the stochastic grammar has a slight chance of producing *[mamumuntol]* from */mampupuntol/*, if NASSUB or *NC̥ should outrank ENTRYLINEARITY, and (ii) the prior probability of */mampupuntol/* is slightly greater than zero: although no existing *p*-stem words fail to nasal-substitute in the *maŋ+RED_{CV}-* construction, *F* makes room for the possibility that a new one could come along.

The difference between (66) and (67) is striking: even if the listener has no relevant listed word, she is quite likely (94% probability) to conclude, after hearing *mamumuntol*, that the speaker was using a listed, substituted word and update her lexicon accordingly. After hearing *mampupuntol*, however, she is somewhat more likely to conclude that the speaker formed the word on the fly than from a listed, unsubstituted word (64% vs. 33% probability). This difference occurs partly because the difference between *P([mamumuntol]|/mamumuntol/)* and *P([mamumuntol] |/maŋ/+/R_{cv}/+/puntol/)* (0.999 vs. 0.399) is greater than the difference between *P([mampupuntol]|/mampupuntol/)* and *P([mampupuntol] |/maŋ/+/R_{cv}/+/puntol/)* (0.993 vs. 0.601), and partly because the prior probability *P(/mamumuntol/)* is large and the prior probability *P(/mampupuntol/)* is small (0.824 vs. 0.041). That is, (i) a nasal-substituted pronunciation is 60 percentage points more likely to occur with a listed input than if synthesized, whereas an unsubstituted pronunciation is only 40 percentage points more likely to occur with a listed input than if synthesized; and (ii) for stems beginning with *p*, the likelihood of a substituted listed form's existing is greater than the likelihood of an unsubstituted form's existing.

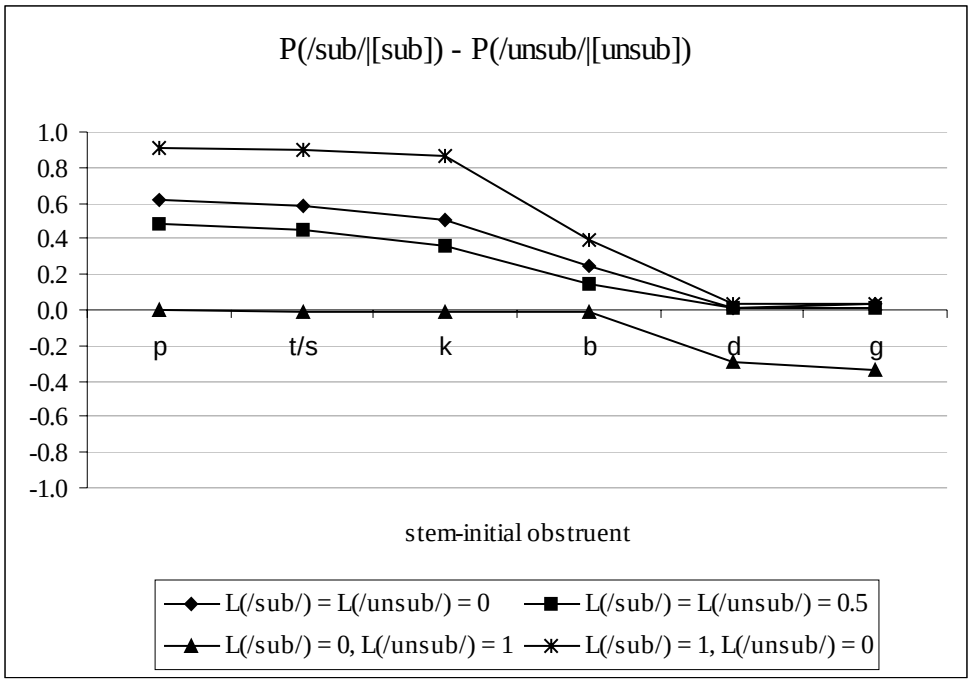
The graph in (68) shows the difference between *P(/substituted/|[substituted])* and *P(/unsubstituted/|[substituted])* for each stem-initial obstruent and for 4 different listedness situations. Values greater than 0 indicate that for that obstruent and listedness situation, a listener is more likely to update her lexicon when she hears a substituted word than when she hears an unsubstituted word. For example, if the listener has neither a substituted nor an unsubstituted word in her lexicon (—◆—), her likelihood of recording a substituted *p*-stem word is about 60 percentage points higher than her likelihood of recording an unsubstituted *p*-stem word.

Nearly all the values are greater than zero; unless the listener has a listed unsubstituted word and no listed substituted word in her lexicon (—▲—), or unless the stem-initial segment is one that rarely undergoes nasal substitution (*d* or *g*[74]), the listener is always more likely when she hears a substituted word than when she hears an unsubstituted word to assume the speaker was using a listed word (and update her own lexicon accordingly). This fact will be crucial in Chapter 3: despite the low rate of substitution on novel words, a new word still has a good chance of eventually being adopted by the speech community as substituted, since listeners will ignore most unsubstituted instances of the word, assuming them to have been formed on the fly.[75]

[74] For these obstruents, P([substituted] | /synthesized/) is low (and so P(/synthesized/ | [substituted]) is low), but P(/substituted/) is low (and so P(/substituted/ | [substituted]) is also low).

[75] I assume that only listeners update their lexicons. It is also possible that speakers update their own lexicons in response to utterances they themselves have produced.

(68) Probability of listener's guessing that speaker used a listed word: substituted - unsubstituted



2.8.3. Acceptability judgments

The other aspect of the listener's behavior to be discussed here is the generation of acceptability judgments. Following Hayes and MacEachern (1998) and Boersma and Hayes (1999), I will assume that the listener's acceptability judgment is a function[76] of the probability that her grammar could generate the utterance she has heard. This probability is directly calculable from the ranking values of the constraints (as discussed in §2.11), although it can also be approximated by running many trials of the constraint

[76] Using the function for acceptability ratings from Boersma & Hayes (1999), *Acceptability([substituted]) - Acceptability([unsubstituted]) = log(1/P([substituted]) - 1) / log(0.2).* The constant 0.2 was arrived at by trial and error for a 7-point rating scale (rather than my 10-point scale), but it seems to work well here also.

system and seeing how often the form in question was generated. Calculating the underlying form (a single word or a concatenation of morphemes) is also essential, because the underlying form must be known in order to determine how well the utterance satisfies CORR-IO constraints, violations of which reduce the utterance's probability of being generated.

Although the listener's own probability of producing novel *[mamumuntol]* (*Listedness(/mamumuntol/) = Listedness(/mampupuntol/)* = 0 for the listener), would be low—*P([mamumuntol]| /maŋ/+/R$_{cv}$/+/puntol/) = .399*—when she hears someone else say *[mamumuntol]*, she cannot be sure what her interlocutor's input form was, and so her estimate of *P([mamumuntol])* for purposes of calculating an acceptability rating must reflect all the possibilities, as shown in (69):

(69) P([mamumuntol])

= P([mamumuntol]|/mamumuntol/) * P(/mamumuntol/) +
P([mamumuntol]|/mampupuntol/) * P(/mampupuntol/) +
P([mamumuntol]| /maŋ/+/R$_{cv}$/+/puntol/) * P(/maŋ/+/R$_{cv}$/+/puntol/)

= 0.999 * 0.824 + 0.00003 * 0.041 + 0.399 * 0.135 = 0.878

(same numbers as in (64))

similarly,

P([mampupuntol])

= P(/mampupuntol/) * P([mampupuntol]|/mampupuntol/) +
P(/mamumuntol/) * P([mampupuntol]|/mamumuntol/) +
P([mampupuntol]| /maŋ/+/R$_{cv}$/+/puntol/) * P(/maŋ/+/R$_{cv}$/+/puntol/)

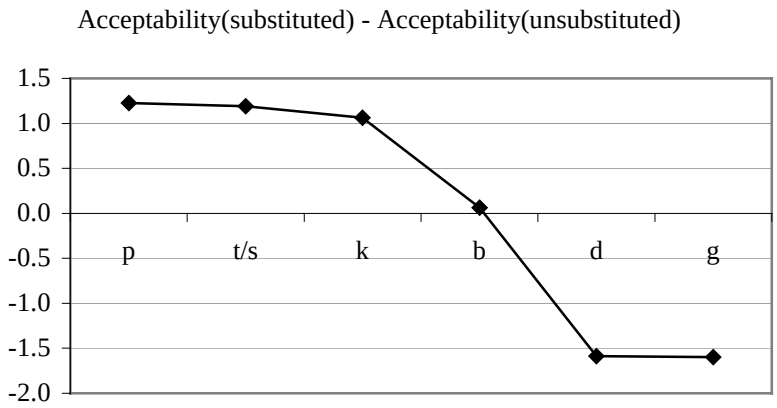
= 0.993 * 0.041 + 0.004 * 0.824 + 0.601 * 0.135 = 0.125

The result is that the probability of producing *[mamumuntol]* when the input can only be guessed at is much higher than the probability of producing *[mamumuntol]* when the input must be */maŋ/+/R$_{cv}$/+/puntol/* (0.399 vs. 0.878). The probability for

[mampupuntol] actually decreases (0.601 vs. 0.125), because the prior probability that the speaker would one of the inputs that would be likely to produce *[mampupuntol]* as output (*/mampupuntol/* or */maŋ/+/R_{cv}/+/puntol/*) is small. This may explain the experimental results in §2.3.3.1: listeners judged novel substituted words to be fairly acceptable (for voiceless-initial stems, they were judged more acceptable on average than the unsubstituted forms of the same words), even though they produced them rarely. The acceptability judgments were high because judges had to allow for the possibility that the interlocutor (in this case, the hypothetical speaker whose utterances were written on the cards shown to the judges) was using a word familiar to herself although unknown to the judge.

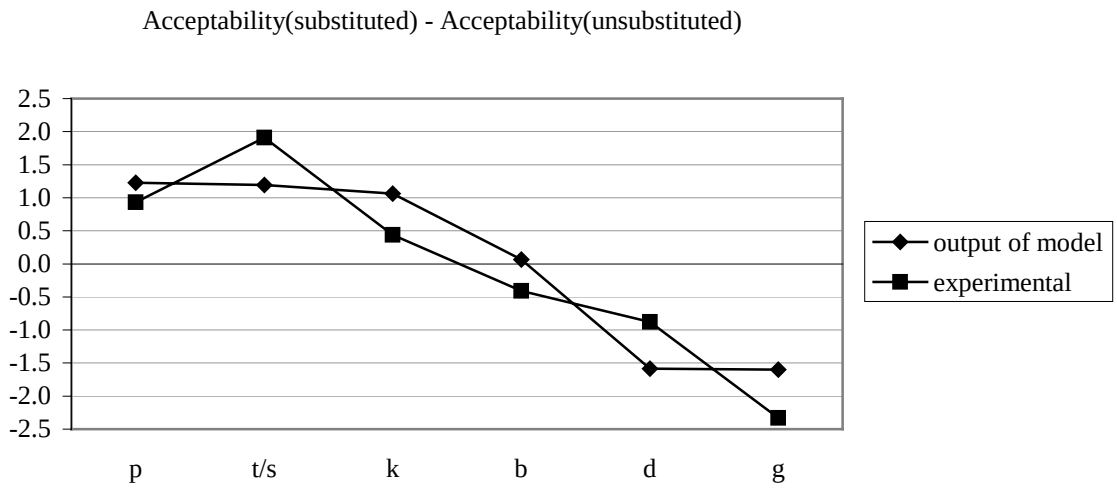
How well does the model reproduce the experimental results? The graph in (70) shows the model's predictions.

(70) Predicted acceptability of substituted vs. unsubstituted for novel words



The model correctly predicts the distinction between voiced and voiceless, and predicts a weak place-of-articulation effect. The graph in (71) shows the model's predicted values from (70) against the experimental values from (25).

(71) Predicted and experimental acceptability values (substituted - unsubstituted)



How good a match is this? The experimental results and the output of the model both reflect a voicing difference: for the voiceless stops, substitution is more acceptable (even though it is the minority pronunciation). For the voiced stops, nonsubstitution is more acceptable (for the model, substitution and nonsubstitution are equally acceptable for /b/). Neither the experimental results nor the output of the model reflects the place effect strongly: for the model, there is little difference among the voiceless obstruents and a strong difference between /b/ versus /d/ and /g/, but no difference between /d/ and /g/.

2.9. Chapter Summary

This chapter has presented a model of lexical regularities using the example of nasal substitution. It was argued that although the characteristics of existing words (substituting or not) are determined by the lexicon, nasal substitution and its regularities are nonetheless represented in the linguistic system. The model presented here attempted to encode knowledge of nasal substitution directly into the grammar, by means of low-

ranked constraints that are relevant only for novel words (for existing words, high-ranked USELISTED and CORR-IO require that the lexical entry be faithfully used).

The probabilistic rankings of the subterranean constraints are learnable through exposure to the existing lexicon and result in variable speaker behavior for novel words that reflects the patterns in the lexicon. The same probabilistic grammar used in speaking can be used in listening, to make a probabilistic guess as to a speaker's underlying form Bayesian reasoning on the part of the listener results in a bias in favor of guessing that a nasal-substituted utterance was generated from a single lexical entry (rather than from morpheme concatenation). The grammar can also be used to generate acceptability judgments for novel words (which are similar to the acceptability judgments seen experimentally). Here, the listener's uncertainty as to whether a novel-to-her word was also novel for the speaker results in higher acceptability ratings for nasal-substituted words than might be expected from the low rate of substitution on novel words when the grammar is used for speaking.

2.10. Appendix: experimental stimuli

For each obstruent (including *ʔ*), three novel-word stimulus stems were created. Each stimulus was two syllables long, did not violate any morpheme structure constraints of which I am aware,[77] and would not be homophonous with an existing stem if substituted (for example, since *dapat* already exists, *sapat* would not be considered as a novel stem). There were no pseudoreduplicated novel stems.

For a given obstruent, each of the three stems had a different first-syllable vowel (*i*, *a*, or *u*), and a prosodic pattern: penultimate stress/length; final stress and closed penult; or final stress with open (short) penult. There were, however, four *d*-initial stems, two flapped and two unflapped. As it turned out, flapping made no difference in participant behavior. (72) gives the complete list of novel stems and the approximate meanings conveyed by each stem's accompanying illustration.

(72) Novel stimulus stems

palím	'push a wheelbarrow'	
pí:hig	'get fruit down from tree by hitting with a stick'	
puntól	'prune a tree'	
tahál	'tie saplings together for support'	
tiklás	'throw feed to chickens'	
tú:kas	'drive pigs into corral'	
sawík	'split cane'	
siglót	'carry water'	
sú:kad	'weave a basket'	
ká:pat	'build a fence'	
kirít	'hoe earth'	
kuntál	'call cattle'	
bá:kad	'stamp down earth over newly planted seeds'	
bilíd	'decorate ceramic jugs'	
bugnát	'chisel strips of plank of wood'	
dagsíl	'remove caught fish from hooks'	(flapped: *pagdaragsîl*)
dampós	'remove flowers from plant'	(not flapped: *pagdadampós*)

[77] including a dispreference for identical consonants within the same root, unless it is pseudoreduplicated (see §4.4 for examples of pseudoreduplicated roots).

dîːkib	‘sew fishing nets’	(not flapped: *pagdidîkib*)
dugól	‘dig up plants’	(flapped: *pagdurugól*)
ganát	‘train vines on supports’	
gíːtap	‘smoothen edges of pot’	
gutláw	‘fish using a trap’	
ʔambój	‘fish using a net’	
ʔiːlab	‘collect eggs from nests’	
ʔúːbon	‘cool hot metal in water’	

stimuli used as practice for Task II

gáːmat	‘pound grain’
pitós	‘rake’

The criteria for choosing the real-word stimuli listed in (73) (used as practice stimuli for both groups, and interspersed with novel stimuli for Group A) were just that they have both an existing *pag+R_{CV}-* form and a *maŋ+R_{CV}-* form. An effort was made to include some common and some rare real words. Some of the real-word stems are sonorant-initial, and thus cannot undergo nasal substitution; in Task II (acceptability judgments), only the unsubstituted forms of sonorant-initial stems were used.

(73) Real-word stimulus stems

Example stimuli for Task I (*maŋ+R_{CV}-* form given)

bitháj	‘sift’[78]
hîːlot	‘massage’

Practice stimuli for Task I (*maŋ+R_{CV}-* form filled in by participant)

láːpiʔ	‘butcher’
búːboʔ	‘smelt’

Stimuli interspersed with novel stems in Group A

háːbi	‘weave’
bunóʔ	‘wrestle’
sajáw	‘dance’
súːriʔ	‘analyze’
sulsí	‘mend’
líːlok	‘sculpt’
taŋgól	‘defend (in court)’
hasík	‘sow seeds’

[78] These are not the actual glosses of the stems when used bare (*bitháj* means ‘sieve’), but rather the glosses for the action to which both the *pag+R_{CV}-* form and the *maŋ+R_{CV}-* form refer.

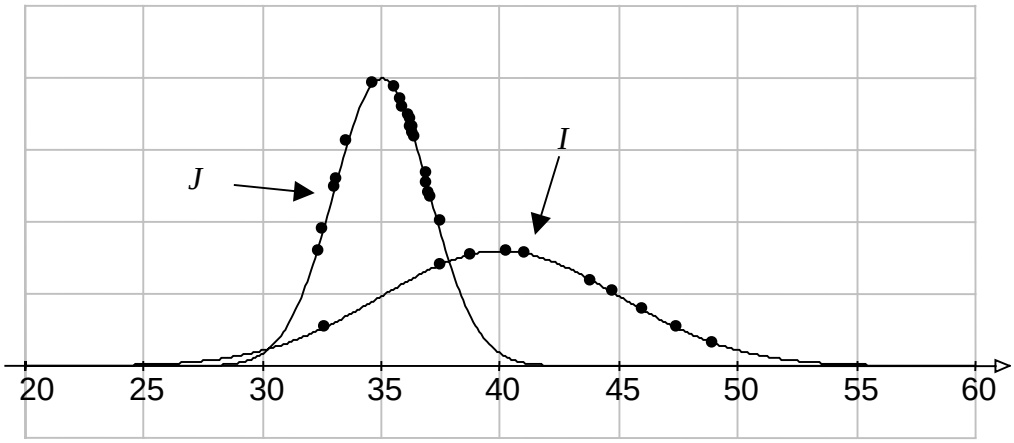
2.11. Appendix: Calculating probabilities of rankings

2.11.1. Pairwise ranking requirements

To calculate a pairwise ranking probability, $P(C_i >> C_j)$, we can use the fact that given two normally distributed populations *I* and *J* with means μ_i and μ_j and standard deviations σ_i and σ_j, if we take samples of size n_i from *I* and samples of size n_j from *J*, the difference between the means of the two samples, $M_i - M_j$, will be normally distributed, with mean $\mu_i - \mu_j$ and standard deviation $sqrt((\sigma_i^2 / n_i) + (\sigma_j^2 / n_j))$.[79] This is illustrated in (74).

(74) $M_i - M_j$

Population *I* has mean $\mu_i = 40$ and standard deviation $\sigma_i = 5$.
Population *J* has mean $\mu_j = 35$ and standard deviation $\sigma_j = 2$.
Sample $n_i = 10$ points from *I* and $n_j = 20$ points from *J*:



Find the mean of each sample: $M_i = 42.2$ and $M_j = 35.5$ ($M_i - M_j = 6.7$)
If we take enough samples, the mean value of $M_i - M_j$ approaches $\mu_i - \mu_j = 5$, with standard deviation $sqrt((\sigma_i^2 / n_i) + (\sigma_j^2 / n_j)) \approx 1.64$

[79] When $n_i = n_j = 1$, as in our case (see below), this means that the variance (σ^2, the square of the standard deviation) of $M_i - M_j$ is equal to the sum of the variances of *I* and *J*.

To see how this applies to our case, first a bit more detail on Boersma's system is necessary. An actual value, or selection point, for a constraint ("disharmony", in Boersma's terms) is generated by adding to the ranking value a random variable with the standard normal distribution, multiplied by a value called "ranking spreading" (following Boersma and Hayes 1999, I use a rankingSpreading of 2):

(75) Arriving at a selection point for a constraint in a given utterance

selectionPoint = rankingValue + rankingSpreading * **z**

where **z** is a random variable, normally distributed with mean 0 and standard deviation 1.

This means that the quantity *(selectionPoint-rankingValue)/rankingSpreading* (= **z**) is normally distributed, with mean 0 and standard deviation 1. We can then employ the method above to any two constraints C_i and C_j, taking samples of size $n_i = n_j = 1$ from the distributions *(selectionPoint$_i$-rankingValue$_i$)/rankingSpreading* and *(selectionPoint$_j$-rankingValue$_j$)/rankingSpreading*, which both have mean $\mu_i = \mu_j = 0$ and standard deviation $\sigma_i = \sigma_j = 1$.

Since the sample sizes are 1, M_i and M_j are just the values of *(selectionPoint$_i$-rankingValue$_i$)/rankingSpreading* and *(selectionPoint$_j$-rankingValue$_j$)/rankingSpreading* on a given occasion. Then we have:

(76) Calculating $P(C_i >> C_j)$

$M_i - M_j$
= (selectionPoint$_i$-rankingValue$_i$)/rankingSpreading - (selectionPoint$_j$-rankingValue$_j$)/rankingSpreading

so

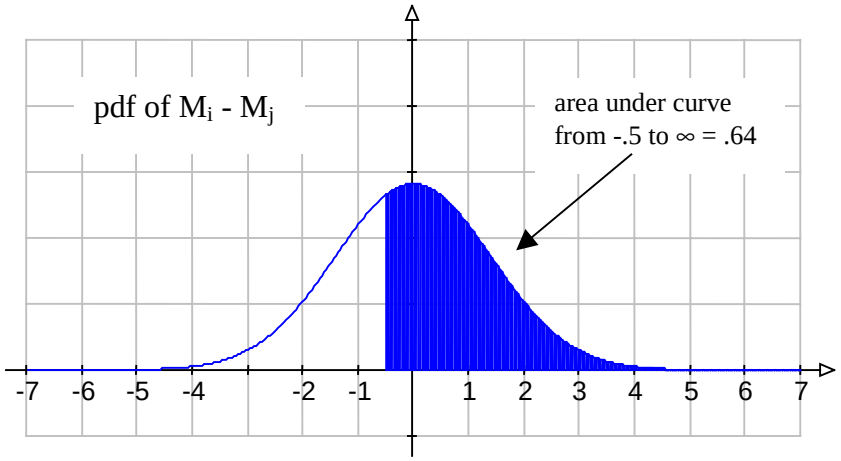
rankingSpreading * $(M_i - M_j)$ + rankingValue$_i$ - rankingValue$_j$
= selectionPoint$_i$- selectionPoint$_j$

$P(C_i >> C_j)$
$= P(\text{selectionPoint}_i > \text{selectionPoint}_j)$
$= P(\text{selectionPoint}_i - \text{selectionPoint}_j > 0)$
$= P(\text{rankingSpreading} * (M_i - M_j) + \text{rankingValue}_i - \text{rankingValue}_j > 0)$
$= P(M_i - M_j > (\text{rankingValue}_j - \text{rankingValue}_i)/\text{rankingSpreading})$

Since we know the mean value of $M_i - M_j$ ($\mu_i - \mu_j = 0$), and its standard deviation (sqrt(1/1 + 1/1) = sqrt(2)), we can calculate the probability that $M_i - M_j$ is greater than any given quantity by integrating under the curve of $M_i - M_j$'s probability density function from that quantity to infinity. A *probability density function* (pdf) is a function of a random variable defined such that the probability that the random variable lies between two values *a* and *b* approaches *pdf(a)*b* as *b* approaches zero. For normally distributed random variables like ***z*** or $M_i - M_j$, the probability density function is the familiar "bell curve". Intuitively, integrating under this curve over some region is equivalent to slicing the region into a series of discrete subregions with boundaries a_i to a_i+b, and adding up, for each subregion, the probability $pdf(a_i)*b$ that the random variable is in that subregion. We make *b* approach zero so that the slices are infinitesimally small, and we get the probability that the random variable lies somewhere in the whole region.

For example, if C_i has the ranking value 101 and C_j has the ranking value 100, then $(rankingValue_j - rankingValue_i)/rankingSpreading$ = -1/ 2 = -0.5. To find $P(C_i >> C_j) = P(M_i - M_j > -0.5)$, we integrate under the probability density function of $M_i - M_j$ (illustrated in (77)) from -0.5 to +infinity, and find that $P(C_i >> C_j) = 0.64$.

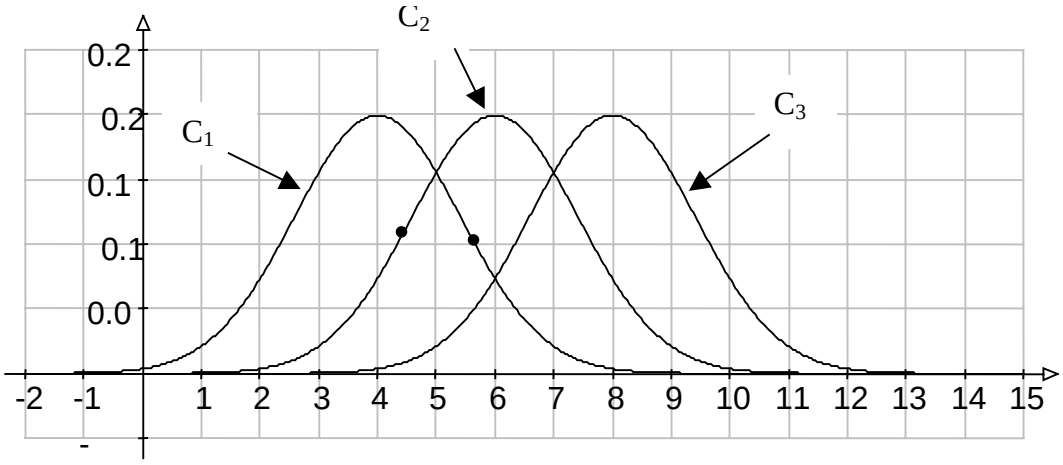
(77) $P(C_i >> C_j) = P(M_i - M_j > -0.5) = .64$



2.11.2. Complex ranking requirements

First, to see why pairwise ranking probabilities involving the same constraints are not independent—and therefore why complex ranking probabilities such as $P(C_1>>C_2$ *AND* $C_3>>C_2)$ can't be calculated by simply multiplying $P(C_1>>C_2)$ and $P(C_3>>C_2)$)—consider the three-constraint system illustrated in (78). If $C_1>>C_2$ in a particular instance, then it is likely that C_1's selection point was chosen from the upper end of its distribution, and thus $C_1>>C_3$ is more likely. Similarly, we must be careful in calculating $P(C_1>>C_2$ *AND* $C_3>>C_2)$, since $P(C_1>>C_2)$ and $P(C_3>>C_2)$ are not independent. For example, in the three-constraint system illustrated in (78), if $C_1>>C_2$ in a particular instance, then it is likely that C_1's actual value was chosen from the upper end of its distribution, and thus $C_1>>C_3$ is more likely.

(78) Pairwise rankings are not independent



To help see why this is so, consider the case in which C_1, C_2, and C_3 all have the same ranking value. For any two of these constraints, $C_i >> C_j$ and $C_j >> C_i$ are equally likely. Therefore, any of the six possible total rankings (shown in)) is equally likely:

(79) Possible total rankings of three constraints

a $C_1 >> C_2 >> C_3$
b $C_1 >> C_3 >> C_2$
c $C_2 >> C_1 >> C_3$
d $C_2 >> C_3 >> C_1$
e $C_3 >> C_1 >> C_2$
f $C_3 >> C_2 >> C_1$

Consider then the probability of $P(C_1 >> C_2 \text{ AND } C_1 >> C_3)$: If $P(C_1 >> C_2) = 0.5$ and $P(C_1 >> C_3) = 0.5$ were independent, we could multiply 0.5 * 0.5 to get $P(C_1 >> C_2 \text{ AND } C_1 >> C_3) = 0.25$. But $C_1 >> C_2$ and $C_1 >> C_3$ in 2 out of the 6 equally possible total rankings (*a* and *b*), so $P(C_1 >> C_2 \text{ AND } C_1 >> C_3)$ is actually 2/6 = 0.3ı. When C_1 is highly ranked (as in *a* and *b*), both $P(C_1 >> C_2)$ and $P(C_1 >> C_3)$ are increased.

Another way of thinking about this example is that the requirement $C_1 >> C_2 \text{ AND } C_1 >> C_3$ is equivalent to the requirement that C_1 be the highest-ranked of the three

constraints. Since each of the three constraints has an equal chance of being ranked highest, C_1's probability of being ranked highest is 1/3.

How then can complex probabilities be calculated? One straightforward method is to integrate the joint probability density function (like a probability density function of a single variable, except that its domain is ordered *n*-tuples consisting of one value for each of the random variables) of all the random variables involved over the region of interest. For example, to find $P(C_1>>C_2 \text{ AND } C_1>>C_3)$, integrate $pdf(z_1, z_2, z_3)$ over the region where $C_1>>C_2$ and $C_1>>C_3$, which is the region where $(rankingValue_1+rankingSpread*z_1-rankingValue_2)/rankingSpread > z_2$ and $(rankingValue_1+rankingSpread*z_1-rankingValue_3)/rankingSpread > z_3$. This operation takes all the points (z_1, z_2, z_3) such that $C_1>>C_2$ and $C_1>>C_3$, and sums the probabilities that each of those points could occur. It is also possible to estimate complex probabilities by simulation (run many trials of the grammar). This section will describe the direct method, which yields exact probabilities.

Because z_1, z_2, and z_3 are standard normal random variables, their joint probability density function $pdf(z_1, z_2, z_3)$ is just

$$pdf(z_1, z_2, z_3) = pdf(z_1)* pdf(z_2)* pdf(z_3) =$$
$$(e^{-z_1^2/2}/\sqrt{2\pi})(e^{-z_2^2/2}/\sqrt{2\pi})(e^{-z_3^2/2}/\sqrt{2\pi})$$

This function cannot be integrated symbolically, so all the probabilities used here were obtained from numerical integration in *Mathematica*.[80]

[80]See §2.12 for an example.

2.12. Appendix: Sample calculation in *Mathematica*

The first calculation performed above in §2.7.2 is

P((*NÇ>>PU OR NASSUB >> PU OR (USELISTED>>PU & ENTRYLIN>>PU))
& (*NÇ>>*[m OR NASSUB>>*[m OR (USELISTED>>*[m & ENTRYLIN>>*[m)))

In order to come up with limits of integration for the joint probability density function for *Mathematica*, the pairwise rankings must all be joined by AND, not by OR. We can achieve this by partitioning the complex ranking requirement into a series of mutually exclusive ranking requirements that together cover all possibilities:

P((*NÇ>>PU OR NASSUB >> PU OR (USELISTED>>PU & ENTRYLIN>>PU))
& (*NÇ>>*[m OR NASSUB>>*[m OR (USELISTED>>*[m & ENTRYLIN>>*[m)))

= P¬(PU>>*NÇ & PU>>NASSUB & (PU>>USELISTED OR PU>>ENTRYLIN)
& *[m>>*NÇ & *[m>>NASSUB & (*[m>>USELISTED OR *[m>>ENTRYLIN))

= P¬((*[m>>PU & PU>>*NÇ & PU>>NASSUB & USELISTED>>ENTRYLIN &
PU>>ENTRYLIN)
OR (*[m>>PU & PU>>*NÇ & PU>>NASSUB & ENTRYLIN>>USELISTED &
PU>>USELISTED)
OR (PU>>*[m & *[m >>*NÇ & *[m >>NASSUB & USELISTED>>ENTRYLIN & *[m
>>ENTRYLIN)
OR (PU>>*[m & *[m >>*NÇ & *[m >>NASSUB & ENTRYLIN>>USELISTED & *[m
>>USELISTED))

= 1-(P(*[m>>PU & PU>>*NÇ & PU>>NASSUB & USELISTED>>ENTRYLIN &
PU>>ENTRYLIN)
+ P(*[m>>PU & PU>>*NÇ & PU>>NASSUB & ENTRYLIN>>USELISTED &
PU>>USELISTED)
+ P(PU>>*[m & *[m >>*NÇ & *[m >>NASSUB & USELISTED>>ENTRYLIN & *[m
>>ENTRYLIN)
+ P(PU>>*[m & *[m >>*NÇ & *[m >>NASSUB & ENTRYLIN>>USELISTED & *[m
>>USELISTED))

To calculate the first item in the sum, P(*[m>>PU & PU>>*NÇ & PU>>NASSUB & USELISTED>>ENTRYLIN & PU>>ENTRYLIN), we want to integrate pdf(z_{PU}, $z_{*[m}$, $z_{*NÇ}$, z_{NasSub}, $z_{UseListed}$, $z_{EntryLin}$) over the region where *[m>>PU & PU>>*NÇ & PU>>NASSUB

& USELISTED>>ENTRYLIN & PU>>ENTRYLIN. These ranking requirements can be put in terms of the z_i. For example:

$$*[m >> PU$$
$$\text{rankingValue}_{*[m} + 2z_{*[m} > \text{rankingValue}_{PU} + 2z_{PU}$$
$$z_{*[m} > (\text{rankingValue}_{PU} - \text{rankingValue}_{*[m} + 2z_{PU})/2$$

Using the following variable names and with the following ranking-value differences,

m	z_m
P	z_{PU}
T	$z_{*NÇ}$
S	z_{NasSub}
U	$z_{UseListed}$
E	$z_{EntryLin}$

$$\text{rankingValue}_{PU} - \text{rankingValue}_{*[m} = 0.691$$
$$\text{rankingValue}_{PU} - \text{rankingValue}_{*NÇ} = -3.817$$
$$\text{rankingValue}_{PU} - \text{rankingValue}_{NasSub} = -0.570$$
$$\text{rankingValue}_{PU} - \text{rankingValue}_{EntryLin} = -11.335$$
$$\text{rankingValue}_{EntryLin} - \text{rankingValue}_{UseListed} = -0.004$$

we can express P(*[m>>PU & PU>>*NÇ & PU>>NASSUB & USELISTED>>ENTRYLIN & PU>>ENTRYLIN) as

$$\int_{-\infty}^{+\infty}\left(\int_{\frac{.69+2P}{2}}^{+\infty}\left(\int_{-\infty}^{\frac{-3.82+2P}{2}}\left(\int_{-\infty}^{\frac{-.57+2P}{2}}\left(\int_{-\infty}^{\frac{-11.34+2P}{2}}\left(\int_{\frac{-.004+2E}{2}}^{+\infty}\left(e^{(-P^2-m^2-T^2-S^2-E^2-U^2)/2}/(2\pi)^{(6/2)}\right)\partial U\right)\partial E\right)\partial S\right)\partial T\right)\partial m\right)\partial P$$

which in *Mathematica* notation is

```
N[Integrate[(e^((-P^2-m^2-T^2-S^2-E^2-U^2)/2)/(2π)^(3/2), {P, -Infinity,
+Infinity}, {m, (0.691250+2P)/2, +Infinity}, {T, -Infinity, (-3.816917+2P)/2}, {S,
-Infinity, (-0.570333+2P)/2}, {E, (-11.334917+2P)/2}, {U, (-003750+2E)/2,
+Infinity}]]
```

where the N[] function instructs *Mathematica* to calculate a numerical result.

3. Simulating the adoption of a new word

3.1. Chapter overview

This chapter shows how the model proposed in Chapter 2 perpetuates lexical patterns as new words come in to the lexicon, still using the example of nasal substitution. Section 3.2 gives evidence from loanwords that nasal substitution and the pattern of its distribution have indeed been replicated in new words. Section 3.3 outlines a model of speaker-listener interaction that draws on the probabilistic behavior of speakers and hearers described in Chapter 2. Section 3.4 describes a simulation of the speech community designed to test whether the model in §3.3 can really produce the desired results on new words. Section 3.5 gives the results of the simulation.

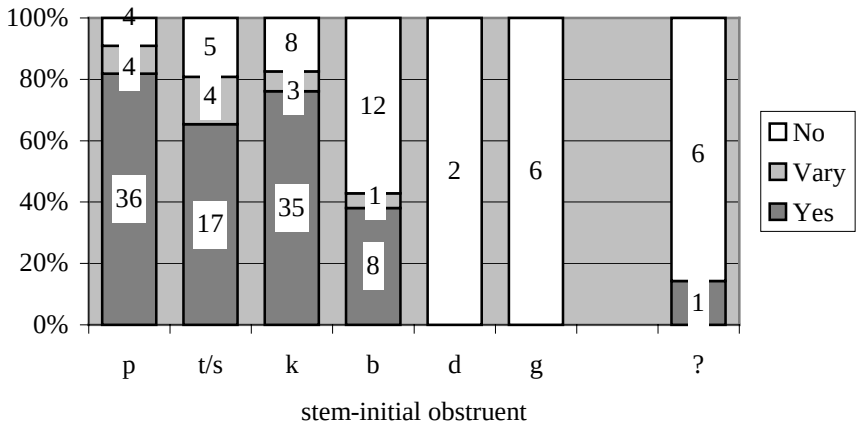
3.2. Assimilated loanwords

It is clear from examining the loanword vocabulary in Tagalog that new words sometimes become listed with nasal substitution. English's (1986) dictionary contains only four potentially substituting derivatives of obstruent-initial English loanword stems, and none of these are substituted. But Spanish stems have been in the lexicon longer and have had more opportunity to accumulate derived forms. There are 152 potentially substituting derivatives of obstruent-initial Spanish loanword stems.[81] Of these, 97 substitute. This suggests that nasal substitution has been productive relatively recently—productive not necessarily in the sense that it applies frequently to novel words, but in the sense that as a novel word becomes assimilated into the lexicon it may become nasal-substituted.

[81] Including some indigenous Mexican words presumably imported through Spanish.

There are too few examples to compare the rates of substitution for various affixes in the Spanish loanword vocabulary to rates in the native vocabulary, but combining all the affixal patterns together, we can get a rough idea of how well the Spanish words are following the native patterns: the voicing effect seems to have been present, and there is a higher rate of substitution for *b* than for *d* and *g*.[82]

(80) Substitution rates for Spanish stems, all affixal patterns combined



Assuming that the grammar of current Tagalog is fairly similar to the grammar of Tagalog at the time these derived forms of Spanish stems were established (anywhere from the mid sixteenth century to the present day[83]), we can use substitution rates in

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[82] Note the small number of words derived from Spanish stems beginning in *d* and *g*, despite the fact that initial *d*, at least, does not seem to be underrepresented in Spanish (52 pages for *p*, 26 for *t*, 66 for [k], 21 for *b*, 39 for *d*, and 12 for [g] in *The American Heritage Larousse Spanish Dictionary* 1986—these page counts are only rough approximations to root or stem counts, since many prefixed words are included). In contrast, root-initial *d* and *g*, though not ill-formed, are quite underrepresented in the native Tagalog vocabulary (see (36) in §2.4.5). Could Tagalog speakers somehow be selecting loans in such a way as to perpetuate the lexical statistics of the native vocabulary?

[83] The coining and establishment of a derived form of a Spanish stem could have occurred long after the adoption of the stem itself. The relative scarcity of derived forms of English stems suggests that the establishment of derived forms of loanword stems tends to occur long after the borrowing of the stem.

Spanish loanwords as an indication of how newly coined derived forms should eventually develop: despite low initial rates of substitution, many words must eventually come to be listed as substituted. In addition, given the Spanish data, a stem's chance of eventually being listed as substituted is probably influenced by the voicing effect, and possibly influenced by the place effect.

This chapter proposes a model of the speech community—and a simulation of the speech community under that model—that produces the following result: novel derived forms have a low initial rate of substitution, but as they come to be listed, the proportion that are substituted reflects proportions in the lexicon.

The crucial assumptions of the model are that (i) speakers generate outputs according to the stochastic grammar they have learned from the lexicon (§2.6), (ii) listeners make a probabilistic guess as to what input the speaker was using (§2.8.2) and update their lexicons accordingly, adding new listed forms and changing listedness values of existing forms. The results of §2.8.2 will be crucial in ensuring that the large number of unsubstituted forms produced early in a word's life does not guarantee that the word will end up being listed as unsubstituted.

Many of the parameters of the simulation (such as values of constants) were arrived at by trial and error. Some parameters could be changed greatly and the simulation would still work; others' exact values are crucial, even though there may be no a priori justification for those values. Therefore, the simulation should be considered an existence proof, rather than an assertion about the details of lexical evolution: it is possible to create a successful simulation of lexical evolution in the speech community

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Note that the past few centuries represent a very small portion of the history of nasal substitution. Dempwolff (1969) traces nasal substitution to Proto-Austronesian itself, which would make it at least 5000 years old (Bellwood 1979).

that is consistent with the model proposed here and in Chapter 2, but the example here may not be the only possibility, and may not be the possibility that is closest to reality.

3.3. Model of the speech community

The structure of the model will be made more explicit in §3.4, which gives details of the simulation, but essentially it is a synthesis of §2.7 and §2.8. When a derived form of a stem does not yet exist, speakers who wish to utter it have no choice but to concatenate morphemes on the fly. For example, if a speaker wishes to express the idea 'one whose job it is to *puntol*', she must combine the morphemes */maŋ/*, */RED$_{CV}$/*, and */puntol/*. Given the grammar in §2.6, there is an approximately 40% chance that the result of this concatenation will be *[mamumuntol]*, and a 60% chance that the result will be *[mampupuntol]*.

The speaker's interlocutors hear either *[mamumuntol]* or *[mampupuntol]*. In order to decide what adjustments, if any, to make to their mental lexicons, they must guess what underlying form the speaker was using. Employing the Bayesian reasoning discussed in §2.8, a person who hears *[mamumuntol]*, and who has no listed word for 'one whose job it is to *puntol*' will guess (incorrectly) that the input was */mamumuntol/* 94% of the time; she will guess (correctly) that the input was */maŋ/+/R$_{CV}$/+/puntol/* 6% of the time. When the guess is */mamumuntol/*, the listener creates a lexical entry for */mamumuntol/*, and gives it a weak initial strength[84]—which means that this new lexical entry is not yet very likely to be available to the listener for future utterances (as it builds in strength, however, it will begin to influence the listener's own utterances, and thereby the lexicons of *her* listeners). When the guess is */maŋ/+/R$_{CV}$/+/puntol/*, the listener does not update her lexicon at all—she already knows these morphemes. Similarly, if the same person hears *[mampupuntol]*, she will guess (incorrectly) that the input was

[84] I assume the same initial strength for every once-heard word. See §3.7 for listedness-updating functions.

/mampupuntol/ 33% of the time and create a new lexical entry (which will eventually influence her own speech); she will guess (correctly) that the input was */maŋ/+/R_{CV}/+/puntol/* 65% of the time and do nothing.

After there have been a few occasions to say 'one whose job it is to *puntol*', many members of the speech community will have formed (weak) lexical entries for */mamumuntol/* and/or competing */mampupuntol*/, and their behavior as speakers and listeners will be slightly changed: along with */maŋ/+/R_{CV}/+/puntol/*, */mamumuntol/* and */mampupuntol*/ will now be available occasionally as inputs to speakers, changing slightly the frequencies at which speakers produce *[mamumuntol]* and *[mampupuntol]*. And listeners will be slightly more likely to guess */mamumuntol/* and */mampupuntol*/ as inputs, further strengthening them.

I assume in addition that lexical entries that differ only phonologically are in competition:[85] if a listener has lexical entries for both */mamumuntol/* and */mampupuntol*/, when she hears an utterance that she takes to be derived from */mamumuntol/*, she will both increase the strength of */mamumuntol/* and decrease the strength of */mampupuntol*/ (and vice versa when she hears an utterance that she takes to be derived from */mampupuntol*/). Disparities in strength between competing lexical entries tend to grow over time, because the stronger */mamumuntol/* becomes, the less likely the listener is to "hear" */mampupuntol/*, since P(*/mampupuntol/*) decreases as Listedness(*/mamumuntol/*) increases (see §2.8.2).[86]

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[85] Cf. the blocking effect (Aronoff 1976): if one member of a stem's paradigm has a certain meaning (e.g., *fury*), synonymous derivatives are blocked (**furiousness*, **furiosity*)

[86] A prediction of this assumption (that the relationship between different pronunciations is antagonistic) is that words with variable pronunciations even within speakers should tend to be low-frequency. For high-frequency words, there should be enough tokens that any small difference in strength between the competing lexical entries will eventually produce one clear winner.

The usual result of competition between */mamumuntol/* and */mampupuntol*/ is that eventually one will emerge as strongly listed, and the other as very weakly listed.[87] For example, with a *p*-initial stem like *puntol*, because of the rates at which listeners guess that the speaker was using each input, the lexical entry */mamumuntol/* initially tends to get strengthened more than */mampupuntol*/. Speakers are then more likely to use */mamumuntol/* as an input (with *[mamumuntol]* nearly always the output, because of high-ranking ENTRYLINEARITY), with the result that listeners guess */mamumuntol/* even more often, widening the gap between */mamumuntol/* and */mampupuntol*/. A disparity in strength between */mamumuntol/* and */mampupuntol*/ in the early stages, then, if consistent across the speech community, is self-reinforcing and leads to the eventual adoption of the stronger option. A member of the next generation may not even form a lexical entry for the weaker option at all (unless she hears a speech error such as */mamumuntol/* → *[mampupuntol]* and guesses that the input was */mampupuntol*/).

Which lexical entry—the substituted or the unsubstituted—eventually wins out depends on an accumulation of many chance decisions by speakers and listeners. Which lexical entry will tend to win out depends on the rate at which the on-the-fly input is pronounced as substituted, and the rate at which listeners guess that a substituted utterance derives from a single input versus the rate at which listeners guess that an unsubstituted utterance derives from a single input.

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[87] In none of my simulations have different pronunciations remained in competition indefinitely, although the situation is possible if *P(/unsubstituted/ | [unsubstituted])* and *P(/substituted/ | [substituted])* are close enough to equal.

3.4. How the simulation works

I constructed a simulation of a speech community following the model outlined above, in order to verify that new words would eventually be assimilated into the lexicon as substituted or unsubstituted at rates similar to those seen for Spanish-stem words in (80).

The simulated speech community has ten slots for members. The simulation begins with eight slots filled: there are two people aged 20, two aged 40, two aged 60, and two aged 80. Each person has a grammar consisting of ranking values learned by the Gradual Learning Algorithm from exposure to a mini-lexicon, as in §2.6. Each grammar represents one run of the Gradual Learning Algorithm, so each is slightly different.

Each run of the simulation involves the community's deciding how to pronounce one new word. On every trial within a simulation, one person is selected randomly as the speaker, and two others as listeners. The speaker generates a constraint ranking (based on the ranking values in her grammar), and produces the optimal candidate for the word under consideration, given that ranking and the available inputs. Which inputs are available is also determined probabilistically: the on-the-fly input (e.g., /maŋ/+/R_{CV}/+/puntol/) is always available; the availability of inputs like */mampupuntol/* and */mamumuntol/* depends on the strength of those lexical entries (Listedness).

Each of the two listeners first decides whether or not to pay attention to the speaker, based on a function of the speaker's age (described in §3.7) such that younger speakers are likely to be ignored (by age 14, the speaker is almost certain not to be ignored). This prevents adults' lexicons from being overly disrupted by children's errors. The listener then makes a probabilistic guess as to what input the speaker was using. If

/mampupuntol/ or */mamumuntol/* was the optimal input, its listedness is increased (and the listedness of the other is decreased[88]) according to the function described in §3.7.

The details of the listener's decision procedure require some elaboration. In §2.8.2, the prior probabilities of inputs, and the probabilities of outputs given inputs, were combined according to Bayes' Law to derive the probabilities of inputs given outputs. The prior probabilities of inputs were relatively simple to calculate: they were a fairly simple function of the productivity of a construction and the strengths of relevant lexical entries. But calculating the probabilities of outputs given inputs required either integrating over many-dimensional areas with complicated boundaries. It might be implausible to require listeners to perform multivariable calculus[89] on every utterance, so the simulation employs a simpler method, which produces values for *P(output|input)* that are, on average, nearly accurate. As long as the simulation works, nearly accurate values are in no way undesirable, since we have no direct evidence as to the accuracy of the values for *P(output|input)* that listeners might use. The method used in the simulation is given in (81).[90]

(81) Listener's procedure for estimating P(output|input_i)

For each input being considered,
a. Generate a constraint ranking from the grammar
b. Run the input through the constraint ranking
c. If the result is the output under consideration, *EstimatedP(output|*$input_i$*)* = 1. Otherwise, *EstimatedP(output|*$input_i$*)* = 0.

---

[88] If the listedness of the input not heard is not decreased, eventually every word ends up with both forms listed, and thus displays variable behavior. This seems empirically implausible, because it predicts that the greatest variation will be found among high-frequency words.

[89] Each *P(output|input)* calculation takes up to one minute in *Mathematica*.

[90] Of course, the simulation also works if exact probabilities are used, so it is not a problem if humans are in fact able to perform the exact calculations

EstimatedP(output|input$_i$) is plugged into Bayes' Law, as shown in (82):

(82) Estimating P(input$_i$|output)

$$\text{EstimatedP}(\text{input}_i|\text{output}) = \frac{\text{P}(\text{input}_i) * \text{EstimatedP}(\text{output}|\text{input}_i)}{\text{P}(\text{output})}$$

where *P(output)* is the sum of *P(input$_i$) * EstimatedP(output|input$_i$)* for all *input$_i$*.

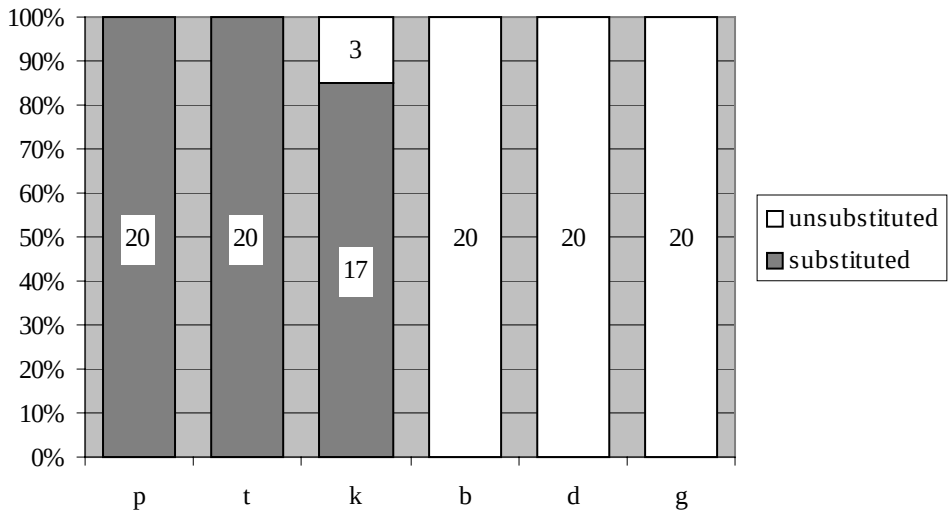
On any given occasion, *EstimatedP(output|input$_i$)* is far from the actual *P(output|input$_i$)*, of course (it is always either 0 or 1). But over many trials, the average *EstimatedP(output|input$_i$)* is equal to the actual *P(output|input$_i$)*. The source of the slight inaccuracy in *EstimatedP(input$_i$|output)* over time is cases in which *EstimatedP(output|input$_i$)* = 0 for all *input$_i$*: in these cases, *P(output)* (which is in the denominator in (82)) would equal zero. We can either throw such cases out, or assign an equal value to each *EstimatedP(output|input$_i$)*; either approach skews the average values of *EstimatedP(input$_i$|output)* somewhat. Fortunately, all-zero cases are rare enough in this simulation (less than 1% of all trials) that the inaccuracy is minimal (less than a percentage point).

Every 50 utterances of the word in question (1 "year"), each person has a chance of "dying" and leaving her slot open; this chance increases with age. If there are empty slots (as there are at the beginning of every simulation), there is a chance that a new person may be "born" to fill it. Younger speakers are (unrealistically, of course) assumed to have adult grammars and adult morphological parsing ability, but what they lack is an adult lexicon: a newborn person in the simulation has no listed form for the word being simulated. If the adults have already agreed on a listed form, the new person will quickly acquire it, since she will be exposed to quite consistent data.

3.5. Simulation results

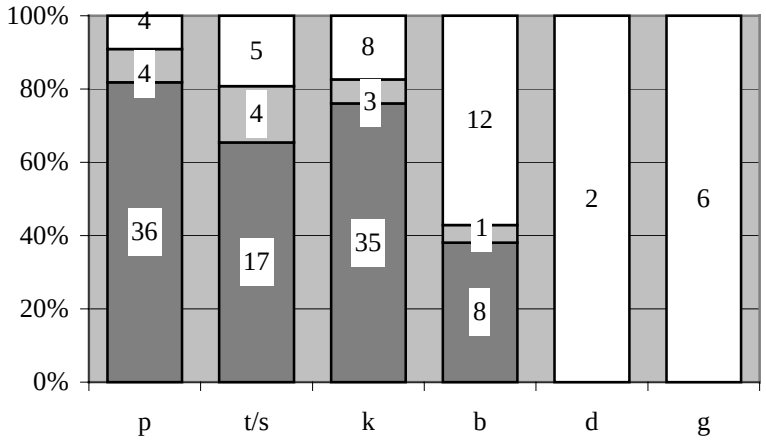
The simulation was run for 120 novel words, 20 each for *p*, *t*, *k*, *b*, *d*, and *g*. Note that since the mini-grammar used here is sensitive only to the initial segment of the stem, there can be no intrinsic difference between one novel stem beginning with *p* and another novel stem beginning with *p*. The reason for running the simulation multiple times is that chance factors can lead to different results of different trials. Each word was used by the speech community for 150 "years". By that point, in every trial, every member of the speech community over 20 years old was producing one pronunciation consistently, and all were in agreement.[91] (83) shows the results, with the distribution of substitution among Spanish loans and in the whole lexicon repeated from (8) and (80) for comparison.

(83) Simulation results for novel words after 150 "years"

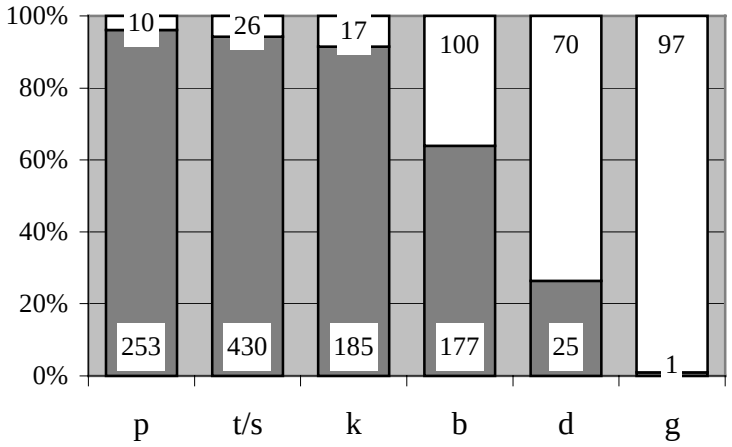


[91] At earlier points in the simulation, though, there was always considerable within- and across-speaker variation. The implication for real words with variable pronunciations is that they have not been used

(84) Nasal substitution in real Spanish loans



(85) Nasal substitution in entire Tagalog lexicon



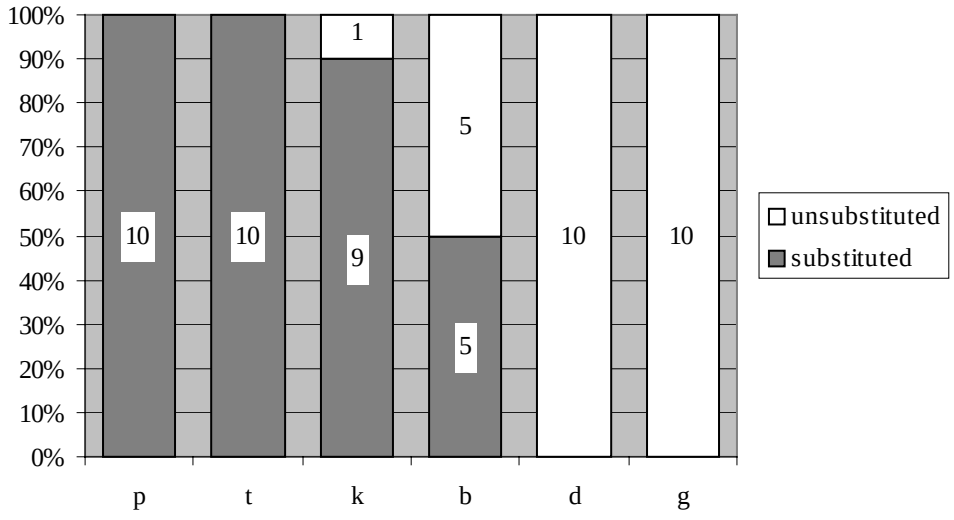
enough to acquire a stable pronunciation. The model predicts, then, that words with variable pronunciations should be low-frequency.

Clearly, *b*-initial stems are not behaving as expected. The desired result was that they be substituted about half the time. It turns out that rate of substitution on *b* produced by the grammars learned in §2.6 is too low for a *b*-initial stem to end up substituted, even with the listener bias described in §2.8.2. It is possible to construct grammars that, when used in the simulation, produce the desired results for *b* and the other segments. For example, the handcrafted grammar in (86) produces the results in (87).

(86) Hand-crafted grammar to produce the desired results for /b/-initial stems

Constraint	*Ranking value*
USELISTED	122
ENTRYLINEARITY	128
MORPHORDER	105
PU	100
*NC̥	104
NASSUB	105
*[ŋ	106
*[n	105
*[m	102

(87) Simulation results using the handcrafted grammar in (86)



Therefore, I do not regard the failure of *b* to substitute as a major problem for the model; it may be that with small changes to the learner, or somewhat different learning data (for example, token rather than type frequencies), grammars would be learned that would produce the desired results. Note also that the model did not always produce all-or-nothing results—as shown in (83), *k*-initial stems were substituted 85% of the time. So it is not the case that mixed results such as those desired for *b* are difficult to obtain, just that the rate of substitution for *b* generated by the learner-generated grammar was too low to get a mixed result.

3.6. Chapter summary

This chapter has presented a model of the speech community that perpetuates lexical patterns on new words, using the case of nasal substitution. The crucial element is the listener bias in favor of nasal-substituted lexical entries discussed in §2.8: this bias allows new words to eventually become listed as nasal substituted even if substitution is not the majority pronunciation when the word is new.

3.7. Appendix: Functions used in the simulation

(88) Deciding whether to pay attention to a speaker

$$P(\text{paying attention}) = 1 / (1 + e^{8 - \text{speaker's age}})$$

The younger the speaker, the less likely that the listener will pay attention to her utterance (a prerequisite for the listener's updating her lexicon in response to the speaker's utterance)

(89) Prior probabilities of inputs (see §2.8.2)

$$P(\text{/on-the-fly/}) = 1/((1+e^{-3+6*\text{Listedness(whole word)}})*(1+e^{3-6*\text{Productivity(construction)}}))$$

where *Listedness(wholeword)* is the greater of *Listedness(substituted)* and *Listedness(unsubstituted)*

$$P(\text{/substituted/}) = (1-P(\text{/on-the-fly /}))*F(\text{/subst./})/(F(\text{/subst./})+F(\text{/unsubst./}))$$

$$P(\text{/unsubstituted/}) = (1-P(\text{/on-the-fly/}))*F(\text{/unsubst./})/(F(\text{/subst./})+F(\text{/unsubst./}))$$

where

$$F(\text{word}) = 1/((1+e^{2-6*\text{Lstdnss(word)}})(1+e^{-4+6*\text{Lstdnss(competingword)}})(1+e^{3-6*\text{ProportionThatSubst}}))$$

(90) Updating listedness

$$\text{Listedness(word)} = 1 / (1 + e^{4 - 0.15 * \text{TimesHeard(word)}})$$

TimesHeard(word) is not a literal record of the number of times a particular (pronunciation of a) word has been heard, and is not even stored long-term. Instead, whenever the listener decides to increase a word's listedness, she calculates *TimesHeard(word)* from *Listedness(word)*:

$$\text{TimesHeard(word)} = (4 - \ln(1/\text{Listedness(word)} - 1)) / 0.15$$

She then increases *TimesHeard(word)* by 1, and recalculates *Listedness(word)*. The value for *TimesHeard(word)* can then be thrown away. When the listener wants to decrease a word's listedness, she performs the same procedure, but instead of increasing *TimesHeard(word)* by 1, she decreases it by 0.5.

This means that *TimesHeard* reflects not the actual number of times an input has been heard, but rather the cumulative effects of hearing the input and hearing competing inputs.

4. The model as applied to vowel height alternations

4.1. Chapter overview

This chapter applies the model developed in Chapters 2 to a different lexical regularity, the distribution of exceptions to vowel raising in Tagalog loanwords. The regularity here is of some intrinsic interest, and the analysis proposes a new phonological mechanism. But the vowel-height case is also important to the main arguments of this dissertation because it differs from nasal substitution in three respects. First, the pattern is found only within loanwords, so the argument that it comes from the grammar (rather than from statistical generalizations over the lexicon) is stronger. Second, the pattern itself is quite abstract: in nasal substitution, words with the same stem-initial consonant behaved similarly, but in vowel raising it is words whose internal similarity is of the same degree that behave differently. Again, this argues for representation in the grammar rather than emergence from the lexicon. Third, in nasal substitution different derivatives of the same stem could behave differently, but in vowel raising the behavior of one relevant derivative predicts the behavior of the rest; this has consequences for the structure of lexical entries. The first and second points are taken up again in Chapter 5.

Section 4.2 presents the data on vowel height in Tagalog and the types of exceptions that are found. Section 4.3 gives an analysis of those basic facts. Section 4.4 introduces Aggressive Reduplication, the mechanism that will be used to explain the distribution of exceptions in loanwords, which is presented in §4.5. Section 4.6 argues that the Aggressive Reduplication analysis is superior to other possibilities by demonstrating that Aggressive Reduplication makes a prediction that other analyses do not, and that that prediction is correct. Section 4.7 considers how vowel height should be

represented in lexical entries. Sections 4.8 and 4.9 discuss what a grammar for vowel raising would look like, and how it could be learned.

4.2. Vowel height in Tagalog

In most of the Tagalog vocabulary, mid and high vowels are in near-complementary distribution. Mid vowels are found only in final syllables, and [u] is found only in nonfinal syllables. [i] can occur anywhere, and many words have [i] and [e] in free variation in the final syllable. Examples in (91) illustrate some typical monomorphemic native words.

(91) Distribution of mid and high vowels

ká⌉l**o**s	‘grain leveler’
bagj**ó**	‘typhoon’
babá⌉ʔ**e**	‘woman’
b**ú**⌉kas	‘tomorrow’
b**u**nsóʔ ~ b**u**nsó	‘youngest child’
h**í**⌉b**i**	‘small dried shrimps’
d**i**td**í**t	‘torn into strips’
pat**í**d	‘cut off’
gá⌉b**i** ~ gá⌉b**e**	‘taro’
pant**é** ~ pant**í**	‘dragnet’

Suffixation induces alternation, by making syllables that were once final nonfinal:[92]

[92] Tagalog has just two native suffixes, *-in* and *-an*, whose most common and productive function is to form verbs (*-in* usually forms direct-object-focus verbs; *-an* usually forms indirect-object-focus verbs). These suffixes are also used alone and in combination with prefixes in various other morphological constructions. There are also loan suffixes such as *-ero* and *-ista* that sometimes combine with native stems.

In most suffixal constructions, stress and length (if any) are shifted one to the right: if the bare stem has final stress, stress falls on the suffix; if the bare stem has penultimate stress and length, the penult of the suffixed form has stress and length. This alternation could be thought of as preserving the (right-aligned) original prosody of the stem. Some suffixal constructions induce different shifts or none at all, and loanstems with long, stressed closed penults (very rare in native words) often behave differently.

(92) Suffixation-induced alternations

ká⌉**lo**s	‘grain leveler’	kal**ú**⌉s-in	‘to use a grain leveler on’
ʔabó	‘ash’	ʔabu-hín	‘to clean with ashes’
babá⌉ʔ**e**	‘woman’	ka-baba**ʔí**⌉-han	‘womanhood’
sist**é**	‘joke’	sist**i**⌉-hín	‘to joke’

There are exceptions to all the generalizations just made, although they are relatively few in the native vocabulary. There are many more exceptions in the loanword vocabulary, which is discussed below.[93]

There are two classes of systematic exceptions to the generalization that mid vowels are found only in final syllables. For completeness, they are described here and accounted for to some extent, but they are not the main area of interest. First, in nonfinal syllables containing an [aw] or [aj] diphthong,[94] coalescence can occur, producing a long/stressed mid or high vowel of the same backness and rounding as the glide. This sometimes produces a nonfinal mid vowel:

(93) Vowel coalescence

ʔ**aj**wán ~ ʔ**é**⌉wan	‘I don’t know’
hint**áj** ka ~ t**áj**ka ~ t**é**⌉ka	‘Wait!’ (*ka* = ‘you’)
b**aja**wáŋ ~ b**aj**wáŋ ~ b**é**⌉waŋ	‘waist’
k**aʔu**ntíʔ ~ k**aw**ntíʔ~ k**ó**⌉**n**tiʔ	‘a little’
b**aʔi**nát ~ b**aj**nát ~ b**í**⌉nat	‘relapse’
s**aj**nát ~ s**í**⌉nat	‘slight fever’

The *h* that appears when a vowel-final stem is suffixed can be thought of as (i) epenthetic, (ii) part of a postvocalic allomorph of the suffix, or (iii) part of the suffixal allomorph of the stem.

[93] I make no claim that there is (or is not) a synchronic difference between the native and loanword vocabularies; the native vocabulary is discussed first in order to make clear the basic pattern.

[94] For coalescence to be possible, the glide must not be obligatorily the onset of the following syllable. The diphthong may, however, be in free variation with a vowel-glide-vowel sequence (as in *b**aja**wáŋ ~ b**aj**wáŋ*). Or, it may be in free variation with a vowel-glottal-vowel sequence (as in *b**aʔi**nát ~ b**aj**nát*).

The second systematic source of nonfinal mid vowels is *VʔV* sequences in which both vowels are nonlow. In these sequences, the vowels must match in backness, as illustrated in (94).[95] If the vowels are back, often the first is high and the second is mid, but often both are mid. If the vowels are front, both vowels are usually high, but occasionally both are mid.[96]

(94) Transglottal vowels

p**o**ʔók	‘place’
puʔón ~ p**o**ʔón	‘master’
suʔót	‘clothing’
m**e**ʔéʔ	‘bleat’
l**e**ʔég ~ liʔig	‘neck’
biʔik	‘piglet’

Finally, there are also seemingly unsystematic exceptions in the native vocabulary: words with mid vowels in nonfinal syllables,[97] words whose final vowels remain mid under suffixation, and words with final-syllable [u]. The list in (95) is close to exhaustive: it includes all of the relevant items that were found in a database of the

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[95] Sequences not matching in backness might be absent because historical *iʔo*, *uʔi*, and *uʔe* sequences have become *ijo*, *uwi*, and *uwe*.

[96] Why should a medial glottal stop license a nonfinal mid vowel? Steriade (1987) identifies translaryngeal harmony (analyzed as spreading of a supralaryngeal feature node) as a cross-linguistically widespread phenomenon in which total identity (except in laryngeal features) between vowels is encouraged across [ʔ] and [h]. Tagalog may not be a case of such harmony, in which [ʔ] and [h] are supposed to behave the same: I found only one case of a nonfinal mid vowel before [h] among the disyllabic roots (*bohol* ‘(shrub species)’) compared to 13 cases of a nonfinal mid vowel before [ʔ].

Whatever the historical origin, [oʔo] and [eʔe] sequences might synchronically be analyzed as long, glottalized vowels (Steriade arrives at a similar conclusion for Yurok)—in that case, they are final, and so should rightly be mid. These roots would have to escape the two-syllable minimal root requirement, however.

[97] For brevity, I will sometimes refer to a vowel in a word-final syllable as “final” even if it is followed by a consonant. I will use “nonfinal” for a vowel in a nonfinal syllable (not for a vowel that is in a final syllable but followed by a consonant).

4619 disyllabic[98] roots in English's 1986 dictionary, as well as all the relevant longer words that I have encountered. Note that many of the words with nonfinal mid vowels appear to have CV- or CVC- pseudoreduplication,[99] and that the words that fail to raise under suffixation have a nonfinal mid vowel of the same backness as the final mid vowel (these facts will be relevant in the explanation of the distribution of exceptions).[100]

(95) Exceptional native words

Nonfinal [o]	
pseudoreduplicated	
ʔ**ó** ⌉ʔo	'yes'
t**o**t**o**ʔó	'true'
k**ó** ⌉kok	'crow of rooster; chickie'
t**ó** ⌉toʔ ~ t**ó** ⌉toy	'(affectionate term of address for little boy)'
g**o**ŋg**ó**ŋ	'gruntfish sp.'
kat**ó** ⌉to	'comrade'
bak**ó** ⌉ko	'fish sp.'
other	
b**o**hól	'shrub sp.'
ʔ**ó** ⌉la	'eagerness'
k**ó** ⌉kak	'croak of frog'
Nonfinal [e]	
pseudoreduplicated	
d**é** ⌉de	'baby bottle'
m**é** ⌉me	'beddie-bye'
k**e**ŋk**é**ŋ	'sound made by beating bottom of frying pan'
n**é** ⌉neʔ ~ n**é** ⌉neŋ ~ n**î** ⌉niʔ	'(affectionate term of address for little girl)'
h**e** ⌉l**e**h**é** ⌉le	'pretense of not liking'
h**é** ⌉le	'lullaby'
other	
k**é** ⌉rwe	'cricket'

[98] The database was limited to disyllabic roots because longer roots are generally polymorphemic (at least historically), and shorter roots are generally clitics.

[99] Pseudoreduplication is discussed further in §4.4. What I mean by the term is that the last two syllables are identical (except that the penult may lack the ultima's coda), but no productive morphological process of reduplication is at work.

[100] Several of the words in (95) are baby-talk words, interjections, or onomatopoeic/mimetic words. As in other languages, some well-formedness requirements seem to be relaxed in the "peripheral" vocabulary of Tagalog (see Itô & Mester 1995).

l**é**⌉teŋ	‘cord’
k**é**⌉toŋ	‘leprosy’
	(raises when suffixed: ket**ú**⌉ŋ-in ‘to have leprosy’)
t**é**⌉pok	‘victimized by hooligans’
h**é**⌉to ~ ʔ**é**⌉to	‘Here it is!’
b**é**⌉lat	‘Serves you right!’
l**é**⌉kat	‘How could you?!’
p**é**⌉klat	‘scar’
t**é**⌉kas	‘swindler’
s**é**⌉laŋ ~ s**é**⌉lan	‘delicacy’
kul**á**⌉lat ~ kul**é**⌉lat	‘last’

Mid vowel that stays mid under suffixation[101]

dé⌉d**e**	‘baby bottle’	padedé⌉-hin	‘give a baby a bottle’
totoʔ**ó**	‘true’	totoʔ**ó**⌉-hin	‘to be sincere’
poʔ**ó**t	‘hatred’	ka-poʔ**o**t-án	‘to hate’

(and all other *oʔo* words; found no *eʔe* words with suffixed derivatives)

Final [u]

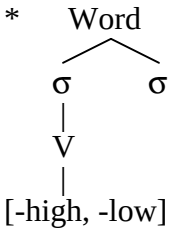
sampú**ʔ**	‘ten’
ʔi⌉m**u**s	‘headland’
kasój~ kas**új**	‘cashew’
bagkós ~ bagk**ú**s	‘on the contrary’
bambó ~ bamb**ú** ~ banb**ú**	‘bludgeon’
dá⌉toʔ ~ dá⌉t**u**ʔ	‘chieftain’
labíw ~ labj**ú**	‘weeds that grow in a burned field’

[101] These are the only exceptions to raising under suffixation that I have found. A vowel can also be made nonfinal through disyllabic reduplication, and here raising is often optional, even in native words (e.g., *háːl**o*** ‘mix’, *haːl**u**-háːl**o*** or *haːl**o**-háːl**o*** ‘(frozen desert/drink)’). The reason for this optionality may be the presence of a prosodic break between the reduplicant and the base (see discussion following (101)).

4.3. Analysis of vowel lowering/raising

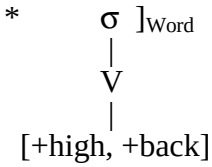
Before moving on to the main subject of this chapter—exceptions to vowel height alternations—I will briefly offer an analysis of the distribution of vowel height itself, although no functional motivation.[102] I propose the following phonotactic constraints:

*(96) *NONFINALMID*



[-high, -low] vowels in nonfinal syllables are forbidden.

*(97) *FINAL[u]*



[+high, +back] vowels in word-final syllables are forbidden.

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[102] The vowel height alternations caused by suffixation are not nearly as ancient as nasal substitution (see below) but phonetic motivation is still hard to find. Crosswhite (1999) proposes that lower vowels' greater sonority (greater jaw opening), makes them better suited to be long. Final lengthening might result in final-syllable lowering (cf. Yokuts, whose long, high vowels lower—Newman 1944). But although Tagalog may have some final lengthening, it also has many long vowels in nonfinal syllables, and these long vowels do not lower (e.g., *bú:kas* 'tomorrow', *hî:bi* 'small dried shrimps'). Compare Yidiŋ (Dixon 1977), whose high vowels lower somewhat in short final syllables, and lower all the way to mid in long final syllables, although nonfinal long vowels do not lower at all.

Could length-driven vowel lowering have arisen at a stage when there were no nonfinal long vowels? Zorc (1972, 1983) argues for contrastive "accent" (length and/or stress) in Proto-Philippine, with some words having a stressed, long penult and others a short penult and a stressed final syllable. Tagalog vowel lowering is a fairly recent innovation, not shared by all Central Philippine languages; so if Zorc is right, long penults would already have existed when vowel lowering began.

The operation of the constraints is illustrated using Inkelas, Orgun, and Zoll's (1997) underspecification approach to exceptionful alternations (the analysis will be modified in §0). Exceptionally high or mid vowels are fully specified as [+high] or [-high]; vowels whose height is predictable are underspecified (indicated in the tableaux below by capital *O* or *E*), with markedness constraints filling in the appropriate height, as illustrated in (98).

In the first tableau, IDENT-IO[HIGH][103] is satisfied by all four fully-specified candidates (*a*, *b*, *d*, *e*), since no height value is specified in the input. Thus it is the markedness constraints that decide the matter, selecting [-high] for the vowel when it is final (*a*), and [+high] when it is nonfinal because of suffixation (*d*) (the dashed line between the two markedness constraints' columns indicates that there is no evidence for ranking one above the other).

The second and third tableaux show that a vowel must be mid if it is so specified underlyingly, even when it is nonfinal. Raising an underlyingly [-high] vowel would violate both IDENT-IO[HIGH]. Similarly, the fourth tableau shows that a final vowel must be [u] if it is so specified underlyingly, because to make it mid would violate MAX[HIGH] and DEP[HIGH].

[103] Perhaps filling in feature values incurs some faithfulness violation; if so, assume the constraint violated is low-ranked. Assume also that a high-ranking constraint prevents underspecified segments on the surface: some value must be filled in.

(98) Tableaux illustrating underspecification analysis

Predictable alternation

	/kalOs/	IDENT-IO[HI]	*FINAL [u]	*NONFINAL MID
a	☞ [kalos]			
b	[kalus]		*!	
	/kalOs+in/	IDENT-IO[HI]	*FINAL [u]	*NONFINAL MID
d	☞ [kalusin]			
e	[kalosin]			*!

Mid vowel in nonfinal syllable

	/tekas /	IDENT-IO[HI]	*FINAL [u]	*NONFINAL MID
g	☞ [tekas]			*
h	[tikas]	*!		

Nonalternating mid vowel

	/dede/	IDENT-IO[HI]	*FINAL [u]	*NONFINAL MID
i	☞ [dede]			*
j	[dedi]	*!		*
	/dede+hin/	IDENT-IO[HI]	*FINAL [u]	*NONFINAL MID
k	☞ [dedehin]			**
l	[dedihin]	*!		*

[u] in final syllable (nonalternating)[104]

	/sampuʔ/	IDENT-IO[HI]	*FINAL [u]	*NONFINAL MID
m	☞ [sampuʔ]		*	
n	[sampoʔ]	*!		
	/sampuʔ+in/	IDENT-IO[HI]	*FINAL [u]	*NONFINAL MID
o	☞ [sampuʔin]			
p	[sampoʔin]	*!		*

Under this analysis, we could generalize *FINAL[u] to *FINALHIGH: a stem with a final [e] that becomes [i] under suffixation would be underspecified (like */kalOs/*); a stem with final [i] would be specified [+high]. There would simply be many, many stems with final *i* that would have to violate *FINALHIGH in unsuffixed form.

[104] As for front vowels in final syllables, either words are always listed as having either [e] or [i], or some are listed and the rest have their value filled in by some constraint(s).

The analysis is not complete, however, because when we examine the data from loanwords, it becomes apparent that there are regularities in the distribution of exceptions. As with nasal substitution, the solution proposed will be the presence of low-ranking constraints, which in this case are of some interest in themselves.

4.4. Aggressive Reduplication

Before the loanword data are described, this section introduces the mechanism that is invoked to explain them. I propose that, in all languages, speakers tend to construe similar syllables (or other units) as being in correspondence (pseudoreduplicated). Such a construal can result in the enhancement or preservation of internal similarity.

For example, in English there are sporadic examples of (often accidental) word-internal similarity between feet or syllables that gets increased, resulting in lexical drift. In (99) are shown some examples. Attestedness was verified by searching on the World-Wide Web (using Altavista, www.altavista.com) for nonstandard spellings that reflect the similarity-enhanced pronunciation. Clearly, some of the newer pronunciations are widespread; others may be sporadic errors.

(99) Similarity enhancement in English[105]

Nonstandard	*hits*	*Standard*	*hits*
orangutan**ng**	773	orangutan	6913
orangouta**ng**	20	orangoutan	17
Ok**ee**fenokee	392	Okefenokee [ˌoʊkəfəˈnoʊki]	2586
smorgasbor**g**	394	smorgasbord	17,228
Inuktitu**k**	125	Inuktitut0	2569
sherb**er**t[106]	about 1000	sherbet	7083
pompo**m**[107]	2072	pompon	2066
Abu D(h)ab**u**[108]	4	Abu Dhabi	21,234
Ab**i** D(h)abi	4		
asteris**t**	12	asterisk	176,510
as**k**erisk[109]	15		

[105] Of course, some of the hits may be from other languages in which the same lexical drifts and errors have taken place (possibly for the same reasons), and from non-native writers of English.

[106] 4496 hits, but about ¾ (based on inspection of the first few dozen) were personal names.

[107] This spelling appears in dictionaries.

[108] Nonstandard spellings of *Abu Dhabi* were individually verified to ensure that they did refer to the city.

Tagalog has a large vocabulary of words that have even more internal similarity than *orangutan* or *Inuktitut*. These are the *pseudoreduplicated* words, which are generally of the form CV-CVC or CVC-CVC; some pseudoreduplicated words also have pseudoprefixes and pseudoinfixes. Some typical examples are given in (100).[110]

(100) Pseudoreduplicated words in Tagalog

CV-CVC
kíːkig ‘cleaning of ears’
gagád ‘mimicry’
púːpog ‘pecking hard; repeated kissing’

CVC-CVC
bakbák ‘peeled off’
damdám ‘feeling’
saksák ‘stab wound’

CVC-a-CVC
busáːbos ‘slave’
sibasíb ‘violent attack by animal’

*pseudoprefixed (*ʔu-, tu-, ku-, bu-, lu-, mu-, ti-, gi-, li-, ʔali-, bali-, sali-, *and* ja-*)*
bukadkád ‘fully opened’
kulimlím ‘overcast’
gipuspós ‘very dispirited’

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[109] The ratio of nonstandard to standard spellings of *asterisk* may seem low enough to be the result of typographical errors or uninteresting perception errors. As a control against perception errors on the part of the writer, I searched for *asterisp* and *asperist*, and found no hits. As a control against typographical errors, I also searched for pages that had both the nonstandard spelling and the standard spelling, and found none.

[110] Although I have not undertaken any statistical analysis, it is apparent from casual inspection of a dictionary that there are far more pseudoreduplicated words than would be expected through random phoneme combination. In addition, two occurrences of the same consonant within a root are very rare except in pseudoreduplicated words. That is (modulo pseudoinfixation or medial *a*), two occurrences of the any *C* within a root are allowed only if the two *C*s are in the same syllabic position (onset or coda), and the vowels of the *C*s’ syllables are the same; if the *C*s are codas, the onsets of their syllables must be the same, and if they are onsets and the first *C*’s syllable has a coda, the second *C*’s syllable’s coda must be the same as the first *C*’s.

In any case, whether or not pseudoreduplicated words form a definable, psychologically real, or historically motivated class is of no consequence to the proposal here. The important characteristic of the words I am calling pseudoreduplicated is only that they display a high degree of internal similarity.

pseudoinfixed (-al-, -aɾ-, -ag-, *or* -aʔ-*)*
balusbós ‘spilling of grain from hole in container’
tagajtáj ‘mountain crest’
daʔigdíg ‘world’

Whatever the historical origin of these words, there are several reasons to call them *pseudo*reduplicated synchronically. First, in Tagalog the minimal root is disyllabic, so if, for example, *saksák* were reduplicated, it would be from a too-small root, (*sak*). Pseudoreduplication might be a repair strategy for just such too-small roots, but there are multiple pseudoreduplicating patterns, so letting just one pattern (say *CVC*-reduplication) be the repair strategy would explain only a portion of the pseudoreduplicated vocabulary. The rest would still have to be listed as-is in the lexicon. Second, although Tagalog does have productive *CV*- reduplication, there is no productive *CVC*- reduplication, nor are the pseudoprefixes and pseudoinfixes productive. And finally, although many pseudoreduplicated roots have a mimetic flavor, there is no fixed meaning associated with any of the pseudoreduplicating patterns—it would be strange to posit a reduplicative morpheme when there does not seem to be any morphosyntactic information associated with it.

Usually, the two halves of a pseudoreduplicated word behave independently. That is, phonological phenomena apply transparently, even if the result is nonidentity between the two halves. But over- and underapplication do occur sporadically, as if some pseudoreduplicated words were being treated as productively reduplicated. I will discuss five types of example, summarized in (101).

(101) Over- and underapplication in pseudoreduplicated roots

nasal substitution

productive reduplication	most pseudoredup.	handful of pseudoredup.
overapplies	*transparent*	*overapplies*
kú:lot ma:-**ŋ**u-**ŋ**ulót 'lock of hair', 'hairdresser'	kamkám ma-**ŋ**am**k**ám 'usurpation', 'to usurp'	budbód ma-**m**ud**m**ód 'sprinkling', 'to sprinkle'

intervocalic flapping

productive reduplication	most pseudoredup.	handful of pseudoredup.
transparent	*transparent*	*overapplies*
mag-**d**a-**ɾ**asál 'will pray'	**d**í:**ɾ**i 'loathing'	**ɾ**ú:**ɾ**ok 'acme'
		underapplies
		dé:**d**e 'baby bottle'

vowel raising

most productive redup.	most pseudoredup.	several pseudoredup.
transparent	*transparent*	*underapplies*
ʔa:b**u**t-ʔá:b**o**t 'continuous'	d**u**bdób 'feeding a fire'	g**o**ŋg**ó**ŋ 'gruntfish'

nasal assimilation

productive reduplication	many pseudoredup.	many pseudoredup.
underapplies	*transparent*	*underapplies*
mag-dunu:**ŋ**-dunú:**ŋ**-an 'to engage in pedantry'	da**n**dá**ŋ** 'toasting'	di**ŋ**dí**ŋ** 'wall'

glottal deletion

productive reduplication	many pseudoredup.	many pseudoredup.
underapplies	*transparent*	*underapplies*
ʔalat-**ʔ**alat-án 'to make a little salty'	**ʔ**utot 'flatulence'	**ʔ**ig**ʔ**ig 'shaking'

First, recall from §2.2.1 that when nasal substitution applies to a productively reduplicated word, it applies to both the base and the reduplicant, even though only the reduplicant is adjacent to the triggering prefix: *kulót* 'lock of hair', *má-**ŋ**u-**ŋ**ulót* 'hairdresser'. In Wilbur's (1973) and McCarthy and Prince's (1995) terms, nasal

substitution *overapplies*.[111] In most pseudoreduplicated words, only the first half undergoes nasal substitution: *kamkám* ‘usurpation’, *ma-**ŋ**amkám* ‘to usurp’. But I have found one pseudoreduplicated root in which nasal substitution overapplies to the second half in some derivatives, one in which it overapplies with an unproductive zero-prefix, and one in which it overapplies with the unproductive prefix *hiŋ-*:

(102) Overapplication of nasal substitution

budbód	‘sprinkling’
ʔipa-**m**ud**m**ód	‘to distribute to many individuals’
ma-**m**ud**m**ód	‘to scatter’
pa-mu-**m**ud**m**ód ~ pa-mu-**m**ud**b**ód	‘distribution of small quantities’
pam-**b**ud**b**ód	‘used for sprinkling’
bá⌉bad	‘soak’
ma**m**ád	‘softened by soaking’
hi-**m**ul**m**ól	‘plucking fine hairs’
bul**b**ól	‘fine hair, feather’

Second is flapping. In the bulk of the native vocabulary, [d] and [**ɾ**] are in complementary distribution: [**ɾ**] occurs intervocalically, [d] elsewhere, except that sometimes root-initial [d] is retained despite prefixation with a vowel-final prefix. Productive reduplication triggers flapping; that is, the constraints driving flapping are obeyed despite the resulting nonidentity between base and reduplicant: *mag-dasál* ‘to pray’, *mag-**d**a-**ɾ**asál* ‘will pray’. Likewise, in most pseudoreduplicated words, flapping applies transparently, both within roots and across morpheme boundaries: ***dîːɾ**i*

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[111] *Transparent application*: a “rule” applies in all and only the expected environments, even though a misidentity between base and reduplicant may result.

Overapplication: either the base or the reduplicant (but not both) is in the expected environment for a rule, and the rule applies to both.

Underapplication: either the base or the reduplicant (but not both) is in the expected environment for a rule, and the rule applies to neither.

‘loathing’; *kadkád* ‘unfolded’, *ka**d**kar-în* ‘to unfurl; *damdám* ‘feeling’, *ma-**r**am**d**ám-in* ‘emotional’. But, there is one pseudoreduplicated word in which flapping underapplies, ***d**é:**d**e* ‘baby bottle’, and two in which it overapplies, ***r**imá:**r**im* or ***d**imá:**r**im* ‘nausea’, ***r**ú:**r**ok* ‘acme’. These words display stronger base-reduplicant identity than productively reduplicated words.

Third is vowel raising. Exceptional nonfinal mid vowels are usually preserved under productive reduplication: *sé:los* ‘jealousy’ *pag-s**e**-s**é:**los-an* ‘jealousy of each other’. Raising usually occurs in disyllabic productive reduplication, despite the resulting misidentity: *ʔá:b**o**t* ‘overtaken’, *ʔa:b**u**t-ʔá:b**o**t* ‘continuous’. That raising is often optional in disyllabic reduplication (*há:l**o*** ‘mix’, *ha:l**u**-há:l**o*** or *ha:l**o**-há:l**o*** ‘(frozen desert/drink)’) may reflect a prosodic break comparable to the break within a compound rather than the effect of reduplicative identity: the reduplicant and the base are each long enough to be a prosodic word, and each has stress/length (if the reduplicant has a long penult, it bears secondary stress; otherwise the reduplicant’s ultima bears secondary stress, even if closed).

In pseudoreduplicated words, vowels usually diverge in height in order to obey markedness constraints (*dubdób*, ‘feeding a fire’), but in a few words, both vowels are mid, as in *k**ó:k**o**k* ‘crow of rooster; chickie’, and *g**o**ŋgóŋ* ‘(gruntfish species)’ We could say that in these words, *NONFINALMID underapplies. I have found no examples in which *FINAL[u] overapplies (i.e., no words like **budbúd*).

Fourth is nasal assimilation. In Tagalog, a nasal usually agrees in place of articulation with a following obstruent. This is true both root-internally and across clitic boundaries. When productive disyllabic reduplication places a root-final nasal next to a heterorganic root-initial stop, nasal assimilation underapplies: *dú:noŋ* ‘erudition’, *mag-*

dunuːŋ-dunúːŋ-an ‘to engage in pedantry’.[112] In pseudoreduplicated words, nasal assimilation often applies transparently, but often underapplies:[113] *dandáŋ* ‘warming over fire’ vs. *diŋdîŋ* ‘wall’.

Finally, glottal deletion: in Tagalog, a postconsonantal glottal stop is often deleted.[114] For example, when a verb ending in [ʔ] syncopates, the glottal stop is deleted: *g-um-awáʔ* ‘to do (ActorFocus)’, *gaw-în* ‘to do (ObjectFocus)’ (instead of **gawʔ-în*). Glottal stop is preserved, at least in careful speech, with most prefixation (*ʔabáŋ* ‘watcher’, *mag-ʔabáŋ* ‘to watch for’), and with productive reduplication: *ʔalát* ‘salt’, *ʔalat-ʔalat-án* ‘to make a little salty’.[115] Root-internally, *Cʔ* clusters are rare, and many pseudoreduplicated words lack an expected glottal stop: *ʔutot* ‘flatulence’. But, in about half of relevant pseudoreduplicated words, glottal deletion underapplies: *ʔigʔig* ‘shaking’.

Thus, there is evidence that words that appear—phonologically—to be reduplicated are sometimes treated as reduplicated, even in the absence of morphosyntactic cues.

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[112] As with vowel raising, the failure of nasal assimilation to apply in the first nasal-obstruent cluster of *dunuːŋ-dunúːŋ-an* may reflect a prosodic break between base and reduplicant rather than reduplicative identity. The boundary between reduplicant and base would have to be sharper, though, than a clitic boundary, where nasal assimilation is usual.

[113] Although I have not performed a complete count, it appears that nasal assimilation underapplies at least a third of the time.

[114] *Pre*consonantal glottal stop seems always to be deleted/absent: at clitic boundaries, in productive reduplication, and in pseudoreduplicated words.

[115] Again, the lack of glottal deletion could reflect the strength of a boundary between base and reduplicant, although glottal deletion is common at clitic boundaries. See fn. 112.

4.4.1. Analysis

I call the constraint driving morphosyntactically unmotivated reduplicative construals REDUP (short for "Reduplicate"), and it penalizes every pair of syllables not in correspondence with each other (to be more exact, REDUP penalizes a pair of syllables when no correspondence relation is defined between the segments of those syllables). I use "correspondence" in the sense of McCarthy and Prince (1995): an arbitrary relation between segments that does not in itself require similarity; violable constraints require the relation to have certain properties, and enforce similarity between segments that are in correspondence. Matching Greek subscripts on syllables indicate that the representation includes a correspondence relation between the segments of those syllables.

(103) REDUP

* Word where $\alpha \neq \beta$

σ_α ... σ_β

Two syllables within the same word must be in correspondence with each other.

For example, *[ba]$_\alpha$[ba]$_\alpha$* does not violate REDUP, because it has just one syllable pair, and that pair is in correspondence; *[ba]$_\alpha$[da]$_\beta$* violates REDUP once, because its one syllable pair is not in correspondence. *[ba]$_\alpha$[ba]$_\alpha$[da]$_\beta$* violates REDUP twice, because the syllable *da* does not correspond to either of the *ba* syllables. Assuming that Correspondence is transitive, we can also have words like *[ba]$_\alpha$[ba]$_\alpha$[ba]$_\alpha$[ba]$_\alpha$*, in which every syllable is in correspondence with every other syllable (no violations of REDUP). The tableau in (104) shows how a word with three syllables can violate REDUP three times, twice, or not at all. Note that the quality of the correspondence relation is a separate matter—REDUP is satisfied by the mere existence of correspondence between the two syllables, regardless of how similar they are.

(104) Violations of REDUP for a 3-syllable input

	/badaka/	REDUP
a	$[ba]_{\alpha}[da]_{\beta}[ka]_{\gamma}$	*(ba-da) *(ba-ka) *(da-ka)
b	$[ba]_{\alpha}[da]_{\beta}[ka]_{\beta}$	*(ba-da) *(ba-ka)
c	$[ba]_{\alpha}[da]_{\beta}[ka]_{\alpha}$	*(ba-da) *(da-ka)
d	$[ba]_{\alpha}[da]_{\alpha}[ka]_{\beta}$	*(ba-ka) *(da-ka)
e	$[ba]_{\alpha}[da]_{\alpha}[ka]_{\alpha}$	

The formulation of REDUP used here is somewhat arbitrary. Many of the English examples in (99) seem to involve correspondence between feet rather than syllables (e.g. *[orang]$_{\alpha}$[utang]$_{\alpha}$*, which could also be correspondence between nonadjacent syllables: *o[rang]$_{\alpha}$u[tang]$_{\alpha}$*), and productive reduplication (in Tagalog as in other languages) can involve foot-copying. Productive reduplication can also place into correspondence strings that do not have the same prosodic shape, as in Ilokano *pjan.-pja.no* 'pianos' (also *pii.-pja.no, pi-p.ja.no*; Hayes & Abad 1989): the reduplicant's *n* is a coda, but the base's is an onset. If REDUP promotes the same correspondence structures that are found in productive reduplication, it should be able to maximize correspondence over segments, then, as well as over syllables and feet. For the case of Tagalog vowel height, however, the definition in (103) is suitable.

Because REDUP promotes correspondence relations, the constraints governing those relations proposed in McCarthy and Prince (1995) are also relevant. McCarthy and Prince propose constraints that enforce similarity between input and output (IDENT-IO[F], MAX-IO, DEP-IO, etc.—I abbreviate the set as CORR-IO) and between corresponding syllables in the output (IDENT-BR[F], MAX-BR, DEP-BR, etc.—I abbreviate the set as CORR-BR).[116] IDENT-AB[F] constraints require that a segment in representation *A* and its

[116] Because the examples here are from Tagalog, which has left-side reduplication, and because all the examples considered here involve correspondence between just two syllables, I will refer to the first as the reduplicant and the second as the base.

correspondent in representation *B* bear identical values of the feature *F*; MAX-AB constraints require that every segment in *A* have a correspondent in *B*; and DEP-AB constraints require that every segment in *B* have a correspondent in *A*.

The correspondence constraints interact with REDUP to (i) restrict which syllables can be in correspondence and (ii) enhance the similarity of corresponding syllables. The schematic factorial typology in (105) illustrates the interaction.

(105) Factorial typology of REDUP, CORR-IO, and CORR-BR

REDUP, CORR-BR >> CORR-IO
underlyingly dissimilar syllables correspond and are made identical

	/bakpak/	REDUP	CORR-BR	CORR-IO
a	☞ $[bak]_\alpha[\ bak]_\alpha$			*
b	$[bak]_\alpha[\ pak]_\alpha$		*!	
c	$[bak]_\alpha[pak]_\beta$	*!		
d	$[bak]_\alpha[bak]_\beta$	*!		*

REDUP , CORR-IO >> CORR-BR
underlyingly dissimilar syllables correspond but remain dissimilar

	/bapa/	REDUP	CORR-IO	CORR-BR
a	$[bak]_\alpha[\ bak]_\alpha$		*!	
b	☞ $[bak]_\alpha[\ pak]_\alpha$			*
c	$[bak]_\alpha[pak]_\beta$	*!		
d	$[bak]_\alpha[bak]_\beta$	*!	*	

CORR-BR, CORR-IO >> REDUP
underlyingly dissimilar syllables cannot correspond

	/bapa/	CORR-BR	CORR-IO	REDUP
a	$[bak]_\alpha[\ bak]_\alpha$		*!	
b	$[bak]_\alpha[\ pak]_\alpha$	*!		
c	☞ $[bak]_\alpha[pak]_\beta$			*
d	$[bak]_\alpha[bak]_\beta$		*!	*

Because there are many CORR-BR and CORR-IO constraints, a language may belong to different classes in this typology for different correspondence constraints—for example, allowing a voiced and voiceless segment to correspond in an output, but requiring correspondents to agree in sonority. The typology also becomes more

complicated when markedness constraints are included, as seen below. In particular, the interplay of REDUP, correspondence constraints, and markedness constraints will show that there is a difference between phonetically identical candidates like *[ba]$_{\alpha}$[pa]$_{a}$* (construed as reduplicated), the winner in the second tableau of (105), and *[ba]$_{\alpha}$[pa]$_{a}$* (not construed as reduplicated), the winner in the third tableau; the presence of internal correspondence can be detected even when internal similarity is not enhanced.

There arises the question of why, if there is such a constraint as REDUP, there are no languages in which all words are reduplicated. Such a language would be quite inefficient—every word's uniqueness point would be at the halfway mark, and the second half of the word would serve no contrastive function. I cannot explain the mechanism that prevents pathological grammars from arising, but it is clear that such a mechanism exists, because it also prevents many other contrast-reducing constraints from rising to the top of the grammar. For example, the silent language, in which *STRUC (Zoll 1993) dominates all faithfulness constraints, does not exist. Similarly, Prince and Smolensky 1993 propose constraints of the form *P/X that forbid X as a syllable nucleus; the less sonorous X is, the more marked it is a nucleus: *P/[t]>> *P/[n] >> *P/[u] >> *P/[a]. But there is no language in which all the *P/X except *P/[a] are undominated, requiring all syllable nuclei to be [a].

Other authors have proposed constraints that encourage word-internal similarity. MacEachern (1999) proposes a constraint BEIDENTICAL, which requires all segments of a word to be identical; violations occur when two segments differ in a feature *F* and IDENT-IO[F] outranks BEIDENTICAL. BEIDENTICAL differs from REDUP in that it is satisfied only by full identity; BEIDENTICAL does not cause partial similarity enhancement or preservation. Suzuki (1999) proposes a constraint that requires onsets of adjacent

syllables to be identical. Suzuki's proposal differs from MacEachern's in predicting that being in the same syllable position is a prerequisite to becoming identical.

Walker (2000, to appear) proposes a family of constraints that require consonants to enter into correspondence if they already share certain feature values. This constraint family is similar to REDUP in that perfect identity is not required—only a correspondence relation is required, and it is left to other constraints to enforce similarity (partial or total) between the corresponding consonants. Walker's proposal, which I will refer to as Consonantal Correspondence does not predict that anything other than the consonants' features (e.g., the consonants' position in the syllable, the shape of the consonants' syllables, vowels tautosyllabic to the syllables) should encourage correspondence.

Aggressive Reduplication and Consonantal Correspondence make largely overlapping empirical predictions about consonantal similarity itself, with one exception.[117] Only Consonantal Correspondence can produce a system in which all consonants that are similar to at least some degree become identical, and less-similar consonants do not assimilate at all. For example, if {IDENT-BR[PLACE], IDENT-BR[VOICE], CORRESPONDIFIDENTICALIN[PLACE],[118] CORRESPONDIFIDENTICALIN[VOICE]} >> {IDENT-IO[PLACE], IDENT-IO[VOICE]}>> CORRESPONDIFIDENTICALIN[SYLLABIC], then */daba/* $\rightarrow$ *[[da]$_\alpha$[da]$_\alpha$]*, and */data/* $\rightarrow$ *[[da]$_\alpha$[da]$_\alpha$]*, but */dapa/* $\rightarrow$ *[dapa]*. In Aggressive Reduplication, by contrast, if REDUP and the IDENT-BR[F] constraints are ranked high enough to force the violations of IDENT-IO[PLACE] and IDENT-IO[VOICE] in */daba/* $\rightarrow$ *[[da]$_\alpha$[da]$_\alpha$]* and */data/* $\rightarrow$ *[[da]$_\alpha$[da]$_\alpha$]*, then they must also require */dapa/* $\rightarrow$ *[[da]$_\alpha$[da]$_\alpha$]*.

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[117] Factorial typologies for the two approaches were calculated using Hayes (1999).

[118] This is not Walker's notation.

Aggressive Reduplication was discussed here because it will be employed to explain the distribution of exceptions to vowel raising among loanwords. The following section describes the loanword data and shows how Aggressive Reduplication could account for them.

4.5. Distribution of exceptions in the loanword vocabulary

As in the native vocabulary, there are exceptions of all kinds to vowel height phonotactics in Tagalog loanwords. Exceptions are more numerous among the loanwords, which come from languages that freely allow nonfinal mid vowels and final [u]:

(106) Loanword stems with nonfinal mid vowels and final [u]

b**é:**nta	‘sales’	(from Spanish *venta*)
k**o**rék	‘correct’	(from English *correct*)
ʔas**ú**l	‘blue’	(from Spanish *azul*)
ʔa:bak**ú**s	‘abacus’	(from English *abacus*)

Some mid-final loanword stems alternate, and some fail to alternate:

(107) Alternation in loanword stems

Alternating stems			
sab**ó**n	‘soap’	sab**u**n-án	‘to put soap on’
atá:k**e**	‘attack’	atak**î:**-hin	‘to attack (object focus)’
gó:lp**e**	‘hit’	g**u**lp**i**-hín	‘to hit (OF)’[119]
Nonalternating stems			
ká:bl**e**	‘cable (message)’	kabl**e**-hán	‘to send a cable to’
mag-mané:h**o**	‘to drive (AF)’	maneh**ó:**-hin	‘to drive (OF)’

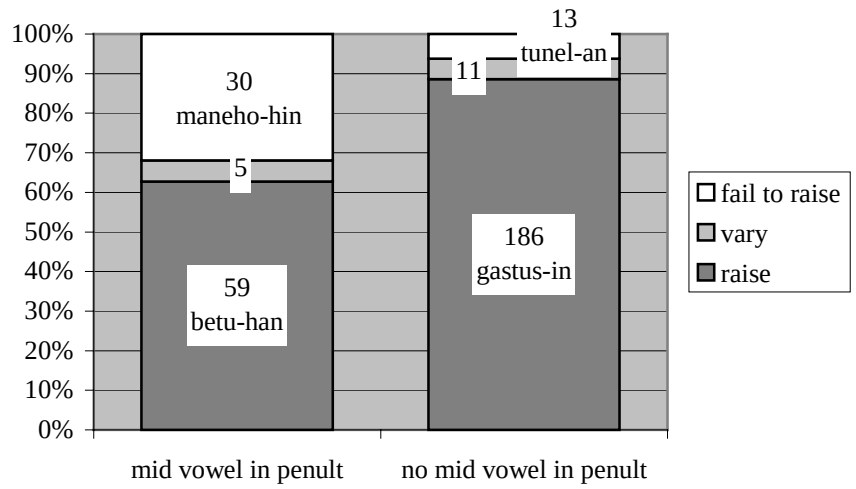
Because vowel height within a bare stem is usually[120] borrowed faithfully from Spanish, it is of little interest—in other words, a nonfinal mid vowel is present because it

[119] Occasionally a nonfinal mid vowel such as the *o* in *gó:lpe* in becomes high under suffixation. I know of no cases in which this happens without the final mid vowel also raising. That fact lends to support to the Aggressive Reduplication analysis of exceptions to vowel raising proposed here: although in most of the examples seen here, the stem-final vowel resists raising in order to remain similar to the stem-penult vowel, in *gó:lpe* the reverse happens—the stem-penult vowel and stem-final vowel remain similar by both raising. “Double raising” cases like *gó:lpe* are not included in the statistical analysis because there are not enough of them. but the prediction of Aggressive Reduplication would be that double raising, like nonraising, is more likely when the stem ultima and stem penult are more similar.

was present in the Spanish or English word. What is of interest is whether or not a loanword alternates when given a native suffix, since that can be determined only by the Tagalog phonology. I constructed a database from English's (1986) dictionary of all 488 Spanish and English loans with a mid vowel in the final syllable and one or more listed suffixed derivatives.

As observed by Schachter and Otanes (1972), the best predictor that a loanword stem will fail to alternate is the presence of a mid vowel in another syllable. As shown in (108), only 6% of stems without a mid-vowel penult fail to raise (like *t**u**n**e**l-an*),[121] but 32% of those with a mid-vowel penult fail to raise (like *man**e**h**o**-hin*).[122]

(108) Effect of mid vowel in penult on probability of raising



[120] though not always—still, there are not enough cases in which vowel height is nativized to investigate what factors make such nativization probable.

[121] The behavior of a stem's derivatives is quite uniform (all raise, all vary, or all fail to raise), so, unlike in the case of nasal substitution, it is possible to speak of stems that do or do not raise.

[122] Statistical significance results are given in §4.11. All differences shown in bar charts are significant except where otherwise noted.

There are several possible explanations for why the presence of another mid vowel discourages raising. First, perhaps the whole word is somehow marked as contrastive for [high], since it contains one vowel with an unpredictable value of [high] (the *e* in *maneho*). The final vowel would thus also be interpreted as contrastively (rather than predictably) [-high], and so remain [-high] under suffixation.

A second explanation is that the presence of the nonfinal mid vowel (rare in native words) marks the whole word as belonging to a foreign stratum, subject to a different constraint ranking (see Itô and Mester 1995), in which Paradigm Uniformity outranks the markedness constraints, preserving the [-high] quality of the vowel in the bare stem even under suffixation. If this is the explanation, we would expect that other markers of foreignness could be found that would also discourage alternation.

I examined several such predictors. Stress/length on a nonfinal closed syllable and prepenultimate stress/length are both rare or nonexistent in the native vocabulary, but neither one nor the other nor both was a predictor of nonalternation. I also examined foreign distribution of [d] and [ɾ] (in the native vocabulary, [ɾ] is normally found intervocalically and [d] elsewhere) as a predictor, but it had no effect on the likelihood of alternation. Finally, I looked at overly large consonant clusters—initially, medially, or finally—as predictors and found only a very small, weakly significant effect. Thus, a nonfinal mid vowel's serving as a cue to foreignness does not seem to be a good explanation for why the presence of such a vowel discourages alternation.

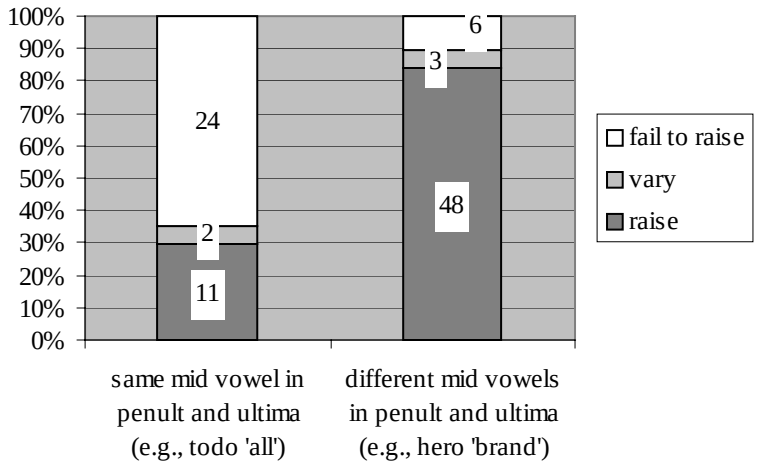
A third possible mechanism by which the nonfinal mid vowel could discourage alternation is vowel harmony. If a [-low] vowel must agree in [high] with a preceding vowel (subject to *FINAL[u]), then the *o* in *maneho* would be prevented from raising under suffixation:

(109) Vowel harmony as a mechanism for preventing alternation

	/mag+lutO/	*FINAL[u]	HARMONY	*NONFINALMID
a	☞ magluto		*	
b	maglutu	*!		
	/manehO+in/	*FINAL[u]	HARMONY	*NONFINALMID
c	☞ manehohin			*!
d	manehuhin		*!	

If vowel harmony is the mechanism at work (in some probabilistic fashion), certain factors might be expected to enhance the effect. First, agreement in backness between target and trigger could encourage harmony (cf. Kaun 1995: agreement in height encourages rounding harmony); and indeed, there is a strong effect, as shown in (110).

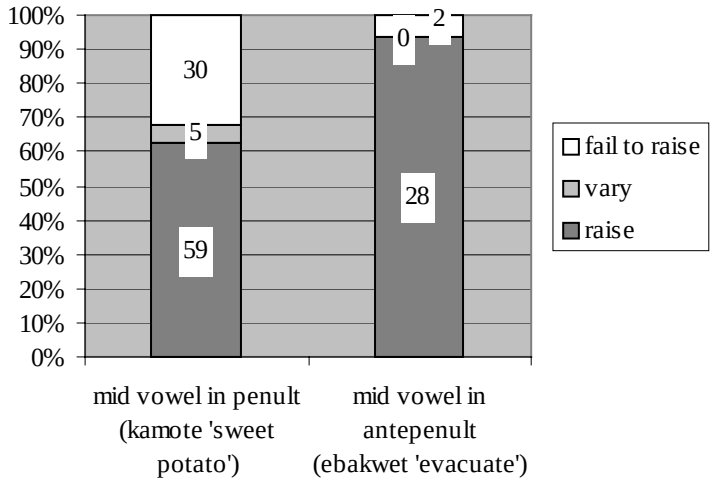
(110) Effect of matching backness between penult and ultima, given a mid penult.



Second, proximity of trigger to target might increase the probability of vowel harmony's applying, and here again, there is a strong effect, as shown in (111).[123]

[123] Aggressive Reduplication's explanation for the proximity effect is that as in productive reduplication, there are constraints (not discussed here) that prefer adjacency between reduplicant and base.

(111) Effect of proximity



Third, among nonadjacent vowel pairs, the quality of the intervening vowel(s) could have an effect—a high vowel could block harmony, by preventing the spread of [-high]. There are, however, not enough relevant cases (stems with nonadjacent final and nonfinal mid vowels that fail to raise) to test this prediction. Thus, vowel harmony fares well as an explanatory mechanism. Still, I propose that Aggressive Reduplication is at work, instead of or perhaps in addition to vowel harmony, because it makes an additional correct prediction that vowel harmony cannot explain, as I will now demonstrate.

4.5.1. Aggressive Reduplication applied to the vowel raising

Recall that Aggressive Reduplication invokes a correspondence relationship between syllables that are fairly similar, and can enhance or preserve similarity. In this case, a pseudoreduplicative correspondence relationship is invoked between the two syllables that contain mid vowels, because they are similar in both having mid vowels. If IDENT-

BR[HIGH] >> *NONFINALMID, raising of the second vowel under suffixation is prevented (for greater visual clarity, lack of subscripts—instead of mismatched subscripts—is used to indicate lack of correspondence relation, as in candidate *e*):

(112) Aggressive reduplication blocks vowel raising

	/tonO + -an/	IDENT-IO [MANNER]	IDENT-IO [HI]	IDENT-BR [HI]	REDUP	*NONFINAL MID
a	☞ $[to]_{\alpha}[no]_{\alpha}$han				**	**
b	$[to]_{\alpha}[nu]_{\alpha}$han			*!	**	*
c	$[tu]_{\alpha}[nu]_{\alpha}$han[124]		*!		**	
d	$[to]_{\alpha}[to]_{\alpha}$han	*!				**
e	tonu han				***!	*

Candidate *b* in (112) fails because the vowels in the base and reduplicant fail to match in height; *c* makes the vowels identical, but at the expense of changing an underlying height specification; similarly, *d* makes the consonants identical at the expense of changing various underlying manner features; and *e* fails because it is not construed as reduplicated. Note that the above tableau assumes that IDENT-BR[SONORANT] (along with other relevant IDENT-BR[F] constraints) is ranked low enough to allow *t* and *n* to correspond.

This type of Aggressive Reduplication is a case of emergence of the unmarked (McCarthy & Prince 1994): even if CORR-IO outranks CORR-BR, preventing enhancement of internal similarity, REDUP can still make itself felt by setting up an

[124] Candidates of this type do sometimes prevail. See fn. 119. Under the allomorph-listing approach argued for in §4.7.2, this fact does not challenge the high ranking of CORR-IO constraints, because the listed form being used is not the bare stem, but a separate, listed allomorph.

internal correspondence relation that preserves internal similarity—here by blocking alternation.[125]

Agreement in backness encourages a reduplicative construal because, assuming stochastic constraint ranking, sometimes IDENT-BR[BACK] will be ranked high enough to prevent a reduplicative construal when the vowels do not agree in backness, as illustrated in (113).

(113) A ranking that prevents correspondence between mismatched vowels

	/donO + -an/	IDENT-IO [BACK]	IDENT-BR [BACK]	IDENT-BR [HI]	REDUP	*NONFINAL MID
a	☞ $[do]_{\alpha}[no]_{\alpha}$han				**	**
b	$[do]_{\alpha}[nu]_{\alpha}$han			*!	**	*
c	donu han				***!	*
	/denO + -an/	IDENT-IO [BACK]	IDENT-BR [BACK]	IDENT-BR [HI]	REDUP	*NONFINAL MID
d	$[de]_{\alpha}[no]_{\alpha}$han		*!		**	**
e	$[de]_{\alpha}[nu]_{\alpha}$han		*!		**	*
f	$[do]_{\alpha}[no]_{\alpha}$han	*!			**	**
g	☞ denu han				***	*

The cross-linguistic preference for reduplicative proximity explains the distance effect.[126] Thus, Aggressive Reduplication can also account for the predictions of vowel

[125] Some casual data suggest that similar cases of similarity preservation through rule-blocking (rather than outright enhancement) may exist in other languages: many English speakers feel that flapping of *d* is almost obligatory in words like the proper name *Frodo*, but only optional in pseudoreduplicated *dodo*. Similarly, *Zulu* allows either light or dark *l*, but pseudoreduplicated *Lulu* requires two light *l*s. Thanks to Bruce Hayes for these observations.

In French, [ɔ] is usually found instead of [o] in nonfinal syllables (e.g., [dɔdy] 'chubby'), but not possible in baby-talk reduplicated words like [dodo] 'beddie-bye' (even though the source word, [dɔʀmiʀ] 'to sleep', has [ɔ]). Thanks to Roger Billerey for this observation.

[126] This preference could be encoded in Alignment constraints that require, for example, the right edge of the reduplicant to coincide with the left edge of the base.

harmony that were seen to be borne out above. But Aggressive Reduplication makes an additional prediction: similarity between penult and ultima[127] along any dimension—not only vowel backness—should also encourage establishment of a reduplicative correspondence relationship, and thus resistance to alternation. Section 4.6 shows that this prediction is also correct, and §4.8 shows how differences in syllable similarity could result in different probabilities of raising.

Aggressive Reduplication also predicts that in stems with a *high*-vowel penult, similarity between penult and ultima should encourage raising. Unfortunately, because nearly all non-mid-penult stems do raise, it is not possible to test this prediction.

Before moving on to §4.6, there is one problem with the rankings in (112) and (113): how likely is the crucial ranking IDENT-BR[HIGH] >> *NONFINALMID? In disyllabic reduplication of two-syllable stems ending in a mid vowel, the reduplicant usually raises (*ʔáːbot* 'reach; overtaken', *ʔaːbut-ʔáːbot* 'one after the other'), although this is not obligatory—nonraised pronunciations are common in many words, such as *haːloʔ* 'mixture', *haːlo-háːloʔ ~ haːlu-háːloʔ* '(drink made with shaved ice)'.[128] The prevalence of raising in disyllabic reduplication would suggest a strong tendency for *NONFINALMID to outrank IDENT-BR[HIGH]. If this is the case, then IDENT-BR[HIGH] should not have a noticeable tendency to prevent raising, even in words that are construed as reduplicated. I have two possible explanations for this apparent contradiction.

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[127] There are not enough stems in which the correspondence relation that would block alternation would be between the ultima and the antepenult (i.e., loanstems with three syllables or more and mid vowels in the antepenult and ultima but not in the penult) to examine the effect of similarity between antepenult and ultima.

[128] It is unclear how lexically conditioned this optionality is. It could result from variability in the ranking of *NONFINALMID vs. IDENT-BR[HIGH], or from variability in whether the reduplicant-base boundary counts is strong enough to prevent raising (i.e., whether disyllabic-reduplicant-final counts as word-final).

First, note that the reduplicative construals involved in blocking raising involve single syllables ([to]$_{\alpha}$[do]$_{\alpha}$). Perhaps the IDENT-BR constraints involved in disyllabic reduplication are different from those involved in CV reduplication. There is little evidence for the ranking of IDENT-BR[HIGH] in CV reduplication of native words, because native roots are at least one syllable long, and mid vowels are usually not found in nonfinal syllables (so the syllable being copied would rarely have a mid vowel). There are some exceptions, though (see (95)), as well as the systematic exception of the transglottals, and in these cases, raising does not occur with CV reduplication:[129]

(114) Vowel non-raising in CV reduplication

téːkas	'swindler'	ma-ne-néːkas	'swindler'
héːle	'lullaby'	nag-he-héːle	'is singing a lullaby'
loʔób	'robbery'	pan-lo-loʔób	'robbery'
		man-lo-loʔób	'burglar'
ma-noʔód	'to look on'	má-no-noʔód	'onlooker'

A possible interpretation is that IDENT-BR$_{1SYLL}$[HIGH] >> *NONFINALMID >> IDENT-BR$_{2SYLL}$[HIGH]. This ranking would produce a strong tendency to resist raising in words with mid penults and ultimas when they are construed as reduplicated.

A second possibility is that the lack of raising in CV reduplication reflects the fact that the vowel being reduplicated is contrastively mid, whereas in disyllabic reduplication, the final vowel of the base is predictably mid. Perhaps IDENT-BR[F] constraints are sensitive to the whether *F* is contrastive (e.g., fully specified) in the base: IDENT-BR[HIGH]$_{CONSTRASTIVE}$ >> *NONFINALMID >> IDENT-BR[HIGH]. A constraint like IDENT-BR[HIGH]$_{CONSTRASTIVE}$ must have access to the reduplicant, the surface form of the

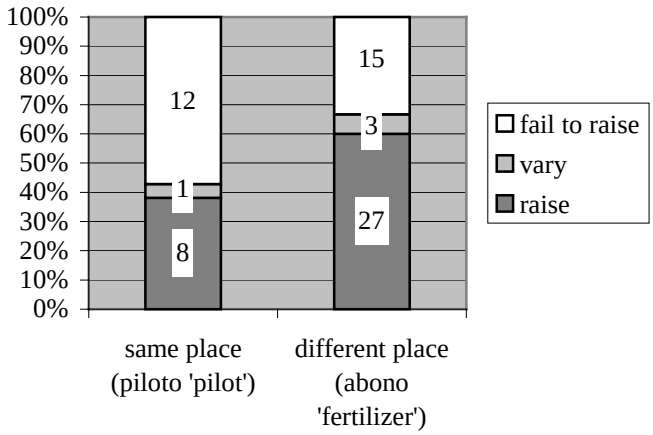
[129] Similarly, raising usually does not occur (although it is often an optional variant) in CV reduplication of loanwords with mid vowels in the initial syllable: e.g., *drówiŋ* 'drawing'; *pag-do-drówiŋ* 'act of drawing'.

base, and the underlying form of the base (if contrastiveness is encoded in the underlying representation), but is otherwise no different from ordinary correspondence constraints.

4.6. Similarity along other dimensions

In stems with mid vowels in both the penult and the ultima, similarity between the onset consonants of the penult and the ultima should encourage nonraising. When both onsets are simple (the majority case), we can simply compare the two consonants on various features. (115) shows that when the penult and ultima onsets have the same place of articulation, nonraising is more likely.[130] The mechanism is the same as that behind the matching-backness effect: the *lo* and *to* in *pi**l**ó ʔ**t**o* 'pilot' can correspond no matter what the ranking of IDENT-BR(PLACE), but the *bo* and *no* of *ʔa**b**ó ʔ**n**o* 'fertilizer' can correspond only if REDUP outranks IDENT-BR(PLACE).

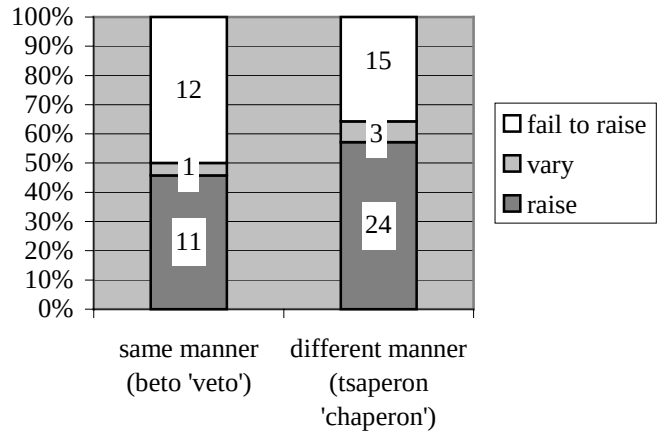
(115) Effect of onset place of articulation on rate of raising



[130] Note that the charts in this section compare all stems whose penult and ultima are similar along the dimension under discussion to all stems whose penult and ultima are dissimilar along the dimension under discussion. For example, in (115), the penult and ultima onsets of the words grouped with *piloto* must be identical in place, but may differ in voicing or manner, and the syllables may differ in shape or vowel quality; the penult and ultima onsets of the words grouped with *abono* must be different in place, but may be different or identical along other dimensions.

Identical onset manner also encourages nonraising. although the difference shown in (116) is not significant (see §4.11):[131]

(116) Effect of onset manner on rate of raising



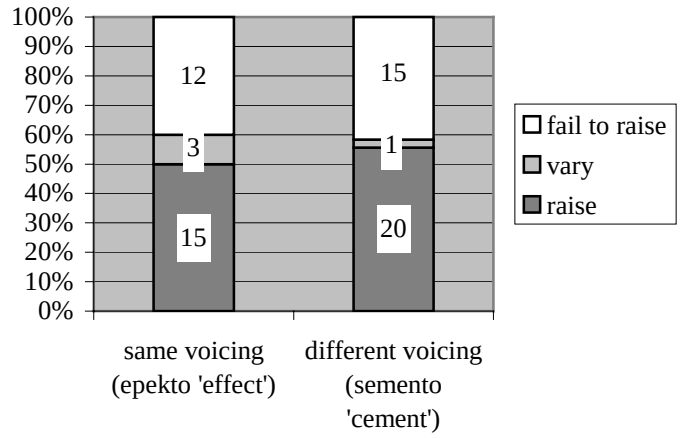
Again, the mechanism is the same: the *b* and *t* of ***bé ɬo*** ‘veto’ can correspond no matter what the ranking of IDENT-BR[SONORANT], IDENT-BR[NASAL], or any other IDENT-BR[MANNER] constraints. But the *p* and *ɾ* of ***ʧa pe ɾón*** ‘chaperon’ can correspond only if REDUP outranks various IDENT-BR[MANNER] constraints.

Voicing has no effect[132] (the small difference in (117) is not significant):

[131] The lack of a significant difference may be because “manner” is too crude a category. There are not enough relevant tokens, however, to compare single-feature distinctions such as “same value for [nasal] vs. different value for [nasal]”.

[132] There were not enough stems in which both onsets were obstruents to examine obstruent voicing.

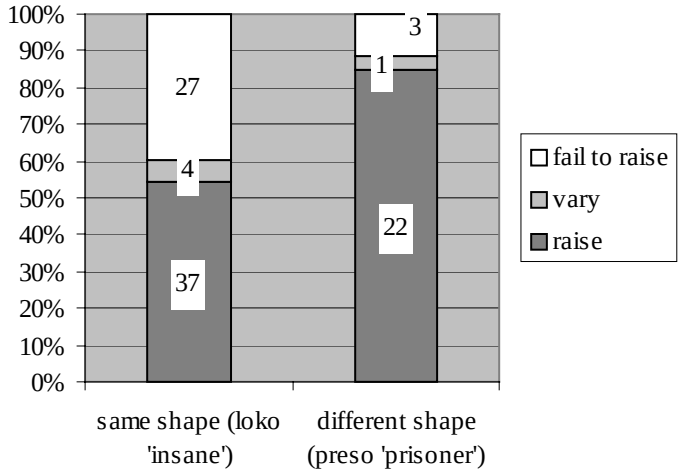
(117) Effect of onset voicing on rate of raising



See §4.9 for a possible reason for the lack of a voicing effect.

When onsets match in shape (simple vs. complex), nonraising is also encouraged:

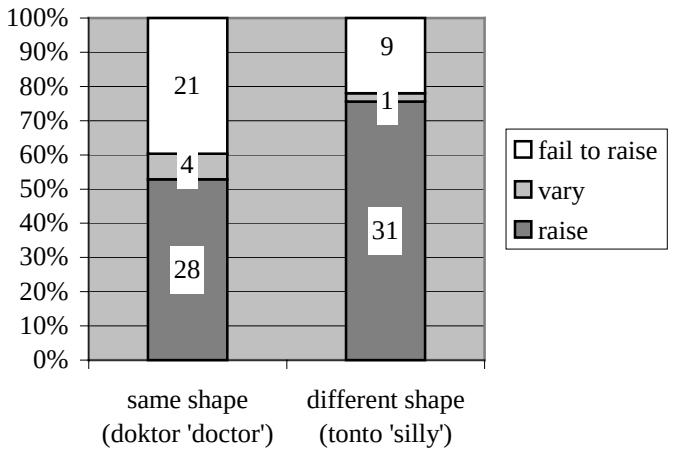
(118) Effect of onset shape on rate of raising



Here the crucial constraints are MAX-BR and DEP-BR: correspondence between the *pré* and the *so* of ***pré so*** 'prisoner' incurs a violation of DEP-BR.

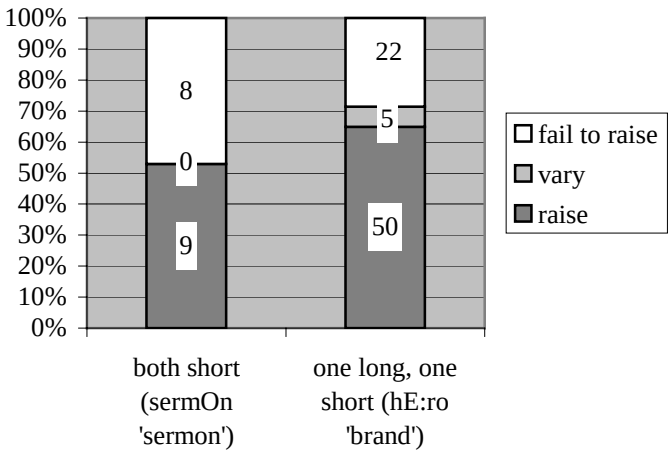
There are not enough cases in which both penult and ultima are closed to compare coda consonants, but we can compare rhyme shape (open vs. closed), and again a match promotes nonraising.

(119) Effect of rhyme shape on rate of raising



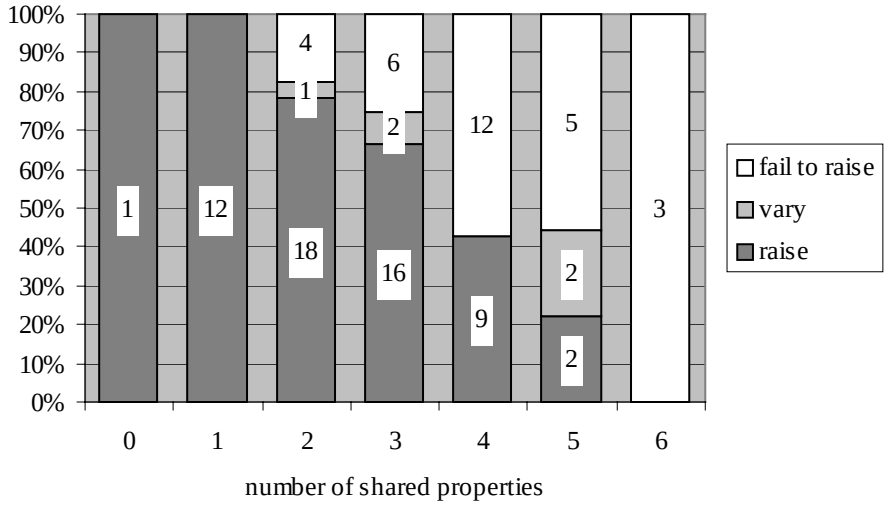
As for vowel length, recall that there are two basic types of stem in Tagalog: those with a long, stressed penult and those with no long vowels and a stressed final syllable. In stems with a long, stressed penult, length and stress shift to the right in the most common suffixing constructions: *héːro* ‘brand’, *herúː-han* ‘to brand’. In stems with no long vowel, stress shifts to the right in suffixed form: *sermón* ‘sermon’, *sermun-án* ‘to preach to’. We might expect that stems of the second type would be more susceptible to a reduplicative construal because there is no length difference between the vowels. Because final stress is unusual in both Spanish and English, there are too few examples of final-stressed loanstems for a significant difference, but the trend is in the predicted direction:

(120) Effect of vowel length on raising



Finally, we can look at the number of properties that the penult and ultima share (i.e., the number of CORR-BR constraints whose ranking is irrelevant to whether a reduplicated construal is possible, because they would not be violated), as a global measure of similarity. With seven properties (onset place, onset manner, onset voicing, onset shape, vowel backness, vowel length, and rhyme shape), stems can be grouped into eight categories: those that share 0, 1, 2, 3, 4, 5, 6, or 7 of those properties (there were no stems that shared all seven properties, so only seven categories are shown). The chart in (121) shows that the more shared properties, the more likely a failure to raise.

(121) Effect of number of shared properties on raising



To summarize: REDUP, interacting with CORR-BR, tends to discourage raising to the extent that the final syllable is similar to a preceding syllable that also has a mid vowel: the more similar the two syllables are, the fewer CORR-BR constraints are violated by establishing a correspondence relation between the two. If a correspondence relation is established, raising is less likely because it would violate IDENT-BR[HIGH].

4.7. Representations

Chapter 2 assumed that all existing, potentially nasal-substituting words are listed to some degree, whether they undergo nasal substitution or not. Listing all words provided a three-way distinction among existing words that reliably substitute, existing words that reliably fail to substitute, and new words, whose behavior should vary. This section argues that for vowel raising, the three-way distinction should be achieved through a different mechanism.

4.7.1. Separate entries for derivatives?

Separate lexical entries for all derived words (or, equivalently, separate sub-entries under the stem's entry) were appropriate for nasal substitution, because different derivatives of the same stem often behave differently. In vowel raising, however, different suffixed derivatives of the same stem nearly always[133] behave the same way (all raise, or all fail to raise). So, although occasional full listing may be a possibility in those rare stems whose derivatives are not uniform, it is not likely the usual state of affairs.

If each stem's raising behavior is uniform, then raising or nonraising should be determined by some property of the stem's own lexical entry; this property would then be inherited by derived forms. This was the assumption in the analysis sketched above (§4.3), which represented raising stems as having final vowels underspecified for [high],

[133] I found three definite exceptions (out of 100 loanstems with multiple suffixed forms), *dó:ble* 'double', *ló:ko* 'crazy person', and *bá:le* 'worth; I.O.U.', although only for *dó:ble* does behavior actually differ between suffixed stems—for *ló:ko* and *bá:le* it differs between suffixed stems on the one hand and disyllabically reduplicated stems on the other hand. There were also three possible exceptions: *ró:ljo* 'roll', *tú:rno* 'lathe', and *jé:lo* 'ice', some of whose derivatives are pronounced variably, and some of whose derivatives are listed as having only one pronunciation (for *ró:ljo*, the difference is between suffixed stems and reduplicant stems).

and nonraising stems as having final vowels specified [-high]. There is a problem, however, with the analysis in §4.3: what do stems that have never occurred in suffixed form yet look like? If they are underspecified, then they are identical in form to underspecified stems that do have established suffixed forms, and should behave just like them (always raising). But then how do nonraising stems come about? Novel suffixed derivatives must have some freedom to raise or not raise (as determined by the stochastic grammar). A three-way contrast is required among raising stems, nonraising stems, and "undecideds" (stems whose suffixed form has not yet been established).

4.7.2. Environment-tagged allomorphs

A three-way contrast between raising stems, nonraising stems, and undecideds can be achieved using environment-tagged allomorphs. Many Tagalog stems do seem to have separate, listed allomorphs that are used in suffixal form, as demonstrated by the sporadic phenomenon of syncope. Some stems (it is not predictable which[134]) undergo vowel syncope under suffixation.[135] The resulting consonant cluster can sometimes undergo metathesis or other, unpredictable changes:

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[134] There is partial predictability, in that some stem shapes are always prevented from undergoing syncope: stems with penultimate stress/length (e.g., *búhaj* 'life') cannot syncopate, because the syncopated vowel would be the one to which stress/length would have shifted under suffixation; and stems with a consonant cluster between the penult and ultima (e.g., *sampál* 'slap on the face') cannot syncopate, because the result would be a cluster of three consonants (**sampl-în*)

[135] At least under verbal suffixation. There are stems that syncopate in some constructions, but not others: e.g., *da**tîŋ*** 'arrival', *ká-hi-na**tn**-án* 'to be the outcome', *ká-ɾa**tn**-án* 'possible result, *ka-ɾa-ɾa**tn**-án* 'expected time of menstrual period', *da**tn**-án/da**tn**-în* 'to arrive at', but *pa-ɾa**tiŋ**-án/pa-ɾa**tiŋ**-în* 'to have (someone or something) sent; to have someone bribed'. It is possible that those constructions that shun the syncopated allomorph have special prosodic requirements, or are separately listed, or that high-ranking Paradigm Uniformity constraints enforce similarity to a related, unsuffixed form (e.g., *pa-ɾa**tîŋ*** 'message sent; bribe').

(122) Syncope

syncope alone (many examples)

mag-bi**gáj**	‘to give (AF)’	bi**gj**-án	‘to give (IOF)’
mag-ta**kîp**	‘to cover (AF)’	ta**kp**-án	‘to cover (LF)’
b-um-i**lî**	‘to buy (AF)’	bi**lh**-ín	‘to buy (OF)’[136]

syncope plus consonant changes (few examples)

d-um-a**tíŋ**	‘to arrive at (AF)’	da**tn**-án	‘to arrive at (LF)’
t-um-i**ŋîn**	‘to look at (AF)’	ti**ŋn**-án ~ ti**gn**-án	‘to look at (LF)’
mag-ta**nîm**	‘to plant (AF)’	ta**mn**-án	‘to plant (LF)’
h-um-a**lík**	‘to kiss (AF)’	ha**lk**-án ~ ha**gk**-án	‘to kiss (OF)’

Just as a stem that undergoes syncope would have a syncopated nonfinal allomorph[137] in its lexical entry, so would a stem that fails to raise have a nonraised allomorph, and a stem that raises would have a raised allomorph:[138]

(123) Suffixal allomorphs—sample partial lexical entries

‘give’	‘basket’	‘adobo’
/bigáj/$_{\_\#}$	/bá:sket/$_{\_\#}$	/ʔadó:bo/$_{\_\#}$
/bigj/$_{\_X}$	/basket/$_{\_X}$	/ʔadobú:/$_{\_X}$

For stems like these that have an existing suffixal allomorph, high-ranking IDENT-IO[HIGH] requires that the underlying height of the final vowel be faithfully parsed. We need, in addition, a constraint that requires allomorphs to be context-appropriate:

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[136] The use of listed allomorphs helps explain why vowel-final stems that syncopate have a final [h], even though the [h] is not needed to resolve hiatus. Listed suffixal allomorphs can also encode the exceptionality of stems like *kitá* ‘visible’, which has final [ʔ] instead of [h] in suffixed form (*pa:-kitá:ʔ-an* ‘showing (something) to one another’).

[137] Constraints against large consonant clusters would have to outrank MATCHCONTEXT (see below), to prevent use of the syncopated allomorph in disyllabic reduplication (**bigj-bigaj*—in this case, the disyllabic requirement also is not met).

[138] The lexical entries for the allomorphs need not be simple phoneme strings as shown here. They could employ diacritics, cross-references to context-insensitive allomorphs, or some other device.

(124) MATCHCONTEXT

> The context requirements [e.g., "__#"] of a morpheme in the input must not contradict the context in which that morpheme's output-correspondent segments occur in the output.

For example, the candidate */$b_1i_2g_3á_4j_5$/$_{\#}$ + /-i_6n_7/ → [$b_1i_2g_3á_4j_5i_6n_7$]* violates MATCHCONTEXT, because the first morpheme in the input requires a nonfinal context, but the output correspondent the last segment (j_5) is not word-final. The tableau in (125) illustrates faithful use of a suffixal allomorph.

(125) Faithful use of suffixal allomorphs

	'to make into adobo'	IDENT-IO [HIGH]	MATCH CONTEXT	*NONFINAL MID	REDUP	PU
a ☞	/ʔadobu/$_{X}$ + /-in/ → [ʔadobuhin]			*	******	*
b	/ʔadobu/$_{X}$ + /-in/ → [ʔadobohin]	*!		*	******	*
c	/ʔadobo/$_{\#}$ + /-in/ → [ʔadobohin]		*!	**	******	
d	/ʔadobo/$_{\#}$ + /-in/ → [ʔadobuhin]	*!	*	**	******	
e	/ʔadobo/$_{\#}$ + /-in/ → [ʔa[do]$_{\alpha}$[bo]$_{\alpha}$hin]	*!	*	**	*****	

When a stem has no listed suffixal allomorph, however, MATCHCONTEXT cannot be satisfied. It cannot be the case that the speaker uses the word-final allomorph instead, because then high-ranking IDENT-IO[HIGH] would always prevent raising, and listeners would always add an unraised allomorph to the lexicons (i.e., no loanwords or other new words would ever raise).

There is evidence in other languages that inflected words whose properties are fully predictable from those of their stems ("regulars") are usually not separately listed (see §5.3.1)—and yet a distinction between existing regulars (not listed but always regular) and novel words (not listed, behavior varies) is preserved. This suggests that

speakers must be able to reason about whether a listed form "should" exist or not (i.e., whether other speakers have a listed form): if a speaker's lexical entry for a stem is strong (i.e., she has heard it many times), and she has no lexical entry for the inflected form, then probably none "should" exist, and the inflected form should be produced synthetically, by inputting the stem and affixes to the grammar. But if the lexical entry for the stem is weak, as in novel words, it is probable that a listed form exists for other members of the speech community, and the speaker has simply never encountered it; in that case, the speaker may feel free to construct potential listed forms.

This dissertation will not attempt to construct a model of how speakers decide whether a listed form exists, or of how the speaker constructs possible listed forms for novel words. This question is related to another that will not be modeled here: how speakers reason from the amount of variation among derivatives of the same stem that for nasal substitution, whole words must be listed, but for vowel raising, only context-tagged allomorphs must be listed.[139]

Assuming that speakers can construct possible suffixal allomorphs for a novel word, multiple candidates would satisfy the two highest-ranked constraints, and the ranking of *NONFINALMID, CORR-IO, PU, and REDUP determines the winner:

[139] This reasoning or some equivalent must take place to perpetuate the uniformity in behavior with respect to vowel raising (and not impose uniformity in behavior with respect to nasal substitution). There may also be a fundamental distinction between suffixal and non-suffixal environments in Tagalog: there are only two suffixes (*-in* and *-an*), which play a variety of morphosyntactic roles. Suffixes condition stress and length shifts, as well as syncope. By contrast, there are many prefixes; a single word may contain several prefixes; and the only alternation triggered by prefixes is nasal substitution.

(126) Variability for constructed suffixal allomorphs

'to *gete*' (novel word)	IDENT-IO [HIGH]	MATCH CONTEXT	*NON FINALMID	IDENT-BR [PLACE]	REDUP	PU
a /gete/$_{\_X}$ + /-in/ → [getehin]			**		***	
a /gete/$_{\_X}$ + /-in/ → [[ge]$_\alpha$[te]$_\alpha$hin]			**	*	**	
b /gete/$_{\_X}$ + /-in/ → [getihin]	*!		*		***	*
c /geti/$_{\_X}$ + /-in/ → [getehin]	*!		**		***	
d /geti/$_{\_X}$ + /-in/ → [getihin]			*		***	*
e /gete/$_{\_\#}$ + /-in/ → [getehin]		*!	**		***	

Given a mechanism by which speakers decide whether to construct a suffixal allomorph, is environment-tagging really necessary? Without environment-tagging, stems that raise would have two listed allomorphs (one unraised and one raised; markedness constraints would select the best allomorph in each context), and stems that fail to raise would have just one (unraised). The difference between stems that consistently fail to raise, and novel stems (which would also have just one allomorph, and should behave variably) would be that for familiar stems, the speaker knows not to entertain the possibility that there exists a raised allomorph that she has simply never heard. The reasoning procedure for determining whether or not to construct a raised allomorph would have to involve the constraints in the grammar, so that a word's phonological properties (e.g., internal similarity) would contribute to the probability of constructing a raised allomorph. Otherwise, since existence of a raised allomorph must always entail raising, all novel words would have the same probability of raising. The remainder of this chapter will continue to assume environment-tagged allomorphs, but with a theory of the

construction of lexical entries for inflected forms of novel words, this might not be necessary.

Note that the phenomenon of syncope does not settle the question of whether or not allomorphs are tagged for context. In most cases, markedness constraints could select the correct allomorph (syncopated or not) for each context (suffixal or non-suffixal). For example, the *bigj* allomorph of 'give' in (122) would be unsuitable word-finally, because of its final consonant cluster; but when suffixation allows the *gj* cluster to straddle a syllable boundary, *STRUC (a constraint against phonological material in the output—Zoll 1993) would disprefer the *bigaj* allomorph. There is one type of case that might support the idea of environment-tagging: when a stem ending in [ʔ] syncopates, the glottal stop is deleted (*g-um-awáʔ* 'to make, to do (actor focus)', *gaw-în* 'to make, to do (object focus)'). A two-syllable minimal-word constraint (only clitics and some loans are monosyllabic) could rule out *gaw* in unaffixed context, but *gaw* is not used even when a prefix is present (e.g., *mag-gawáʔ* 'to manufacture'). It is possible that the minimal-word constraint applies to post-prefix material, so a conclusive test would be a trisyllabic stem ending in glottal stop that syncopates, but I have found none.

A final point concerns the possible difference between loanwords and native words. The uniformity of raising under suffixation among native words (except pseudoreduplicateds and transglottals) contrasts with the variability seen among loanwords, even those with no mid vowel in the penult (in which cases the only motivation for nonraising would be PU). It seems plausible that there is an additional force against raising in loanwords: if bilinguals are the primary creators of suffixed forms of loanstems, then trans-language correspondence constraints would tend to disprefer raising. This dissertation will not develop a theory of trans-language correspondence constraints, but their existence seems probable.

4.8. Modeling raising

Aggressive Reduplication's influence on the distribution of exceptions to vowel raising can be explained in the model proposed above for nasal substitution: listed forms generally prevail, but low-ranked constraints shape the lexical entries of new words in a probabilistic fashion.

To summarize the model proposed for nasal substitution, as it would apply to vowel-height alternations: when a stem undergoes suffixation for the first time, Paradigm Uniformity constraints prefer nonraising (preserving identity to the final vowel of the unsuffixed form). *NONFINALMID, however, prefers raising; if *NONFINALMID outranks PU, the speaker raises the stem-final vowel, and the listener updates her lexicon accordingly. REDUP and the CORR-BR constraints also influence the outcome, by discouraging raising in stems that have a high degree of internal similarity and are thereby susceptible to a reduplicative construal.

Sample tableaux in (127)-(129) illustrate how internal similarity affects the chances of raising in a novel word. The tableau in (127) shows that in the case of perfectly identical syllables, if REDUP >> *NONFINALMID, raising does not occur, even if *NONFINALMID >> PU. Candidate *d* fails because it does not have reduplicated structure (no subscripts). Candidate *b* fails because its two corresponding syllables are not identical in height.

(127) Vowel height in a novel word: identical syllables

	suffixed form of saklolo	IDENT-IO [HI]	IDENT-BR [HI]	REDUP	*NONFINAL MID	PU [HI]
a	☞ /saklolo/$_{\_X}$ + /-an/ → saklolohan			**	**	
b	/saklolu/$_{\_X}$ + /-an/ → sak[lo]$_\alpha$[lu]$_\alpha$han		*!	**	*	*
c	/saklolu/$_{\_X}$ + /-an/ → sakloluhan			***!	*	*

The tableau in (128) shows that in syllables that are fairly similar (in this case, identical in place and manner, but differing in voice), if REDUP outranks *NONFINALMID and the relevant CORR-BR constraints (here, IDENT-BR[VOICE]), raising is blocked despite imperfect identity: candidate *d* wins despite its violation of IDENT-BR[VOICE]. Note that candidate *g*, in which the two syllables' onsets are made identical, fails as long as IDENT-IO[VOICE] >> REDUP.

(128) Vowel height in a novel word: similar syllables

	suffixed form of todo	ID-IO [HI]	ID-BR [HI]	ID-BR [PL]	ID-IO [PL]	ID-IO [VOICE]	REDUP	*NON FNL MID	PU [HI]	ID-BR [VOICE]
d	☞ /todo/$_{\_X}$ + /-an/ → [to]$_\alpha$[do]$_\alpha$han						**	**		*
e	/todu/$_{\_X}$ + /-an/ → [to]$_\alpha$[du]$_\alpha$han		*!				**	*	*	*
f	/todu/$_{\_X}$ + /-an/ →toduhan						***!	*	*	
g	/todo/$_{\_X}$ + /-an/ → [to]$_\alpha$[to]$_\alpha$han					*!	**	**		*

The tableau in (129) shows why when the syllables are less alike (in this case, differing in place and manner), it is less likely that they will be construed as reduplicated: there are more CORR-BR constraints that would have to be outranked by REDUP. In the example shown here, the same ranking produces a reduplicative construal for *todo*, but a nonreduplicative construal for *ʔestorbo*: candidates *h*, and *i* violate IDENT-BR[PLACE] (as

well as DEP-BR, not shown); candidate *l* corrects the place misidentity, but violates IDENT-IO[PLACE]. Since a reduplicative construal is impossible, *NONFINALMID chooses the best nonreduplicated candidate, *j*.

(129) Vowel height in a novel word: dissimilar syllables

	suffixed form of ʔestorbo	ID-IO [HI]	ID-BR [HI]	ID-BR [PL]	ID-IO [PL]	ID-IO [VCE]	REDUP	*NON FNL MID	PU [HI]	ID-BR [VCE]
h	/ʔestorbo/$_X$ + /-an/ → ʔes[tor]$_\alpha$[bo]$_\alpha$han			*!			*****	**		*
i	/ʔestorbu/$_X$ + /-an/ → ʔes[tor]$_\alpha$[bu]$_\alpha$han		*!	*			*****	*	*	*
j	☞ /ʔestorbu/$_X$ + /-an/ → ʔestorbuhan						******	*	*	
k	/ʔestorbo/$_X$ + /-an/ → ʔestorbohan						******	**!		
l	/ʔestorbo/$_X$ + /-an/ → ʔes[tor]$_\alpha$[do]$_\alpha$han				*!		*****	**		*

These tableau only illustrate possible rankings that might occur on a given occasion. Because IDENT-BR[PLACE] >> REDUP >> IDENT-BR[VOICE], consonants that differed in place could not correspond, but consonants that differed in voice could. On another occasion, a ranking might be generated that would prevent consonants that differ in voice from corresponding (IDENT-BR[VOICE] >> REDUP), or would allow consonants that differ in place to correspond (REDUP >> IDENT-BR[PLACE]). Similarly, whether or not consonants that differ in manner can correspond depends on the relative ranking of REDUP and IDENT-BR[MANNER] (a shorthand, like IDENT-BR[PLACE], for several IDENT-BR[F] constraints); whether syllables that differ in onset or rhyme shape can correspond depends on the ranking of REDUP versus MAX-BR or DEP-BR; whether vowels that differ in backness can correspond depends on the ranking of REDUP versus IDENT-BR[BACK].

The key point is that there are many constraint rankings under which a word with similar mid-vowel syllables will be construed as reduplicated, but fewer rankings under

which a word with less similar mid-vowel syllables will be construed as reduplicated. *todo* will be construed as reduplicated—and so fail to alternate—whether IDENT-BR[PLACE]>>REDUP or REDUP>>IDENT-BR[PLACE]. *ʔestorbo* can be construed as reduplicated only if REDUP >> IDENT-BR[PLACE]. Under stochastic constraint ranking, it is thus more likely that a word like *todo* will fail to alternate.

4.9. Learnability

In Chapter 2, it was argued that the rankings of the constraints involved in nasal substitution were learnable from exposure to existing potentially nasal-substituted words; this was possible because the patterns within nasal substitution (the voicing and place effects) were found throughout the set of nasal-substituted words. Vowel height, by contrast, is close to exceptionless within the native vocabulary (at least under suffixation—see §4.4.1's discussion of disyllabic reduplication), so very little information about the relative ranking of, for example, REDUP and *NONFINALMID could have been learned before the influx of the Spanish and English loanstems whose behavior these constraints shaped.

Some information about the rankings of CORR-BR constraints can, however, be learned from the reduplicative identity effects seen in productive reduplication (see examples in §4.4). For example, the overapplication of nasal substitution (/maŋ/+/RED$_{CV}$/+/kulót/ → [má-**ŋ**u-**ŋ**ulót] 'hairdresser') tells the learner that IDENT-BR[NASAL] >> IDENT-IO[NASAL].[140] The underapplication of nasal assimilation and

[140] If the ranking IDENT-BR[NASAL], REDUP >> IDENT-IO[NASAL] is expected to occur occasionally, nothing prevents inputs like */tanak/* from surfacing as *[nanak]* (the issue arises only for coronals; roots of the form */pVm.../, /bVm.../, /kVŋ.../* and */gVŋ.../* are not attested). It must be assumed, then, as for the other CORR-IO constraints, that REDUP is ranked low that it virtually never outranks IDENT-IO[NASAL]. By transitivity, this means that REDUP can also never outrank IDENT-BR[NASAL]—that is, mid-penult stems whose penult and ultima onsets differ in nasality should be no more likely to resist raising that are low-penult or high-penult stems.

This is not the case, however: mid-penult stems whose penult and ultima onsets differ in nasality have a 29.4% chance of resisting raising (compared to 44.9% for mid-penult stems whose penult and ultima onsets match in nasality), whereas low-penult and high-penult stems have only a 6% chance of not raising. Perhaps nasal substitution does not exhibit true overapplication. See Inkelas 2000 for an argument that apparent overapplication in Tagalog nasal substitution really reflects Output-Output Correspondence.

glottal deletion[141] (/mag/+/RED$_{2syll}$/+/dúːnoŋ/ → [mag-dunuːŋ-dunúːŋ-an] ‘to engage in pedantry’; /RED$_{2syll}$/+/ʔalát/ → [ʔalat-ʔalat-án] ‘to make a little salty’) means that IDENT-BR[PLACE] >> IDENT-IO[PLACE] and DEP-BR[142] >> *Cʔ (or whatever the constraint is that forbids postconsonantal glottal stop). There are no cases of reduplicative identity that suggest a high ranking for IDENT-BR[VOICE], though, and this lack of evidence may explain why voicing identity has no effect on rate of raising (see (117)).

There are other scattered sources of evidence for the rankings of CORR-BR constraints, such as the fact that in disyllabic reduplication, the second syllable of the reduplicant has a coda only if the base is just two syllables long (i.e., *mag-ka-basa**g**-basá**g*** ‘to get thoroughly broken’ from *básag* ‘break’, but *mag-pa-baliː-bali**g**tád* ‘to toss and turn’ from *baligtád* ‘upside-down’); we could say that TOTAL[143] >> NOCODA >> MAX-BR; this pushes the ranking of MAX-BR down.

Because the frequencies of all these types of evidence are not known, and in some cases, such as nasal assimilation, the analysis itself is disputable (see fn. 112), this chapter does not present simulations of learning like the one in §2.6. The somewhat arbitrary grammar shown in (130), produces the rates of raising on novel words with mid-vowel penults shown in): greater internal similarity leads to a greater probability that raising will be suppressed.

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[141] though see fnn. 112 and 115.

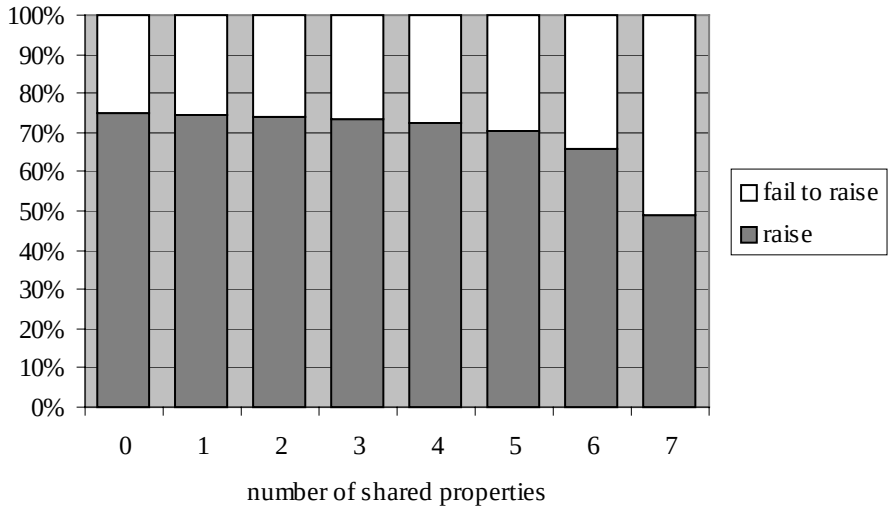
[142] The glottal stop that *Cʔ would delete is that of the base. The glottal stop of the reduplicant cannot be deleted (to yield CORR-BR-satisfying *alat-alat-án*) because it would create an onsetless syllable, which is prohibited in careful speech.

[143] a binary constraint requiring the reduplicant to copy all of the base.

(130) Grammar used in simulation

constraint	*ranking value*
MATCHCONTEXT	120
IDENT-IO[HIGH]	120
REDUP	108
IDENT-BR[HIGH]	110
IDENT-BR[BACK]	110
IDENT-BR[PLACE]	110
IDENT-BR[MANNER]	110
IDENT-BR[VOICE]	110
IDENT-BR[LENGTH]	110
MAX-BR	110
DEP-BR	110
*NONFINALMID	108
PU[HI]	106

(131) Rate of raising in novel words with mid penults, using the grammar in (130)



The effect of internal similarity is not as sharp as in (121), but these are only the rates of raising for novel words. In Chapter 3, small differences in rate of nasal substitution in novel words became magnified as words were assimilated into the lexicon (compare, for example, (57) and (83)).

4.10. Chapter summary

This chapter has applied the model of lexical regularities developed in Chapter 2 to the case of vowel raising in Tagalog, exceptions to which are found almost exclusively among loanwords. The best predictor that a loanword would fail to raise under suffixation is a mid vowel in the penult; it was argued that the mechanism preventing raising in these cases is reduplicative correspondence between the penult and the ultima. This analysis was supported by the finding that within mid-penult loanwords, similarity along other dimensions between penult and ultima further increases the probability of nonraising (because internal similarity favors a reduplicative construal).

4.11. Appendix: statistical significance of influences on raising

To determine the statistical significance of the various claimed influences on raising, I used contingency table analysis (see §2.2.2). To test whether the mid-vowel-in-penult effect in (108) was significant, we can construct a table with the observed number of stems with and without a mid vowel in the penult that raised or failed to raise,[144] as in (10), and a similar table with the "expected" values—the values that we would see if raising and mid-vowel penult were independent of each other—as in (11).

(132) Raising and mid vowel in the penult: observed frequencies

	raise	don't raise	total
yes mid vowel in penult	**59**	**30**	89
no mid vowel in penult	**186**	**13**	199
total	245	43	288

(133) Raising and mid vowel in the penult: expected frequencies

	raise	don't raise	total
yes mid vowel in penult	**75.712**	**13.288**	89
no mid vowel in penult	**169.288**	**29.712**	199
total	245	43	288

The observed and expected values are quite different. It was expected that about 30 non-mid-penult stems would fail to raise, but only 13 did; it was expected that only about 13 mid-penult stems would fail to raise, but 30 did. In other words, nonraising is more common than expected among mid-penult stems, and less common than expected among non-mid-penult stems.

[144] Stems whose pronunciation varies were not included. The more rows and columns in a contingency table, the more likely that the table of observed values will differ significantly from the table of expected values. Using fewer rows and columns produces more conservative results.

To test the significance of the differences between the observed and expected values, we look at χ^2. In this case, $\chi^2 = 35.8$. Given the number of rows and columns in the table, the probability *p* that a χ^2 value this big or bigger would be obtained by chance is less than 0.0001. We can conclude that it is extremely likely that having a mid vowel in the penult encourages nonraising. Fisher's Exact Test also yields a $p < 0.0001$ that a table with this degree of skew or higher could have arisen by chance if the two variables (penult vowel and raising) were independent.

Significance measures for all proposed inhibitors of raising are summarized in (134).

(134) Statistical significance of various inhibitors of vowel raising

	χ^2	Fisher's exact test
mid (not high or low)vowel in penult	$\chi^2 = 35.756$, $p < 0.0001$	$p < 0.0001$
matching backness	$\chi^2 = 32.508$, $p < 0.0001$	$p < 0.0001$
mid vowel in penult (not antepenult)	$\chi^2 = 8.345$, $p = 0.0039$	$p = 0.0037$
simple onset-same place	$\chi^2 = 3.250$, $p = 0.0714$	$p = 0.1012$
simple onset-same manner	$\chi^2 = 1.107$, $p = 0.2928$	$p = 0.4268$
onset shape	$\chi^2 = 7.331$, $p = 0.0068$	$p = 0.0066$
rime shape	$\chi^2 = 4.178$, $p = 0.0433$	$p = 0.0705$
vowel length	$\chi^2 = 1.676$, $p = 0.1654$	$p = 0.2552$

The results for onset place and manner are not very impressive, probably because the number of relevant observations is very small (remember, we are looking only at stems with a mid vowel in the ultima and the penult, and with simple onsets in both ultima and penult) and so the skew would have to be very great to get a satisfactorily small value for *p*. The lack of significance for vowel length may also reflect the number of observations: because penultimate stress is so common in English and Spanish, most of the English and Spanish loanstems have penultimate stress/length; there were only 17 stems in which both vowels were short.

5. Alternatives to Encoding Lexical Regularities in the Grammar

The preceding chapters have developed a model in which speakers' apparent knowledge of lexical regularities is encoded directly into the grammar, by constraints whose ranking is learned through exposure to the lexicon: constraints that many words violate become lower-ranked than constraints that few words violate. Although these constraints are ranked low enough to be irrelevant in the production and perception of common, existing words (for which only the requirement that listed words be faithfully used matters), they come into play in the production of novel words and in rating their acceptability. As discussed in Chapter 0, however, there are other ways to model behavior that appears to reflect knowledge of lexical regularities. This chapter will consider some of those alternatives. Section 5.1 discusses the possibility of encoding lexical regularities in a separate perception grammar; §5.2 discusses the possibility of letting lexical regularities emerge from the lexicon itself, using associative memory; and §5.3 discusses the dual-mechanism model.

5.1. A separate module

An alternative to encoding lexical regularities in the same grammar that maps inputs to outputs (the production grammar) is to encode them in a separate perception grammar. The perception grammar would be responsible for recognizing words, and for generating acceptability judgments.[145]

One advantage of having separate production and perception grammars is that it could explain the disparity between speakers' low rate of nasal substitution on novel

[145] Similarly, rather than a grammar specifically for perception, the language system might contain a module that lists lexical regularities in some form and is available for use in a variety of tasks.

words (in the production grammar, the constraints inhibiting nasal substitution usually outrank the constraints promoting nasal substitution) and listeners' high acceptability ratings for certain novel substituted words (the perception grammar directly reflects lexical frequencies, and for some obstruents, substitution is more frequent—and therefore more acceptable—than nonsubstitution). The production grammar would still have to encode nasal substitution, however (although the experimental results in §2.3.2.1 do not provide evidence that the production grammar must include the patterns within nasal substitution). And the perception grammar would have to somehow assign high ratings to correctly produced existing words, even if they went against the prevailing pattern.[146]

But the account in §2.8.3 of acceptability judgments solves the problem of the production/perception disparity without resorting to separate grammars: acceptability ratings for novel substituted words can be high because the listener must consider the possibility that the word in question, although novel to her, is not novel for her interlocutor. As shown in (71), the acceptability ratings generated by the single-grammar model were close to those produced by experimental participants.

Can the separate-grammars approach account for the assimilation of new words? The single-grammar model used in Chapter 3 depended on Bayesian reasoning on the part of the listener to give an advantage to substituted pronunciations of novel words such that they were more likely to become listed in the lexicon than unsubstituted pronunciations. A separate-grammars approach could achieve the same result by having listeners use acceptability judgments to determine whether or not to add a pronunciation

[146] This is not to say that an existing word that goes against the patterns of the lexicon must be rated as high as an existing word that does not, but rather that an existing word that goes against the patterns must be ranked higher than a novel word that goes against the patterns.

to the lexicon.[147] For example, if a listener hears unsubstituted novel *mampupuntol*, the perception grammar will assign it a low acceptability rating (because most *p*-stems in the lexicon do substitute), and this low rating would inhibit adding *mampupuntol* to the lexicon. Substituted novel *mamumuntol*, on the other hand, would receive a high acceptability rating and thus be likely to be added to the lexicon.

The single-grammar model in Chapter 3 also relied on both speakers and listeners to ensure that novel words with certain stem-initial obstruents have a higher probability of becoming listed as substituted than novel words with other stem-initial obstruents. The separate-grammars approach would rely solely on the listener, which does not seem problematic.

The use of separate production and perception grammars, then, is workable, but offers no empirical advantages over the use of a single grammar. The separate-grammars model is not simpler than the single-grammar model: lexical regularities still must be learned from the lexicon and stored. Moreover, there is duplication between the two grammars: both perception and production grammars must encode at least nasal substitution, if not the regularities within it.

5.2. Associative memory

It is possible that discrete knowledge of lexical regularities is not present anywhere in the mind: behavior that appears to reflect such knowledge could emerge directly from the lexicon itself. For example, in order to decide how to produce a novel word, the speaker would not consult the grammar, but rather would select one or more similar, existing words—perhaps the words that are activated first by feeding the novel word into an

[147] A possible mechanism: the probability of adding a pronunciation to the lexicon as a single word is equal to the acceptability of that pronunciation.

associative network (see, e.g., Rumelhart & McClelland 1986, Daugherty & Seidenberg 1994). The speaker would then apply the behavior of the existing words (or, if the existing words disagree, perhaps the majority pattern) to the novel word.

In the case of nasal substitution, a novel *p*-stem word would tend disproportionately to activate existing *p*-stem words, whereas a novel *g*-stem word would tend to activate existing *g*-stem words. As a result, a speaker would substitute novel *p*-stem words at a higher rate than novel *g*-stem words, and thus the behavior of novel words would tend to match that of existing words. There would have to be some additional bias against nasal substitution in the system to reproduce the experimental result in §2.3.2 that the rate of substitution on novel words was much lower than the rate of substitution among existing words.

Acceptability ratings would be derived similarly: the closer a novel word is to a randomly selected (similar) existing word or group of words, the more acceptable it would be. For example, in order to rate the acceptability of a nasal-substituted novel *p*-stem word, the novel word could be compared to the first several existing words that were activated by feeding the novel word into an associative network. The activated existing words would be likely to derive from *p*-stems, and thus would be likely to substituted. Because many of the activated existing words would be substituted, nasal substitution on the novel stem would receive a high acceptability rating. A novel *g*-stem word, on the other hand, would be likely to activate *g*-stem words, which are unlikely to be substituted, and so substitution on the novel word would receive a low acceptability rating. This idea is not refuted by the experimental data for nasal substitution in §2.3.3.1.

We would still need a mechanism that allows new words to become listed as nasal-substituted despite a low initial rate of substitution. This could be accomplished by having the listener use Bayesian reasoning as in §2.8, but using the comparison-to-

existing-words method rather than the grammar to estimate *P([output] | /input/)*—assuming, still, some mechanism that keeps the rate of substitution lower on novel words than the lexicon alone would dictate.

Even with a mechanism to prevent alternation in new words, and preserving Bayesian reasoning, the very idea of comparison to existing words becomes problematic in the case of vowel raising. As argued in Chapter 4, it is apparent from the distribution of exceptions to vowel raising among loanwords that an important factor in determining whether or not a novel word will undergo raising is the degree of similarity between the word's penult and ultima. How would a "similar existing word" be chosen when deciding whether to apply vowel raising to a novel word? We would need a novel word like *geke*, whose penult and ultima are identical except in onset voicing, to activate existing words whose penult and ultima are similar to the same degree, such as *todo*. This means that the criteria for similarity cannot involve merely shared segments or features, but would need to include "internal similarity score" as a possible dimension of similarity.

Even if the lexicon could be structured in such a way as to allow words to activate other words with similar internal similarity scores (whether through explicit encoding of internal similarity, through computing similarity scores afresh when necessary, or by some other mechanism), there remains a problem: exceptions to vowel raising under suffixation are found almost exclusively among recent loanwords (I found only one exception in the native vocabulary, *pa-dede-hin* 'to give a baby a bottle'), although failure to raise in disyllabic reduplication is fairly common, perhaps because of the prosodic boundary between the reduplicant and the base (e.g. *haːloʔ* 'mixture', *haːlo-háːloʔ ~ haːlu-háːloʔ* '(drink made with shaved ice)').[148]

[148] See §4.4.1.

Perhaps today new loanwords' behavior could be determined by analogy to existing loans, but what determined the behavior of the first loans? The existing words activated by any then-novel word would have displayed raising; differences in probability of raising among early loans could not have come from the lexicon. The model of vowel raising presented in Chapter 4 avoids this problem by having differences in probability of raising come from the grammar, not from the lexicon. The constraints responsible for the differences (REDUP, CORR-IO, and CORR-BR) are universal, and their ranking can be learned from facts other than vowel raising itself (see §4.9).

5.3. The dual mechanism model

The dual mechanism model (Pinker & Prince 1994) combines associative memory with a traditional output grammar. The output grammar is responsible for productive morphology and phonology; lexical regularities emerge from associative memory. Pinker and Prince proposed the dual-mechanism to account for the behavior of English past tense: in the majority (typewise) of verbs, the past tense is formed by adding the suffix *-ed*, whose allomorphs [t], [d], and [əd] are predictably distributed (as in [lʊk] 'look', [lʊk-t] 'looked; [bɛg] 'beg', [bɛg-d] 'begged'; [æd] 'add', [æd-əd] 'added'). There are quite a few irregular verbs (many of which are highly frequent), whose past tenses are irregular (e.g., [sɪŋ] 'sing', [sæŋ] 'sang'; [tiʧ] 'teach', [tɔt] 'taught'). The irregulars are patterned, in the sense that often irregulars whose past tense is formed in the same way share other characteristics. For example, many of the verbs whose past tense is formed by changing the vowel [ɪ] to [æ] have a velar nasal in the coda and an alveolar in the onset (sing, ring, sink, shrink, drink).

Pinker and Prince propose that when a verb has a listed past tense (this is true of irregulars and perhaps some very frequent regulars), that past tense is used, but when a

verb lacks a listed past tense, the grammar supplies the regular suffix and chooses the correct allomorph. Speakers sometimes supply irregular past-tense forms for novel words (Bybee & Moder 1983), and their probability of doing so is influenced by the novel word's resemblance to existing irregulars (Prasada & Pinker 1993); these facts are attributed to the effects of associative memory: the process of checking the lexicon to see if a word has a listed past tense form activates the past tense forms of similar words, and may result in the coining of an irregular past tense form.[149]

Pinker and Prince seem to conceive of the difference between regulars and irregulars as twofold: (i) irregulars' past tense forms must always be listed, whereas regulars' past tense forms are usually[150] not listed and must be synthesized; and (ii) patterns in the distribution of irregulars (such as the [ɪŋ]/[æŋ] pattern) exist only in the lexicon, whereas the regular pattern (add *-ed*) comes from the grammar. But only (i) is crucial: the evidence for a qualitative difference between regulars and irregulars can be explained solely in terms of the difference between listed and synthesized forms.

The remainder of this section goes through several pieces of evidence for a qualitative difference between regulars and irregulars, attempting to explain them in terms of the model proposed in Chapter 2, with the assumption that regulars generally lack a listed past tense (why this should be so is returned to at the end of the section). The stochastic grammar for English past tense would have very high-ranking USELISTED and faithfulness constraints (to ensure that listed pasts are used, and faithfully so), as well as a large group of constraints $X_{present}$ / Xt_{past} ("a verb stem of the form *X* in the present tense

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[149] This raises again the question from §2.5 and §4.7 of a three-way distinction: existing irregulars vs. existing regulars vs. novel words that may be treated as irregular or regular. See §4.7.2.

[150] See below for the conditions that can lead to listing of regulars.

should be of the form *Xt* in the past tense"),[151] $X\text{ɪ}\eta_{present} / X\Theta\eta_{past}$, $X\text{ɹ}\text{ɪ}\eta Y_{present} / X\text{ɹ}\Theta\eta Y_{past}$, etc.[152] Note that these constraints are of varying degrees of specificity, so a given verb would be subject to more than one. Some of these present/past constraints are ranked high (because there is much evidence for them), others low (such as $Xe\text{ɪ}_{present} / X\varepsilon d_{past}$, exemplified only by *say/said*).

5.3.1. Evidence for a qualitative difference between irregulars and regulars

One piece of evidence for a difference between irregulars and regulars is Ullman's (1999) study of acceptability judgments for the past-tense forms of existing words. Ullman found that the acceptability of irregular pasts depended on both the frequency of the past itself and the frequency of the verb stem. Acceptability judgments for regular pasts, however, depended only on the frequency of the stem. The interpretation is that only irregulars have a listed past tense: without a separate lexical entry to reflect its frequency, a regular past's acceptability must rely solely on information in the stem's lexical entry.

With the assumption that (most) regulars lack a listed past tense, the result is also easy to interpret in the model proposed here. Under the view of acceptability adopted in §2.8.3, a word's acceptability is a function of its probability of being pronounced (Hayes & MacEachern 1998, Hayes to appear). The probability of a particular pronunciation depends, in turn, on two factors: what the set of available inputs is likely to be, and which input-output pair the grammar is likely to choose. The frequency of an irregular past like *sang* affects its acceptability because frequency largely determines Listedness, which in

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[151] There might be separate constraints for the three allomorphs of *-ed*, or just one that interacts with markedness constraints to produce the correct allomorph in each situation.

[152] See Albright & Hayes (1999) for how such constraints can be synthesized, and their relative rankings learned, on the basis of evidence from the lexicon.

turn affects the likelihood that */sΘŋ/* would be available as an input. For example, if */sΘŋ/* is available, the high ranking of USELISTED and faithfulness constraints will almost always make */sΘŋ/→ [sΘŋ]* the optimal candidate. If */sang/* is not available, then */sɪŋ/+past→ [sΘŋ]* is still a reasonable candidate (it satisfies $X\text{ɪ}\eta_{present}$ / $X\Theta\eta_{past}$), but so are */sɪŋ/+past→ [sɪŋd]*, */sɪŋ/+past→ [sʌŋ]*, and others, so the probability of getting the output *[sΘŋ]* (and thus its acceptability) is reduced. For a regular verb with no listed past, however, only synthesized candidates can be under consideration—the probability of retrieving a listed past is always zero, no matter what the frequency.

Ullman also found that acceptability ratings of irregulars depended on their "neighborhood size" (the number of similar stems whose past tense is formed in the same way), whereas acceptability ratings of regulars did not. The dual-mechanism interpretation is that regular pasts are unaffected by neighborhood size because they are generated by a rule of the grammar, which is not sensitive to how many words follow it. The explanation for Ullman's finding in the model proposed here is that neighborhood size affects the acceptability of irregular pasts because it determines (during learning) the ranking of the past/present constraints that those pasts obey. For example, because *sing/sang* is in a large neighborhood, the constraint $X\text{ɪ}\eta_{present}$ / $X\Theta\eta_{past}$ is high-ranked, increasing the production probability of every candidate with the output *[sΘŋ]*. Why no neighborhood effect for regulars? It may be that in English, the general constraint $X_{present}$ / Xt_{past} is ranked so high that it swamps the effects of more specific constraints like $X\text{ɔ}k_{present}$ / $X\text{ɔ}kt_{past}$. Albright (1998, 1999), found that in assigning novel Italian verbs to conjugation classes and rating their acceptability, judges were indeed sensitive to neighborhoods within the default (regular) pattern. This may be because the particular facts of Italian do not lead to a one single constraint for the regulars that is strong enough

to swamp the effect of the others; the fact that Albright's search for neighborhoods was more exhaustive may also have played a role.

Qualitative difference also exist in producing past-tense forms. Prasada, Pinker, and Snyder (1990) found that speaker's speed in producing irregular past tense forms depended on the frequencies of both the past tense form itself and the verb stem. The speed of producing regulars, on the other had, depended only on the frequency of the stem. This finding makes sense in the model proposed here, because producing an irregular past tense involves both retrieving it from memory and applying the grammar—the frequency of the listed past would affect the speed of retrieving it. But in producing a regular, there is never a listed past tense to affect the computation.[153]

A final qualitative difference between regulars and irregulars is in priming: Stanners et al. (1979) found that irregular pasts prime their stems somewhat, but that regulars prime their stem as well as the stem itself (in an all-visual-priming task). The interpretation is that because irregular pasts are listed separately, recognizing them only weakly activates the related entry for the stem. But recognizing a regular past requires accessing the stem itself, because there is no separate, listed past. In the model presented here, recognizing a regular past requires looking for the stem that, when run through the grammar, would produce the right result. Recognizing an irregular past, on the other hand, would not require activating the stem as thoroughly. If the grammar operates by whittling away the set of candidates, starting by eliminating those that violate the highest-ranked constraints, then once a listed irregular past was found, candidates synthesized

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[153] I assume, as the dual-mechanists do, that searching the lexicon and applying the grammar can apply in parallel—if the grammar were applied only after the search of the lexicon was complete, regulars would always be slower than the slowest irregular, because the speaker would have to search the entire lexicon before concluding that no listed form existed and moving on to applying the grammar to synthesized inputs. In my case, the grammar could work on evaluating the synthesized input-output pairs while waiting to see what listed inputs might be available.

from the stem and an affix would be eliminated from consideration (because they violate top-ranked USELISTED), and so the period during which the stem was activated would be brief.

To summarize, the qualitative difference between regulars and irregulars can be reduced to the difference between having a listed past-tense form (irregulars), and lacking one (regulars). The English past tense may not be a case that argues strongly for putting constraints that capture lexical regularities into the grammar (e.g., $X\text{ɪ}ŋ_{present}$ / $X\text{ʌ}ŋ_{past}$), but neither is it an argument for keeping lexical regularities out of the grammar. The next section considers the reasons for the difference in listedness between regulars and irregulars.

5.3.2. Why are regular pasts not listed?

The account of listener behavior in §2.8 proposed that when a listener hears a word for which she has no lexical entry, she must guess whether or not her interlocutor might have been using a lexical entry unfamiliar to the listener (as opposed to concatenating some familiar morphemes). If the listener guesses that the speaker was using a lexical entry, the listener begins to build one herself. Every time the listener guesses that some speaker was using a lexical entry for this word, she strengthens her own entry. In order to guess whether or not the speaker was using a lexical entry, the listener applies Bayes' Law: all else being equal, the probability that the speaker was using a lexical entry is proportional to the probability that the utterance the listener heard would have occurred if the listener had been using a lexical entry. Similarly, the probability that the speaker was creating a synthetic form is proportional to the probability that the utterance heard would have been produced if the speaker had been using a synthesized input.

When a listener hears a past tense form like *said* whose probability of being produced by synthesis is low (the $Xe\imath_{present}$ / $X\varepsilon d_{past}$ constraint is not very high-ranked), she is likely to conclude that it must have come from a listed form and update her lexicon accordingly. When she hears a regular past like *jumped*, on the other hand, she is likely to conclude that it was produced by synthesis (because $X_{present}$ / Xt_{past} is ranked so high) and not add anything to her lexicon.

Regular pasts can become stored under certain circumstances. Because the probability of obtaining a regular result from synthesis is never 100%, the listener may occasionally guess that a regular past was listed and add it to her lexicon. If this listed guess happens enough times for a particular past, that past can develop a strong lexical entry. One way to produce many incidents in which the listener guesses that a word is listed, even if such guesses are improbable, is simply for the word to be highly frequent. There is indeed evidence that high-frequency regulars have a tendency to become stored: Stemberger and MacWhinney (1986) found that error rates in forming the past tense of regular verbs were lower for verbs with high-frequency past-tense forms; Baayen, Dijkstra, and Schreuder (1997), found faster reaction times in a lexical-decision task for high-frequency regular noun plurals in Dutch than for low-frequency noun plurals, even holding constant the frequency of the singular form;[154] Sereno and Jongman (1997) found that for English regular noun plurals, reaction time was also correlated with frequency of the inflected form. When frequency of the inflected form has an effect on behavior, the interpretation is that the inflected form must be listed (i.e., if the inflected form were not listed, behavior would depend solely on the frequency of the stem).

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[154] Baayen et al. did not find a frequency effect for Dutch verbs.

Being a regular in a strong irregular neighborhood should also encourage the formation of a lexical entry. For example, *blink* (past tense *blinked*, not **blunk* or **blank*), violates the constraint *XɪŋX / XaŋX*. Because a large neighborhood gives *XɪŋX / XaŋX* a high ranking (see Albright & Hayes 1999), the irregular synthesized candidate */blɪŋk/ + past→ [blƟŋk]* makes the regular synthesized candidate */blɪŋk/ + past→ [blɪŋkt]* less of a sure winner than it would be for most regulars. This decreases the probability of obtaining *[blɪŋkt]* from synthesis, and thus makes the listener more likely to guess that the word is listed. Ullman and Pinker 1991 found evidence that past-tense forms like *blink* are indeed stored—their frequency influences their acceptability ratings.

Finally, the regular members of past-tense doublets (such as *dived/dove*—many speakers are unsure which is the correct past-tense form of *dive*, and both are common) have a tendency to become listed. This is because the presence of the strong competing candidate */doʊv/ → [doʊv]* reduces the likelihood that *[daɪvd]* would be the optimal output if the input */daɪvd/* were not available. When the listener hears *[daɪvd]*, then, she is more likely to guess that it was listed. Ullman and Pinker (1990), found that acceptability ratings regular (and irregular) members of doublets correlated with their frequency.

To summarize, the difference in listedness between regulars and irregulars need not depend on a prior qualitative difference between the two. Rather, given a grammar that tends to produce regular outputs for synthesized inputs, listener reasoning will prevent most regulars from becoming listed. This difference in listing then leads to the apparent qualitative difference between regulars and irregulars discussed in §5.3.1.

6. Summary

The preceding chapters have proposed a model of grammar to account for the effect of lexical regularities in speaking, listening, and the evolution of the lexicon. The grammar is a basic OT grammar, but with stochastic constraint ranking. Reliably high-ranked constraints ensure the stable behavior of listed words, but variably ranked subterranean constraints come in to play for novel words. Boersma's (1998) Gradual Learning Algorithm (which was designed to handle free variation) was shown to be capable of learning a grammar of this type through exposure to rates of lexical variation.

Candidates in this model consist of input-output pairs (rather than outputs that all share the same input), so for both speakers and listeners, single-lexical-entry inputs compete with synthesized inputs composed of strings of morphemes. In particular, in order to form acceptability judgments and to decide whether and how to update her lexicon, a listener must guess whether her interlocutor has used a listed word or has synthesized a new word.

When a speaker utters a novel, morphologically complex word, only synthesized input-output pairs are available. In the case of nasal substitution, the grammar that the Gradual Learning Algorithm learned produces a low rate of nasal substitution when only synthesized candidates are available. But when a listener hears a novel word, she cannot be certain that the word was novel for her interlocutor; she must take into account the chance that the pronunciation she heard could have come from a listed input. By performing this reasoning, the model was able to emulate the experimental finding of high acceptability for nasal-substituted novel words despite the low productivity of nasal substitution on novel words.

The low rate of nasal substitution on novel words also produced a challenge for the assimilation of new words into the lexicon: if nonsubstitution is the majority pronunciation, why does it not always win out? Why do some words eventually become listed as substituted? The answer given was that in assimilating new words into the lexicon (i.e., gradually developing lexical entries for them that are nasal-substituted or not), Bayesian listener reasoning produces a bias in favor of nasal-substituted pronunciations such that they have a disproportionately good chance of being added to the lexicon. A computer simulation confirmed that high rates of nasal substitution in assimilated words can be obtained despite low initial rates of nasal substitution when the words are new.

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