Stress and its Effect on Vowel Length

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1 Introduction

It is generally accepted that stress is attracted to long vowels. Another question we might ask is, do stressed vowels in general tend to be longer than unstressed vowels? A simple way to test this is to choose a syllable and place it in a variety of stress environments and measure the vowel length. There is an interesting phenomenon in English that can possibly provide useful phrases to test with. The fact is: English compound stress predicts that the phrases *apple pie* and *apple cake* should have the same stress pattern (*apple* should be stressed in both). However, what we observe is *apple píe* and *ápple cake* (i.e. stress correlates with the long vowel in *pie*). The goal of this project is to measure the vowel length for both stressed and unstressed *pie* to determine if stress affects the underlying vowel length.

2 Procedure

To answer this question, I recorded a native English speaker producing both stressed and unstressed *pie* in three separate experiments. First, I had a speaker read a short story that placed the word *pie* in a variety of environments such as pre-stop, pre-vowel, and sentence final position. The environments also varied in amount and position of intonational stress. I measured the vowel length of each instance of *pie* and recorded whether or not there was a pitch accent associated with it. Those instances of *pie* with an obvious pitch accent were recorded as stressed while those without an obvious pitch accent were recorded as unstressed. The purpose of this was to survey a variety of effects on vowel length. (The full story is attached at the end.)

Since there were many factors in the story that could contribute to variation in vowel length, I also developed a set of more controlled sentences for a speaker to read. These sentences placed the word *pie* only in pre-consonantal positions. The purpose of this was to try to isolate the effect of stress on vowel length in semi-uncontrolled, natural speech.

As a final experiment, I had a speaker produce one sentence three different ways, ten times each (sentences shown below).

1. The apple pie became my favorite.

2. The APPLE pie became my favorite.

3. The apple PIE became my favorite.

The first sentence is a control sentence. The second sentence places artificial emphasis on the word *apple*, de-emphasizing the word *pie*. The third sentence adds artificial stress to the word *pie* to force the speaker to stress it. Each sentence was repeated ten times in order to get reliable measurements for vowel length. The reason I chose this particular sentence was because it is easiest to measure vowel length when the vowel is followed by a stop. I also didn't want the phrase *apple pie* to occupy utterance initial or final position because those positions sometimes carry special intonational stress.

The vowel lengths for instances of stressed *pie* were then compared to the vowel lengths for instances of unstressed *pie* in order to determine effect of stress on vowel length.

3 Results

The results from the story are shown below in the table. Interestingly, the speaker only produced one instance of stressed *pie*. The mean value of vowel length on unstressed *pie* was 0.195 seconds with a standard deviation of 0.037 seconds. This is substantially less than the vowel length for the single stressed *pie* (0.285 seconds) but this result shouldn't be trusted since it was based on a single data point. [1]

[1] In each of the tables, *pie* was written in small caps to clearly mark its position in the sentence. Elsewhere in this paper, I use small caps to signify stress, but not in the tables.

Environment	Stressed?	Vowel Length (s)
We are going to make a beautiful apple PIE with all of these apples you brought me.	no	0.213
But I don't like apple PIE.	no	0.230736
Sally's grandma knew very well that Sally had never tried apple PIE before.	no	0.124232
Can we just use the apples to make apple sauce and instead use the peaches to make PIE?	yes	0.285
I suppose we could make peach PIE and apple sauce.	no	0.232983
Maybe we can use some of the blueberries too and have peach blueberry PIE.	no	0.219254
Why don't we make four different kinds of PIE?	no	0.185
I used to love banana PIE when I was your age.	no	0.163
And we bought enough apples to make both sauce and PIE.	no	0.193

The vowel length in *pie* clearly varies greatly throughout the story, spanning a 0.2 second range of values. From this, we can gather that the environmental factors played a large role in vowel length. In order to isolate the effect of stress, we look at the results from the set of more controlled sentences where *pie* always precedes a consonant. Below are the measurements from this experiment.

Environment	Stressed?	Vowel Length (s)
Mary ate apple PIE before lunch.	yes	0.267297
Mary eats PIE nearly every Tuesday.	yes	0.339681
John eats PIE sometimes, but not always.	no	0.178
Sue only eats PIE for Christmas.	no	0.191849
Jane has tasted PIE before but doesn't remember it.	no	0.125
Anne doesn't like PIE for some reason.	no	0.238361
Susan happily eats PIE made by her grandmother.	yes	0.288

This time the speaker produced more instances of stressed *pie* but the vowel length again varies widely. The mean vowel length of unstressed *pie* is 0.183 seconds with a standard deviation of 0.047 seconds and the mean vowel length of stressed *pie* is 0.298 seconds with a standard deviation of 0.037 seconds. It appears that the stressed instances of *pie* have longer vowels than the unstressed instances of *pie* but there is insufficient data to determine if these results are statistically significant.

The final experiment had the clearest results. Below are the waveforms for each sentence, including the mean vowel length from all 10 measurements. In the control sentence, there is a small pitch accent on *pie*, but it is smaller than on the artificially stressed/emphasized *pie*. There is no real pitch accent on the de-emphasized *pie* (though there is a small bump at the stop closure). Interestingly, we find that there is no significant difference between the

vowel length on neutral *pie* and the vowel length on emphasized *pie*. On the other hand, the vowel length on de-emphasized *pie* is significantly shorter.

An odd phenomenon that I noticed while taking this data is that the speaker shortened the vowels in *pie* slowly throughout the ten sentences during each set. This is possibly due to the fact that the speaker got tired of producing the same sentence repeatedly and spoke more quickly as time went on. Since this was a uniform drift across all three data sets, I did not do any extra data analysis to more accurately model vowel length. For the present purposes we are interested in relative differences as opposed to absolute numbers.

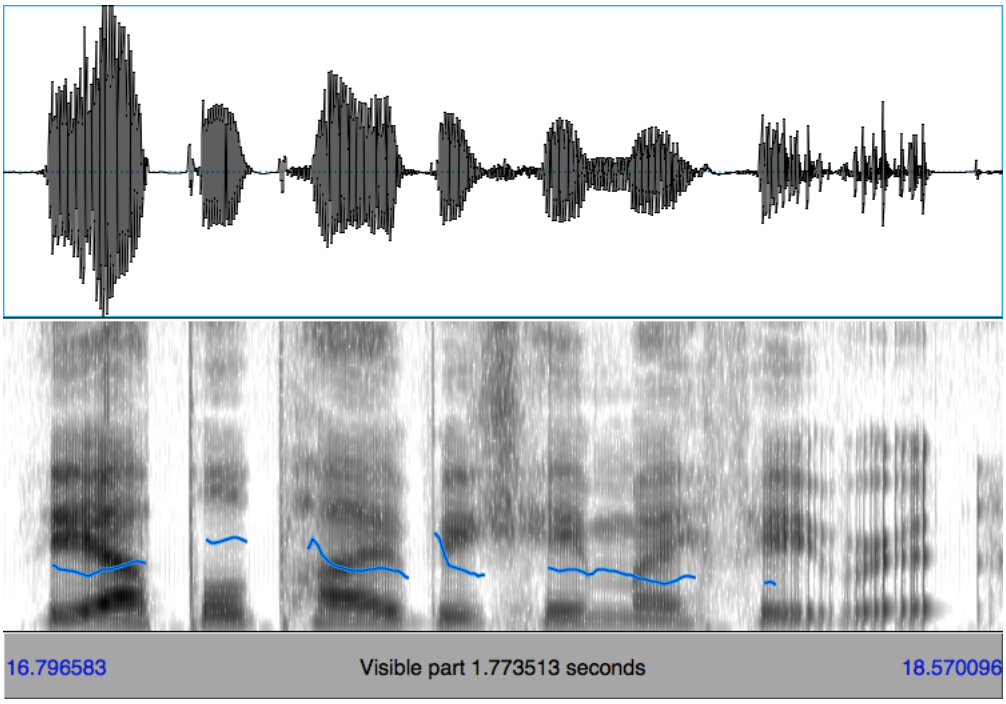

Figure 1: The apple pie became my favorite. $\mu = 0.174$ s, $\sigma = 0.015$ s

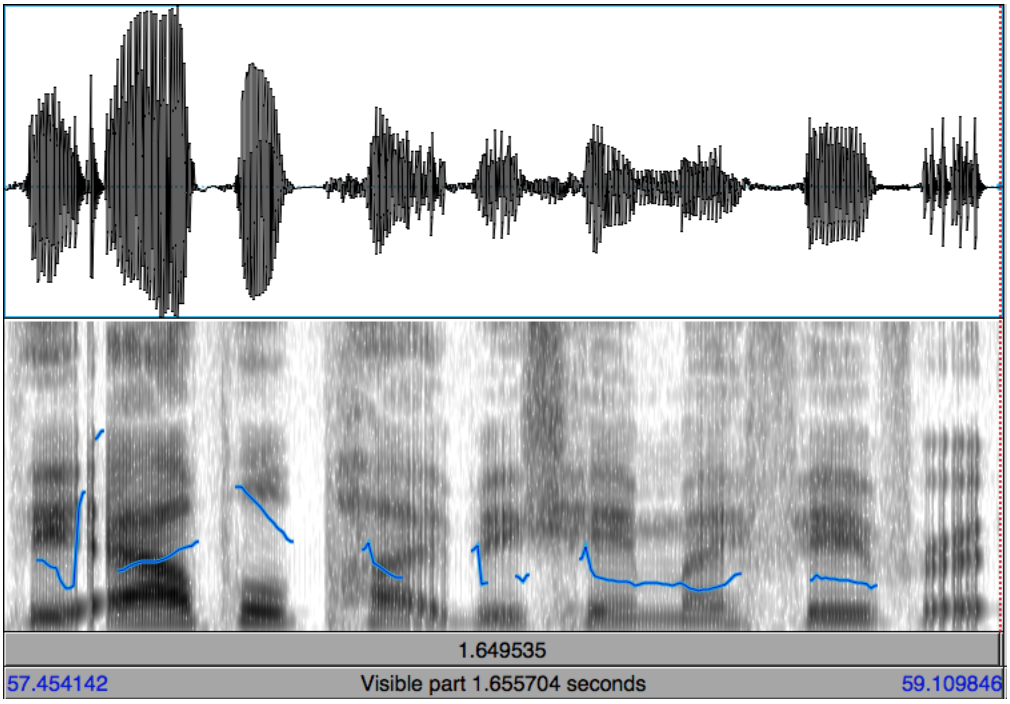

Figure 2: The APPLE pie became my favorite. $\mu = 0.136$ s, $\sigma = 0.011$ s

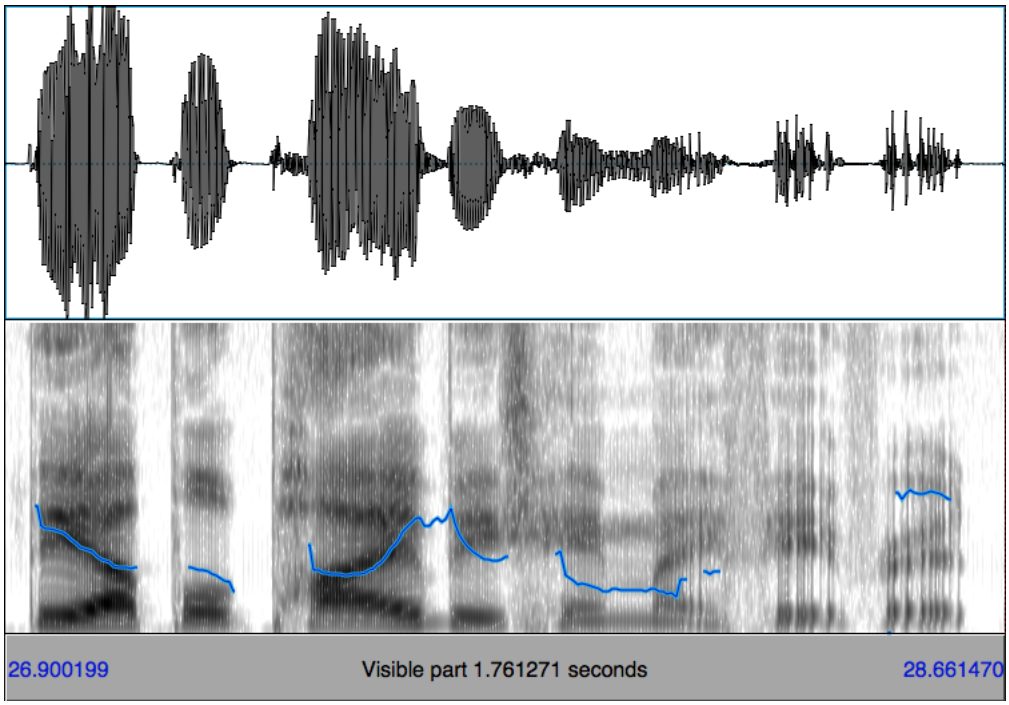

Figure 3: The apple PIE became my favorite. $\mu = 0.180$ s, $\sigma = 0.017$ s

4 Discussion

These three experiments showed that vowel length is greatly affected by many different factors, including stress. In general the vowel length of stressed *pie* was greater than that of unstressed *pie*. This is evidence that stress lengthens vowels. The results from experiment three showed another interesting result as well. It appears that, while de-emphasized *pie* had a much shorter vowel length than emphasized *pie*, there was not a significant difference between the vowel length of emphasized *pie* and neutral *pie*. This is interesting because it shows that vowel length does not correlate linearly with amount of stress. It looks instead as if stress behaves more like an on-off switch for vowel length. There is a discrete amount of vowel lengthening that can occur given the presence of stress but it doesn't vary significantly with the amount of stress.

Another interesting question that I could pursue in the future is: when does the word *pie* get stress in a sentence? This seems like a very complicated question. The answer clearly depends on a great many factors.

The Story About Fruity Pastries

Once upon a time there was a girl named Sally. One day Sally's mom told Sally that they were going to visit her grandmother for the weekend. Sally's grandmother was an excellent baker and Sally loved going to visit grandma.

They decided to stop at a fruit farm along the way so they could make all sorts of cobblers and pies and cakes with the fresh fruit. Sally excitedly picked apples and peaches and her mother picked bananas and blueberries.

When they arrived, Sally's grandmother greeted them at the door and looked at all of the fruit.

"Why, Sally!" she said, "We are going to make a beautiful apple pie with all of these apples you brought me."

Sally was horrified. She replied, "But I don't *like* apple pie!" Sally's grandma knew very well that Sally had never tried apple pie before, but she also knew that Sally was very wary of trying new foods. So she said,

"Well, you like apples don't you?"

"Yes, I like apples," said Sally.

"And do you like apple juice?"

"Yes, I like apple juice…"

"How about apple cake?"

"Apple cake sounds weird." Sally was frowning now because she didn't realize there were so many ways to prepare apples. Finally she said, "Grandma, can we use the apples to make apple sauce and instead use the peaches to make pie?"

Grandma thought for a minute, "I suppose we could make peach pie and apple sauce. Maybe we can use some of the blueberries too and have peach blueberry pie." Upon hearing this, mom had an idea.

"Why don't we make four different kinds of pie? That way if you don't like one of them, you have other options. We can have apple pie, peach pie, blueberry pie, and banana pie."

"*Banana* pie?!" exclaimed Sally.

"Yes," her mother replied, "I used to love banana pie when I was your age. And we bought enough apples to make both sauce and pie."

"Great idea, we will have peach, banana, blueberry, and apple pies, and apple sauce to accompany them."

They baked for many hours and then tried each of the pies. To Sally's great surpise, the apple pie was her favorite. Mom liked the blueberry pie the best and grandma like all of the fruit pies equally.