Frequency Effects in Morpheme Segmentation

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Abstract

The present study explores the effects of frequency in learning to parse novel morphological patterns. In two experiments, suffixes were divided into three classes: high, medium and low frequency, based on the proportion of stems in the input that each suffix attached to (high frequency = 12/12, medium frequency = 6/12, and low frequency = 2/12). In Experiment 1, learners were better at segmenting words containing high frequency suffixes compared to low frequency suffixes, even when the stems were novel. In Experiment 2, token frequency was controlled for across all three suffix frequency classes, but learners were still better at segmenting high frequency suffixes, even when words containing high frequency suffixes were less frequent. These results suggest that learners are sensitive to the frequency distributions of the morphemes in their language, supporting work suggesting that a Zipfian distribution may be ideal for language learning.

Keywords: statistical learning; type frequency; morpheme segmentation.

Introduction

Morphology is the study of how form and meaning are combined to form complex words. A word like *running* is composed of two morphemes: *run* and *–ing*. In order to understand the meaning of a complex morphological word like *running,* the language user must be able to break the word apart into its constituent morphemes, a process referred to as morpheme segmentation. The problem of morpheme segmentation, while seemingly simple, could easily pose problems for the learner. First, many words partially overlap in phonological form without being morphologically related (e.g., *canned* and *bend* both end in the sounds /nd/ but only *canned* is morphologically complex). The present study extends previous research on how learners make use of distributional information to segment complex words (Finley & Newport, 2010, 2011). Specifically, this study manipulates the type and token frequency of affixes to better understand how lexical statistics can affect morpheme segmentation.

Background

Previous research has shown that even though spurious phonological regularities could easily lead the learner astray when segmenting complex words, both adult and child learners are nonetheless sensitive to these distributional regularities (Finley & Newport, 2010, 2011). This research is in line with computational models of morpheme segmentation that make use of statistical regularities of the phonological form of the input to find morpheme boundaries in complex words (Goldsmith, 2006).

In their experiments, Finley and Newport (2010, 2011) showed that learners were able to extract morphological regularities from trisyllabic words where the first two syllables were a stem and the final syllable was a suffix. Results demonstrated that learners segment complex words into their component parts through mere exposure, and minimal training. However, the highly controlled statistics of the words in these experiments (e.g., all suffixes were equally frequent across stems) do not reflect the variable frequencies of morphological information found in natural language. The present study addresses how learners may use variable frequencies of affixes to parse the morphological information of the language.

Previous research has suggested that type frequency (the number of words containing a morpheme) is more important in determining productivity of an affix than token frequency (the frequency of the word containing the type) (Albright, 2002; Bybee, 1995). For example, Ernestus and Baayen (2003) showed that Dutch speakers chose past tense variants based on similarity to existing words in the lexicon proportionally to the number of similar items, rather than frequency. While there is some work on how type and token frequency may affect morphological learning (Albright, 2002; Ellis & Schmidt, 1998), this research has focused on the learnability of irregular morphological patterns, rather than segmentation of the morphemes themselves.

There are several reasons why it is important to study human morphological learning at the stage of morpheme segmentation. First, there are many reasons to believe that learning about the morphological patterns of one's language occurs relatively early, even before the child has acquired the meaning of the semantic classes that the morphemes may represent (Jusczyk, 2000). Second, because phonological factors play an important role in morphology (Albright, 2002), it is important to understand how learners acquire both form independently of meaning.

Zipfian Distributions

As noted above, one reason that type frequency may play a larger role in morphological productivity than token frequency may be due to the overall distribution of different types of morphological patterns. Zipf's Law (Zipf, 1935) states that the number of tokens increases as a function of type frequency: there are a few high frequency words/morphemes, and a very large number of low frequency words/morphemes. The high frequency morphemes may be easier to learn than lower frequency morphemes because the combination of a small number of morphemes appearing in many words may help these high frequency morphemes 'stand out' from the many lower frequency morphemes. A Zipfian distribution may therefore be optimal for creating a learning environment in which a few morphemes are learned very fast, and this early learning serves to bootstrap the learning of lower frequency morphemes (Bortfeld, Morganm, Golinkoff, & Rathbun, 2005).

Previous research has shown that learners make use of Zipfian distributions in word segmentation (Kurumada, Meylan, & Frank, 2013), and verb constructions (Ellis & Donnell, 2012). While Zipfian distributions have been assumed to play an important role in language acquisition, it is important to understand that the assumption of Zipfian distributions may be a simplification of more complex statistical patterns in the language (Piantadosi, 2014). However, recent computational models of morphology learning have shown a benefit for Zipfian distributions (Chan & Lignos, 2010), suggesting that the optimal lexicon for language learning may follow a Zipfian distribution, potentially explaining why such distributions tend to be stable and common across languages.

The Present Study

In order to better understand how learners make use of affix frequency in morpheme segmentation, the present study builds on work by Finley and Newport (2010, 2011), who found that learners easily segment stems and affixes from an evenly distributed lexicon. The present study makes use of a frequency distribution for suffixes in which there are a few suffixes that appear with many stems (high frequency), more suffixes that appear with several stems (medium frequency), and many suffixes that appear with only a few stems (low frequency). Participants were tested on their ability to segment complex lexical items for both familiar and novel words. If learners are sensitive to the type frequency of the suffixes, learners will be better able to segment complex words for high frequency suffixes, even when the learner has never encountered that word before. In Experiment 1, only type frequency was manipulated, and in Experiment 2, token frequency was controlled for so that words containing morphemes with a high type frequency had a low token frequency, and words containing morphemes with a low type frequency had a high token frequency. Previewing results, participants showed greater accuracy for segmentation of words containing the high (type) frequency suffixes compared to the low frequency suffixes, and this effect remained when token frequency was controlled for (Experiment 2).

Experiment 1

The goal of Experiment 1 was to explore the ability of adult learners to parse stems and suffixes into constituent parts using only distributional information. The distribution of affixes varied such that a small selection suffixes were highly frequent (appearing with all possible stems), a larger selection of affixes were relatively frequent (appearing with half of the stems), and an even larger number of suffixes were highly infrequent (appearing with only two stems).

Method

Participants All participants were adult monolingual native English speakers. Forty-eight participants were recruited from the Elmhurst College community. Participants were given course credit for participation. Participants were randomly assigned to one of two languages (A and B, differing only in vocabulary) and one of two test conditions (Stem Parsing and Suffix Parsing), for a total of four distinct training and test conditions, with 12 participants in each condition.

Design The experiment was designed to test the ability of adult learners to parse morphologically complex words with a varying distribution of the frequency of suffixes. The language contained all properties of a suffixing language with a suffix concatenated to a stem. Stems were all of the shape CVCV and suffixes were all of the shape CV, creating tri-syllabic words of the form CVCVCV (where C is a consonant and V is a vowel). Consonants were drawn from the set [p, t, k, b, d, g, m, n, s, v, z, f], and vowels were drawn from the set [a, e, i, o, u]. Care was taken so that all the words satisfied English phonotactics, but did not overlap with real English words. To ensure that the results were not due to any unforeseen peculiarity of the stimuli, we created two languages (Language A and Language B) with the same properties, but different sets of stems and suffixes. Each language had 12 stems and 20 suffixes.

Table 1: Exposure Phase Statistics.

Experiment	Suffix Type	Number Stems	Number Suffixes	Times Repeated
Exp 1				
	High	12	2	5
	Med	6	6	5
	Low	2	12	5
Exp 2	High	12	2	2
	Med	6	4	4
	Low	2	12	12

Stems were paired with a varying number of suffixes for the training phase based on the assigned frequency of the suffix. There were two high frequency suffixes, each paired with all 12 stems (e.g., /basomi/, /basobu/, /vegubu/, etc.). There were six medium frequency suffixes, each paired with six of the 12 stems (e.g., /basodo/, /basoke/, /vegupe/, etc.). There were 12 low frequency suffixes, each paired with two stems (e.g., /basoze/, /veguki/, /veguma/, etc.). Each of the 12 stems was paired with seven suffixes, creating a total of 84 affixed forms for presentation during training phase. The Stem+suffix concatenations were counterbalanced so that to avoid patterned restrictions, which set of stems went with which affixes (in other words, we did not create categories or sub-categories with the affixed forms). The general statistics of training items can be found in Table 1.

Participants heard each item in the training set five times during exposure in randomized blocks (participants heard all 84 items before hearing the same set again in a different random order). The words were presented as isolated utterances (i.e., not as part of a larger speech stream). All phases of the experiment were run in Psyscope X (Cohen, MacWhinney, Flatt, & Provost, 1993).

Following exposure, participants were given a two-alternative forced-choice test for their ability to parse morphemes. There were two different between-subjects test conditions: Novel Stem/Suffix (Table 2) and Suffix Parsing (Table 3), each representing different groups of participants. The items in the Novel Stem/Suffix condition were designed to test whether participants could parse novel words containing a novel suffix or a novel stem. The Novel Suffix (ABQ) test items probed whether learners would accept a novel suffix as a part of the language, requiring learners to have familiarity with the stems; it is expected that if participants have learned the general Stem+Suffix affixation pattern, that learners will accept a stem with a novel affix (AB-Q, where Q represents a syllable not heard in training, and AB refers to a familiar stem) more often than the ungrammatical scrambled counterpart (AQB).

Table 2: Examples of Novel Stem/Novel Suffix Test Stimuli, Language A.

	Grammatical (ABQ/CDX)	Ungrammatical (AQB/CXD)
ABQ	befada ditipa	bedafa dipati
CDX-High	basomi mekimi	bamiso memike
CDX-Med	vopina zikuna	vonapi zinaku
CDX-Low	tenoki basovu	tekino bavuso

The Novel Stem (CDX) test items probed whether learners could recognize a novel stem containing a familiar suffix (CDX) compared to its scrambled counterpart (CXD). Items were separated for High, Medium and Low frequency suffixes. It is expected that learners will be more likely to select a novel stem when it contains a high frequency suffix compared to a low frequency suffix.

The Suffix Parsing Items tested whether learners had parsed the affixes into separate units from the stems. Familiar (ABX) items compared a word heard in training to its scrambled counterpart (ABX vs. AXB). There were three types of these items based on the frequency of the suffix: High, Medium and Low. Novel (ABY) items compared new stem-affix combination (ABY) with a scrambled familiar item (AXB). There were two types of these items, based on the frequency of the suffix: Medium and Low. Because all stems appeared with each of the High Frequency suffixes, it was impossible to have Novel items for High Frequency suffixes. If participants learned the Stem+Suffix structure of the language, they should choose both the ABX and ABY items significantly above chance, compared to items that contain familiar syllables, but do not conform to the Stem+Affix pattern. In addition, it was expected that learners will show more accurate responses to items containing high frequency suffixes compared to low frequency suffixes.

Table 3: Examples of Suffix Parsing Exposure Stimuli, Language A.

	Grammatical (ABX/ABY)	Ungrammatical (AXB)
ABX-High	befabu guvami	bebufa gumiva
ABX-Med-	veguna kovefu	venagu kofuve
ABX-Low	fibago koveki	figoba kokive
ABY-Med	nidefu mubefu	difupi befufa
ABY-Low	mubego befape	nigode vepegu

Stimuli All stimuli were recorded in a sound-attenuated booth by an adult female native English speaker. While the speaker was aware that the stimuli were to be used for an artificial grammar learning study, the speaker was unaware of the hypothesis of the study. Tokens were individually recorded. Each token was spoken four times in list format. A single token was chosen from the second or third element of the set in order to keep the prosody as uniform as possible. The first and last elements were avoided to avoid the intonation of first and last elements in a list. The speaker was told to speak each word as clearly and accurately as possible (without reducing vowels). Stress was placed on the final syllable. All stimuli were normalized to 70dB in Praat (Boersma & Weenink, 2015).

Procedure Participants were told that they would be listening to words from a language they had never heard before and that their task was to listen to the way the novel language sounded, but that they need not try and memorize the forms. Following the exposure phase, participants were told that they would hear two words, one belonging to the language they heard, and the other not belonging to the language. If they believed the first word belonged to the language, they were to press the ‘a’ key; if they believed the second word belonged to the language, they were to press the ‘l’ key. Participants were told to respond as quickly and accurately as possible, but no time limit was given for responses. The experiment took approximately 20 minutes to complete.

Results

All analyses were performed separately for the Novel Stems/Suffix tests and the Suffix Parsing tests, and combined the data from Languages A and B.

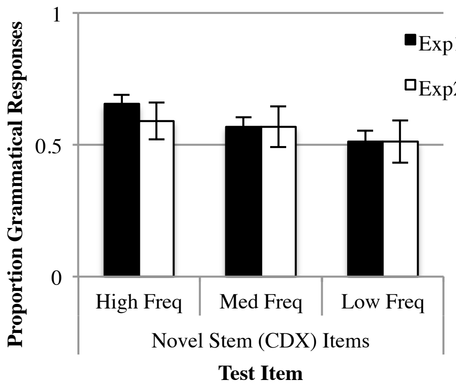

Figure 1: Novel Stem (Means and Standard Errors).

Novel Stems and Suffixes Each of the means for the Stem-Parsing Items were compared to chance (50%) via Bonferroni corrected one-sample t-tests. The Novel Suffix Items (ABQ vs. AQB), with a mean of 0.54, $t(23) = 0.96$, $p = 0.35$, were not significantly greater than chance. However, as expected, the Novel Stem Items (CDX vs. CXD) were only significantly different from chance for the high frequency suffixes, with a mean of 0.65, $t(23) = 4.95$, $p < 0.001$. The medium (mean = 0.55, $t(23) = 1.14$, $p = 0.26$) and the low (mean = 0.52, $t(23) = 0.44$, $p = 0.66$) frequency suffixes were not significantly different from chance, supporting the hypothesis that learners parse suffixes containing high frequency items more easily than low frequency items. To verify this hypothesis, a within-subjects ANOVA compared high frequency suffixes to low frequency suffixes, and high frequency suffixes to medium frequency suffixes. The comparison between high and low suffixes was significant, $F(1, 23) = 8.44$, $p = 0.008$, while the comparison between the high and medium frequency suffixes was only marginally significant $F(1, 23) = 3.50$, $p = 0.074$, generally supporting the hypothesis that learners are more likely to parse a novel suffix if it contains a high frequency suffix.

Suffix Parsing Results for Suffix Parsing Test Items appear in Figure 2. Each of the means for the Suffix Parsing Items were compared to chance (50%) via Bonferroni corrected one sample *t*-tests.

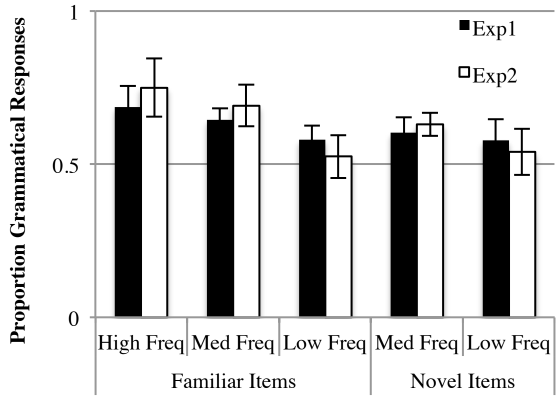

Figure 2: Suffix Parsing (Means and Standard Errors).

Participants scored above chance on the Familiar (ABX) Items, for High (mean = 0.75, $t(23) = 7.55$, $p < 0.001$), Medium (mean = 0.68, $t(23) = 4.95$, $p < 0.001$), but only marginally for Low (mean = 0.50, $t(23) = 2.49$, $p = 0.063$) frequency suffixes. To test the hypothesis that learners were more accurate on items containing high-frequency suffixes, a within-subjects ANOVA was performed comparing high frequency suffixes to low and medium frequency suffixes. The comparison between high and low suffixes was significant, $F(1, 23) = 9.62$, $p = 0.005$, while the comparison between the high and medium frequency suffixes was not significant $F(1, 23) = 2.24$, $p = 0.15$. These results support the hypothesis that high frequency suffixes are more easily recognized in familiar items even when the familiar items were heard the same number of times.

The Novel (ABY) items were significantly different from chance for medium frequency suffixes (mean = 0.61, $t(23) = 2.95$, $p = 0.021$), but not for low frequency suffixes (mean = 0.56, $t(23) = 1.47$, $p = 0.48$), but there was no significant difference between medium and low frequency suffixes for these items ($t(23) = 0.94$, $p = 0.36$). The results partially support the hypothesis that frequency affects parsing of novel items, as only medium frequency items were significant from chance, but there was no significant difference between medium and low frequency items.

Discussion

Experiment 1 demonstrated that frequency distribution plays an important role in morpheme segmentation, particularly for novel items. While learners failed to show evidence of learning the twelve stem items, learners did show evidence of more accurate responses for items containing novel stems when the frequency of the novel suffix was higher. This suggests that learners are sensitive to the frequency of the suffix. Participants in Experiment 1 heard each suffix the same number of times, but because the type frequency of high frequency suffixes was higher, learners heard more high frequency suffixes. Because it is unclear whether the type frequency or the token frequency produced the results in Experiment 1, Experiment 2 controlled for token frequency. If learners are responding to type frequency, learners should still perform better on high frequency items compared to low frequency items.

Experiment 2

Experiment 2 extends the results of Experiment 1 by controlling for type and token frequency: token frequency of the suffixes was equal, while type frequency was manipulated in the same way as Experiment 1. It is expected that learners will show a similar pattern of results as Experiment 1; learners will show more accurate responses on items containing high frequency suffixes compared to low frequency suffixes.

Participants

All thirty one participants were adults who were fluent English speakers recruited from the psychology subject pool at Pacific Lutheran University, a small liberal arts college in Western Washington, USA. No participants had any previous experience with a vowel harmony system, natural or artificial, nor did they participate in Experiments 1 or 2.

Design

The design of Experiment 2 was identical to Experiment 1 except that the learners heard each of the various morphological endings the same number of times (24). In order to achieve this, the number of stems appearing with each suffix was varied slightly (as in Table 1). For example, each high frequency suffix was paired with all twelve stems. These were repeated twice each, meaning that each high frequency suffix was heard 24 times in the training set, across 12 tokens. The low frequency suffixes, on the other hand, were only paired with two stems, but were repeated 12 times each, meaning that the low frequency suffixes were heard 24 times across two tokens.

Results

All analyses were performed separately for the Novel Stems and Suffixes tests and the Suffix Parsing tests.

Novel Stems and Suffixes Each of the means for the Stem-Parsing Items were compared to chance (50%) via Bonferroni corrected one-sample *t*-tests. The Novel Suffix (ABQ), Items with a mean of 0.59, $t(15) = 1.67$, $p = 0.11$, were not significantly greater than chance. The Novel Stem Items (CDX) were not significantly different from chance for either the high (mean= 0.52, $t(15) = 0.29$, $p = 0.77$), medium (mean = 0.53, $t(15) = 0.77$, $p = 0.45$) or the low frequency suffixes, (mean = 0.50, $t(15) = 0$, $p = 1.0$), suggesting that participants failed to extend the pattern to novel stems in this experiment. A within-subjects ANOVA was compared high frequency suffixes to low and medium frequency suffixes. Neither comparison was significant (F<1 for both comparisons).

Suffix Parsing Results for Suffix Parsing Test Items appear in Figure 2. Each of the means for the Suffix Parsing Items were compared to chance (50%) via Bonferroni corrected one sample *t*-tests. Participants scored above chance on the Familiar (ABX) Items, for High (mean = 0.75, $t(14) = 5.29$, $p < 0.001$), Medium (mean = 0.69, $t(14) = 5.00$, $p < 0.001$), and Low (mean = 0.52, $t(14) = 0.68$, $p = 0.51$) frequency suffixes. To verify that learners were better able to recognize words containing familiar items stems with a high frequency suffix, a within-subjects ANOVA was performed with contrasts comparing high frequency suffixes to low and medium frequency suffixes. The comparison between high and low suffixes was significant, $F(1, 14) = 21$, $p < 0.001$, while the comparison between the high and medium frequency suffixes was not significant $F(1, 11) = 1.21$, $p = 0.29$. These results support the hypothesis that high frequency suffixes are more easily recognized in familiar items even when the familiar items were heard the same number of times.

The novel items (with familiar stems, ABY vs. AXB) were significantly different from chance for medium frequency suffixes (mean = 0.63, $t(14) = 3.41$, $p = 0.008$), but not for low frequency suffixes (mean = 0.54, $t(14) = 0.84$, $p = 0.42$), but there was only a marginally significant difference between medium and low frequency suffixes for these items ($t(14) = 1.83$, $p = 0.088$). The results are in line with the Experiment 1, as participants actually did numerically better on the novel items for low frequency stems.

Discussion

Experiment 2 showed a similar pattern of results as Experiment 1 for familiar items; learners were better at parsing complex words that contained high frequency words compared to low frequency words. However, learners in Experiment 2 did not show any ability to segment words containing novel stems. It may be that hearing the same lexical items so many times changed the learner's focus from the structure of the language to the specific lexical items in the language, making it more difficult to respond to items containing novel stems. It is possible that having high frequency suffixes with low token frequency is an unnatural statistical pattern for languages, making it harder to learn; more training, or more statistical power may be needed to find traces of learning under these unnatural circumstances. Note, however, that there were no overall differences for CDX items when comparing Experiment 1 to Experiment 2, $F(1,38) = 1.86$, $p = 0.18$ (with no effect of frequency, $F(2,76) = 1.70$, $p = 0.19$, and no interaction $F(2,76) = 1.09$, $p = 0.34$).

Discussion and Conclusions

The present study demonstrated the effects of frequency on morpheme segmentation. When presented with CVCVCV words with a two syllable stem followed by a monosyllabic suffix, with suffixes that followed a pseudo-Zipfian distribution: two high frequency suffixes, six medium frequency suffixes and twelve low frequency suffixes, but even distribution of stems. Learners were better at recognizing lexical items that followed the morphological structure when the suffix was of high frequency, even if the items were novel. These results held for familiar items, even when the type frequency was accounted for. This provides evidence that type frequency is more important for morpheme segmentation than token frequency, in line with previous discussions of morphological processing (Albright, 2002).

In the present study, medium frequency suffixes showed an intermediate level of response between high and low frequency suffixes, but because many of the comparisons with the medium frequency suffixes did not reach significance, it is unclear exactly how learners responded to these suffixes. Future research will work to understand more precisely how learners respond to various levels of frequency of suffixes, which may integrate nicely with a probability-based computational algorithm (Goldwater, Griffiths, & Johnson, 2009).

Finley and Newport (2010; 2011) showed that learners can parse novel affixes with familiar stems, but learners in the present study did not fare better than chance on the ABQ items, suggesting that learners in the present study may not have fully learned the Stem+Suffix grammar, or the nature of the stems. It is possible that the high frequency of the suffixes may have drawn participants' attention away from the stems and towards the suffixes. Future research will work to better understand how stems are parsed. For example, future research could add two layers of complexity to the present paradigm: manipulation of frequency of stems, as well as manipulation of the types of affixes that affix to a particular stem. While the present research only scratches the surface at how frequency affects morpheme segmentation, there is a great potential to use the present paradigm for creating a better understanding of how the distributional patterns found in language interface with the language learner.

Finally, the present set of experiments was performed on adults. Because Finley and Newport (2010; 2011) found similar results when comparing adults to children, it is expected that children may show similar patterns of preference to items containing high-frequency suffixes.

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