The Effects of Frequency and Composition on Production Duration in Morphological Processing

by

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Submitted to the Department of Linguistics and Philosophy
in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Linguistics

at the

Massachusetts Institute of Technology

February 2008

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A further test was conducted to determine whether prosodic prominence of a structure as entailed by a preceding semantic context determines boundary duration and evidence was found in favor of such an effect. Both studies reported herein show that production slows before morpheme boundaries. These results suggest duration to be an effective tool for studying structure-dependent effects in morphological processing.

ACKNOWLEDGMENTS

A special thank you first and foremost goes to my advisor, Adam Albright, whose enduring patience and guidance has had an impact on every aspect of this work. Thanks also are due to committee members David Pesetsky and Donca Steriade, for always being there with helpful discussion and various brands of encouragement.

Particular gratitude is in order for the generosity of Angela Davis, Edward Flemming, Michael Kenstowicz, Jillian Mills, and Andrew Nevins, who read drafts of pilot and post-pilot studies and made valuable comments. I am equally indebted to Peter Graff, David Hill, Sabine Iatridou, Cilene Rodrigues, Junri Shimada, Raj Singh, and Michael Wagner for conversations full of ideas and support. All errors or omissions are, of course, my own.
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1. Introduction

Parts of words combine just like parts of sentences. This property of Distributed Morphology (Halle and Marantz 1993) raises the empirical question: if duration is manipulated at prosodic boundaries in sentences, is it likewise manipulated within words?

There is scant literature addressing the question whether there are phonetic correlates to boundaries in morphological processing. In the domain of sentence production, pauses before intonational phrase (IP) boundaries have been shown to vary in duration depending on properties of subsequent material (Ferreira 1991, Krivokapić 2007). Segments lengthen before IP boundaries whether or not pauses occur (Klatt 1975). Under the view that there is no difference between combining morphemes and composing larger phrases, it is expected for segments near morpheme boundaries to vary in the same way segments near larger phrase boundaries vary. This is the line taken in Marvin (2002) where it is argued that stress can diagnose sisterhood domains word-internally.

A relationship between base form frequency and surface form frequency has been argued to influence the perception of word complexity (Hay 2001, 2003). Under the assumption that segments preceding boundaries are longer than those that do not precede boundaries in phonetic implementation, and given that lexical access is involved in the retrieval of a phonological representation during production, it is an empirical question whether a property of lexical access affects production delay at a morpheme juncture. In experiment 1, it is tested whether there is an effect of whole-form versus decomposed lexical access in production. The prediction is that segments next to boundaries in decompositionally-accessed words are longer than corresponding segments in whole-accessed words.

An effect of boundary strength is predicted under an assumption that planning takes longer for more syntactically complex material. Experiment 2 tests the prediction that a boundary between adjacent morphemes that are not sisters is longer than a boundary between morphemes that are sisters. An effect is expected if morphemes combine like words as units of processing. Positive results in either experiment 1
or 2 would introduce segment duration as a tool for investigating morphological processing.

Various factors contributing to the ease of decomposition have received attention in the domain of perception (Bertram, Schreuder, and Baayen 2000; Hay 2003). The experiments presented in this work explore morphological production. In section 2, it is investigated whether segmental duration is affected by a preceding boundary posited by lexical access. Section 3 tests predictions about relative boundary strength at different levels of word-internal prosodic structure. Section 4 concludes.

2. Relative Frequency
Models of morphological parsing provide two ways for words to be retrieved from lexical storage. Either the word is accessed as a whole or it is split into its constituent parts. Race-based models, such as Baayen (1992), posit that both routes are available and compete during lexical access. In a basic implementation of such a model, the form that is easiest to access wins and a number of factors conspire to provide an outcome.

Bertram, Schreuder and Baayen (2000) suggest that the inflectional or derivational status of an affix, affixal productivity, and affix homonymy determine whether a whole word or subparts are accessed by a listener. Each of these factors are taken to have an effect on the ease of decomposition. Complex words that are formed from productive, transparent, and non-homonymous affixes are readily decomposed.

That two types of word frequency affect lexical decision time of affixed forms has been studied in Taft (1979) and Butterworth (1983). When base frequency is kept constant while surface frequency varies, lexical decision time is influenced by surface frequency. When surface frequency is held constant across comparisons, lexical decision time is influenced by base frequency. Hay (2001) argues that the notion of frequency relevant for determining the outcome of lexical access is a base's independent frequency relative to the surface frequency of the derived form containing it. For example, she reports
that listeners reliably rate words like *illegible*, where the surface frequency is higher than the independent frequency of the base form *legible* \((F_s=14 > F_b=10)^1\), as “sounding less complex” than similar words like *illiberal*, where the base frequency is greater than the surface form \((F_s=11 < F_b=55)\).

**Figure 1:** Race-based competition of illegible \((F_S=14 > F_B=10)\) and illiberal \((F_S=11 < F_B=55)\) Shaded arrows indicate path of lexical access. Double brackets indicate the most frequent form.

![Diagram](image)

In (a), it is fastest to access the whole form *illegible*. However, in (b), the fastest route is via the decomposed form *liberal*. If a base’s independent frequency exceeds the surface frequency of a target word which contains it, the base is always accessed. If a base’s independent frequency is below that of the surface form, the whole form is always accessed. Thus both frequencies are required information in an account of whatever mechanism forces speakers to judge one form more complex than the other.

In a purely decompositional model, such as that of Taft and Forster (1975), semantically transparent morphemes are always decomposed in accessing the meaning of a complex word. *Illegible* and *illiberal* are considered equally “complex” in that they are both comprised of two parts. Under such a view, above judgments would seem unrelated to lexical access.

The effect of relative frequency is documented not just for perception but also for production. A model with such expectations must be one where lexical access occurs at a stage of phonological planning. One stage that has been suggested is during the process of retrieving the correct phonological codes for a target handed down by lexical selection (Levelt 2001). An external system of lexical selection

---

1 \(F_s=\text{surface frequency and } F_b=\text{base frequency. Frequencies listed throughout are the lemma frequencies found in Baayen et al. (1995).}\)
feeds the form encoding module with a representation. The process of retrieving phonological codes by lexical access is, in correlation with perception, facilitated by the availability of whole word representations in addition to rule based decomposition. For the model to obtain a gradient effect in the articulation of a boundary that is weighted by lexical frequency, let the method of access be a team-based convergence during the retrieval of phonological code, similar to the method in Schreuder and Baayen (1995), Baayen and Schreuder (1999, 2000) for morphological segmentation. As soon as phonological code is retrieved (by either whole-form access or rule-based decomposition), it is phonetically implemented. When both representations become available for phonetic implementation, the hypothesis suggested here is that an approximation of the two is then articulated.

Figure 2: Productions of swiftly and softly

The approximation of the two representations during articulation of a segment is taken to be determined by the ratio of phonological code retrieval time (\( y/x \)).

Hay (2003) tests the hypothesis that whole word representations are phonologically encoded in production by looking at /t/-deletion in CtC clusters. Comparisons were drawn between forms such as swiftly (\( F_s = 268 > F_B = 221 \)) and softly (\( F_s = 440 < F_B = 1464 \)). The surface frequency of these two words is
roughly equivalent. However, swiftly is more frequent than swift, whereas soft is more frequent than softly. Since the phonetic context of /t/ is unstable in both these words, the consonant cluster is likely to be simplified through gestural overlap of the surrounding phonemes.

Assuming that boundaries induce lengthening and that presence of a boundary in the phonetic encoding hinges on whether a base’s independent frequency outstrips that of the derived form containing it, one prediction is that time available for the realization of /t/ should be greater in softly compared with swiftly. Swiftly occurs more often than its subpart swift, and with no boundary cued to phonetics, its /t/ is highly prone to simplification. On the other hand soft occurs more often than softly. With a boundary cued to phonetics before the last consonant of the cluster, implementation slows and the possible gestural overlap is reduced.

Hay predicts that the amount of articulatory slow-down is a function of the relative base-derived frequency. To test this, her comparisons include forms with quite low absolute frequencies, such as daftly (Fs=0 < FB=56). The relatively strong boundary was anticipated to prevent simplification in such conditions. These predictions bore out: /t/ is shortest in a high whole-relative-to-base frequency word like swiftly. /t/ is longest in a high base-relative-to-whole frequency word such as daftly. Forms like softly fall in between.

Evidence has been presented for relative frequency playing a role in both the perception and production of morphologically complex forms. While /t/-deletion is a clear durational effect in speech production, predictions of a model allowing whole-access phonological assembly in segmental planning extend beyond gestural timing in clusters that straddle boundaries. As introduced in section 1, segments are expected to generally be longer in a pre-boundary condition.

The prediction made for phonetic implementation is that segments before a boundary posited by decomposed access should be longer than corresponding segments within a whole-form accessed word. Corresponding segments are ones that belong to matching prosodic structures with near-identical
phonemic contexts, independent of the different global properties of the string subsuming them. The remainder of this section describes tests of this prediction using bimorphemic and trimorphemic forms.

2.1 Pilot Study 1

A pilot with three subjects was run to establish whether duration of boundary-proximate segments is a function of relative base-derivative frequency in bimorphemic forms.

Items were selected for closely matching prosodic environments and a maximum difference in relative base-derived frequencies while matching as much as possible for surface frequency. Both prefix and suffix boundary conditions were tested. Items were elicited in related carrier sentences matched for number of syllables. The following comparisons were drawn:

Prefix condition:

<table>
<thead>
<tr>
<th></th>
<th>FS, FB</th>
<th>FS, FB</th>
</tr>
</thead>
<tbody>
<tr>
<td>inanimate</td>
<td>(34, 102)</td>
<td>inaccurate (53, 377)</td>
</tr>
<tr>
<td>unleash</td>
<td>(65, 16)</td>
<td>unleech (0, 0)</td>
</tr>
<tr>
<td>unassailable</td>
<td>(1, 0)²</td>
<td>unavailable (0, 2468)</td>
</tr>
</tbody>
</table>

Suffix condition:

<table>
<thead>
<tr>
<th></th>
<th>FS, FB</th>
<th>FS, FB</th>
</tr>
</thead>
<tbody>
<tr>
<td>listless</td>
<td>(42, 0)</td>
<td>tasteless (30, 1027)</td>
</tr>
<tr>
<td>virility</td>
<td>(41, 31)</td>
<td>sterility (0, 121)</td>
</tr>
</tbody>
</table>

Prefix condition comparisons yielded an average difference between corresponding initial segment durations (mean difference in duration as a percent of word length across speakers: inaccurate longer than inanimate by 3.7%, unleech longer than unleash by 2.5%; mean difference in raw measures

---
² The CELEX-determined relative frequency for assail compared to unassailable is at odds with the distribution in American English vernacular. Informal survey sufficiently supported taking unassailable as a whole-access word. Speakers interviewed unanimously rated unassailable as more common than either assail or assailable.
are 40 m.s. and 13 m.s. respectively). Because of its baseline frequency, the comparison with *unleech* speaks only to a general frequency effect. On the other hand, both *inanimate* and *inaccurate* have higher base frequencies than surface frequencies, but lengthened segments occur before the more frequent base form. If this trend is significant, then a relative frequency effect is supported. Furthermore, in *unavailable* vs. *unassailable*, *lun-* is on average longer in the former (mean=7%, raw measures=46 m.s.).

In suffix condition, the comparison between *virility* and *sterility* revealed a longer /t/ in the latter (mean=2.8%, raw measures=12 m.s.). /st/-duration in the comparison of *listless* and *tasteless* showed similar lengthening in the second form, where the base is more frequent than the surface form (mean=2.2%, raw measures=17 m.s.). These initial observations support the hypothesis that a word's most frequent route of lexical access has an influence on boundary-proximate segment length in production. Since significance was not determined in the pilot, a further study was conducted.

### 2.2 Experiment 1a

#### 2.2.1 Aim:

An experiment was designed to test if relative frequency is a determining factor of boundary-proximate segment duration in production. The following hypothesis can be made about segment duration near prefix boundaries:

**Hypothesis 1:** Relative frequency has an effect on segment duration in prefix boundary condition.

We expect segments inside whole-form accessed items should be shorter than corresponding segments in decomposed access items.

---

3 While an average difference of raw m.s. durations is reported throughout wherever mean length is given, without relativizing to word length, differences are not independently significant. One exception is in the case of *uncoverable* in experiment 2a.
2.2.2 Materials:

Experimental items were selected on the basis of similar prosodic contexts of measurement, such as location of stress, number of syllables and weight. In prefix condition, vowel-initial roots were favored in light of pilot findings. The items and relevant comparisons are below, with accessed strings emboldened:

<table>
<thead>
<tr>
<th>Direct</th>
<th>$F_s, F_B$</th>
<th>Decomposed</th>
<th>$F_s, F_B$</th>
</tr>
</thead>
<tbody>
<tr>
<td>unassailable</td>
<td>(1, 0)</td>
<td>unimpalable</td>
<td>(0, 0)</td>
</tr>
<tr>
<td>unassailable</td>
<td>(1, 0)</td>
<td>unentailable</td>
<td>(0, 1)</td>
</tr>
<tr>
<td>unassailable</td>
<td>(1, 0)</td>
<td>unattainable</td>
<td>(0, 234)</td>
</tr>
<tr>
<td>unavailable</td>
<td>(1, 0)</td>
<td>unavailable</td>
<td>(0, 2468)</td>
</tr>
</tbody>
</table>

Note: the frequency reported as the base of *unavailable* is for the subpart *lavailable*, since *lavail* is not transparently related to the surface form as an intransitive.

Brief narrative contexts preceded items of interest. Each item appeared as the final content word in a declarative phrase. Carrier phrases were constructed with the same number of syllables to minimize influence of utterance length on speech rate.

**Table:** Examples of items of interest in the immediate context of elicitation.

<table>
<thead>
<tr>
<th>Direct access item</th>
<th>“Hate is what the government made to be unconscionable.”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decomposed access item</td>
<td>“Collectors believed that the painting was unauctionable.”</td>
</tr>
</tbody>
</table>

Each item was elicited twice. To counter-balance any potential effect of repetition, a speaker was presented one of four orderings of stimuli and their repeated forms. The non-repeated stimuli is available in Appendix C.
2.2.3 Recordings, segmentation, and analysis

Eight native speakers of American English\(^4\) between the ages of 18 and 56 years, recruited from around MIT, were recorded reading the items of interest embedded in sentences. Participants were asked to read in a relaxed manner, similar to talking to a friend. The recordings were taken in an acoustically treated room.

Experimental items and their immediate phonetic context were isolated from the digital recordings into individual files for analysis. Word/segment durations were transcribed in Praat from wideband spectrograms and waveform displays. The following section describes the criteria used to demarcate segments.

\(^4\) It is worth mentioning that the group of speakers exhibited a heterogeneous mix of dialects (from West-coast to New England). However, speaker variation seemed to not influence the significance of any findings in this report.
Decision for marking the release of a nasal stop was made on the basis of a rapid increase in amplitude and a changing periodic shape in the waveform as well as shifting formant in the spectrograph. In cases where these criteria did not specify the same moment of release, I used increase amplitude and the changing shape of the waveform as the main offset indicators.

Figure 3: Subject 3: Second repetition of *unconscionable* indicating nasal offset.
offset: Decision for release of a lateral was similar to that of a nasal. Primary indicators of offset were swift rise in amplitude, shift in formants, and change in period shape in the waveform.

Figure 4: Subject 3: First elicitation of un[ravelable] indicating lateral offset.

Since the effects predicted are of the duration of boundary-neighbor segments, to minimize the number of decisions made, measurements were taken of /un−/ in prefix condition and the last VC of the stem in suffix condition.
Stop and fricative release: Stop releases were identified based on the release transient evident in the waveform. A stop was considered finished and marked as such at its final closure. Fricative release was identified by rapid rise in amplitude and onset of clear formants.

**Figure 5:** Subject 3: First instance of [unlock]able illustrating stop offset.
The above description of recording, segmentation, and analysis is valid for experiment 1b and 2a–b as well.

2.2.4 Results

A comparison of the mean percent durations across subjects provide evidence that support hypothesis 1.
**Figure 7:** Mean duration of /An–/ as a % of word length across subjects.

Table: mean difference in duration of /An–/ in m.s.

<table>
<thead>
<tr>
<th>Decomposed (Fₘ, Fₚ)</th>
<th>Direct access (Fₘ, Fₚ)</th>
<th>Mean m.s. difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>unavailable (0.2468)</td>
<td>unassailable (1, 0)</td>
<td>8 m.s. (120–112)</td>
</tr>
<tr>
<td>unattainable (0.234)</td>
<td>unassailable (1, 0)</td>
<td>24 m.s. (136–112)</td>
</tr>
<tr>
<td>unimpalable (0,0)</td>
<td>unassailable (1, 0)</td>
<td>11 m.s. (123–112)</td>
</tr>
<tr>
<td>unentailable (0,1)</td>
<td>unassailable (1, 0)</td>
<td>51 m.s. (163–112)</td>
</tr>
</tbody>
</table>

Table: unpaired t-tests for each comparison set

<table>
<thead>
<tr>
<th>Decomposed (Fₘ, Fₚ)</th>
<th>Direct access (Fₘ, Fₚ)</th>
<th>Two-tailed P val.</th>
<th>dF</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>unavailable (0.2468)</td>
<td>unassailable (1, 0)</td>
<td>0.0125</td>
<td>(1,29)</td>
<td>0.011</td>
</tr>
<tr>
<td>unattainable (0.234)</td>
<td>unassailable (1, 0)</td>
<td>0.0045</td>
<td>(1,28)</td>
<td>0.013</td>
</tr>
<tr>
<td>unimpalable (0,0)</td>
<td>unassailable (1, 0)</td>
<td>0.1108</td>
<td>(1,28)</td>
<td>0.022</td>
</tr>
<tr>
<td>unentailable (0,1)</td>
<td>unassailable (1, 0)</td>
<td>0.1781</td>
<td>(1,28)</td>
<td>0.016</td>
</tr>
</tbody>
</table>
In the *unassailable* vs. *unattainable* comparison, because of its relatively more frequent surface form than base, *unassailable* is accessed via the direct route and no measurable effect of a boundary is predicted between /un–l/ and /lassailable/. On the other hand, *unattainable* has a much more frequent base than surface form and is predicted to have a longer preceding /un–l/ than in *unassailable*. The variance between the two is significant (p < 0.05). If relative frequency is a determining factor in realizing morpheme boundaries, this result is expected.

In *unassailable* and *unavailable*, /available/ is more frequent than the surface form containing it. A race-based model predicts an increase in the duration of /un–l/ before /available/ but not /lassailable/. The relative frequency predictions are born out and the variance is significant across speakers (p < 0.05).

Under a view that anticipates more slow-down before more syntactic material, and “more material” includes the number upcoming morphemes, /un–l/ is expected to be longer in *unassailable* (Fs=1 > Fb=0) than in *unavailable* (Fs=0 < Fb=2468).

(1)

```
un + available  un + assail + able
```

Given the structures in (1), *available* does not transparently decompose into two morphemes whereas *assailable* does. The structures expected under race-based lexical access are different.

(2)

```
un + available  un – assail – able
```

The fact that this effect was observed does not exclude the possibility of other syntactic effects.

While comparisons of *unassailable* vs. *unimpalable* and *unassailable* vs. *unentailable* showed a difference in mean durations across speakers, the effect was not significant. This does not seem surprising due to a less than ideal comparison in terms of phonetic context. Relativization of the measurement to the
duration of the whole word and perhaps potential influence of coda [m] and [n] on neighboring duration
in one sample but not the other make it unsurprising that useful temporal measurements could not be
extracted. Finally, a comparison was tried between /un-Is of unalienable and unauctionable. The
insignificant difference could have been due differences in syllable weight.

2.3 Experiment 1b

2.3.1 Aim:

An effect of relative frequency was tested for in the suffix condition.

**Hypothesis 2a:** Relative frequency determines segment duration in suffix boundary
condition.

Segments inside whole-form accessed items are expected to be shorter than corresponding segments in
decomposed access items.

2.3.2 Materials

The items selected were matched for syllable weight, identical stress environment, and an effort made to
minimize segmental differences. The items and comparisons drawn are:

<table>
<thead>
<tr>
<th>Direct access</th>
<th>$F_S &gt; F_B$</th>
<th>Decomposed access</th>
<th>$F_S &lt; F_B$</th>
</tr>
</thead>
<tbody>
<tr>
<td>unassailable</td>
<td>(1, 0)</td>
<td>unimpalable</td>
<td>(0, 0)</td>
</tr>
<tr>
<td>unavailable</td>
<td>(2468, 0)</td>
<td>unimpalable</td>
<td>(0, 0)</td>
</tr>
<tr>
<td>unavailable</td>
<td>(2468, 0)</td>
<td>unentailable</td>
<td>(0, 1)</td>
</tr>
<tr>
<td>unalienable</td>
<td>(2, 0)</td>
<td>unportionable</td>
<td>(0, 0)</td>
</tr>
<tr>
<td>unalienable</td>
<td>(2, 0)</td>
<td>unmentionable</td>
<td>(19, 224)</td>
</tr>
<tr>
<td>unalienable</td>
<td>(2, 0)</td>
<td>unauctionable</td>
<td>(0, 98)</td>
</tr>
<tr>
<td>unconscionable</td>
<td>(6, 0)</td>
<td>unportionable</td>
<td>(0, 0)</td>
</tr>
<tr>
<td>unconscionable</td>
<td>(6, 0)</td>
<td>unmentionable</td>
<td>(19, 224)</td>
</tr>
<tr>
<td>unconscionable</td>
<td>(6, 0)</td>
<td>unauctionable</td>
<td>(0, 98)</td>
</tr>
</tbody>
</table>

Stems with different base-derivative relative frequency ratios were selected.
2.3.3 Results

A comparison of the mean percent durations across subjects showed a difference that supports hypothesis 1.

Figure 8: Mean duration of root-final /\~n−/ as a % of word length across subjects.

Table: Difference in mean duration of raw root-final /\~n−/ measurements.

<table>
<thead>
<tr>
<th>Decomposed (F_s &lt; F_B)</th>
<th>Direct access (F_s &gt; F_B)</th>
<th>Mean m.s. difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>unportionable (0, 0)</td>
<td>unconscionable (6, 0)</td>
<td>8 m.s. (79–71)</td>
</tr>
<tr>
<td>unauctionable (0, 98)</td>
<td>unconscionable (6, 0)</td>
<td>19 m.s. (90–71)</td>
</tr>
<tr>
<td>unmentionable (5, 19)</td>
<td>unconscionable (6, 0)</td>
<td>−12 m.s. (59–71)</td>
</tr>
<tr>
<td>unauctionable (0, 0)</td>
<td>unmentionable (19, 224)</td>
<td>31 m.s. (90–59)</td>
</tr>
</tbody>
</table>

In unconscionable vs. unportionable, unauctionable, unmentionable, all comparisons yielded significance. This is taken as evidence in support of hypothesis 2.

Table: Significant results of unpaired t-tests for each comparison set.
<table>
<thead>
<tr>
<th>Decomposed ($F_S &lt; F_B$)</th>
<th>Direct access ($F_S &gt; F_B$)</th>
<th>Two-tailed $P$ val.</th>
<th>$dF$</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>unportionable (0, 0)</td>
<td>unconscionable (6, 0)</td>
<td>0.0020</td>
<td>(1,27)</td>
<td>0.008</td>
</tr>
<tr>
<td>unauctionable (0, 98)</td>
<td>unconscionable (6, 0)</td>
<td>0.0023</td>
<td>(1,25)</td>
<td>0.007</td>
</tr>
<tr>
<td>unmentionable (19, 224)</td>
<td>unconscionable (6, 0)</td>
<td>0.0345</td>
<td>(1,27)</td>
<td>0.008</td>
</tr>
</tbody>
</table>

It is worth noting that outside the margin of error, *unauctionable* exhibited longer /un–l than *unmentionable*. This can be taken as evidence that it is not merely the frequency of the base that determines boundary salience. What is missing is a comparison where base frequency is held constant and surface frequency is varied. Such evidence would be required to show that both base and derived frequency factor into boundary salience.

Comparisons between *unportionable*, *unauctionable*, *mentionable*, and *unalienable* were not included due to unmatched syllable weight in the context of measurement. The set of comparisons *unassailable*, *unavailable* vs. *unimpalable*, *unentailable* did not yield a significant effect. Given the effect of a boundary between *unauctionable* and *unconscionable*, it is not clear why stress on the ultimate syllable of a morpheme should interfere with the observation of a boundary lengthening effect any more than stress on the penultimate syllable. More work is needed to determined whether stress might interact with the more general effect of morpheme boundary-lengthening described here.

Duration has been shown to significantly vary with the strength of morphological boundaries posited on the basis of speed of lexical access. Segments before boundaries are longer than corresponding segments not before boundaries. The degree of lengthening appears to correlate with frequency, though more testing is needed. We now can ask what other factors might influence the duration of boundary-proximate segments. Does structure-induced lengthening occur within words in anticipation or planning of upcoming material? This issue is addressed in the next section.
3. **Structural Context**

There have been proposals that delay durations in production are a function of the number of phonological words in the upcoming sentence (Wheeldon & Lahiri 1997). Ferreira (1991) presents evidence that number of syntactic nodes has an effect on the length of pauses before intonational phrases. There are nuanced ways in which the complexity of upcoming phrases might hamper processing. Krivokapić (2007) shows that both intonational phrase length and sister branching have independent effects on pause duration. A basic view is that more structure requires more time for planning. Watson and Gibson (2004) have suggested that intonational phrase boundaries provide the time necessary to plan upcoming prosodic units. Wightman et. al. (1992) show that IP boundaries vary in strength, and that the stronger the boundary, the greater the lengthening effect. Are these boundary effects visible within words?

An implicit assumption being challenged in this discussion is that the word is the smallest relevant unit of phonological processing (Levelt 1989). No principled reason has been presented against the idea that morphemes might play a similar role in planning. The experiments in the following sections address the question whether morphemes exhibit properties of prosodic structure like other units of planning.

3.1 **Pilot Study 2**

A pilot study was run with three subjects to determine whether two syntactic structures entailed by different semantic contexts result in significantly different boundary-proximate segment durations in a given string. The hypothesis under examination is that boundary proximate segments in a given string are affected by the structure imposed on them. Specifically, it is predicted that segments near strong
boundaries are longer than corresponding segments near weak boundaries.

The task was production of structurally ambiguous words in disambiguating contexts. Reversative roots fit the criteria of being structurally ambiguous in that two different semantic compositions can yield the same surface string.

(3) 

\[
\begin{array}{c}
\text{[un – do]} + \text{able} \\
\text{un} + \text{[do – able]}
\end{array}
\]

In (3a), the prefix /un–/ combines initially with the verb, projects a verbal category which then combines with /–able/ to derive an adjective. In (3b), the base combines with /–able/ to project an adjective and then with /un–/ as the negation of that adjective. I assume a difference between syntactic labels in the representations above are irrelevant for comparing their prosodic associative structures.

The following list is of items elicited under each context:

- undoable
- unsnappable
- uncoverable
- unlockable
- uncoilable
- undressable
- unflippable

**Table:** Examples of item of interest in its context of elicitation.

**Left-branching context**  Conservative mothers have tried to stop Mattel from releasing the Skank barbie, which comes with a peroxide kit for her hair, cheap perfume, and all-velcro clubbing outfits that come off in a snatch. The mothers are concerned that this [undress]able figure is encouraging the wrong values.

**Right-branching context**  Preparing for a date, Merryl looked at himself carefully in the mirror. The cut of his expensive suit was distorted by his paunch. This was the third outfit he had tried on, and still no fit. He felt that his un[dressable] figure was getting in the way of his social life.
Measurements of vowel and boundary-proximate consonant duration were relativized to morpheme length for comparison.

Root-final consonants of left-branching contexts were longer than those in right-branching contexts. There was also the suggestion of highly velarized /l/ in items such as *uncoilable* before strong boundaries but not weak ones. Given the literature on /l/ in different prosodic positions (Sproat and Fujimura 1993), a wider sampling of /l/s in this boundary condition is desirable.

Prefix */un-*/ showed no significant effect of semantic context on duration. This might be because of the privileged status of the left edge of the word in processing.

Lengthening is expected by a production model where contextually implied prosodic grouping/boundary strength can have an effect on a neighboring segment duration. In cases such as *unflippable*, when the context primes the left branching structure, speakers seem to lengthen at the end of the root, regardless of the null frequency for *unflip*. The pilot materials have been replicated with a larger set of subjects but are not fully analyzed.

### 3.2 Experiment 2a

#### 3.2.1 Aim

An experiment was conducted testing whether the syntactic structures entailed by a given semantic context had an effect on the duration of segments near morphological boundaries. The following hypotheses were tested:

**H3**  **Composition has an effect on segment duration near prefix boundaries.**

**H4**  **Composition has an effect on segment duration near suffix boundaries.**

A boundary strength account makes the prediction that segments before prefix junctures in a right branching context should be longer than corresponding segments in a right branching context. We also predict that segments preceding suffix boundaries in a right branching context should be longer than
corresponding segments in a left branching context.

3.2.2 Materials

The following items were tested in two contexts.

\[
\begin{align*}
\text{unrufflable} \\
\text{uncoverable} \\
\text{unravelable}^5 \\
\text{unwranglable} \\
\text{unhexable} \\
\text{unflexible}
\end{align*}
\]

As in pilot 2, in one elicitation, the words were preceded by contexts that primed a left-branching structure. In another, the words were preceded by contexts that primed a right-branching structure.

3.2.3 Results

In suffix condition, comparison between different measures of uncoverable yielded a significant effect in a comparison of raw m.s. duration. The /\text{r}/ in tokens elicited under a left-branching context was longer than corresponding /\text{r}/ from in a right-branching context.

\[
\begin{array}{ccc}
\text{uncoverable} & 0.0020 & (1,29) \\
\text{Error} & 0.008 & \\
\end{array}
\]

However, no effect of context was found in the comparisons for prefix boundary condition. These are consistent with the pilot findings.

Comparisons containing /\text{l}/ were insignificant. While duration did not differ significantly where expected, the variability of /\text{l}/ quality might have weakened the effect (p=0.12).

5 A potential confound of this item is not all speakers produce independent forms of ravel. Furthermore, even speakers who have ravel, may not attribute to it reversed semantics (analagous to the synonymy of unpeel and peel).
Further Observations:

The phonetic context and quality of laterals were not the same across conditions. For instance, it was noted that no syllabic/velarized root-final /l/’s occurred in contexts requiring un[root–able] semantic composition). Exceptionally long /l/’s were tallied across tokens in each condition. 90 m.s. was selected as the cutoff for this comparison because fewer than 20% (14/72, mean 64 m.s.) were longer.

Table: /Vl/ or exceptionally long /l/’s (greater than 90 m.s.)

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>[un [wrangl]]able</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>/əl/</td>
<td>/əl/</td>
</tr>
<tr>
<td>un[[wrangl]able]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[un[ravel]]able</td>
<td>/əl/</td>
<td>/əl/</td>
<td>/əl/</td>
<td>/əl/</td>
<td>/əl/</td>
<td>/əl/</td>
<td>/əl/x2</td>
<td></td>
</tr>
<tr>
<td>un[[ravel]able]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[un[ruffl]]able</td>
<td></td>
<td></td>
<td>/əl/</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>un[[ruffl]able]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

There are two main observations: velarized and/or lengthened /l/’s, and those preceded by a measurable vowel were most common in unravelable with the left branching structure (that is, one reinforcing the boundaries predicted by lexical access).

Also, no comparably long /l/’s were found in right branching structures even in cases where whole-form lexical access posits a boundary. When branching matches the direct access representation, lengthening is observed. When decomposition is required and at odds with the path of fastest access, the direct route form leaves no phonetic trace of a boundary. If this is correct, then whole-accessed forms ought to be able to decompose on-line when facilitated by context.

In the case of onset /l/, whether both duration and backness vary needs to be established. Sproat and Fujimura (1993) show that onset /l/’s are subject to velarization just as coda /l/’s. In rimes, dorsum
backing begins in advance of the apical gesture and the rime duration scales proportionally with the amount of backing. In onsets, either the dorsum gesture is simultaneous with or follows the apical gesture, which narrows the window for backing. Huffman (1997) shows that intervocalic onset /l/’s show temporal variation across items. She also shows that in onset position, longer /l/’s are not always backer. This correlation may be complicated by constraints on backness particular to each speaker. A profile of a speaker’s natural amount of velarization plus some form of vowel-detection would be needed to determine an effect of duration in the environment of a pre-boundary syllabic light /l/.

3.3 Experiment 2b

3.3.1 Aim

While the evidence so far is small, we might conclude that disambiguating contexts bring out structural differences in the duration of segments preceding morpheme boundaries. An experiment was run to test if morpheme boundaries are longer in decomposed access forms when the context supplies no cue to structure. In this condition, an effect of pre-boundary lengthening should obtain just in case the speaker's structural intentions, since otherwise undetermined, are aligned with boundaries in the accessed phonological code.

**H5 Segment lengthening is predicted before boundaries posited by route of lexical access in ambiguous contexts.**

The prediction is that boundaries are longer in the case of decomposed access forms than whole-access forms.

3.3.2 Materials

The following items were compared:

<table>
<thead>
<tr>
<th>Decomposed</th>
<th>Direct</th>
</tr>
</thead>
<tbody>
<tr>
<td>unrufflable</td>
<td>unravelable</td>
</tr>
<tr>
<td>unwranglable</td>
<td>unravelable</td>
</tr>
</tbody>
</table>
The prediction is /un-/ in unruflable and unwranguable is longer than /un-/- in unravelable. Similarly, the /x/ in unhexable should be longer than the /x/ in unflexible.

3.3.3 Results

In the ambiguous cases, there no significant effect. This may be in part due to a relatively high error rate both within and across speakers (17% of measurements excluded due to long pauses after /un-/). The errors might be an artifact of the unnatural task of out-of-the-blue elicitation from a carrier sentence that for each item was identical.

4. Conclusion

Frequency has an effect on the production of morphologically complex words insofar as it determines route of access for phonological representation in production. Experiments 1a–b show that segments before the edge of an accessed subpart are significantly longer than corresponding segments internal to an accessed string. A subset of the comparisons are significant in both prefix and suffix conditions. In suffix condition, an effect of base frequency is observed in the comparison of unportionable and unmentionable.

Contexts imposing different structural branching also have an effect on the production of complex words. Segments before suffix boundaries when the structure is left branching (root and next unit are non-sisters) are longer than when the structure is right branching (root and following unit are sisters). Segments before prefix boundaries are not significantly different across the two branching conditions.

There are a number of ways in which the procedures above could be improved. From a design perspective, stress and syllable weight should have been better controlled for across individual comparisons. Retreating to bimorphemic stimuli and covering a broader a range of relative base-
derivative frequencies is needed to address the extent that frequency determines the amount of lengthening. Another possibility would be nonce-form testing where frequencies and segmental material can be controlled well and a paradigm varied across subjects can be employed.

An automated criterion for distinguishing dark and light /l/ could be implemented to better address the spectral differences and length of /l/ in disambiguated conditions as in Huffman (1997). While observations were sketched of exceptionally long, syllabic, or velarized /l/s across conditions, there were shorter duration /l/s that might be considered pre-boundary if syllabic. With an effect of pre-boundary lengthening and also a separate availability of syllabic /l/, having an idea of when /l/ is syllabic and not just a heavily velarized /l/ is crucial for distinguishing among three possible pre-boundary conditions for lengthening: V/l/[−dark], V/l/[+dark], /l/[−dark]. The foremost condition, V/l/[−dark], could be insufficiently long to meet the criteria of what is characterized as a “long rhyme,” with the present method yielding fewer boundaries across tokens than what is posited by lexical access/structure. Nevertheless, the preliminary findings based duration alone seem to show that when semantic context requires decomposition, morphological-relatedness trumps a potential relative frequency effect on boundary duration.

In mapping syntax to prosody, hierarchical arrangement of two prosodic units entails a difference in the prominence of each unit. Wagner (2005) posits that prominence is realized as relatively extended duration of pre-boundary segments. When two units combine, they are on prosodic par. After this new complex object combines with another unit, segments preceding the most recent concatenation are longer than before the earlier boundary formation. Carlson et al. (2001) also present evidence of prosodic boundary scaling in adjunct attachment ambiguity. Given the evidence shown here for structural effects on boundary duration, examinations of multiple levels of embedding and alternating directions of branching are required to test whether the amount of lengthening is determined by relative prominence.

Since a relative frequency effect has been established for some of the data, it should no longer be a restriction that stimuli be of roughly equal surface-form frequencies.
within words as well. It is unlikely that such comparisons could be drawn from English derivational morphology, but the area is open to exploration.

It may also be worth exploring priming recency as a factor mediating the choice between retrieved phonological codes. If a trace exists in the buffer of a subpart form whose activation was a previously primed element of planning, its phonological code is retrieved for reduced cost and emerges the de facto winner of a lexical-access race.

Figure 9: Retrieval of phonological codes with post-lexical semantic pre-priming.

![Diagram](image)

(Rest ing activation codes: \{unravel+able\})
(Activation codes with priming: \{un+ra\(\mathbf{v(e)}\)able\})

... "unrav(e)lable" ...

Ravel is assumed to be activated and to leave a trace in the set of inputs to form encoding if an unfolding context presupposes the left-branching decomposition of unravelable. When form encoding for unravelable is triggered by lexical selection, phonological codes are trivially copied from the set already mapped to the input buffer instead of a more remote traversal.

The claim is that lexical access can be accelerated by recent activation of conceptually related words. Hay and Baayen (2002) argue for a threshold value at which relative frequency becomes a determining factor in the race to lexical access. One hypothesis is that sufficient priming pushes even low
frequency strings above such a threshold to become viable contenders for access.

While evidence has been shown that morpheme boundaries can reflect relative structural embedding in the produced acoustic signal, it is unclear whether listeners are sensitive to these phonetic cues. A line of exploration left for future research is to test whether slow-downs that result from morphological complexity are available for acoustic perception. One way to investigate this might be using a method modeled after Gussenhoven (1983)'s experiments on the perceptibility of stress. Tokens of a string from disambiguating contexts can be spliced across contexts recorded in experiment 2 and listeners might be asked to compare which utterance sounds better. Our prediction is that a string spliced into its originally matching environment will be rated as improved compared to a non-matching environment only if these duration manipulations are anticipated by the listener.
References


Appendix A: List of figures

Figure 1: Race-based competition of illegible (F_s=14 > F_b=10) and illiberal (F_s=11< F_b=55) Shaded arrows indicate path of lexical access. Double brackets indicate the most frequent form.

(a) [[illegible]]
   [in] + legible
   .. "illegible"..

(b) [illiberal]
   in+ [[liberal]]
   .. "illiberal"..

Figure 2: Productions of swiftly and softly

LEXICAL SELECTION
/swift + ly/
/soft + ly/

FORM ENCODING
Accessing correct phonological codes
step x /swiftly/ /swift+ly/ /soft+ly/
step y
Articulation
"swiftly" "softly"
Figure 3: Subject 3: Second repetition of *unconscionable* indicating nasal offset.
Figure 4: Subject 3: First elicitation of un[ravelable] indicating lateral offset.
Figure 5: Subject 3: First instance of \textit{unlock}able illustrating stop offset.
Subject 3: Fourth instance of [unhex]able illustrating fricative offset.
Figure 7: Mean duration of /ʌn-/ as a % of word length across subjects.

Figure 8: Mean duration of root-final /ʌn-/ as a % of word length across subjects.
Figure 9: Retrieval of phonological codes with post-lexical semantic pre-priming.

(Resting activation codes: \{unravel+able\}) cost
(Activation codes with priming: \{un+rav(e)able\}) free

... “unrav(e)able” ...
## Appendix B: Word frequencies

**CELEX lemma frequencies (Baayen et al 1995)**

<table>
<thead>
<tr>
<th>Word</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
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<td>31</td>
</tr>
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</table>
Appendix C: Stimuli

Jefferson believed that human rights are unalienable.

The oil tycoon's estate was ruled to be unentailable.

The well-fortified castle seemed to be unassailable.

Buffy knows that the vampires will be unimpalable.

The girl knew that any innocence was unattainable.

The judge said that his identity was unmentionable.

Hate is what the government made to be unconscionable.

Collectors believed that the painting was unauctionable.

Caroline wondered why the title was unavailable.

Hillary asks what part of the pie is unportionable.

A farmer had two types of sheep. One that he kept enclosed (because they misbehaved) and others that he let wander freely for most of the day. He would round them up at night, but they still were allowed more freedom than the naughty sheep. A wolf happened upon the farmer's sheep and thought of ways to get dinner. One idea he had was to scatter the free sheep with his howling and find a prey amidst the chaos. He figured these sheep would be easily unwranglable.

Sturgeon was a star witness. Immune to countless counts of murder, he stood protected at the witness stand, accusing another man of murder. The truth from his lips appeared completely unwranglable.

John broke the lid of his cookie jar. I suppose the uncoverable cookies should be eaten.

Jane knows where the chest of gold is... not such a big secret. We suppose the uncoverable treasure will be taken soon.

Bill's toy chicken looks very realistic. The smooth plumage is firmly cast around the body and all of the bird's feathers appear to be unrufflable.

A good manager sees a solution to every problem. The worst of issues are taken to be unrufflable.

The princess had glossy golden locks and they were so slippery that loose braids would not keep. She
found out that her hair handiwork was unravelable.

John couldn't put on his winter gear with his gloves on and in the wind. He was annoyed to find the scarf was unravelable.

If a muscle locks under duress and goes into severe spasm, it's best to take pressure off it. Wait a moment for the muscle to become unflexible.

It is a wonder people persist to argue about politics. Discourse participants have already convinced themselves of the absolute truth of their views. It's guaranteed that opinions will be unflexible.

The priest took one look at the demonically possessed child and was pleased with the prognosis. He proclaimed the afflicted boy to be unhexable.

Despite all his efforts, The witch-doctor couldn't make his voodoo-doll work. Perhaps the intended victim already was under such magical influences or maybe he wore an amulet of protection. In either case, the target seems to be unhexable.

Ted had sent Richard to the hotel to get his backpack. Leaving the room with the backpack, Richard jiggled the handle to make sure it was locked. the door swung open so he played with the lock settings for a while. Impatient, he decided to leave the unlockable door the way it was. He told Ted that it was still open later.

Tufts was convinced that his family heirlooms were secure in the safe behind his family portrait. The butler told him one day that it was rather easy to open the safe with rapid jiggling of the knob. Tufts decided he return the unlockable safe to the manufacturer.

Every person believes that the things are unravelable.
Every person believes that the things are uncoverable.
Every person believes that the things are unrufflable.
Every person believes that the things are unwranglable.
Every person believes that the things are unhexable.
Every person believes that the things are unflexible.