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Output-Output Faithfulness to Moraic Structure: Evidence from American English*

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1. Introduction

Moraic theory has been successful in formally representing the distinction between long and short vowels and between single consonants and geminates (Hayes 1989). In this sense, the mora represents a timing unit – segments attached to two moras are longer than segments attached to one. Such a conception of the mora is also appropriate when length distinctions are not binary. Broselow et al. (1997) propose a theory of mora-sharing that accounts for multiple distinctions in length. In this paper I will extend the idea of mora-sharing to explain predictable variations in vowel length in monosyllabic words in English. I will furthermore show that polymorphemic outputs in English are sensitive to the moraic structure of their bases.

It is well understood that the duration of vowels in monosyllables varies inversely with the number of segments in the rime, as shown in (1). In English, vowels that are followed by one coda consonant are approximately 7% longer than the same vowels followed by two coda consonants (Munhall et al. 1992). Given the diverse morphological compositions of monosyllables in English and the fact that a morphologically complex word can be phonologically influenced by its base, the vowel length hierarchy in (1) poses an interesting question. How long is the vowel of a dimorphemic monosyllable like *passed*? Is *passed* faithful to its VC base *pass* or is it truly homophonous with VCC *past*? In other words, does *passed* pattern with VC or VCC words?

(1) V̲C > V̲CC

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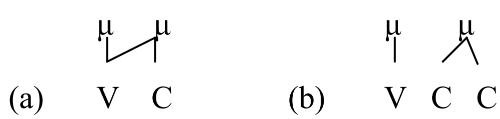
The present study is designed to answer this question and fit the answer within the theoretical framework of Optimality Theory (henceforth OT, Prince and Smolensky 1993). The experimental data presented in this paper will show that vowels in morphologically complex monosyllables are longer than in monomorphemic words composed of the same segments, but shorter than the vowels of their bases. This shows that the hierarchy in (1) is not complete and should be amended as seen in (2).

(2) VC > VC+C > VCC
pass > passed > past

This paper proceeds as follows. In §2 I will propose moraic structures to account for the durational differences of vowels in monomorphemic monosyllables and an OT constraint ranking that derives the structures. The conclusions reached in §2 will lead to the experiments described in §3, which will show that dimorphemic monosyllables have longer vowels than monomorphemic monosyllables. This new evidence will be accounted for using Transderivational Correspondence Theory (Benua 1997, see also Burzio 1994) in §4. I will investigate an alternative theory that makes reference to relative word frequency in §5, which will not be able to account for the data. In §6 I will present further discussion and final conclusions.

2. Moraic Structure of English Monomorphemic Monosyllables

The vowel length distinction shown in (1) is represented by the moraic structures in (3), assuming the mora as a timing unit. These moraic structures for English monosyllables are determined by the number of segments in the coda[1]. In a syllable with one coda consonant, the vowel is attached to two moras, but it shares one of them with the consonant. When there are two coda consonants, the vowel is only attached to one mora, while the coda consonants share a different mora. The mora-sharing structure in (3a) captures the fact that this vowel is longer than the one in (3b) because it is attached to two moras instead of just one. These structures incur no violations of FTBIN, but come at the cost of NOSHRM, two constraints motivated in previous literature as noted.

(3)


(4) FOOTBINARITY – Feet are minimally and maximally bimoraic. (McCarthy & Prince 1996)
Assign a * for every foot that is not bimoraic.

[1] The differences between the structures in (3) are the result of the number of coda segments. These structures are not influenced by whether the vowel is tense or lax, and thus they differ from other work on English phonology that handles the tense/lax distinction by using bimoraic representations for tense vowels and monomoraic ones for lax vowels (such as Hammond 1999). This usual approach is inconsistent with the experimental data that supports the hierarchy in (1). For example, (3b) represents both *sword* with a tense vowel and *past* with a lax vowel. Structure (3a) represents both *soar* and *pass* and shows why the vowels of these words are longer than in *sword* and *past*.

(5) NOSHAREDMORA – Moras may not be shared. (Broselow et al. 1997)
Assign a * for each segment (beyond one) attached to a mora. (If a mora is attached to *n* segments, the number of violation marks = *n*-1.)

While English requires coda consonants to be moraic, they never exclusively bear a mora, i.e. any mora attached to a consonant must also be attached to at least one other segment (be it a vowel or another consonant). Two constraints will be needed to insure this status for consonants: NOCEXMORA and WBYP. It is important that in the formulation of NOCEXM consonants are defined as [-syllabic], which means that offglides of diphthongs pattern with coda consonants. *Weigh* [wej] and *rue* [ɹuw][2] would have the moraic structure of (3a), just as *pass* does. According to this analysis, all monosyllables in English end with minimally a glide or a consonant, making it unnecessary to define a moraic structure for just a V monosyllable[3]. While NOCEXM is a previously unmotivated constraint, its formulation is a general extension of the phenomenon of mora sharing. It is not surprising that if languages can penalize mora sharing, they can require it of less sonorous segments.

(6) NOCEXMORA – Consonants may not exclusively bear a mora.
Assign a * for every consonant ([-syllabic]) that exclusively bears a mora.

(7) WEIGHTBYPOSITION – Coda segments must be moraic. (Hayes 1989, Morén 2003)
Assign a * for each segment that follows a tautosyllabic vowel and is not attached to at least one mora.

Moraic structure of monosyllables is entirely predictable; it is determined by the ranking of constraints (4)-(7). English freely violates MAXLM I-O and DEPLM I-O.

(8) MAXLINKMORA I-O – Do not delete mora links. (Morén 2003)
Let a mora link z be defined as an association line connecting a segment s with a mora μ. Every z_i (s_i-μ_i) should have a correspondent z_o (s_o-μ_o). Assign a * for each z_i that has no correspondent.

(9) DEPLINKMORA I-O – Do not insert mora links. (Morén 2003)
Let a mora link z be defined as an association line connecting a segment s with a mora μ. Every z_o (s_o-μ_o) should have a correspondent z_i (s_i-μ_i). Assign a * for each z_o that has no correspondent.

The tableaux in (10-11) show how the above constraints interact to yield the moraic structures seen in (3). For simplicity, underlying representations contain no

[2] Chomsky and Halle (1968) propose that all tense vowels in English have offglides, which are inserted according to a diphthonization rule (p. 183 (21)).

[3] Vowels in open syllables are known to be longer than vowels in closed syllables. This fact is still accounted for here, even though there are no vowel-final monosyllables. For example, the diphthong of *weigh* is longer than it is in *wade*. In *weigh* (see (3a)), the diphthong bears two moras (with the offglide sharing a mora with the nucleus). In *wade* (see (3b)), the diphthong exclusively bears one mora but shares the second mora with the final coda consonant, and this explains its shorter length.

onsets or mora links and are shown with generic Vs and Cs, where a V represents a simple nucleus and a C represents a [-syllabic] coda segment/offglide. Also, the faithfulness constraints MaxLM I-O and DepLM I-O are condensed into one general constraint MFaith, since neither of these constraints would be informative. More tableaux would be needed to show this explicitly, but for reasons of space I will simply say that, taking richness of the base into consideration, FtBin, NoCExM, and WByP must dominate any moraic faithfulness constraints on the I-O correspondence string.

(10) syllable with one coda consonant, i.e. *pass* [pæs]

/VC/	NoCExM	WByP	NoShrM	FtBin	MFaith
(a) μ μ VC	*!				**
(b) μ VC			*	*!	**
(c) μ μ VC		*!			**
(d) ☞ μ μ VC			*		***

(11) syllable with two coda consonants, i.e. *past* [pæst]

/VCC/	NoCExM	WByP	NoShrM	FtBin	MFaith
(a) μ μ μ VCC	*!*			*	***
(b) μ μ VCC	*!	*			**
(c) μ μ VCC			**!		****
(d) μ μ VCC	*!		*		***
(e) ☞ μ μ VCC			*		***

(12) (a) FtBin, NoCExM, WByP » MFaith (MaxLM I-O, DepLM I-O)
(b) NoCExM, WByP » NoShrM

Tableau (10) yields the dominance relation in (12a), which insures that (regardless of moraic structure in the input) all (monosyllabic) outputs are bimoraic and that all segments in the rime are attached to at least one mora with nonsyllabic segments never exclusively bearing a mora. Furthermore, lines (a) & (c) yield the dominance relation in (12b), which insures that coda segments bear and share moras.

3. New Experimentation

Given the moraic structures in (3) that are predictable based on coda content and the fact that English has monosyllabic words composed of more than one morpheme, we have an interesting situation for testing the extent to which polymorphemic words can be influenced by the phonology of their bases. Are the moraic structures of dimorphemic monosyllables predicted by coda content (as the monomorphemic monosyllables are) or does the base exert an influence through higher-ranking Output-Output (hereafter O-O) faithfulness constraints? The faithfulness constraints in (8) and (9) can also apply to the O-O correspondence relation, as shown below.

(13) (a) MAXLINKMORA O-O – Do not delete mora links.
(b) DEPLINKMORA O-O – Do not insert mora links.

The length of vowels in dimorphemic monosyllables should correlate with how the constraints in (13) are ranked within the established rankings in (12). If the O-O faithfulness constraints are ranked low, dimorphemic monosyllables behave just like monomorphemic ones, i.e. the vowels of dimorphemic words are the same length as monomorphemic homophones (*passed*=*past*). If they are undominated, dimorphemic monosyllables behave just like their bases, i.e. vowels of dimorphemic words are the same length as their bases (*passed*=*pass*). If neither of these is the case, dimorphemic monosyllables behave differently from both base and homophone, i.e. vowels of dimorphemic words are not as long as their bases, but not as short as monomorphemic homophones (*pass*>*passed*>*past*).

Three experiments were designed to determine the length of vowels in dimorphemic monosyllables, and hence the ranking of the O-O faithfulness constraints. Two production experiments determined the vowel length of a dimorphemic monosyllable as compared to both the vowel length of its base and a monomorphemic word composed of the same segment. One perception experiment determined if listeners used the durational differences between di- and monomorphemic monosyllables as a cue to morpheme content.

3.1 Production Experiments

Nineteen native American English speakers participated in the first production experiment (13 female/6 male, ages 18-52), henceforth called experiment A. For both production experiments, the participants were recorded in a sound-treated room as they read sentences shown to them one at a time; the recordings were made with PRAAT (Boersma and Weenink, version 4.2.14, http://www.praat.org) at a sampling rate of

22050 Hz using a head-mounted microphone.

Each sentence consisted of the frame sentence "'____', *they said*", which was designed so that the target word would remain one stress foot and resyllabification of coda consonant(s) from the target word would be prevented by the [ð] in *they* (as no words in English begin with CðV). Three types of target words were used: BASE (monomorphemic word that is the BASE for the dimorphemic word, e.g. *pass*), DI (dimorphemic word composed of BASE + 'past tense' morpheme, e.g. *passed*), and MONO (monomorphemic word composed of same segments as DI word, e.g. *past*). Each subject read 80 sentences in a random order, with 66 containing target words and 14 containing fillers. The target words consisted of 18 groups of BASE, DI, and MONO words and 6 groups of BASE and DI words only, e.g. *sue/sued*, where no MONO word exists.

The second production experiment (experiment B) involved 13 native American English speakers (6 female/7 male, ages 19-33). Again, the participants read randomly ordered sentences. This time the sentences consisted of the frame sentence "I said '____', not '____'", where the blanks were filled with two "homophonous" target words, one being monomorphemic and the other dimorphemic (e.g. (a) "I said '<u>band</u>' not '<u>banned</u>'" and (b) "I said '<u>banned</u>', not '<u>band</u>'"*)*. The speakers were asked to stress the underlined words. The frame sentence was designed as such to encourage participants to highlight any characteristics that might differentiate the two words. Only MONO and DI word types were used in this experiment.

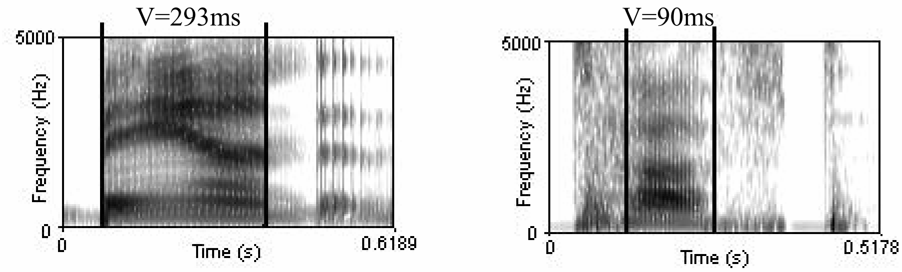
Each subject read 12 sentences in a random order, with 6 sentences containing target words (half of the sentences had the DI word in the first blank, the other half had the MONO). Comparisons for vowel length between DI and MONO words were made using words in the same environment, but across sentences. For example, the first-word comparison (W1) compared *band* of sentence (a) in the above paragraph to *banned* of sentence (b). The second-word comparison (W2) compared *band* of sentence (b) to *banned* of sentence (a).

For both production experiments, the target words were viewed as spectrograms in PRAAT, and vowel duration was determined. The spectrogram examples in figure 1 show that vowels were segmented by locating the onset/offset of their characteristic dark, solid formant structure and voicing (if bordering sounds were voiceless).

The results of the production experiments (figure 2) clearly show that the DI words contain longer vowels than MONO words composed of the same segments. In experiment A DI vowels were 7.3% longer than MONO vowels, and this difference was greater in experiment B (10.5-16.7%), which suggests that the speakers are able to actively control (and emphasize) the durational difference when it might be necessary for clarification. Experiment A also showed that the vowels of DI words were not as long as the vowels of BASES, with the BASE vowel being 12.8% longer ($p<.0001$, Z test controlling for multiple observations within subjects).

Figure 1: examples of spectrogram segmentation

(a) *band* (b) *tuft*



(c) *banned* (d) *toughed*

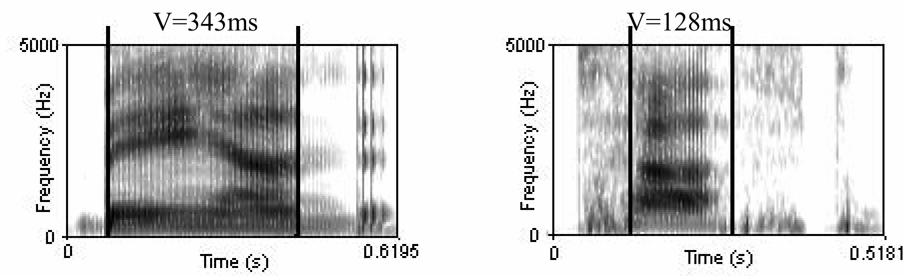
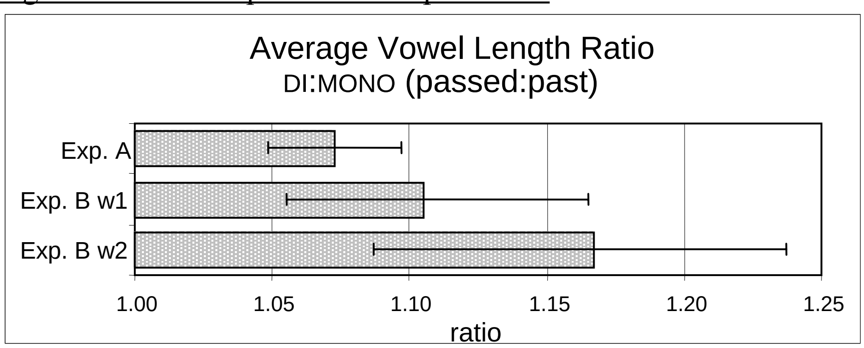


Figure 2: results of production experiments



|—| = 95% confidence interval

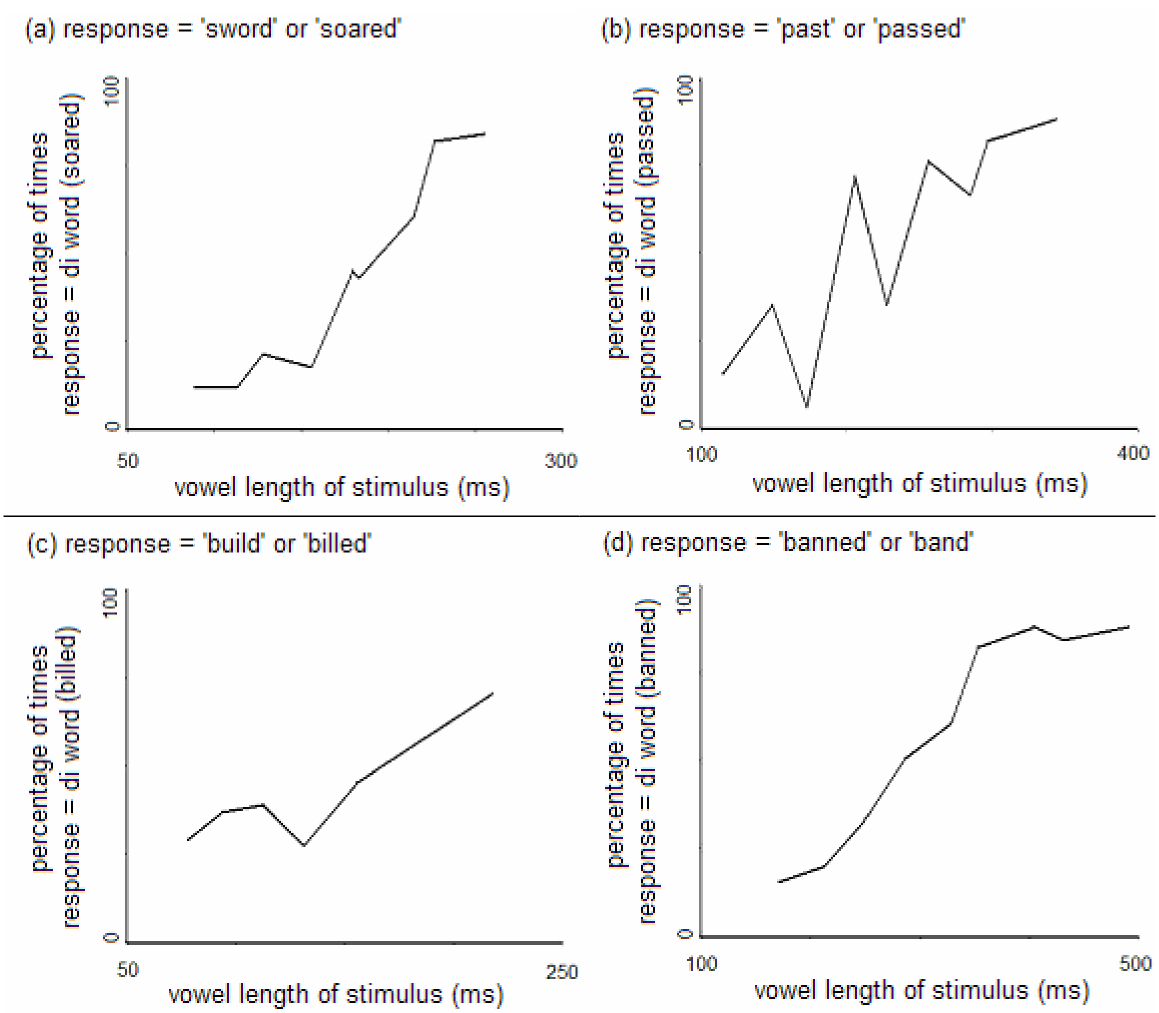
H_0: ratio=1; H_a: ratio>1; z test controlling for multiple observations within subjects; $p<.0001$ for each ratio average

3.2 Perception Experiment

Seventeen native American English speakers (9 female/8 male, ages 18-51) underwent the perception experiment (some had first participated in experiment A in the same session). The stimuli consisted of MONO and DI words, most of which were manipulated for vowel length. There was one original recorded token of *band* that had a vowel length nearing the average vowel length obtained from a pilot experiment, and one original recorded token of *banned* with a vowel length 15% greater than the vowel length of *band*, which approximates the percent increase that was measured in experiment B (W2). Manipulations of these two original tokens were then done in PRAAT to match the following criteria: original vowel length minus 50%, minus 25%, plus 25%, and plus 50%. All manipulations were done by adding/deleting whole pitch periods (beginning and ending at a zero-crossing) to/from the middle of the vowel (or the part of the vowel with the most stable formant structure if this was not the middle), and so all percent increases and decreases are approximate. All tokens for the experiment were spoken by the same speaker.

The result of the manipulations was a set of 10 tokens with 10 different vowel lengths ranging from the original *band* minus 50% to the original *banned* plus 50%. The above steps for the selection of original tokens and the manipulations of them were then repeated for the tokens *past/passed*; *sword/soared*; *build/billed* for a total of 40 stimuli. Participants heard each stimulus three times in a random order while performing a multiple forced-choice task administered by PRAAT (with the stipulation that each token was heard once before repeating tokens).

<u>Figure 3: results of perception experiment</u>



a logistic regression model with a null hypothesis of no logit linear association,
a z test yields $p < .005$ for each graph

The results of the perception experiment (figure 3) demonstrate that speakers are increasingly likely to select a dimorphemic word as the vowel gets longer, in accord with the production experiment results. In summary, vowels of dimorphemic words are longer than vowels of monomorphemic words with the same segment content. This vowel length distinction is actively used by speakers to avoid ambiguity (production experiment B) and is recognized by listeners as a cue to morpheme content. Since there is no other difference between the two words, the inflectional morpheme must in some way be responsible for the lengthened vowel.

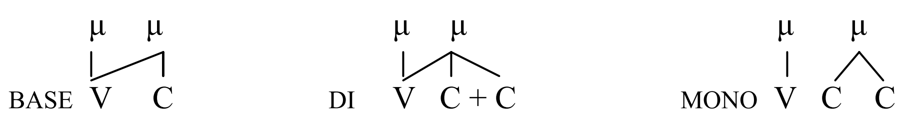
4. Moraic Representations for Dimorphemic Words

The data obtained from production experiment A shows that a dimorphemic word differs from its monomorphemic counterpart in a way that makes it more similar to its base than it would be otherwise, as predicted if the O-O moraic faithfulness constraints are ranked high enough to do any work in English. However, these constraints cannot be undominated, as the DI word is not completely faithful to the BASE, i.e. its vowel is still shorter than the vowel of the BASE. This data yields the vowel hierarchy first shown in (2), and repeated below in (14). Moraic structure will again be able to represent this hierarchy, as demonstrated in (15).

(14)[4]

VC	>	VC+C	>	VCC	
BASE	>	DI	>	MONO	
pass	>	passed	>	past	[pæs(t)]
rue	>	rued	>	rude	[ɹuw(d)]
weigh	>	weighed	>	wade	[wej(d)]

(15)[5]



The moraic structures shown in (15) account for the vowel length of the DI word as compared to the others. This vowel is shorter than in the BASE because it shares its second mora with an extra segment; it is longer than in the MONO word because it is attached to an extra mora. For words with diphthongs, where the vowel length measurement includes the V and the first C, the analysis is still appropriate. In the DI word, the first two rime segments (VC) should still be shorter than in the BASE because they share the second mora with another segment and should still be longer than in the MONO word because the final consonant in this word could be said to claim half the mora, while this final consonant can only claim one third of the mora in the DI word.

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[4] The dashed underlining of the first C for each word type represents the fact that in words like *rue* and *weigh* this segment (the glide) is a part of the vowel and thus of the vowel length measurement taken in the production experiments (as separating the offglide from the nucleus would be a less reliable measurement).

[5] These structures lend support to the idea that all tense vowels are followed by an offglide in English. Without this extra segment, there would not be a way to account for the vowel length difference between DI and MONO words like *rued*/*rude*. The constraint ranking would predict both structures to be identical (both would look like (3a)).

The following tableau demonstrates how the O-O faithfulness constraints must be ranked to yield the structures in (15). The same steps towards simplicity have been taken as with tableaux (10-11). The tableau in (16) yields the rankings shown in (17). The high ranking MAXLM O-O explains the DI word's similarity to its BASE, as candidate (c), which would win if the word was monomorphemic, incurs a fatal violation of this constraint. The high ranking WBYP explains the DI word's failure to exactly replicate the BASE, as candidate (a), which fully replicates the BASE, incurs a fatal violation of this constraint.

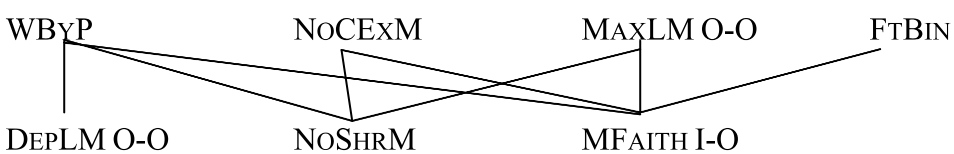
(16) dimorphemic words, i.e. *passed*

base /VC/	*derivative* /VCC/	MAXLM O-O	NOC EXM	WBYP	DEPLM O-O	NO SHRM	FT BIN	MFAITH I-O
(a) μμ VC	μμ VCC			* !		*		***
(b) μμ VC	☞ μ μ VCC				*	**		****
(c) μμ VC	μ μ VC C	*!			*	*		***

(17) (a) MAXLM O-O » NOSHRM, MFAITH I-O
(b) WBYP » DEPLM O-O, NOSHRM, MFAITH I-O

A summary of all constraint rankings demonstrated by tableaux (10, 11, 16) is shown in (18). The grammar created by this constraint ranking guarantees that monomorphemic monosyllables will be attached to two moras with mora-sharing used to insure that all rime segments are attached to a mora. Dimorphemic monosyllables obey the same regulations as monomorphemic ones, provided they do not delete mora links from the base.

(18) <u>summary of constraint rankings</u>

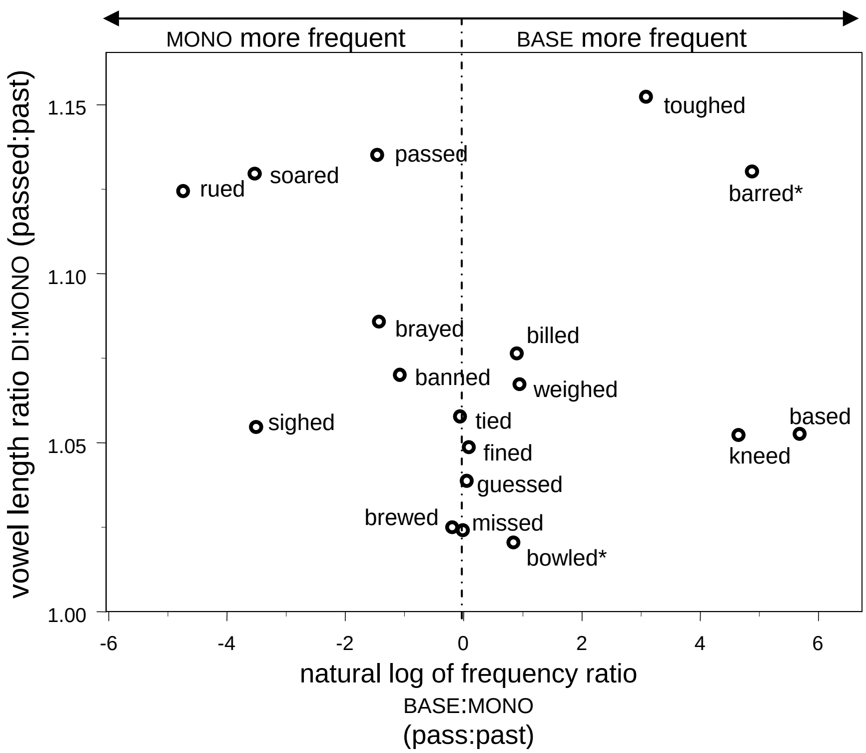


5. Frequency Effects

The DI words have a connection both to the BASE and MONO words: the BASE forms part of the DI word and the MONO word has an identical segment composition. According to some exemplar-based work (for example, Pierrehumbert 2001, Bybee 2002), these competing relationships could influence the production of the DI word through associated exemplar clouds. For this reason it is important to explore the possibility of any correlation between the vowel length and word frequency. There are various ways to look for such a connection, only one of which I will explore here.

If the BASE and MONO words are competing for influence over the DI words, the word with a higher frequency should win. The "winner" could exert this influence in one of two ways – it could force the DI word to be more like it or less like it. This yields two hypotheses: (a) the more frequent the MONO word is as compared to the BASE, the more it will drive the DI word toward homophony, i.e. *past* is more frequent than *pass*, so *passed* is more homophonous with *past* (a lower vowel length ratio); (b) the more frequent the MONO word is as compared to the BASE, the more it will drive the DI word away from homophony, i.e. *past* is more frequent than *pass*, so *passed* is less homophonous with *past* (a higher vowel length ratio). Both of these hypotheses predict a linear relationship between frequency ratio of BASE:MONO and vowel length ratio of DI:MONO.

Figure 4: word frequency ratio compared to vowel length ratio



*actual measurement was V+ length (vowel + following inseparable liquid)

a linear regression model with a null hypothesis of no association: $t_{(16)}$= -.45, p=.6621,

Figure 4 compares the ratio of the frequency of the BASE to the MONO and the ratio of the measured vowel length of the DI to the MONO for each word used in experiment A. Frequency counts were obtained from the CELEX database (Baayen et al. 1995). Some words used in the experiment had multiple entries in CELEX; for example, *band* was listed as both a noun and a verb. Because the participants read the word in a context that gave them no clues as to word meaning or grammatical category, frequency counts were totaled from all entries listed for a particular word. The natural log was then taken of the frequency, following previous experimentation indicating that native speakers can accurately judge relative word frequency based on a logarithmic scale

(Smith & Dixon 1971). If hypothesis (a) is correct, we would see an upward (positive) slope in figure 4; hypothesis (b) would yield a downward (negative) slope. The results shown in figure 4 allow us to reject both hypotheses. Word frequency is not able to account for this phenomenon.

6. Discussion and Conclusions

As exemplified by the durational patterns of vowels in English monosyllables, moraic structure in these words is entirely predictable. For monomorphemic monosyllables, moraic structure is determined by the number of segments following the nucleus. This is also true of dimorphemic monosyllables, though moraic structures for these words are additionally determined by the number of segments in the coda of the base.

Moraic structure is thus affected by morpheme boundaries. Dimorphemic monosyllables do not exhibit the same moraic structure that an identical sequence of segments would without the morpheme boundary. This difference in moraic structure provides evidence for O-O faithfulness constraints that penalize changes in association lines between moras and segments. Due to high-ranking MaxLM O-O, dimorphemic monosyllables contain longer vowels than expected of monomorphemic words of the same segment content.

This result has several implications for future work. A similar pattern exists as part of the Scottish Vowel Length Rule (SVLR), also know as Aitken's Law (Aitken 1981), according to which a stressed vowel becomes long when it occurs before a segment that is [+voice, +continuant] or a word boundary. Derived words contain a long vowel if the appropriate environment existed before the derivation, such that *brewed* has a long vowel, but *brood* does not. Previous analysis of the SVLR has appealed to cyclicity in various forms (Borowsky 1993, Carr 1992, Harris 1991), but new analysis could appeal to high-ranking O-O faithfulness constraints. Due to the occurrence of similar phenomena in Scottish and American English, this constraint ranking could be a historical relic. It would be valuable for future research to look for similar patterns found in other Germanic and/or Indo-European languages.

Due to the typological nature of OT, there should be evidence of such O-O constraints doing work in other languages. A factorial typology can be presented if we simplify the list of relevant constraints. The chart in (19) shows three grammars that emerge from six different constraint rankings. Considering only the constraints relevant for the formation of moraic structure, M stands for all markedness constraints, while I-O and O-O stand for all faithfulness constraints applicable to the particular correspondence relationship. When markedness completely dominates (as in (a-b)), moraic structure is entirely predictable (based on the ranking of the markedness constraints) in both base and derivative. When I-O completely dominates (as in (c-d)) or when O-O»I-O»M (as in (e)), all moraic structure is realized as it is lexically indicated, resulting in phonemic vowel and/or consonant length. The ranking of O-O»M»I-O in (f) produces visible effects of the O-O constraints. According to such a grammar, bases obey markedness constraints. In derived words, the base is faithful to the original output predicted by the grammar, even if the new word has a marked structure due to the phonological content of the affix. The affix is then subject to markedness. A language with a grammar as seen in (f) would contain noticeable effects of the O-O constraints. As we have seen in English, though, it is not essential that the O-O constraints dominate all markedness constraints in order to create visible results.

<table>
<tr><th>(19)</th><th>ranking</th><th>base</th><th>derivative</th></tr>
<tr><td>(a)</td><td>M»I-O»O-O</td><td colspan="2" rowspan="2">predictable</td></tr>
<tr><td>(b)</td><td>M»O-O»I-O</td></tr>
<tr><td>(c)</td><td>I-O»O-O»M</td><td colspan="2" rowspan="3">lexical</td></tr>
<tr><td>(d)</td><td>I-O»M»O-O</td></tr>
<tr><td>(e)</td><td>O-O»I-O»M</td></tr>
<tr><td>(f)</td><td>O-O»M»I-O</td><td>predictable</td><td>faithful to base; affixes are predictable</td></tr>
</table>

The moraic structure account presented here predicts that monosyllables with a morpheme boundary before the nucleus would not be susceptible to such durational patterns. While this is not applicable to English (because the lexicon does not include the relevant words), it could be applicable to future studies in other languages. Similarly, in different frame sentences, where resyllabification is expected, the English words might not be liable to the same variation, i.e. "say______again", where coda consonants of target words are likely to become onsets of the following syllable.

The ultimate conclusion of this paper is that the prosodic structure of polymorphemic words can be influenced by the prosodic structure of the base, motivating the constraints MaxLM O-O and DepLM O-O. An alternative theory, one referring to frequency effects, is not adequate to analyze the phenomenon. On the other hand, using the mora as a timing unit and Transderivational Correspondence Theory provide adequate tools for analyzing the moraic structure of English monosyllables.

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