# Lexical Access, Effective Contrast and Patterns in the Lexicon

Adam Ussishkin and Andrew Wedel
University of Arizona

1.   Introduction

Patterns in the physical, 'extra-grammatical' world and patterns in grammar often show suggestive relationships. For example, gradient biases in articulation and perception are frequently mirrored in categorical patterns in phonological grammars. This relationship has led linguists from many different theoretical backgrounds to suggest that there exist some mechanism(s) by which a gradient tendency derived from the environment can be transformed into an element of the grammar (e.g., Baudoin de Courtenay 1895/1972, Donegan and Stampe 1979, Prince and Smolensky 1993, Archangeli and Pulleyblank 1994, Blevins 2004, Hayes and Steriade 2004, Wedel 2004). If we accept that there exist some general mechanism(s) for grammar-external biases to influence grammar and/or lexicon structure, the most general hypothesis is that biases anywhere along the pathway from production through perception may come to be reflected in grammar or the lexicon. A diagram of processes and representations in this pathway that may be of interest to the phonologist is shown in (1) below.

(1)   Heuristic schematic of steps in the pathway from production through perception
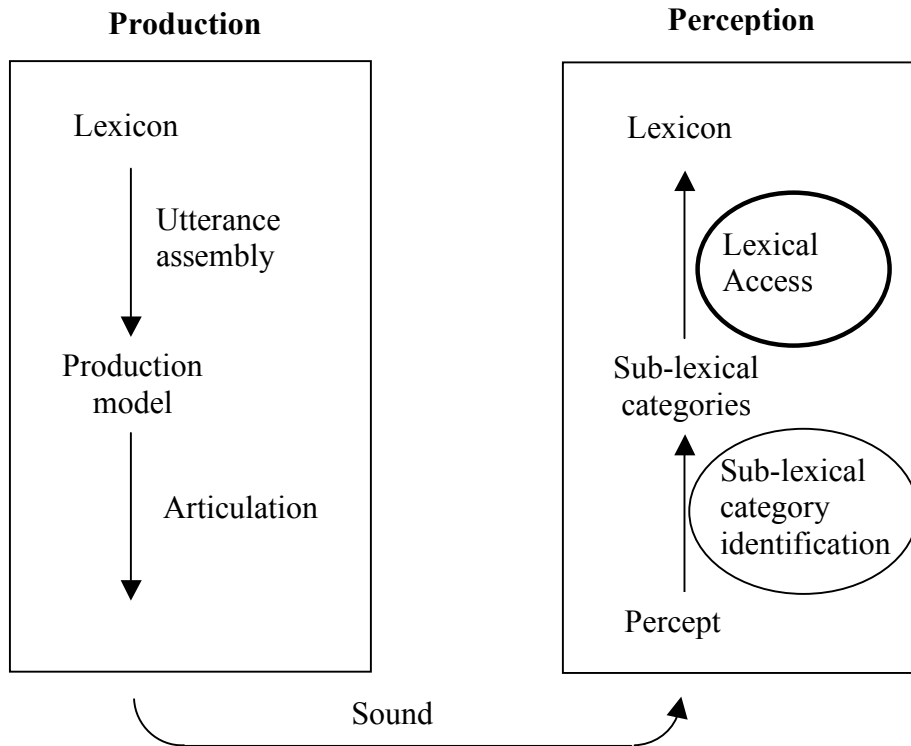
Many papers in this volume provide examples of phonological patterns based in biases in the mapping from percepts to sub-lexical categories in perception (light oval in (1)). Here, we present an argument that two distinct surface patterns in language – (i) the stem-suffix faithfulness distinction (Jakobson 1965/1990:414, Willerman 1994, McCarthy and Prince 1995, Bybee 2004), and (ii) the tendency for small stems to resist alternation (Wedel 2002) – may share a source in biases found within the process of lexical access, that is, the mapping from sub-lexical categories to lexical entries (heavy oval in (1)). Below, we summarize research on this lexical access step suggesting that at least three competing factors influence its efficiency: lexical neighborhood density, relative lexical token frequency, and morpho-phonological alternation. Then we propose that lexicons and grammars may evolve to balance these influences in such a way that acts to support lexical access efficiency above some threshold, using patterns in morpheme structure from a variety of languages as evidence.

The remainder of this paper is structured as follows. First, we provide a discussion of neighborhood density and its relationship to lexical access. We then introduce token frequency as a factor that can mitigate inhibitory effects of high neighborhood density. We discuss how these two factors combine to yield a functional notion of *effective contrast* that goes beyond traditional ideas relating to sound-contrast. We then turn to two types of phenomena that on the surface might seem unrelated to each other. First, we introduce distinctions in contrast that play out in stems vs. affixes, showing how the usual cross-linguistic pattern can be explained once factors like neighborhood density and token frequency are taken into account. We then examine the unusual pattern observed in Modern Hebrew, which turns not to be so unusual once our notion of contrast is broadened to include effective contrast. Second, we discuss contrast distinctions that appear to be dependent on morpheme size. In the same section, we examine phonological alternations in Catalan and Czech that seem to pattern exceptionally in stems whose segment number falls below a particular threshold. By expanding our notion of contrast to include effects of neighborhood density the exceptional behavior observed in small stems receives a principled explanation.

2.   The Neighborhood Density Effect and Sound Contrast

In the last fifteen years, research on the process of matching a sound-percept to an entry in the mental lexicon has shown that the efficiency with which a word is recognized is affected by the number of other similar words in the lexicon. For example, in the lexical decision task, the speed and accuracy with which it can be determined if a phonologically licit sequence of sounds corresponds to an actual word is inversely related to the number of similar words in the lexicon (Luce 1986, see also Goldinger, Luce and Pisoni 1989, Cluff and Luce 1990, Luce and Pisoni 1998).

For the purposes of these studies, similarity is usually operationally defined as a Hamming distance of one segment (Luce 1986), in which a lexical entry will be counted as similar to another if it can be changed into the other by adding, subtracting or changing one segment. For example, entries that are similar to the lexical entry *cat* under this definition include *cast*, *at*, *sat*, *kit*, and *can*. (This is clearly a very coarse measure of similarity; that it is sufficient for experimental purposes is perhaps a testament to the

robustness of this phenomenon.) The set of words that are identified by this measure are termed that word's lexical *neighbors.* In the lexical decision task for example, experiments show that English speaking subjects are able to decide that a sound string with few neighbors like *orange* is a real word more rapidly and accurately than a string with many neighbors like *cat*. This is termed the neighborhood density effect, illustrated graphically below in Figure 2.

(2)   Neighborhood density and access efficiency
Lexical access in a low-density neighborhood (the left oval) is faster and more accurate than in a high-density neighborhood (the right oval).

low-density neighborhood   high-density neighborhood

(Figures adapted and extended from Dirks et al. 2001.)

In (2), ovals represent lexical neighborhoods and bars represent lexical entries. The distance between bars represents the degree of phonemic similarity. The lexical entry represented by the solid bar on the left is accessed more efficiently because it has relatively few neighbors. On the right, the lexical entry represented by the solid bar has many more near neighbors, and is found to be accessed less efficiently. The Neighborhood Activation Model (NAM; Luce 1986, Luce and Pisoni 1998 and references therein) accounts for the neighborhood density effect by proposing that a sound sequence activates all lexical entries in the lexicon relatively to their degree of similarity to the stimulus. Selection of a lexical entry as the best match to the sound sequence is made on the basis of differential levels of activation, with the lexical entry with greatest relative activation most likely to be selected.

By positing a competition between activated lexical entries for recognition, NAM predicts that entries in high-density phonological neighborhoods will be recognized less efficiently than entries occurring in low-density neighborhoods because when an input activates words in a high density neighborhood, there will be many competitors with similar activation levels. Rephrased in terms of phonotactics, NAM predicts that entries that share many segments in sequence with other entries will be responded to less quickly and accurately than those that have rarer segments and segment sequences. Over the last two decades, many studies using a variety of methodologies have confirmed these predictions (e.g., Luce 1986, Goldinger, Luce and Pisoni 1989, Cluff and Luce 1990, Metsala 1997, Newman, Sawusch and Luce 1997, Wright 1997, Luce and Pisoni 1998, Vitevitch and Luce 1998, Vitevitch et al. 1999, Boyczuk and Baum 1999, Dirks et al. 2001, Brown 2002).

Although NAM is couched in terms of 'neighbors' and 'density', it can be rephrased in terms of contrast, a term more familiar to the linguist. A lexical item in a high-density neighborhood, such as *cat*, is a lexical item that does not contrast highly with other words in the English lexicon, that is, very nearly all of the features that make

up the lexical entry *cat* are required to distinguish it from all its neighbors. A word like *cat* then can be thought of as having a relatively low phonemic contrast within the English lexicon. A lexical item in a low-density neighborhood on the other hand, such as *orange,* is highly contrastive: it is distinguished from its nearest neighbors by a large number of features. The useful insight to be gained from this line of research is that for the purposes of lexical access, the contrast of a lexical item may be largely dependent on the number and similarity of its actual lexical neighbors, rather than possible words or any other more abstract factor.

3.   Frequency and Effective Contrast

Alongside neighborhood density, lexical frequency also has a strong effect on the efficiency of lexical access: all else being equal, the higher a lexical item's relative token frequency, the more rapid and accurate its access (e.g., Gordon 1983, Dirks et al. 2001). The factors of neighborhood density and relative frequency interact, as a sufficiently high relative token frequency can mitigate the deleterious effects of a dense neighborhood on lexical access (Luce 1986). This is illustrated below in (3).

(3)   High relative frequency and efficiency of access
High relative frequency mitigates the otherwise inhibitory effect of high neighborhood density: access efficiency can be similar for the low-density neighborhood (leftmost oval) and the high-density neighborhood (rightmost oval) when the target item has a higher token frequency relative to its neighbors.

low-density neighborhood   high-density neighborhood
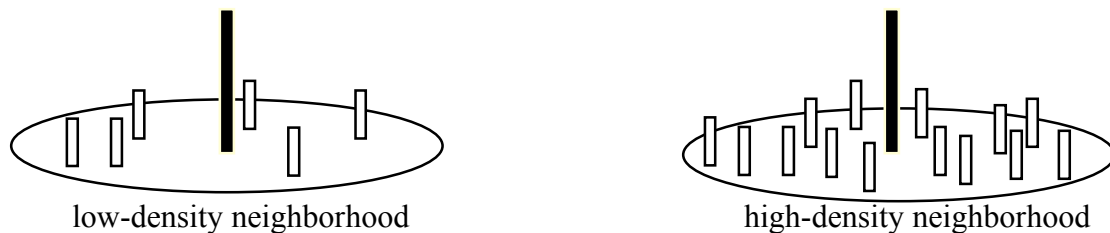
In (3), as before in (2), ovals represent lexical neighborhoods, bars represent lexical entries, and the distance between bars represents degree of phonemic similarity. New to (3) is the factor of token frequency, illustrated using bar height, where the higher a bar the higher its token frequency. On the left, the lexical entry represented by the solid bar is accessed relatively efficiently because it is very frequent relative to its lexical neighbors, which are, in addition, few and far between. On the right, the lexical entry represented by the solid bars has many more neighbors, but is still accessed efficiently because it is much more frequent than any of those neighbors.

The diagrams in (3) illustrate the finding that a high relative token frequency renders access efficiency less sensitive to neighborhood density; in other words, a high frequency lexical item in a dense neighborhood may be accessed nearly as efficiently as one in a low density neighborhood. Thus, efficiency of access is affected by (at least) two factors. On the one hand, the lower a lexical entry's phonemic contrast with other entries

(i.e., the denser its neighborhood), the lower its efficiency of access. On the other hand, the more often a lexical entry is accessed (i.e., the higher its token frequency), the more efficient that access is.

Lexical access efficiency provides a useful frame for thinking about contrast, because in functional terms, lexical items that are accessed efficiently are definitionally those that contrast well. Because the degree to which a lexical item contrasts with its neighbors is not solely a function of its phonemic contrast, we suggest that a reconception of contrast in terms of the composite influences on access may be useful for guiding hypotheses about patterns of contrast. To distinguish this idea from the notion of contrast defined in terms of strictly sound-based difference (whether phonemic, featural or cue-based), we use the term *effective contrast*, first introduced in Ussishkin and Wedel (2002). Because effective contrast is sensitive to both sound contrast and relative token frequency, two lexical items can have the same effective contrast but be in neighborhoods of different densities. For example, a relatively frequent lexical entry in a dense neighborhood may have the same effective contrast as an infrequent one in a sparse neighborhood. Within the psycholinguistic literature, this combined influence of neighborhood density and relative frequency on lexical access is often expressed by the descriptors 'hard' versus 'easy', where a hard word is one that has low effective contrast due to some combination of neighborhood density and relative frequency, and an easy word has high effective contrast through some different combination of these factors (e.g., Luce 1986, Wright 1997, Brown 2002).

Over the last century, a variety of linguistic theories have grappled with accounting for the maintenance of phonemic contrast in synchronic grammars and/or over diachronic change (e.g., Martinet 1955, Lindblom 1986, Flemming 1995, Padgett 2003). While these models focus on mechanisms for the maintenance of an abstract system of differences in the sound system, we propose the hypothesis that maintenance of a system of phonemic distinctions instead proceeds indirectly through maintenance of effective contrast, that is, through functional pressure to support the lexical access efficiencies of actual lexical items above some threshold. A model for indirect maintenance of phonemic contrast through maintenance of lexical access efficiency is presented in Wedel (2004, 2005). Because high token frequency increases effective contrast, this hypothesis predicts that the evidence for sound contrast maintenance effects will be weaker in context of high token frequency.

4.　　The stem-affix faithfulness distinction

We turn now to our first set of data, which focuses on the distinctions in contrast played out in stems vs. affixes. This distinction has been long noted by many researchers, going back at least as far as Jakobson (1965/1990, see also Willerman 1994, Bybee 2004). The distinction itself can be very simply stated: cross-linguistically, it has been observed that within individual languages, affixes tend to make use of a less marked subset of the overall inventory of segments and structures. Theoretical linguists have proposed that this distinction be encoded via a universal preference to preserve contrast in stems (allowing for a wider array of contrasting segments and structures) while disallowing as much contrast in affixes. In Optimality Theory, this preference has been elevated to the status of a universal metaconstraint, known as the Stem-Affix Faithfulness Metaconstraint

(McCarthy and Prince 1995), which bifurcates faithfulness into two types: Faith-Stem and Faith-Affix. If Faith-Stem is always ranked above Faith-Affix, with a markedness constraint sandwiched in between the two, the prediction is that affixes will never allow an instance of the marked structure to surface, contrary to stems, whose higher-ranking faithfulness allows that structure to serve as a way to contrast. This proposed universal would then describe, for instance, why in Arabic relatively marked segments (such as pharyngeal consonants) occur in stems but never in affixes. A skeletal ranking illustrating the metaconstraint is given in (5):

(5)   Stem-affix faithfulness metaconstraint (McCarthy and Prince 1995)

        FAITH-STEM » MARKEDNESS » FAITH-AFFIX

        Rather than appealing to a descriptive device such as the McCarthy and Prince metaconstraint, the account proposed here provides a psycholinguistically grounded explanation for the distinct behavior of stems vs. affixes.[1] First, like all function morphemes, an individual affix is likely to have a much higher token frequency than any given root (Segalowitz and Lane 2000 and therein). Second, affixes as a group have a much lower *type* frequency than stems – from language to language, the tendency is to find a much larger number of stems than affixes. Clearly, then, this distributional difference between stems and affixes motivates a possible separation of one from the other in terms of how the grammar might treat them. In the psycholinguistic literature, there exist two general models of the lexical storage of affixes and other function morphemes relative to content morphemes or stems. In the first model (termed here the 'single lexicon model'), content and function morphemes are stored together in a single lexicon (Segalowitz and Lane 2000). Under this model, all lexical entries, whether of function or content morphemes, compete with each other in lexical access. In the second model (termed here the 'split lexicon model'), function and content morphemes are stored in distinct lexicons, and so cannot compete with one another in lexical access (Bradley 1978, Biassou et al. 1997).
        We will first consider the stem-affix distinction under the single lexicon model. Here, the much greater token frequency of affixes relative to stems in the single lexicon means that lexical access for affixes will be efficient even if their sound-contrast is low – in other words, the effective contrast of affixes remains high because of the compensatory effects of high frequency.
        Looking now at lexical access under the split lexicon model, we still expect efficient access of affixes. In this model, the affix lexicon contains only affixes, so any given affix is not likely to be accessed more frequently than its neighbors. However, the affix lexicon necessarily contains many fewer members than the stem lexicon, resulting in a relatively low neighborhood density for affixes. Under this model, then, we expect affixes to be efficiently accessed even if sound-contrast is low, because any given lexical entry has so few near neighbors.
        Therefore, in both the single lexicon model and the split lexicon model, affixes maintain high effective contrast. Depending on which model is adopted, this is due either

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[1] For conceptually parallel accounts of the influence of experience and token frequency on the mapping from percepts to sublexical categories, see Boersma 1998, Hume 2004.

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to their high token-frequency or their low neighborhood density. Earlier, we proposed that in the balance between reduction of markedness and maintenance of contrast, sufficient effective contrast is the relevant goal. This understanding of the conflict between maintenance of contrast and minimization of markedness predicts that reduction in markedness will have the least impact for morphemes with the highest effective contrast, whether due to a sparse neighborhood or high relative token frequency.

Given that as a group affixes have high effective contrast, a natural consequence is that they should, as a group, tolerate greater reduction in markedness than stems, which have lower effective contrast. In stems, an equivalent reduction in markedness would have a greater impact on effective contrast than in affixes, and thus the expectation is that stems will require use of more marked elements.

In recent work, Bybee (2004) suggests that the tendency for affixes to be composed of less marked elements is unsurprising due to their greater frequency in production, because lenition proceeds more rapidly in high-frequency items (see Bybee 2001). However, if this were the only factor governing lenition, we would be unable to explain the many examples of contrast-enhancing effects (e.g., Kirchner 1997, Smith 2002) and effects of morpheme realization, in which affixal material retains some minimal phonological exponence even when the phonology would otherwise prefer full deletion (e.g., Yip 1998, Kurisu 2001). Further, there is evidence that speakers use more contrastive phonetic detail when producing words in high-density lexical neighborhoods (e.g., Goldinger and Summers 1989, Wright 1996, Brown 2002), suggesting that frequency is not the only factor influencing the degree of lenition in individual production events. We suggest that while lenition may proceed through small changes over individual productions, the rate with which lenited production exemplars can drive changes in the underlying form of a lexical entry may be limited by the effective contrast of the entry (Wedel 2005).

5.   Allomorphy and effective contrast

Tsapkini et al. (1999) show that phonological difference between a derived form and a base slows the lexical access of derived forms in auditory presentation. If we assume that allomorphy generally imposes a processing cost on some members of a paradigm, alternation will result in lower effective contrast for those members. Given our hypothesis that lexical and grammatical systems evolve to maintain adequate effective, rather than solely sound-based contrast, it follows that we should find evidence that allomorphy is less frequent in paradigms where effective contrast is already low, through low phonemic contrast and/or low frequency.

In addition to the cross-linguistic tendency for affixes to contain material that is less marked than stems, a second relevant tendency instantiating the stem-affix asymmetry concerns alternation. Alternation is more prevalent in affixes than in stems. As an example, consider the English regular plural suffix, which undergoes voicing assimilation to match its voicing with the final segment of the stem it attaches to. A priori, this voicing assimilation might be expected on crosslinguistic grounds to have regressively affected the stem-final segment, but instead, spreads voicing progressively to the suffix. Harmony processes provide yet a more dramatic case; since such processes are overwhelmingly stem-controlled (e.g., Baković 2003). That is, harmony tends to affect

affixal segments, resulting in alternation in the phonological realization of affixes but not stems.

This asymmetry in alternation can also be described via the McCarthy and Prince metaconstraint. Since alternation in Optimality Theory is driven by ranking markedness above faithfulness, high-ranking Faith-Stem protects stems from undergoing alternation, but since Faith-Affix is ranked below the markedness constraint the effects of the markedness constraint emerge in affixes. In other words, the metaconstraint provides coverage for two sets of facts: a cross-linguistic tendency for stems to contain more highly marked structures and segments than affixes, as well as a similarly broad tendency for affixes to undergo alternation rather than stems.

6.   Avoidance of alternation in affixes: NAM predicts the Hebrew pattern

In Modern Hebrew (hereafter referred to simply as "Hebrew"), verbal derivational affixes (and some inflectional affixes) occur as patterns of two vowels (sometimes with a concomitant prefix), resulting in the system of verbal classes known as binyanim. This type of nonconcatenative templatic morphology has been analyzed as a word-based phenomenon (Bat-El 1994, 2003, Ussishkin 1999, 2000, 2005), rather than on the traditional but language-specific basis of the consonantal root. These researchers argue, on the basis of morphological and phonological evidence, that Hebrew presents robust evidence in favor of a word-based model for Semitic. This evidence comes from several domains, including the preservation of consonant clusters in denominal verbs, vowel transfer effects in denominal verbs, and templatic effects within the verbal system as a whole. Recent psycholinguistic evidence from studies by Berent et al. (2005) demonstrate a need for whole-word storage in Hebrew, thus strengthening the view that the word-based model, which finds much psycholinguistic support in other languages, is also a valid approach to Semitic.

Under the word-based approach, Hebrew requires a ranking in which Faith-Affix outranks all other faithfulness constraints, including Faith-Stem. Such a situation contradicts the metaconstraint proposed by McCarthy and Prince (1995), but is necessary in order to achieve what is known as melodic overwriting, the mechanism by which nonconcatenative templatic morphology is carried out. Hebrew verbs are prosodically restricted to two syllables, and are formed by concatenating a bisyllabic base form with a bivocalic affix. Given the maximal word size of two syllables, as established by Ussishkin (2000, to appear), the resulting complex form can only accommodate the affixal material by deleting base material. The following section details the relevant data.

As an example of melodic overwriting in nonconcatenative templatic morphology, consider the following paradigm, which presents verbs derived from the base verbal form *gadal* 'he grew'.
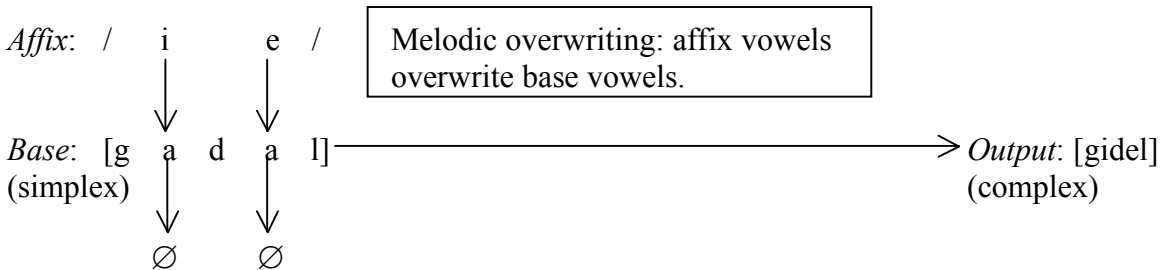
(6)   The verbal paradigm for *gadal*, 'to grow'

Base form   *+affix*   *Derived form*   *Gloss*

[gadal]   'he grew'
                /i e/   [gidel]   'he raised'
                /u a/   [gudal]   'he was raised'
                /hi i/   [higdil]   'he enlarged'
                /hu a/   [hugdal]   'he was enlarged'

For each derived form, it is clear that the output has failed to parse part of the original base form: namely, the vowels of the base. This is schematically represented for the derivation of the form *gidel* from the base form *gadal* in the following diagram:

(7)   Schematic illustration of melodic overwriting

Affix: /   i   e   / | Melodic overwriting: affix vowels overwrite base vowels. |

Base: [g   a   d   a   l]————————————————————————⟶ *Output*: [gidel]
(simplex)   (complex)

                ∅   ∅

Given the bisyllabic maximum, the only way for the affix /i e/ to be realized is by violating Faith-Stem, because material in the stem must be deleted to accommodate the affix. In other words, if the metaconstraint were universally obeyed a language like Hebrew would be predicted as impossible. The upshot is that we need to weaken the status of the metaconstraint from a universal to a tendency, thus reducing its explanatory power. The next question, then, concerns both the metaconstraint's viability and the real source for the tendency it describes in most cases. In such cases the metaconstraint seems to adequately describe the observation that affixes tend to be less marked than stems, as well as the observation that if a stem and an affix compete for phonological exponence the stem tends to win. How can we maintain these observations – valid in many languages – while at the same time capturing a seemingly abnormal pattern like melodic overwriting in Hebrew?

Under the single lexicon model, the Neighborhood Activation Model predicts that affixes will tolerate markedness reduction better than roots because they are more frequent. This higher relative frequency endows affixes with a high effective contrast so that any effect of phonemic markedness reduction is mitigated. Likewise, under the split lexicon model, the low number of affixes means that affixes will be unlikely to have many near neighbors, again resulting in a high tolerance for markedness reduction given the resulting high effective contrast. However, any special conditions resulting in lower effective contrast for affixes, such as an unusually high number of high frequency neighbors, should make affix faithfulness a higher priority.

In Hebrew, affixes for different verbal classes are composed of two vowels. Given the five-vowel inventory of Hebrew (*i, e, a, o, u*) a total of only 25 possible affixes exist. Compare this with, e.g., English, where the contrast space available to affixes is much larger. In Hebrew, seventeen of the 25 possibilities are actually attested, so there exist few opportunities to further reduce phonemic contrast without neutralization to homophony. Therefore, because of special restrictions on what may serve as verbal affixal material, verbal affixes are all near neighbors of one another, as the following table shows:

(8)   Table of extant bivocalic melodies in Modern Hebrew (from Ussishkin 2005): the first vowel of the affix is represented by the vowels in the leftmost column; the second vowel of the affix is represented by the vowels in the topmost row, and each attested combination is provided in the intersecting cells.

V2 \ V1	i	e	a	o	u
i	past tense of hifʕil forms	past tense of piʕel forms	past tense of some piʕel forms; past tense of nifʕal forms; deverbal noun of paʕal	infinitive of some paʕal forms	deverbal noun of piʕel forms
e	past tense of some hifʕil forms	some segolate nouns	some segolate nouns		
a	present tense of some hifʕil forms; infinitive and future stem of some hifʕil forms	present tense stem of piʕel forms; infinitive stem of piʕel forms	past tense of paʕal forms	some nominal and adjectival forms	participle of paʕal forms
o	present tense of some hifʕil forms	present tense of paʕal forms; past tense of some piʕel forms	nominal pattern		
u			past tense of puʕal and hufʕal forms; present tense stem of puʕal and hufʕal forms		

With the potential contrast space almost filled (shading in the table indicates gaps), we can understand that neutralization of any phonemic contrast it likely to result in neutralization of a morphological contrast, thus explaining the need to maintain a high level of phonemic contrast in order to maintain the necessary effective contrast. In other words, high token affix frequency in Hebrew is not sufficient to guarantee a high enough effective contrast.

This is illustrated below in (9) under the single lexicon model[2].

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[2] Under the split lexicon model, (9) would be identical but for the absence of the unfilled bars, with the same consequences as those described here for the single lexicon model.

(9)   Affix neighborhood density in most languages vs. Hebrew

*Most languages*   *Hebrew*
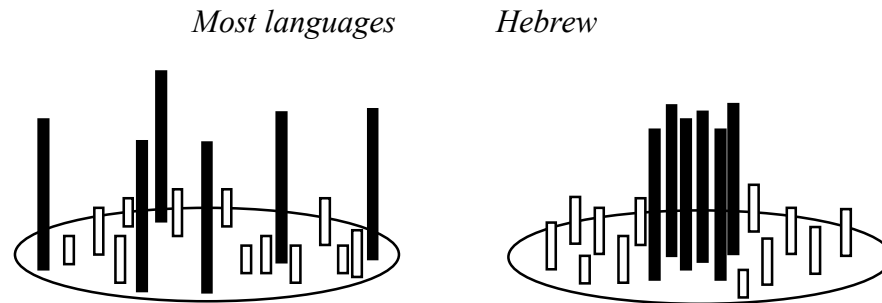
        In (9), the ovals represent regions of the lexicon and the bars represent lexical entries. Bar height represents token frequency. The solid bars are representative of affix entries. For the case depicted on the left, which is meant to represent the commonly found situation in most languages, affixes are distributed relatively evenly throughout lexical space, due to the facts that affixes are relatively few and that affixal material is drawn from a relatively large set of elements, at least in contrast to Hebrew where affixes tend to be vocalic. For Hebrew, represented on the right, affixes are taken from a very limited set of elements that are very similar to each other – vowels. Therefore, Hebrew verb class affixes are grouped very closely together in lexical space.
        Above we saw that the high frequency of affixes relative to their neighbors makes their access efficient even when phonemic contrast is low. In Hebrew, however, we see that verbal affixes are *not* more frequent than their near neighbors, because since those neighbors are affixes they have the same type of phonological content, so in effect relative frequency is cancelled out as a factor in effective contrast. Unlike in other languages, the high frequency of a verbal affix in Hebrew cannot compensate for a low phonemic contrast, with the result that phonemic contrast must be maintained to preserve adequate effective contrast; essentially, in the Hebrew case, effective contrast is equivalent to phonemic contrast. Hebrew demonstrates that Faith-Affix must outrank Faith-Stem in cases where following the metaconstraint would obliterate the contrast between affixes entirely. This important functional motivation for the reversal of the metaconstraint has precedence in work of Boersma (1998:189), who states, for Mixtec tone deletion based on an analysis in Zoll (1996), "it is more important to keep *some* information about the affix than to keep *all* the information about the base."

7.   Avoidance of allomorphy in small stems

Morpheme length is a very robust predictor of neighborhood density, as illustrated for English below in (10), adapted from Frauenfelder, Baayen, and Hellwig (1993). This obtains because while the number of *possible* words increases exponentially with phoneme number, the rate of increase in the number of *actual* words with phoneme number is much slower. Phrased differently, relatively more of the *possible* small words are also *actual* words.

(10)

The Mean Number of Neighbors Decreases
with Root Length in English
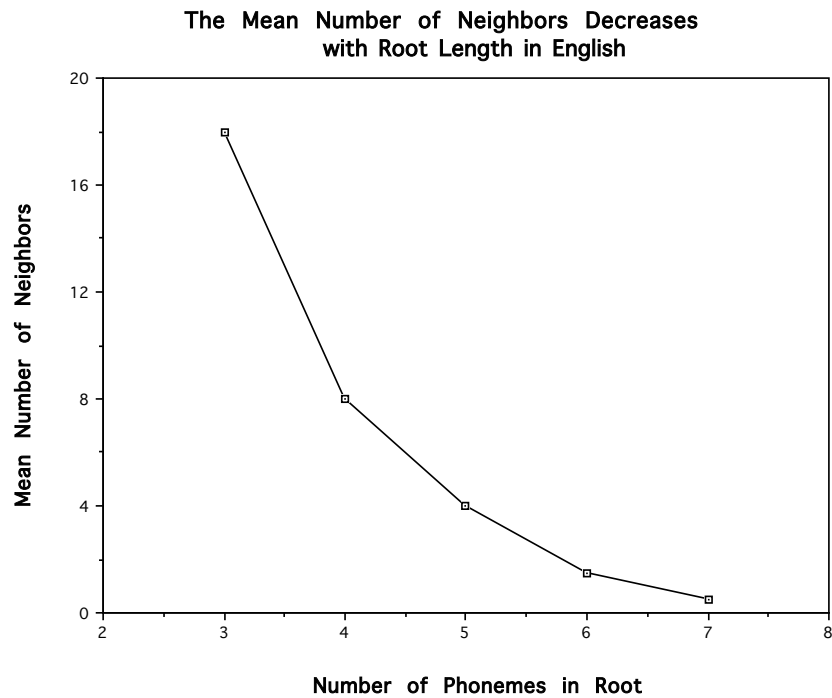
This strong relationship between morpheme length and neighborhood density provides us an indirect way to test the prediction that phonological alternation should be avoided in high density neighborhoods, because it allows us to rephrase the prediction in terms of morpheme length.

7.1   Final stop devoicing in Catalan

Catalan exhibits the crosslinguistically common pattern of devoicing underlyingly voiced obstruents word-finally, as illustrated in (11) below.

(11)　Word-final devoicing in Catalan.

	Stem	*Masculine*	*Feminine*	*Gloss*
a.	/vɛrd/	[vɛrt]	[vɛrda]	'green'
b.	/sɛrt/	[sɛrt]	[sɛrta]	'certain'

If Catalan were under pressure to avoid alternation in dense neighborhoods, it could in principle accomplish this in two ways: (i) final devoicing could be waived for lexical items in dense neighborhoods, or (ii) lexical items in dense neighborhoods could preferentially end with underlyingly unvoiced stops, which do not alternate. Because Catalan does not ever violate final-stop devoicing, strategy (i) can be discounted. To ask whether strategy (ii) is employed, all monomorphemic nouns and adjectives ending in p/b, t/d, and k/g in the Diccionari Catalá Invers amb Informació Morfológica (Mascaró and Rafel 1990) were collected and categorized by number of segments[3]. The data is presented in graphic form in (12) below.

(12)

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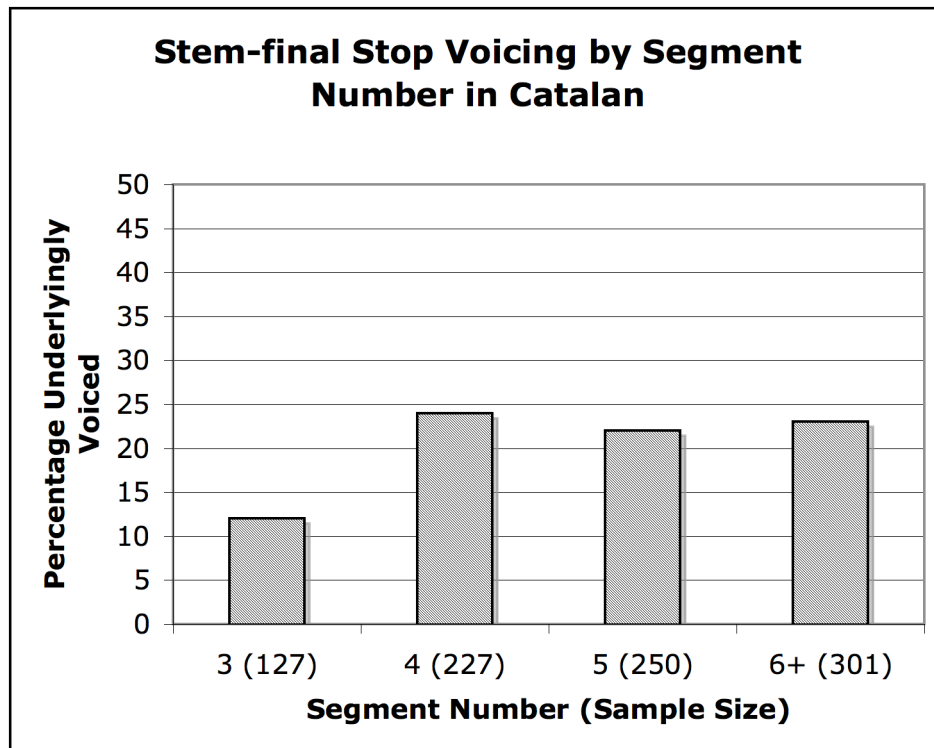
[3] By Catalan orthographic convention, alternating stems are consistently written with a voiced stop, and non-alternating stems with an unvoiced stop. Multimorphemic forms were identified and discarded with the help of a native informant.

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The data shown in (12) suggests that 3-segment noun and adjective stems are less likely to end in an underlyingly stop than longer stems. Chi-square analysis confirms this, indicating that the 3 segment class is distinct from the classes with more segments taken together at a confidence of greater than 0.01. None of the classes with greater than three segments are significantly distinct from each other. Note that the crosslinguistic preference for unvoiced stops is in evidence here as well, as even in sparser neighborhoods, i.e., for those forms with greater than three segments, stops are underlyingly voiced on average in only about 22% of the stems.
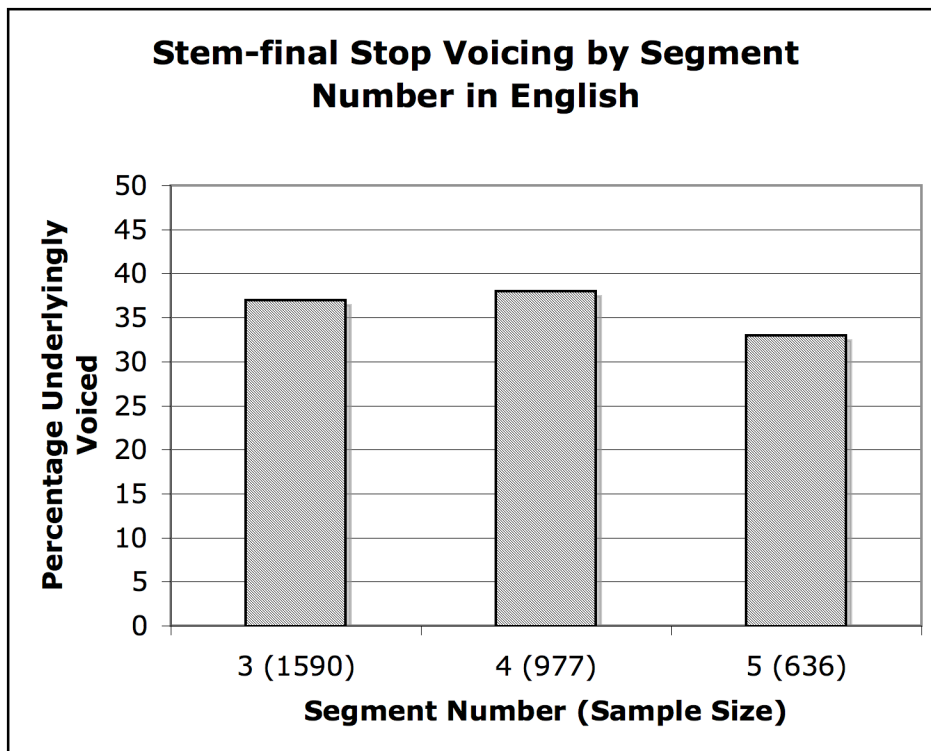
7.2   Distribution of final stops in English

The hypothesis that alternation is marked in high-density lexical neighborhoods provides an account for the relative paucity of underlyingly voiced stops in small stems in Catalan. Under this same hypothesis however, if there is no alternation, then there should be no relation between stem size and the proportion of voiced to unvoiced final stops. English can serve as a test for this hypothesis: as English does not exhibit final-stop devoicing, there is no alternation in the voicing of stem-final stops under suffixation. Therefore, the proportion of voiced to unvoiced stem-final stops should be constant regardless of stem size.

To test the hypothesis, all monomorphemic stems in the CMU database of English[4] between three and five segments ending in [b/p], [d/t] and [g/k] were collected and categorized by segment number. (13) below shows the pooled proportions of stems ending in voiced stops by segment number.

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[4] This is a phonemic list of English words at http://www.speech.cs.cmu.edu/cgi-bin/cmudict.

(13)

Stem-final Stop Voicing by Segment Number in English

[bar chart: Percentage Underlyingly Voiced (y-axis, 0 to 50) vs. Segment Number (Sample Size) (x-axis); bars: 3 (1590) ≈ 37, 4 (977) ≈ 38, 5 (636) ≈ 33]

In contrast to Catalan, English displays no relative preference for unvoiced stops in smaller stems, consistent with the hypothesis that the pattern in Catalan derives from the alternation in voicing of final stops in noun and adjective stems under suffixation. Examination of the graph shows however that English, like Catalan, displays the expected overall preference for unvoiced stem-final stops.

7.3   Suffix-induced palatalization in Czech

Word-final devoicing imposes phonological neutralization on base forms, allowing the underlying voicing specification of a stem-final stop to surface faithfully only in suffixed form. Does the phenomenon of alternation avoidance in dense neighborhoods depend on the fact that this neutralization occurs in the base form, or does it also occur when neutralization occurs in the derived form?
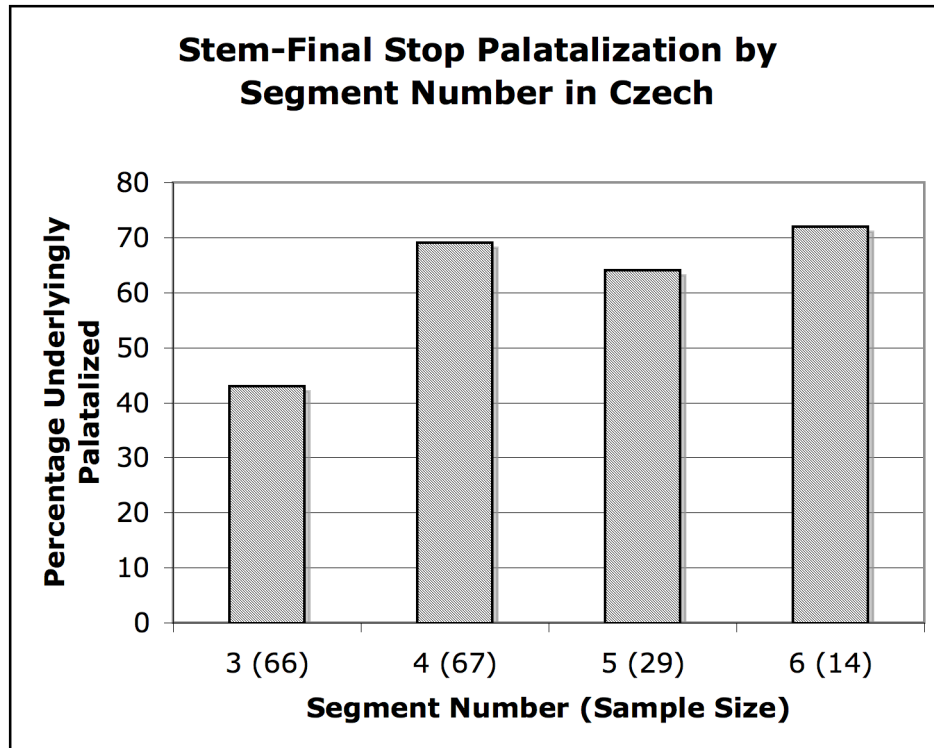
Some suffixes in Czech, (and in Slavic languages in general) palatalize certain stem-final consonants, with the result that phonological neutralization to palatal phonemes occurs in these suffixed forms. For example, these suffixes mutate /k/ to [t͡s] or [t͡ʃ], depending on the suffix, and mutate /t/ to [c], as shown in (14):

(14) Czech palatal neutralization

	Stem	Nominative Singular	Nominative Plural	Diminutive	Gloss
a.	/kra:li:k/	[kra:li:k]	[kra:li:t͡si]	[kra:li:t͡ʃek]	'rabbit'
b.	/student/	[student]	[studenci]		'student'
c.	/kli:t͡ʃ/	[kli:t͡ʃ]	[kli:t͡ʃe]	[kli:t͡ʃek]	'key'
d.	/lac/	[lac]	[laci]		'lath'
e.	/limet͡s/	[limet͡s]	[limet͡se]		'collar'

Underlying palatal consonants generally surface faithfully under suffixation (see (c, d, e) above). Because stems with final palatal consonants do not alternate under suffixation, we predict that small stems in Czech may show a relative preference for ending in a palatal over non-palatal consonants. To test this prediction, monomorphemic, native stems ending in [k], [t], [t͡s], [t͡ʃ] or [c] between three through six segments were collected from a reverse, morphologically and etymologically coded Czech dictionary (Slavickova 1975). The proportion of each size class ending in a palatalized versus unpalatalized consonant was calculated, and is presented below in (15).

(15)

Stem-Final Stop Palatalization by Segment Number in Czech

Percentage Underlyingly Palatalized

Segment Number (Sample Size): 3 (66), 4 (67), 5 (29), 6 (14)

Recall that some suffixes in Czech stem-final non-palatal stops palatalize As we saw above for Catalan with respect to final-devoicing, Czech appears to relatively disfavor stem-final non-palatal stops precisely in small morphemes where neighborhood density should be highest. Again, Chi-square analysis confirms this, indicating that the 3 segment class is distinct from the classes with greater than three segments taken together at a confidence of greater than 0.01; none of the classes with greater than three segments are significantly distinct from each other. This result suggests that the paradigmatic locale of the neutralization is not crucial to the effect.

7.4   Word-internal alternations in Catalan

The two alternations shown in the previous sections are located at the right word edge. Are alternations in other domains also under-represented in small stems? Vowel reduction-driven alternations in Catalan provide a good test case for this question. In Catalan, a subset of the vowels that appear in stressed syllables are neutralized in unstressed syllables, as illustrated below in (16).

(16)   Vowel reduction in Catalan
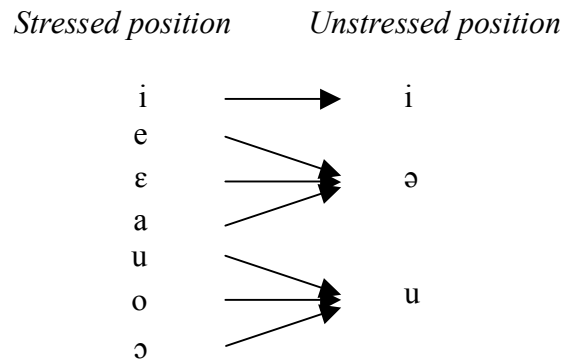
The relevant feature of this pattern for our purposes here is that the non-high vowels [a, ε, e, o, ɔ] alternate with [ə] and [u] in unstressed syllables, but the high vowels [i, u] remain constant.

Primary stress in Catalan is default-penultimate, but there are many suffixes, particularly in the verbal paradigm, that are underlyingly stressed resulting in stress shift upon suffixation as illustrated below.

(17)   Stress-shift under suffixation in Catalan verbs.

	Verb stem	+ 1sg. pres. ind. /-o/	+ 1pl. pres. ind. /-ém/	Gloss
a.	/din/	[dínu]	[dinɛ́m]	'eat lunch'
b.	/sum/	[súmu]	[sumɛ́m]	'add'
c.	/don/	[dónu]	[dunɛ́m]	'give'
d.	/pas/	[pásu]	[pəsɛ́m]	'pass'

The first person singular present indicative suffix /-o/ is not underlyingly stressed, so suffixation to a verb stem such as e.g., /din/ 'eat lunch' results in surface stress on the verb stem under default penultimate stress. The first person plural present indicative /-ɛ́m/, on the other hand, is underlyingly stressed, such that the same verb stems surface without stress under suffixation as shown in the third column in (17). In these forms, we can see that the difference in the positions of stress between the first person singular present indicative and the first person plural present indicative suffixed forms does not change the vowel quality of the stem vowel if it is high. Compare (17a,b) with (17c,d), in which, upon stress shift, the stem vowel alternates between [o] and [u] in (17c) and [a] and [ə] in (17d). The existence of both underlyingly unstressed and underlyingly stressed suffixes in the verbal paradigm results therefore in an alternation between surface vowels in verb stems containing underlyingly non-high vowels. Monosyllabic verb stems with underlyingly high vowels in contrast show no alternation in vowel quality across the verbal paradigm.

The hypothesis advanced here that alternation is avoided in dense lexical neighborhoods predicts then that in Catalan, monosyllabic verb stems in dense neighborhoods should preferentially contain high vowels over non-high vowels, because the latter alternate under suffixation.

To test this prediction, all monomorphemic mono- and disyllabic verb stems containing between two and six segments were collected from a small Catalan/English dictionary (Sabater and Freixinet 1990), and divided into initial-high vowel and initial-non-high vowel classes. For each size class, the number of initial high vowel verbs was divided by the number of initial non-high vowel verbs to give a simple proportion. These proportions are shown plotted against phoneme number in (18) below.

(18)

Verb-final Vowel Height by Segment Number in Catalan
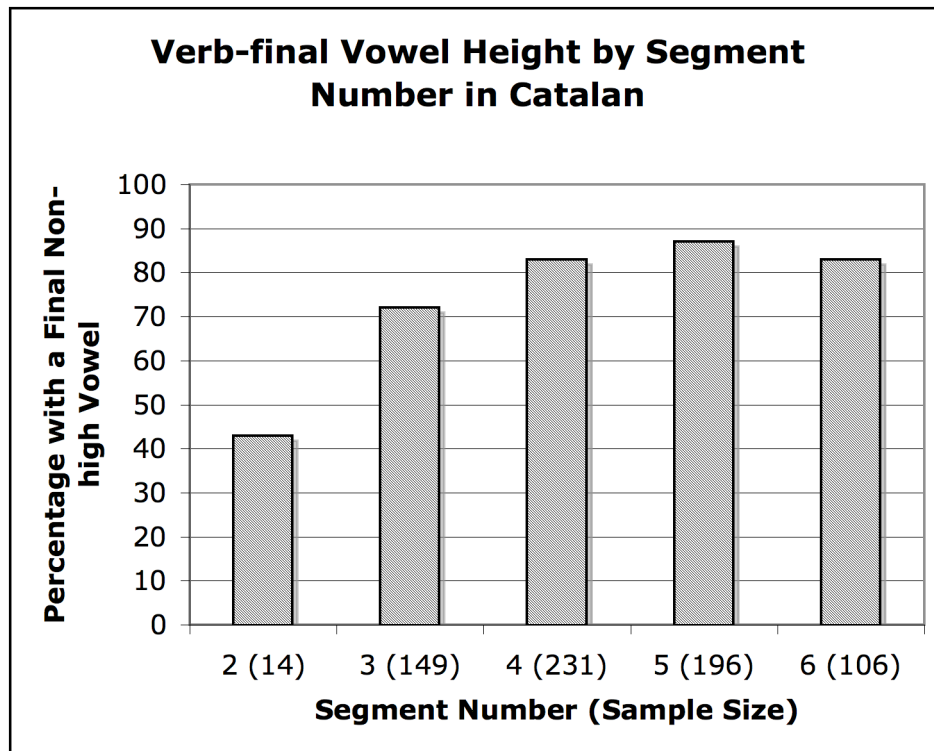
The graph in (18) makes clear that as segment number decreases below four, the proportion of verb stems with final non-high vowels decreases relative to those with final high vowels. Chi-square analysis shows that the two and three segment classes are distinct from each other ($p < .05$), each from the larger classes taken together ($p < .001$), and that the 4-6 segment classes are not significantly distinct from one another. As segment number is a reliable proxy for neighborhood density, these results are consistent with the hypothesis that alternation is avoided in dense lexical neighborhoods. Note that because the vast majority of the verb stems under five segments are monosyllabic, the results presented here are unlikely to be due to distinctions in syllable number: the 2 and 3 segment classes are each distinct from the 4 segment class at significance levels of .001 and .05 respectively. Furthermore, the majority of the 5, and all of the 6-segments stems in the sample are disyllabic, but do not form distinct classes relative to the majority monosyllabic 4-segment verb stems.

The converging pattern of non-alternation in small stems found within the diverse class comprising final devoicing and vowel reduction in Catalan, and palatalization in Czech suggest that the phenomenon derives from a general property of allomorphy, rather than something specific to a particular kind of alternation. In conjunction with the hypothesis that allomorphy imposes some cost in lexical access, the finding that allomorphy is relatively rare in the densest parts of the lexicon supports the proposal that effective contrast is under optimizing pressure in the lexicon.

8. Conclusion

This paper represents an initial foray into a new domain, asking whether there is support for the hypothesis that biases in lexical access may drive the development of lexical and grammatical patterns. Evidence from a wide range of psycholinguistic experiments shows that all kinds of words are not accessed equally well, but rather, (i) neighborhood density, (ii) frequency, and (iii) allomorphy, all influence the efficiency of access. In functional terms, contrast comes down to the ability to efficiently map a sound onto a lexical entry, so it is a sensible question to ask whether it may be this *effective* contrast that has a more significant influence on language patterns, rather than a more abstract system of sound-contrast per se. In support of this proposal, we have summarized data suggesting that a wide variety of observed patterns may result from pressure to maintain adequate effective-, as opposed to sound-contrast within the lexicon:

- Stems often exhibit more marked structures than affixes.
- Stems are less likely to alternate than affixes.
- Small stems are less likely to alternate than larger stems.

Additional work to support or refute this hypothesis is necessary (see Wedel 2005). For example, in languages where small stems are preferentially composed of non-alternating phonemes, it could be fruitful to trace the diachronic development of such stems. In addition, there remains a need to confirm the correlation of avoidance of allomorphy in small stems with neighborhood density. On the psycholinguistic front, further experimental work needs to be done to investigate the processing cost of alternation. For instance, some Hebrew affixes alternate to satisfy phonotactic requirements, though these requirements are no longer necessarily transparent. Does this affect the processing of these affixes compared to affixes that don't alternate? Pursuing work in these directions will help in determining if this research program – looking outside what linguists strictly define as the grammatical domain – is viable as an explanatory track for the linguistic tendencies examined here.

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