Front Vowel Raising in Southern Californian American English

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1.0 Introduction

English distinguishes five front vowels phonetically and phonologically, as illustrated below:

1. a. bead [bid]
   b. bid [bɪd]
   c. bade [bed][1]
   d. bed [bɛd]
   e. bad [bæd]

This five-way distinction is often realized before virtually every coda allowable by English. One notable exception is a velar nasal coda. Consider the following:

2. a. bing [bɪŋ]
   b. bang [bæŋ]

Traditionally (see Ladefoged, 1999, Hammond, 1999, and Glass, 2001 for examples), the vowels in these words ending orthographically in "-ing" and "-ang" have been transcribed as above, with the lax vowels [ɪ] and [æ], rather than their tense counterparts [i] and [e], respectively[2]. This is, in part, because words that at present end in a velar nasal derived historically from words that ended in the complex coda [ŋg]. Any word which ended in a complex coda such as this one had a short vowel in older forms of English (see Sweet, 1874), so even when the complex [ŋg] coda disappeared later on (by at least 1966) due to a sound change which deleted voiced non-alveolar stops after a homorganic nasal (e.g., "bomb", "lamb", "rung", etc.), the short vowel

[1] The IPA and phoneticians within the British tradition (e.g., Sweet, 1874) have often transcribed this vowel as [eɪ] in English, but for the purposes of this paper, it will be transcribed simply as [e].
[2] The *phonologically* tense counterpart of [æ] is [e], in the sense that there are several semantically related pairs where the "short a" sound becomes a "long a" sound, as with "bath" [bæθ] and "bathe" [beð].

remained (see Trnka, 1966 for an example). For that reason, the vowel has always been transcribed as a short (or lax) vowel[3].

Recent research has shown (Hagiwara, 1997; Zeller, 1997; Liu, 2004), and Ladefoged (2001) has suggested, though, that the vowels in, for example, "bing" and "bang" are much higher (i.e., their F1 measurements are much lower) in Southern Californian American English than one might expect, based on the traditional view. This has come to light in part because of the recent attention paid to Southern Californian American English as a separate dialect group (cf. Hagiwara, 1995 and 1997, in particular), quite distinct from what has been considered the "standard" American English dialect (Peterson and Barney, 1952; Hillenbrand, et al., 1995). Table 1 presents the results from three studies—Peterson and Barney, Hillenbrand, et al., and Hagiwara—for the vowels under investigation in the current study:

Vowel Type	Study	F1		F2	
		M	F	M	F
[i]	Peterson and Barney	270	310	2290	2790
	Hillenbrand, et al.	342	437	2322	2761
	Hagiwara	291	362	2338	2897
[ɪ]	Peterson and Barney	390	430	1990	2480
	Hillenbrand, et al.	427	483	2034	2365
	Hagiwara	467	418	1807	2400
[e]	Peterson and Barney	—	—	—	—
	Hillenbrand, et al.	476	536	2089	2530
	Hagiwara	403	440	2059	2655
[ɛ]	Peterson and Barney	530	610	1840	2330
	Hillenbrand, et al.	580	731	1799	2058
	Hagiwara	529	808	1670	2163
[æ]	Peterson and Barney	660	860	1720	2050
	Hillenbrand, et al.	588	669	1952	2349
	Hagiwara	685	1017	1601	1810

Table 1: A summary of the F1 and F2 results in Herz for male and female adults of three studies of American English vowels (front vowels only). Vowels were measured in the context [hVd], e.g. "hid", "heed", etc. Peterson and Barney didn't measure words with the vowel [e].

[3] English used to distinguish long and short vowels. During its history, long vowels became what are now known as tense vowels, and short vowels became what are now known as lax vowels.

Hagiwara's results show that the low vowels for Southern Californian American English speakers seem to be more widely spaced out. That is, the Southern Californian [æ] appears to be lower, on average, than the [æ] in the other two studies (for males, only slightly so), and the [e] appears to be higher, while the [ɛ] (for male speakers, at least) appears to be comparable. Additionally, the space between [i] and [ɪ] appears to be greater for Hagiwara's male speakers than for either Peterson and Barney or Hillenbrand, et al.'s male speakers. Below is a table which shows the difference (in Hz) between the F1 values of [i] and [ɪ] in the three previously mentioned studies:

Study		**F1 of [ɪ] in Hz**	**F1 of [i] in Hz**	**Difference in Hz**
Peterson and Barney	M	390	270	120
	F	430	310	120
Hillenbrand, et al.	M	427	342	85
	F	483	437	46
Hagiwara	M	467	291	176
	F	418	362	56

Table 2: The F1's of [ɪ] and [i], and the difference between them, in Peterson and Barney, Hillenbrand et al., and Hagiwara's studies, all measured in Hz.

Among those that noticed differences in the speech of Southern Californian American English was Ladefoged (2001), who noted that the vowel in "sing" was closer to [i] than [ɪ]. Liu (2004) went on to investigate this claim. Liu hypothesized that there would be raising before a velar nasal for both the lax high vowel [ɪ] and the lax mid vowel [ɛ][4]. To do so, he tested three words from each vowel height: a word with a tense vowel ("bean" or "bane"), a word with a lax vowel ("bin" or "Ben"), and the test word ("bing" or "bang"). Liu found that the vowels before velar nasals had been "neutralized", which, in his terminology, means that the vowels were intermediate between a tense and a lax vowel. Liu attributes this raising to the presence of a velar

[4] Liu assumes that the vowel in "bang" is [ɛ], and not [æ].

nasal. However, he does not test words with non-nasal velar codas (or non-nasal non-velar codas), so the exact cause of the raising remains unclear.

In another study, Zeller (1997) reports on a sound change in progress in Midwestern English which has resulted in a word like “flag” rhyming with a word like “vague”—the vowel in the former raising from [æ] to [e] before a voiced velar coda (including velar nasal codas). Before a different type of coda (e.g., before a voiced alveolar in the word “bad”), the quality of the vowel is still very much like a standard [æ]. As Liu (2004) reports raising before velar nasal codas only, and Zeller (1997) reports raising before all voiced velar codas, one might postulate that a velar place of articulation in a coda is what causes a previous lax vowel to raise. However, Zeller also reports that a general trend of low vowels raising before nasals can be seen in her data. If this turns out to be the case for Southern Californian English, then the exact cause of the raising Liu (2004) reports could be attributed to the place of articulation of the coda (velar vs. non-velar), or to the nasality (nasal vs. oral).

The present study aims to answer the question left open by Liu’s study and suggested by Zeller’s about whether nasality or place of articulation or a combination of the two causes a preceding lax front vowel to raise. Following Zeller, it is hypothesized that nasality plays an important role in the raising of a preceding lax vowel. Additionally, the effect of a non-nasal velar coda will be tested, to see if place of articulation plays a significant role in the raising of a preceding lax vowel. Finally, Liu’s claim regarding the quality of the lax vowels before velar nasal codas will be examined. It is hypothesized that the lax vowels before velar nasals have indeed raised in Southern Californian American English, but the extent to which they have raised will be examined.

2.0 Methods

2.1 Materials

The goal of the present study was to test five different vowels ([i], [ɪ], [e], [ɛ], and [æ]) in four different environments: (1) before velar nasals; (2) before voiced velar oral stops; (3) before voiced alveolar oral stops; and (4) before alveolar nasals.

		Coda			
		Nasal, Velar	Nasal, Alveolar	Oral, Velar	Oral, Alveolar
Vowel	[i]	—	bean	beag	bead
	[ɪ]	bing	bin	big	bid
	[e]	—	bane	vague	bade
	[ɛ]	—	Ben	beg	bed
	[æ]	bang	ban	bag	bad

Table 3: A list of the words tested in the present study.

One nonsense word was used for the form [big] ("beag", as in "beagle", as subjects were told) in order to preserve the similarity in onsets. Additionally, the word "vague" was included, because there is no obvious way to prompt the form [beg]. In order to record the vowels in these environments, a test word from each environment was chosen. These words are listed in table 1 below. The test words were put into the carrier phrase "Say __ eight times". In order not to bias the subjects, a series of words before voiceless velar stops was included as fillers[5].

2.2 Subjects

A total of eleven subjects (6 female, 5 male) were recorded. Of those, only ten subjects were used, because one female subject did not fully complete the experiment (i.e., she completed only three out of the requisite five repetitions). All were from

[5] In a pilot study, words with voiceless velar codas were tested, and they proved to have no significant raising effect on the preceding vowel. Zeller (1997) found the same thing in her study. Where both velar nasal and voiced velar stop codas had a raising effect on the previous vowel, voiceless velar codas actually had a lowering effect on the previous vowel.

Southern California. A speaker was considered to be from Southern California if they met the following criteria:

a. They were born in LA, OC or San Diego County.
b. They lived in one or more of the areas mentioned for *all* of their childhood, with no significant gaps.
c. They lived in Southern California for the majority of their adult life. People who'd left Southern California for a few years while attending college were included.

Subjects were collected mainly from the coastal areas within San Diego, Orange and Los Angeles Counties, as speakers from these areas are more representative of the particular variety of Southern Californian American English under investigation in the present study. Specifically, the breakdown of the subjects used in this study by area was as follows:

a. Orange County	3	(*3 Male*)
b. San Diego County	6	(*2 Male, 4 Female*)
c. Los Angeles County	1	(*1 Female*)
d. *Total*	10	(*5 Female, 5 Male*)

All subjects were between the ages of 18 and 30. Each of the speakers was raised as a monolingual English speaker by parents who themselves were monolingual English speakers. This is important, because bilingual speakers may exhibit small but reliable phonetic differences when compared to monolingual speakers, in general (e.g., Walpole, 2000). No speakers reported any history of speech or hearing problems. Each speaker was very cooperative, and eager to participate, though speakers were not compensated in any way.

2.3 Procedures

Most subjects (nine) were recorded in a sound-proofed booth at the UCSD phonetics lab. Two subjects were recorded using a DAT recorder in a quiet room. The procedures employed in these two conditions differed slightly.

For recording in the booth, subjects were asked to come to the UCSD phonetics lab. The recordings were done directly to hard disk using an analog to digital converter sampling at 44,100 kHz. with 16-bit resolution. The subject was seated comfortably in front of the computer in the booth so that their mouth was at the level of the microphone. At this point, the experimenter began a Microsoft Office PowerPoint presentation in which one test sentence or filler was presented at a time (see appendix to see a sample of the slides that the PowerPoint presentation used). The presentation, which was randomized differently for each subject, presented the subject with some information about what was expected of them (see appendix for introductory slides), asked subjects to produce each of the five vowels being studied in isolation, and then listed the sentences they were to read. There were 22 sentences in total (17 test sentences, 5 fillers), each produced five times, for a total of 110 sentences, 85 of which contained test words. The experimenter controlled the rate of presentation the entire time. Thus, the subject was responsible only for reading what was on the screen and speaking into the microphone.

Once the experiment concluded, the subject was asked to fill out a survey (see appendix). After the subject had filled out the survey (and only at that time), they were invited to ask questions about the experiment if they so wished.

The subjects who could not come to the lab were recorded in a quiet room using a DAT recorder. The DAT recordings were done with a sampling rate 44,100 kHz. and 16-bit resolution. The microphone was placed on a flat surface so that the subject wouldn't have to hold it. The materials were presented to speakers written on 3" x 5" index cards, one sentence per card. Before each repetition the experimenter randomized the order of the cards. During the experiment, the experimenter held each card up to the subject to read, so that, as with the recordings in the booth, the rate of presentation was not controlled by the subject. The procedure at the end of the recording was the same as before.

<u>2.4 Measurements</u>

Three measurements were taken: F1, F2, and vowel duration. To obtain these measures, each recording was broken up into smaller, sentence-sized files, which were then analyzed using PRAAT.

Vowel duration was measured using PRAAT. The vowel was measured from the beginning of the stop burst of the preceding stop (or the beginning of the vowel, for words where a fricative preceded the vowel), to the point of energy decrease (for nasal codas), or the point of closure (for stop codas). The beginning of the stop burst was located by finding the sharp spike in the waveform (following the previous word) which coincided with a large energy increase in the spectrogram (see figure 1 below). In determining the place where a nasal coda began (i.e., the place to stop measuring vowel duration in words with nasal codas), first the area of sharp energy decrease was located. Then the ends of the formant bands in the spectrogram were located and matched up with the levelling out of the waveform above to determine where the vowel ended and the coda began (see figure 1 below). After the appropriate selection was highlighted in the PRAAT window, the selection length was calculated, and the value was entered into the same spreadsheet.

To measure F1 and F2, the experimenter found the steady state of the vowel and obtained the formant listing using PRAAT's formant tracker. There were a few exceptions, as a few speakers had a diphthong for [e], and most had a diphthong for [æ]. In each of these cases, a steady state was found towards the beginning of the vowel and measured. Additionally, in the case of a nasalised vowel (defined as a vowel followed by a nasal coda, following Glass and Zue, 1985), the non-nasalized portion from the beginning was used to measure formant frequencies. Since PRAAT's formant tracker is not always reliable, the automatic measurements were manually inspected each time, in order to ensure that, for example, PRAAT's formant tracker didn't mistake a higher energy band between formants one and two for the second formant. Once inspected, the measurements were inserted into a Microsoft Excel spreadsheet. Below in figure 1 is an example of a measurement made of the word "bing":

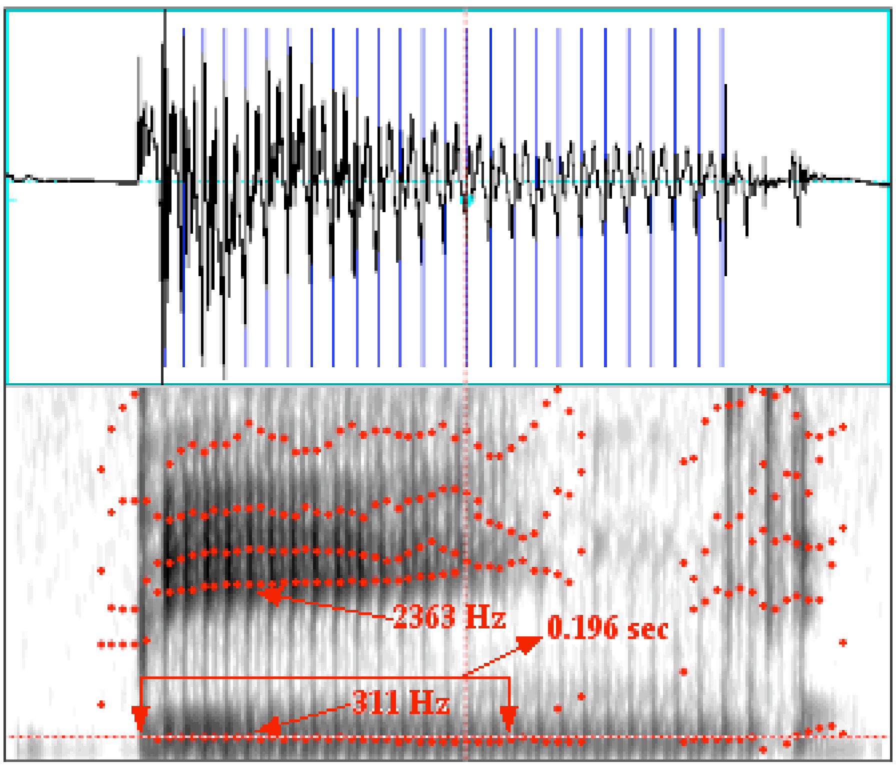


Figure 1: Sample measurement of the word "bing" using PRAAT[6].

Below in figure 2 is a sample measurement of the word "vague". Measuring for "vague" was different than for the other test words, because it was the only test word that didn't begin with [b]. To determine the starting point for the vowel duration

[6] Each of the elements listed in figure 1 is rounded off to either the nearest one (for the formant measurements) or the nearest thousandth (for the duration measurement) purely for expository purposes. When the measurements were taken and stored for the actual experiment, nothing was rounded off.

measurement for "vague", the area of dramatic energy increase was located. This was done both by looking at the formant bands, and by looking at the waveform, and comparing the two, to determine where the first large spike of the waveform coincided with the beginning of the formant bands in the spectrogram (see figure 2 below). The end point was the point of the closure for the coda [g] (where the second and third formants come together). The cut-off point was determined by finding the area of sharp energy decrease which coincided with a levelling out of the waveform (see figure 2 below).

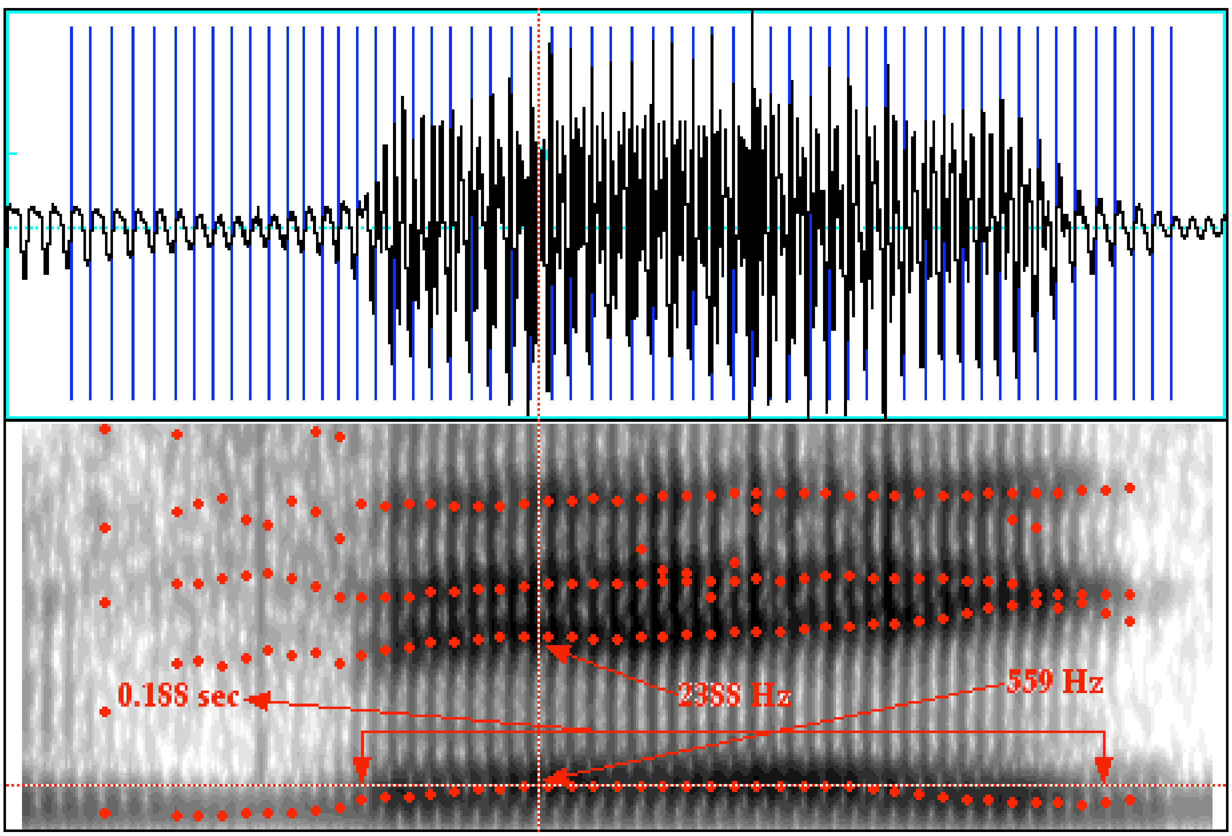


Figure 2: Sample measurement of the word "vague" using PRAAT.

The second, third and fourth repetitions were used for measurements, with two exceptions. For the speaker that was recorded using the DAT recorder that was included in the study, two tokens were never recorded properly, due to a malfunction. For that reason, replacements were measured from the first and fifth repetitions.

2.5 Statistical Analysis

In order to analyze the data statistically, the computer program Statistica was used. An ideal way to analyze this data would be to separate it by vowel and by coda, separating codas into those that were nasal and non-nasal, velar and non-velar. This isn't possible, though, due to the lack of vowel contrast before a velar nasal, which meant that there were no data-points for [ɛŋ], [eŋ] or [iŋ] (see table 1).

Because of this asymmetry, repeated measures ANOVAs were done on all the data with "condition" as a repeated-measures factor with 7 levels for the high vowels and 10 levels for the low vowels (i.e., [VC], where V was [i], [ɪ], [e], [ɛ] and [æ], and C was [ŋ], [n], [g] and [d]), and gender as a between-subjects variable with two levels (male and female). The dependent variables were F1 (in Hz), F2 (in Hz), and vowel duration (in seconds). If the repeated measures ANOVA indicated that there was an interaction between gender and vowel type, a series of Bonferroni tests were run to see from whence the significance arose. Otherwise, planned comparisons were run across vowel types.

3.0 Results

3.1 F1, High Vowels

There was no significant interaction between gender and vowel type [$F(6, 48)=0.22$, n.s.] (see figure 3 below), so the female and male data were grouped together. A planned comparison showed that the F1 value of [ɪŋ], which will hereafter be referred to as “ing” (because the quality of the vowel has yet to be determined), was higher than the value of the test words with [i] as their main vowel [$F(1,8)=13.21$, $p < 0.007$], but lower than the value of the test words with [ɪ] as their main vowel [$F(1,8)=38.18$, $p < 0.001$]. On the other hand, in a general comparison between coda types, words with nasal codas (including “ing”) were not significantly different from words with non-nasal codas [$F(1,8)=1.96$, n.s.], and words with velar codas (again, including “ing”) were not significantly different from words with non-velar codas [$F(1,8)=3.29$, n.s.].

In pair-wise comparisons with specific vowel/coda contexts, the F1 of “ing” proved to be lower than the F1 of words with [ɪn] [$F(1,8)=52.69$, $p < 0.001$], [ɪd] [$F(1,8)=21.13$, $p < 0.002$], and [ɪg] [$F(1,8)=14.93$, $p < 0.005$], but higher than the F1 of words with [id] [$F(1,8)=21.80$, $p < 0.002$] and [ig] [$F(1,8)=9.30$, $p < 0.016$]. However, there was no significant difference between the F1 of “ing” and the F1 of words with [in] [$F(1,8)=4.98$, n.s.]. A summary of these results can be found in table 3.

In figure 3 below, a shorthand is used to refer to the vowels rather than using the IPA. The vowel correspondencies are as follows: (a) “i” = [i]; (b) “ih” = [ɪ]. Additionally, “ing” is used to represent the vowel in “bing”.

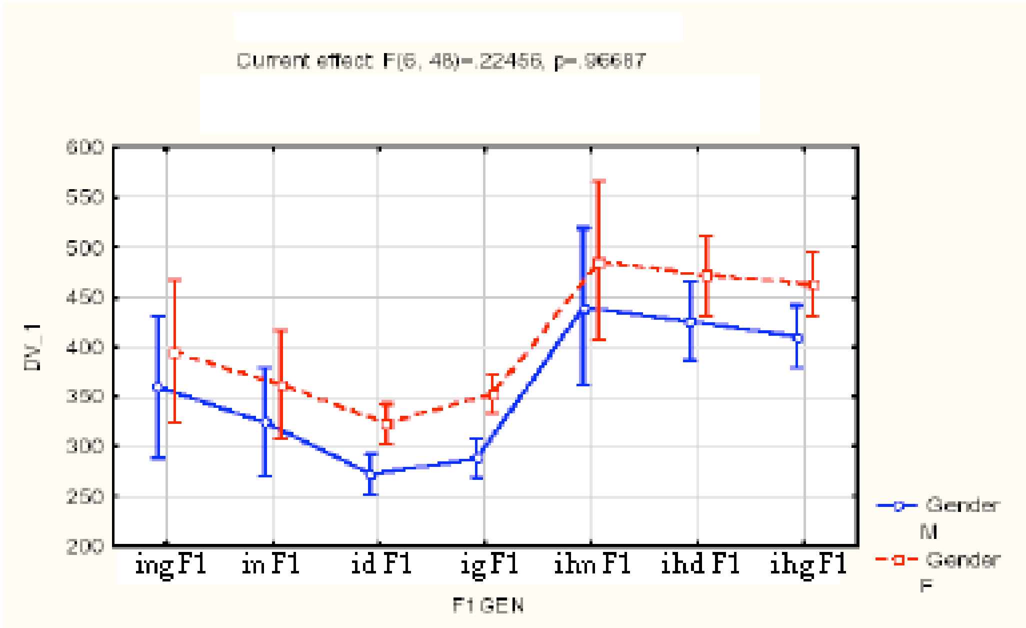


Figure 3: Mean value and standard errors of F1 (in Hz), separately for the male and female subjects.

The table below summarizes the results of the planned comparisons detailed above. In the table below (and throughout the paper in tables like this one), a capital C stands for any coda consonant.

"ing" compared to…	In comparison, F1 of "ing" is…	F(1, 8)	p Value
[iC]	*higher*	13.21	< 0.007
[ɪC]	*lower*	38.18	< 0.001
[in]	*not different*	4.98	*not significant*
[id]	*higher*	21.80	< 0.002
[ig]	*higher*	9.30	< 0.016
[ɪn]	*lower*	52.69	< 0.001
[ɪd]	*lower*	21.13	< 0.002
[ɪg]	*lower*	14.93	< 0.005

Table 4: A summary of the results of the planned comparisons run on the F1 of the vowel in "ing".

3.2 F2, High Vowels

There was no significant interaction between gender and vowel type [F(6, 48)=1.18, n.s.] (see figure 4 below), so the female and male data were grouped together.

A planned comparison showed that the F2 of “ing” was lower than the F2 of the test words with [i] as their main vowel [$F(1,8)=19.82$, $p < 0.003$], and higher than the F2 of the test words with [ɪ] as their main vowel [$F(1,8)=48.62$, $p < 0.001$]. On the other hand, in a general comparison between coda types, words with nasal codas (including “ing”) were not significantly different from words with non-nasal codas [$F(1,8)=4.30$, n.s.], and words with velar codas (again, including “ing”) were not significantly different from words with non-velar codas [$F(1,8)=0.22$, n.s.].

In pair-wise comparisons with specific vowel/coda contexts, the F2 of “ing” proved to be higher than the F2 of words with [ɪn] [$F(1,8)=46.02$, $p < 0.001$], [ɪd] [$F(1,8)=44.69$, $p < 0.001$], and [ɪg] [$F(1,8)=34.65$, $p < 0.001$], but lower than the F2 of words with [in] [$F(1,8)=22.20$, $p < 0.002$], [id] [$F(1,8)=18.10$, $p < 0.003$], and [ig] [$F(1,8)=15.48$, $p < 0.005$].

In figure 4 below, a shorthand is used to refer to the vowels rather than using the IPA. The vowel correspondencies are as follows: (a) “i” = [i]; (b) “ih” = [ɪ]. Additionally, “ing” is used to represent the vowel in “bing”.

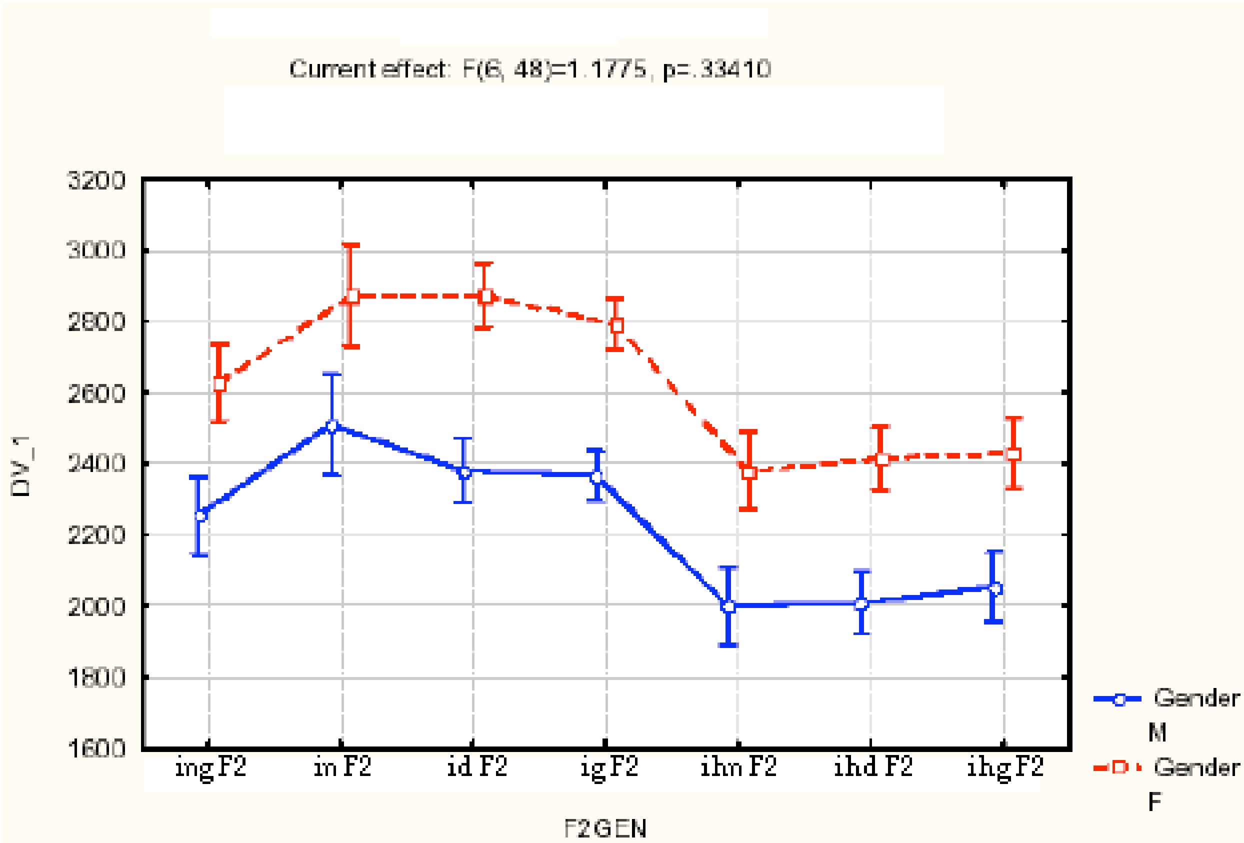


Figure 4: Mean value and standard errors of F2 (in Hz), separately for the male and female subjects.

The table below summarizes the results of the planned comparisons detailed above.

“ing” compared to…	In comparison, F2 of “ing” is…	F(1, 8)	p Value
[iC]	*lower*	19.82	< 0.003
[ɪC]	*higher*	48.62	< 0.001
[in]	*lower*	22.20	< 0.002
[id]	*lower*	18.10	< 0.003
[ig]	*lower*	15.48	< 0.005
[ɪn]	*higher*	46.02	< 0.001
[ɪd]	*higher*	44.69	< 0.001
[ɪg]	*higher*	34.65	< 0.001

Table 5: A summary of the results of the planned comparisons run on the F2 of the vowel in "ing".

3.3 Summary of F1 and F2 Results for the High Vowels

Below are twelve graphs[7] showing the vowel space of each speaker in the present study, as well as the male and female speakers collectively. These graphs simply represent the mean values for the high vowels for each speaker and each set of speakers.

In figure 5 below, a shorthand is used to refer to the vowels rather than using the IPA. The vowel correspondencies are as follows: (a) "i" = [i]; (b) "ih" = [ɪ]. Additionally, "ing" is used to represent the vowel in "bing".

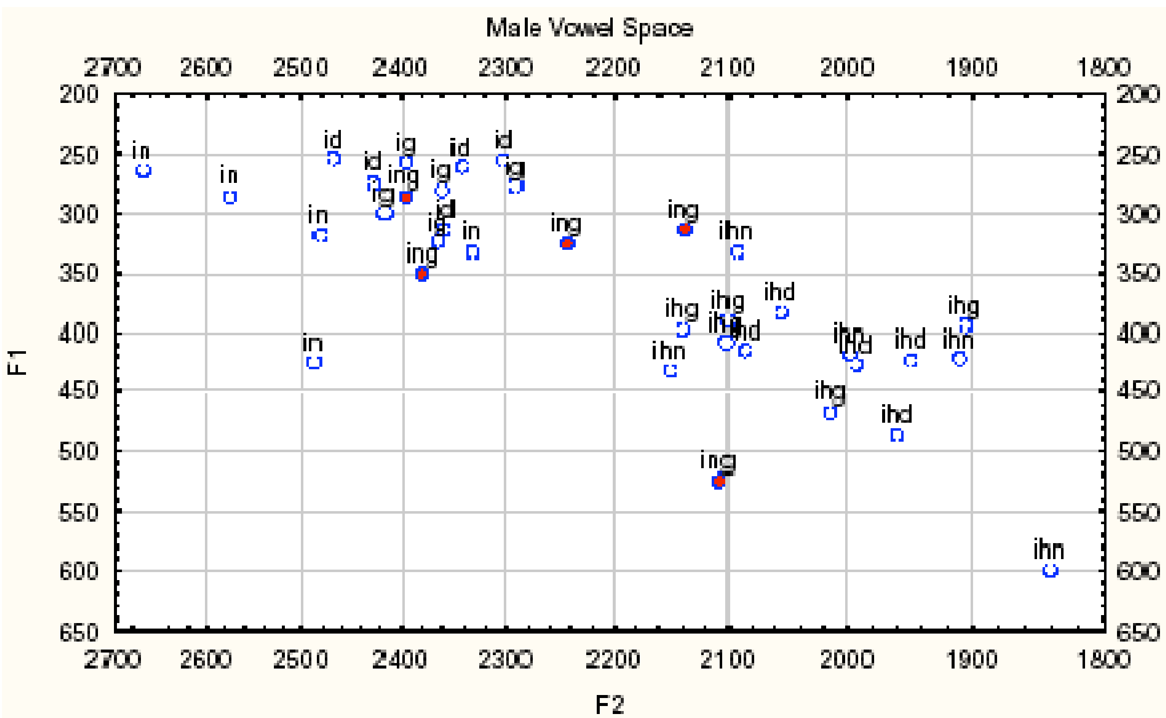


Figure 5: Vowel space showing the location of the high vowels of the male speakers.

In figure 5, there are two general groupings. The grouping in the upper left is a cluster of the [i] vowels, and the grouping in the middle on the right is a cluster of the [ɪ] vowels. The "ing" vowels seem to be in between the two main clusters, though, with

[7] For the graphs below, and all others like it in this paper, F1 and F2 are given in Hz. On the graphs themselves, F1 is presented with a linear scale, while F2 will be presented with a logarithmic scale.

the exception of one outlier, they overlap more with the values for [i] than they do with the values for [ɪ].

In figure 6 below, a shorthand is used to refer to the vowels rather than using the IPA. The vowel correspondencies are as follows: (a) “i” = [i]; (b) “ih” = [ɪ]. Additionally, “ing” is used to represent the vowel in “bing”.

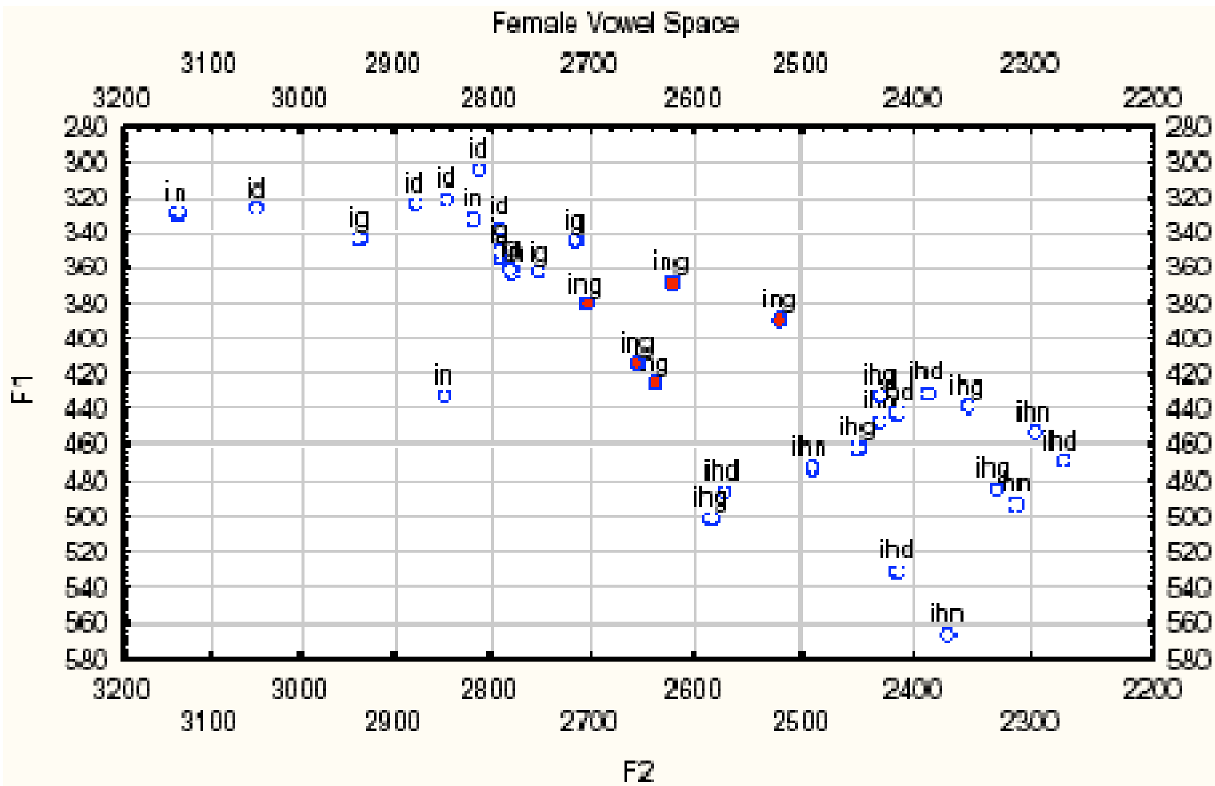


Figure 6: Vowel space showing the location of the high vowels of the female speakers.

In figure 6, the female data look a lot like the male data, with an [i] cluster in the upper left, and an [ɪ] cluster in the lower right. More so than in figure 5, it appears that the “ing” vowels are clustering right in between the two main clusters, their values not overlapping greatly with either the values for [i] or the values for [ɪ].

Below are graphs of the individual vowel spaces of the high vowels investigated in the present study for each speaker. In each graph, the “ing” vowel is pointed out with a red arrow.

In figures 7, 8 and 9 below, a shorthand is used to refer to the vowels rather than using the IPA. The vowel correspondencies are as follows: (a) “i” = [i]; (b) “ih” = [ɪ]. Additionally, “ing” is used to represent the vowel in “bing”.

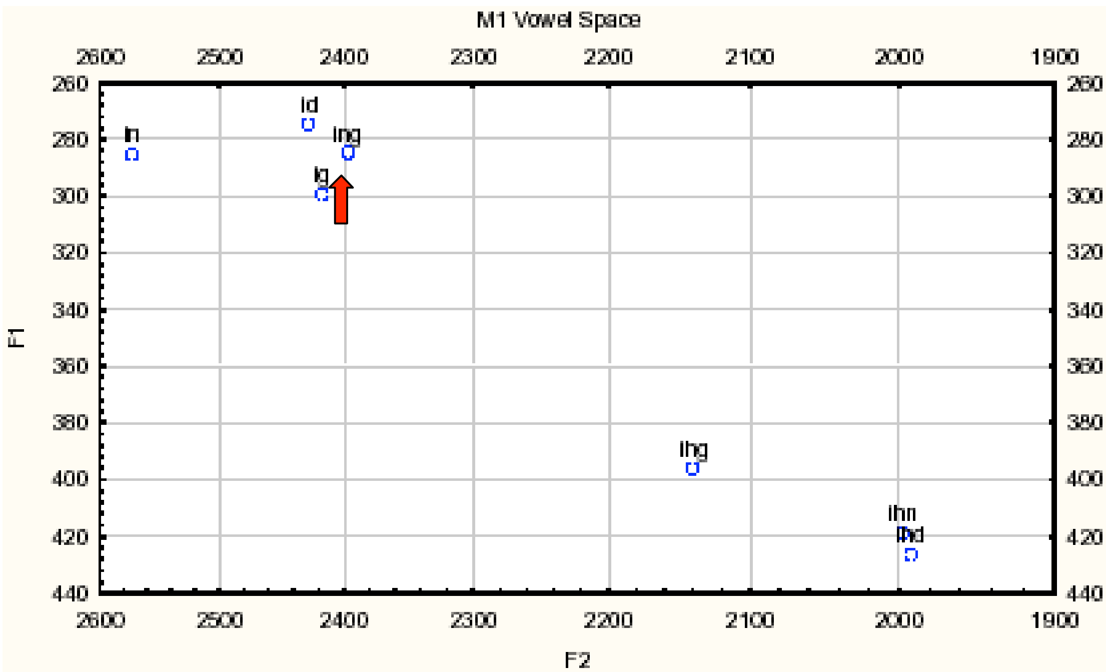


Figure 7: Vowel space showing the location of the high vowels of M1.

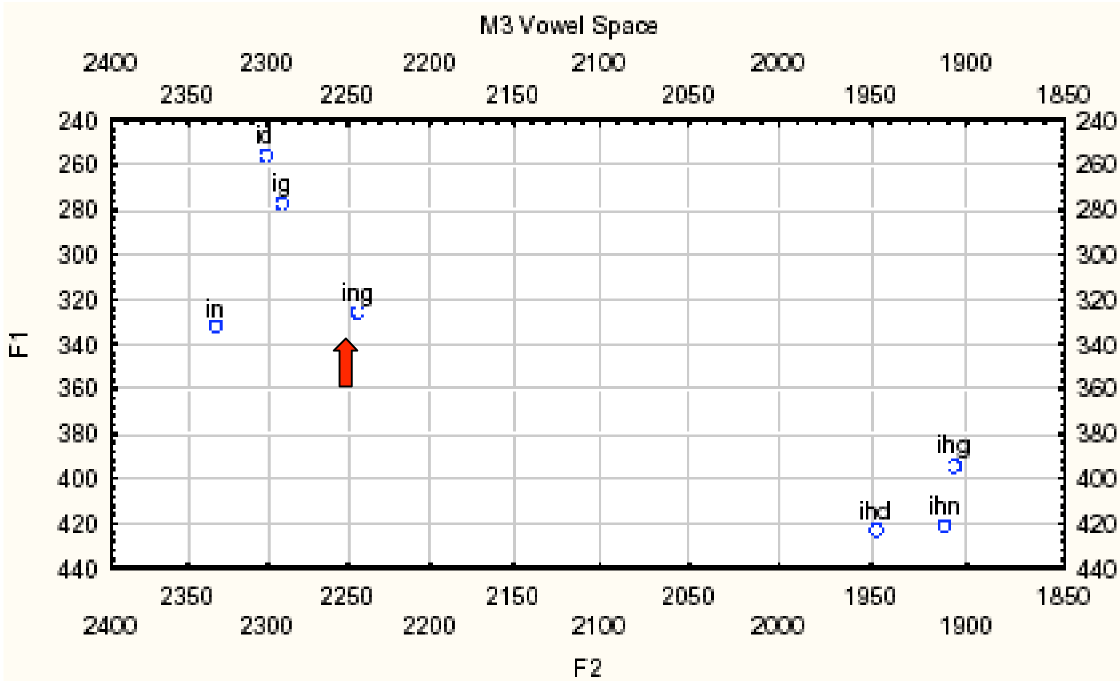


Figure 8: Vowel space showing the location of the high vowels of M3.

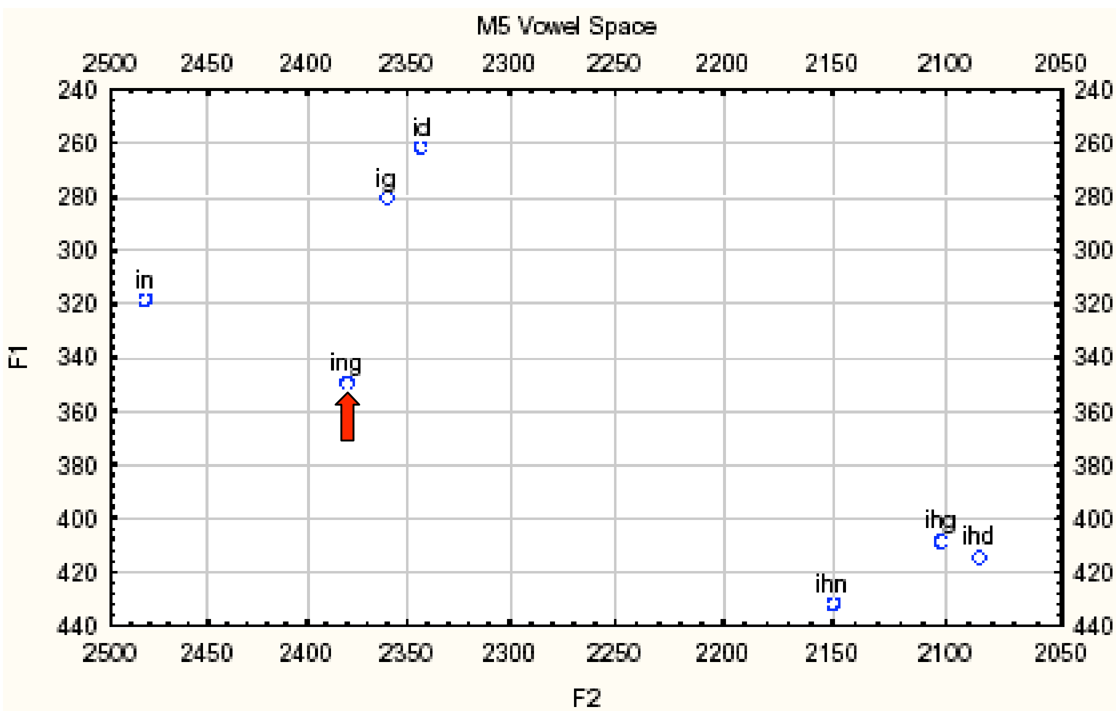


Figure 9: Vowel space showing the location of the high vowels of M5.

Figures 7 through 9 show the vowel spaces of M1, M3 and M5, respectively. The vowel for "bing" for each of these speakers clusters with the vowels in "bead", "beag" and "bean". In the case of M5, the vowels in "bead" and "beag" were consistently higher (i.e., with a lower F1) than the vowels in "bean" and "bing". The same basic pattern can be seen with M3, though the effect is less pronounced. In the case of both M3 and M5, though, the vowel in "bing" is much closer to the [i] vowels than the [ɪ] vowels. And with speaker M1, there seems to be little difference between the vowel in "bing" and the other [i] vowels. For these speakers, the formant values of the vowel in "bing" appear either to be indistinguishable from the formant values of the other [i] vowels, or to be closer to, and, perhaps, moving towards the formant values of the other [i] vowels.

In figures 10 and 11 below, a shorthand is used to refer to the vowels rather than using the IPA. The vowel correspondencies are as follows: (a) "i" = [i]; (b) "ih" = [ɪ]. Additionally, "ing" is used to represent the vowel in "bing".

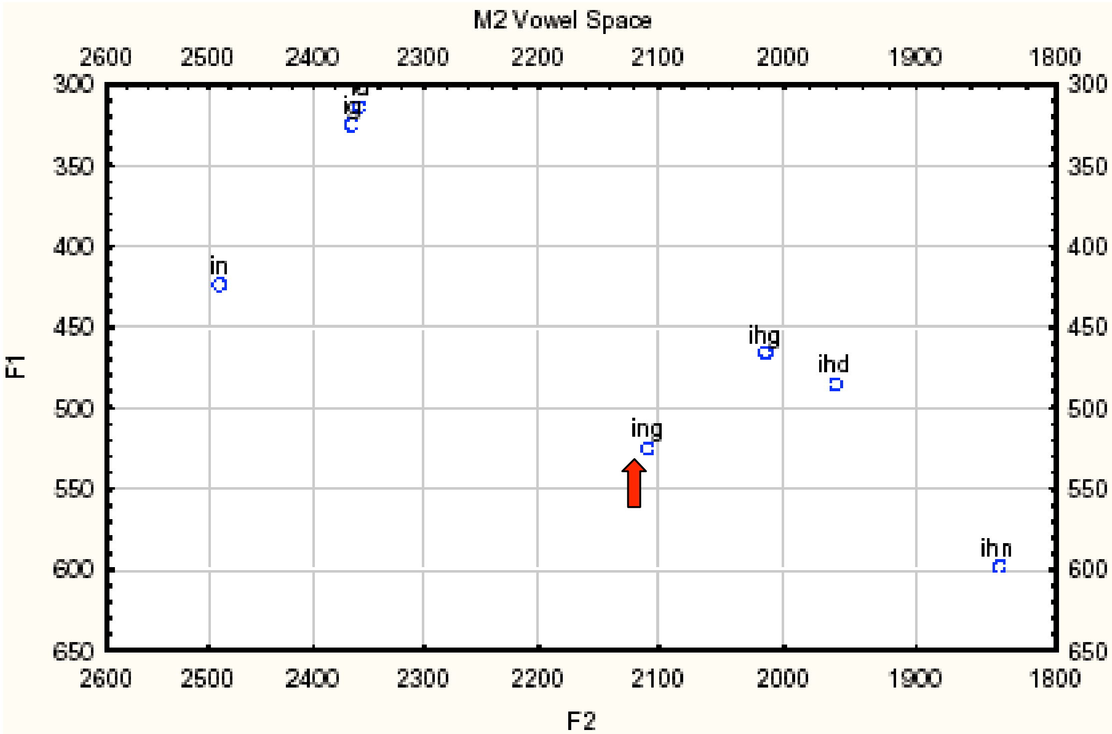


Figure 10: Vowel space showing the location of the high vowels of M2.

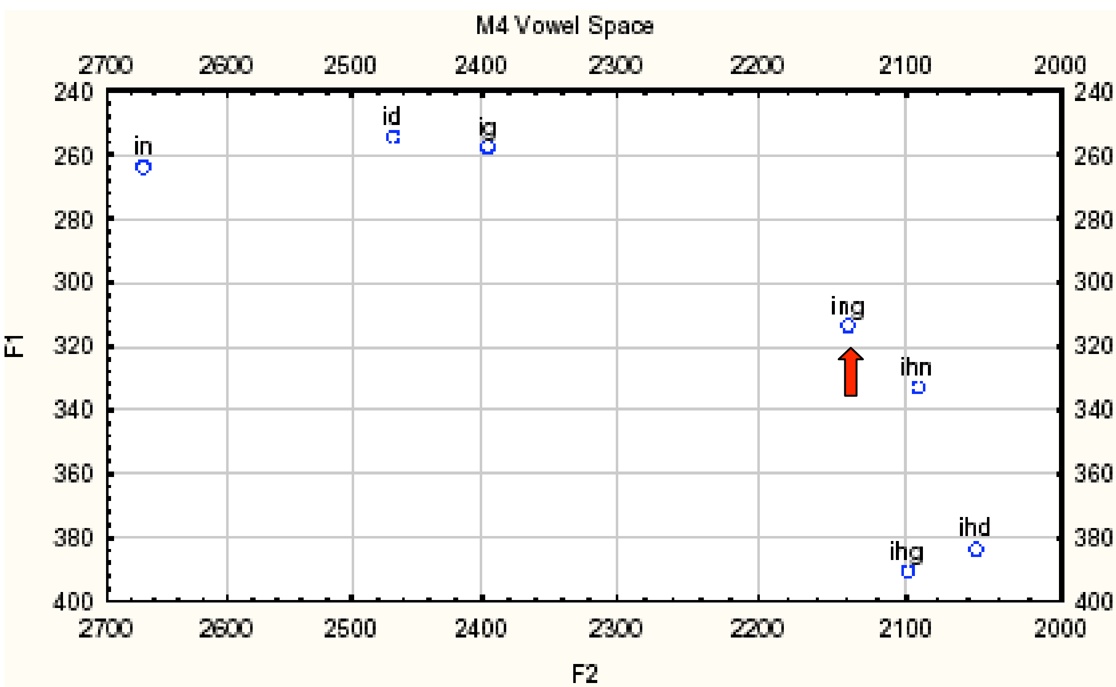


Figure 11: Vowel space showing the location of the high vowels of M4.

The vowel spaces of the remaining male speakers, shown above in figures 10 and 11, appear to be closer to the previously assumed standard. That is, given the traditional claim that the vowel in "bing" is [ɪ], these two vowel spaces appear to conform to traditional expectations. However, there are a couple of things to notice. First, the lax vowels of M4 are lower (corresponding to a higher vowel) than the lax vowels of M2. Looking at specific measurements (again, these tables show the means only), the lowest F1 measurement amongst the high lax vowels for M2 is 455 Hz (the fourth repetition of "big"). The highest F1 measurement amongst the high lax vowels for M4, conversely, is 408 Hz (the second repetition of "bid"). The high vowels of M4, then, are, as a whole, higher (i.e., with lower F1 measurements) than the high vowels of M2. Additionally, for both speakers, the nasal lax vowels cluster together ("bing" and "bin"), and the non-nasal lax vowels cluster together separately ("bid" and "big"). However, for M2, the nasal vowels have a higher F1 (corresponding to a lower vowel) than the non-nasal vowels, whereas the opposite is true for M4. So with these two speakers, the nasalized lax vowels appear to be behaving differently.

Now the individual vowel spaces of the female speakers will be presented. In figures 12, 13 and 14 below, a shorthand is used to refer to the vowels rather than using the IPA. The vowel correspondencies are as follows: (a) "i" = [i]; (b) "ih" = [ɪ]. Additionally, "ing" is used to represent the vowel in "bing".

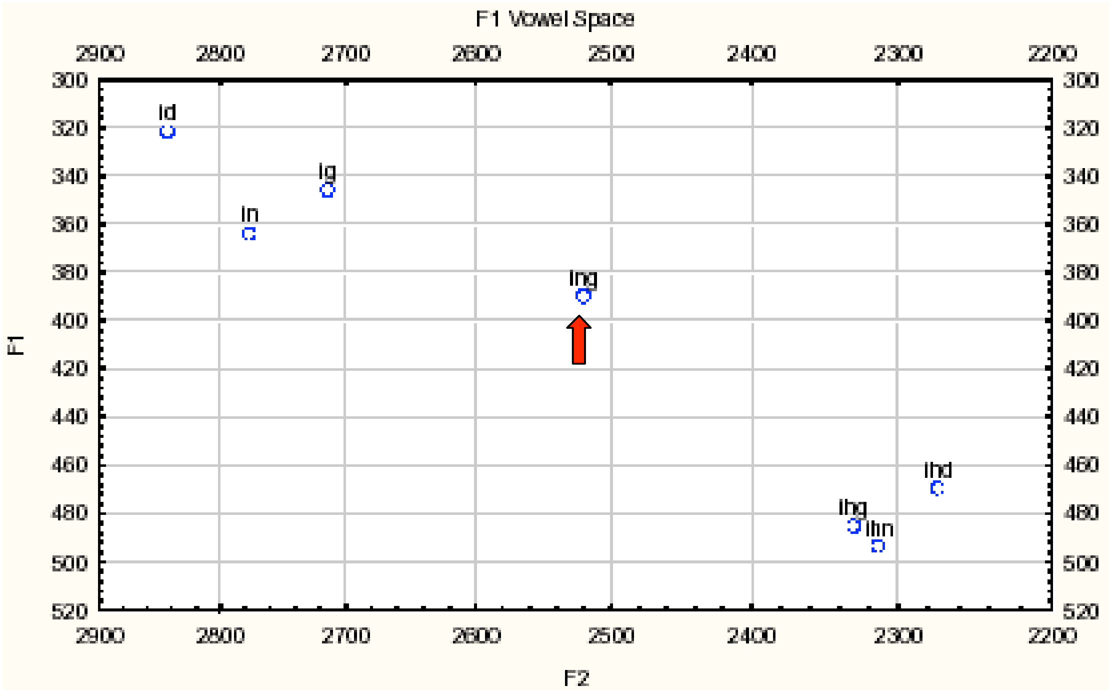


Figure 12: Vowel space showing the location of the high vowels of F1.

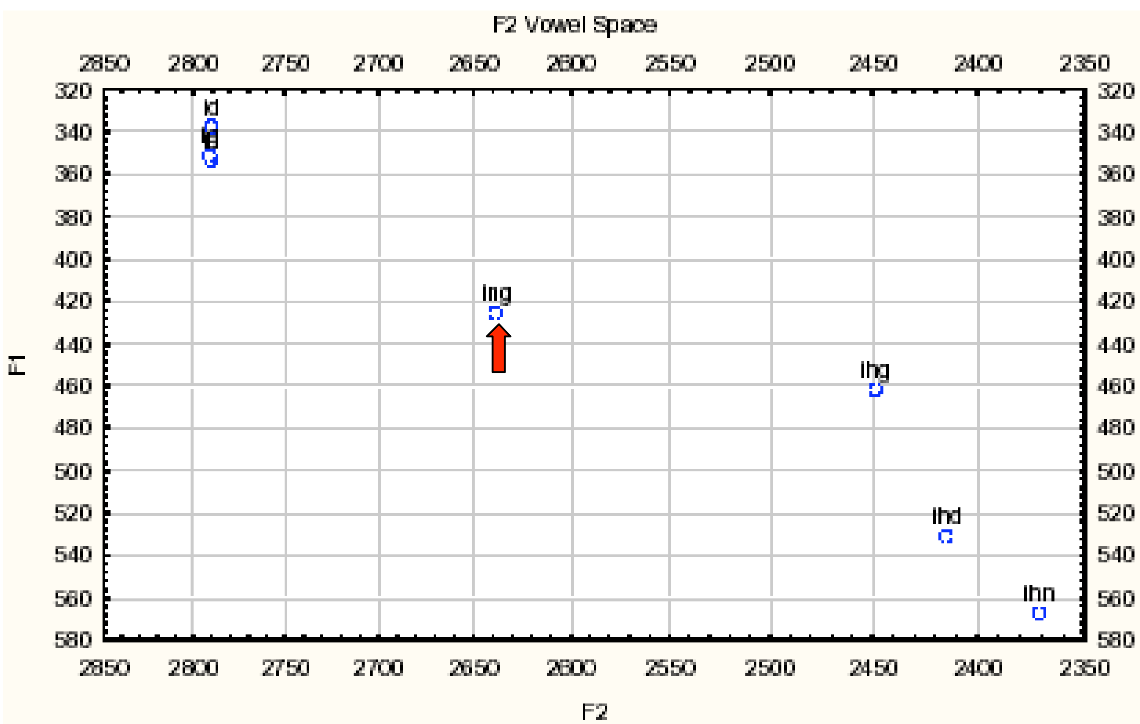


Figure 13: Vowel space showing the location of the high vowels of F2.

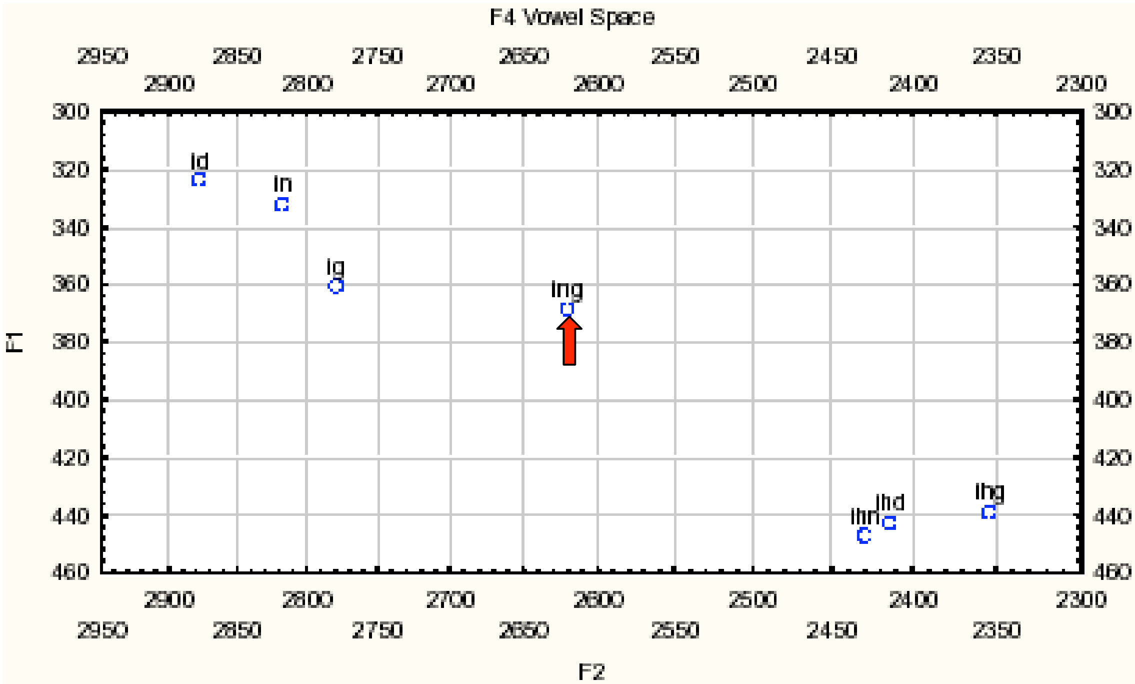


Figure 14: Vowel space showing the location of the high vowels of F4.

Figures 12 through 14 show that the vowel in "bing" for F1, F2 and F4 is somewhere in between the tense and lax vowels. In the case of F1 and F4, the value of the first formant of "bing" is closer to the value of the first formant for the other [i] vowels than the lax vowels. The value of the second formant of "bing", though, is significantly lower than the other [i] vowels, placing the vowel in "bing" almost squarely in between the tense and lax vowel clusters. In the case of F2, the value of the first formant is actually closer to the first formant values of the lax vowels, while the value of the second formant still places it squarely in between the lax and tense vowels. Thus for these speakers, it appears that the vowel in "bing" cannot be classified as either phonetically [i] or phonetically [ɪ]. This, of course, says nothing about the vowels phonemic status; it merely is an attempt to characterize its phonetic properties.

In figures 15 and 16 below, a shorthand is used to refer to the vowels rather than using the IPA. The vowel correspondencies are as follows: (a) “i” = [i]; (b) “ih” = [ɪ]. Additionally, “ing” is used to represent the vowel in “bing”.

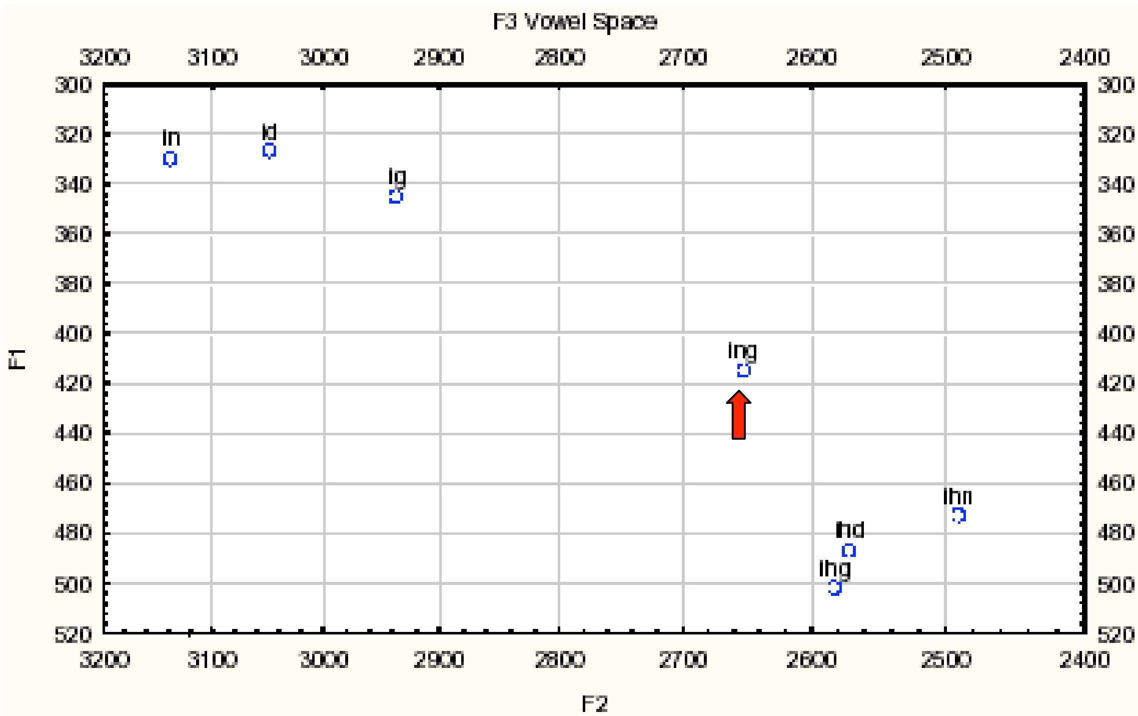


Figure 15: Vowel space showing the location of the high vowels of F3.

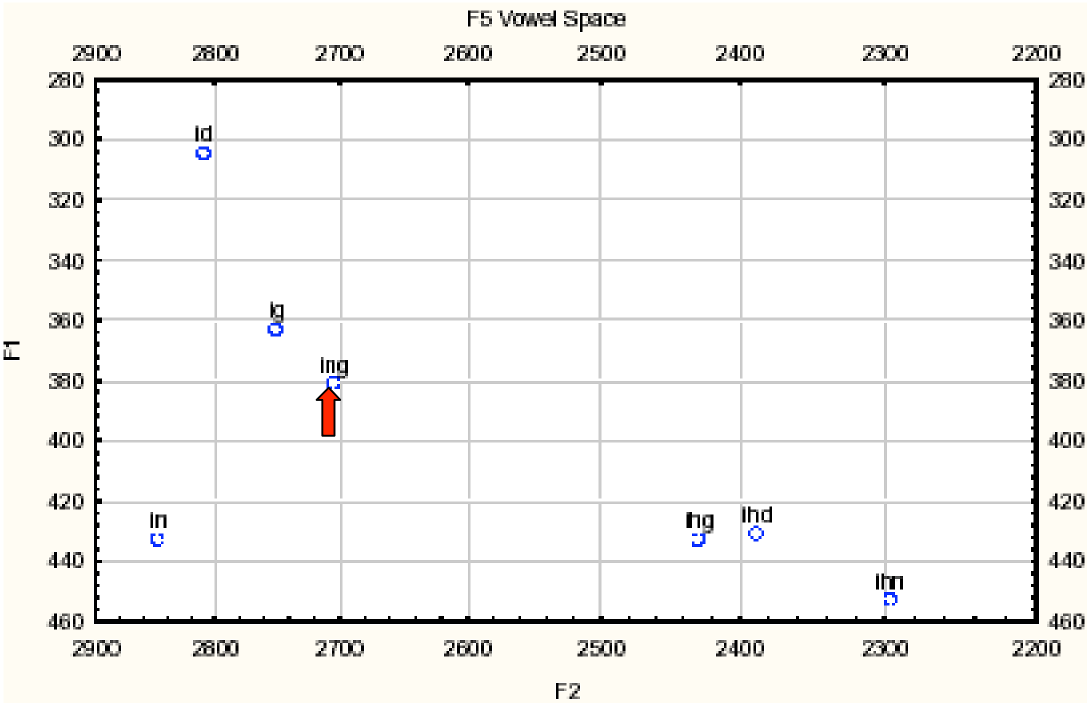


Figure 16: Vowel space showing the location of the high vowels of F5.

The remaining speakers have remarkably different vowel spaces. For F3, the vowel in "bing" does not form a tight cluster with the other lax vowels, but it is significantly closer to the lax vowels than the tense vowels. For F5, the opposite appears to be true, though F5's vowel space is rather atypical. Nevertheless, the lax vowels cluster in the lower right-hand corner, and the tense vowels (including "bing") appear to cluster on the left-hand side. It's worth noting that the nasal tense vowels (both "bean" and "bing") have a higher F1 (corresponding to a lower vowel) than the non-nasalized tense vowels.

3.4 F1, Non-High Vowels

There was a significant interaction between gender and vowel type [$F(9, 72)=3.31$, $p < 0.002$] (see figure 17 below), so the female and male data were analyzed separately using a Series of Bonferroni tests.

Focusing on the male data, the F1 value of "ang" was not significantly different from *any* test word whose main vowel was either [e] or [ɛ]. Additionally, the F1 value of "ang" was not significantly different from the test word whose rime was [æn]. However, the F1 value for "ang" was lower than the F1 values for both [æd] and [æg], which corresponds to a higher vowel for "ang".

The female data differs from the male data in two respects. The F1 value for "ang" was lower than the F1 values for test words with a rime of both [ɛn] and [ɛd]. Like the male data, the F1 value of "ang" was also lower than the F1 values for test words with a rime of [æd] and [æg]. Otherwise, the F1 value of "ang" was not significantly different from the rest of the data.

In figure 17 below, a shorthand is used to refer to the vowels rather than using the IPA. The vowel correspondencies are as follows: (a) "e" = [e]; (b) "eh" = [ɛ]; and (c) "ae" = [æ]. Additionally, "ang" is used to represent the vowel in "bang".

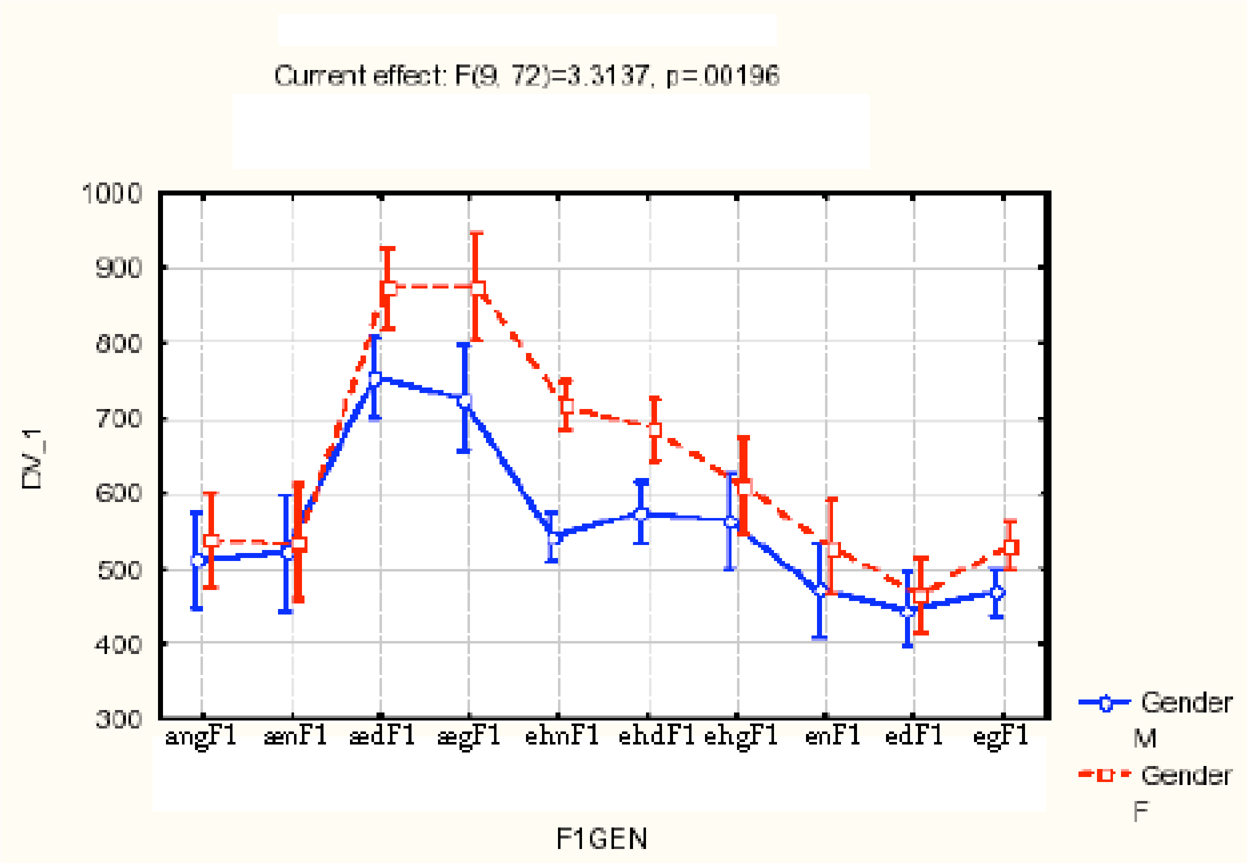


Figure 17: Mean value and standard errors of F1 (in Hz), separately for the male and female subjects.

The table below summarizes the results of the Series of Bonferroni tests detailed above.

"ang" compared to…	In comparison, F1 of "ang" is…	p Value (F)	p Value (M)
[en]	*not different (both)*	*not significant*	*not significant*
[ed]	*not different (both)*	*not significant*	*not significant*
[eg]	*not different (both)*	*not significant*	*not significant*
[ɛn]	*lower (F); not different (M)*	< 0.001	*not significant*
[ɛd]	*lower (F); not different (M)*	< 0.003	*not significant*
[ɛg]	*not different (both)*	*not significant*	*not significant*
[æn]	*not different (both)*	*not significant*	*not significant*
[æd]	*lower (both)*	< 0.001	< 0.001
[æg]	*lower (both)*	< 0.001	< 0.001

Table 6: A summary of the results of the Series of Bonferroni tests run on the F1 of the vowel in "ang".

3.5 F2, Non-High Vowels

There was a significant interaction between gender and vowel type [$F(9, 72)=2.35$, $p < 0.023$] (see figure 18 below), so the female and male data were analyzed separately using a Series of Bonferroni tests.

Focusing on the male data, the F2 value of "ang" was not significantly different from *any* test word whose main vowel was either [e] or [ɛ]. Additionally, the F2 value of "ang" was not significantly different from the test word whose rime was [æn]. However, the F2 value for "ang" was higher than the F2 values for both [æd] and [æg], which corresponds to a more front vowel for "ang" (see Zeller, 1997 for a similar interpretation of a higher F2 value).

The female data differs from the male data in three respects. The F2 value for "ang" was higher than the F2 values for test words with a rime of both [ɛn] and [ɛd]. Additionally, the F2 value for "ang" was lower than the F2 value for test words with a rime of [ed]. Like the male data, the F2 value of "ang" was also higher than the F2 values for test words with a rime of [æd] and [æg]. Otherwise, the F2 value of "ang" was not significantly different from the rest of the data.

In figure 6 below, a shorthand is used to refer to the vowels rather than using the IPA. The vowel correspondencies are as follows: (a) "e" = [e]; (b) "eh" = [ɛ]; and (c) "ae" = [æ]. Additionally, "ang" is used to represent the vowel in "bang".

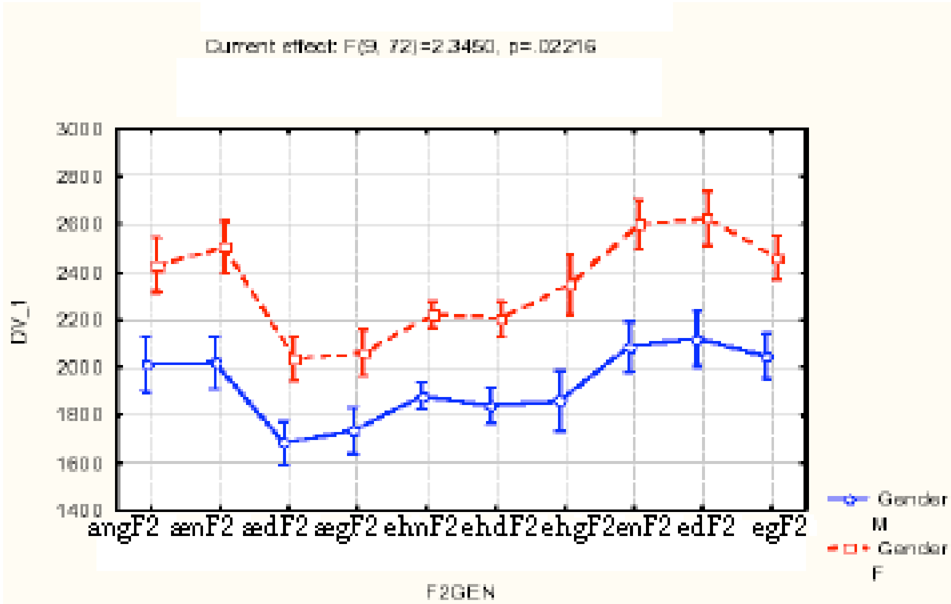


Figure 18: Mean value and standard errors of F2 (in Hz), separately for the male and female subjects.

The table below summarizes the results of the series of Bonferroni tests detailed above.

"ang" compared to…	In comparison, F2 of "ang" is…	p Value (F)	p Value (M)
[en]	*not different (both)*	*not significant*	*not significant*
[ed]	*lower (F); not different (M)*	< 0.021	*not significant*
[eg]	*not different (both)*	*not significant*	*not significant*
[ɛn]	*higher (F); not different (M)*	< 0.008	*not significant*
[ɛd]	*higher (F); not different (M)*	< 0.002	*not significant*
[ɛg]	*not different (both)*	*not significant*	*not significant*
[æn]	*not different (both)*	*not significant*	*not significant*
[æd]	*higher (both)*	< 0.001	< 0.001
[æg]	*higher (both)*	< 0.001	< 0.001

Table 7: A summary of the results of the series of Bonferroni tests run on the F2 of the vowel in "ang".

3.6 Summary of F1 and F2 Results for the Non-High Vowels

Below are twelve graphs showing the vowel space of each speaker in the present study, as well as the male and female speakers collectively. These graphs simply represent the non-high vowels for each speaker and each set of speakers.

In figure 19 below, a shorthand is used to refer to the vowels rather than using the IPA. The vowel correspondencies are as follows: (a) "e" = [e]; (b) "eh" = [ɛ]; and (c) "ae" = [æ]. Additionally, "ang" is used to represent the vowel in "bang".

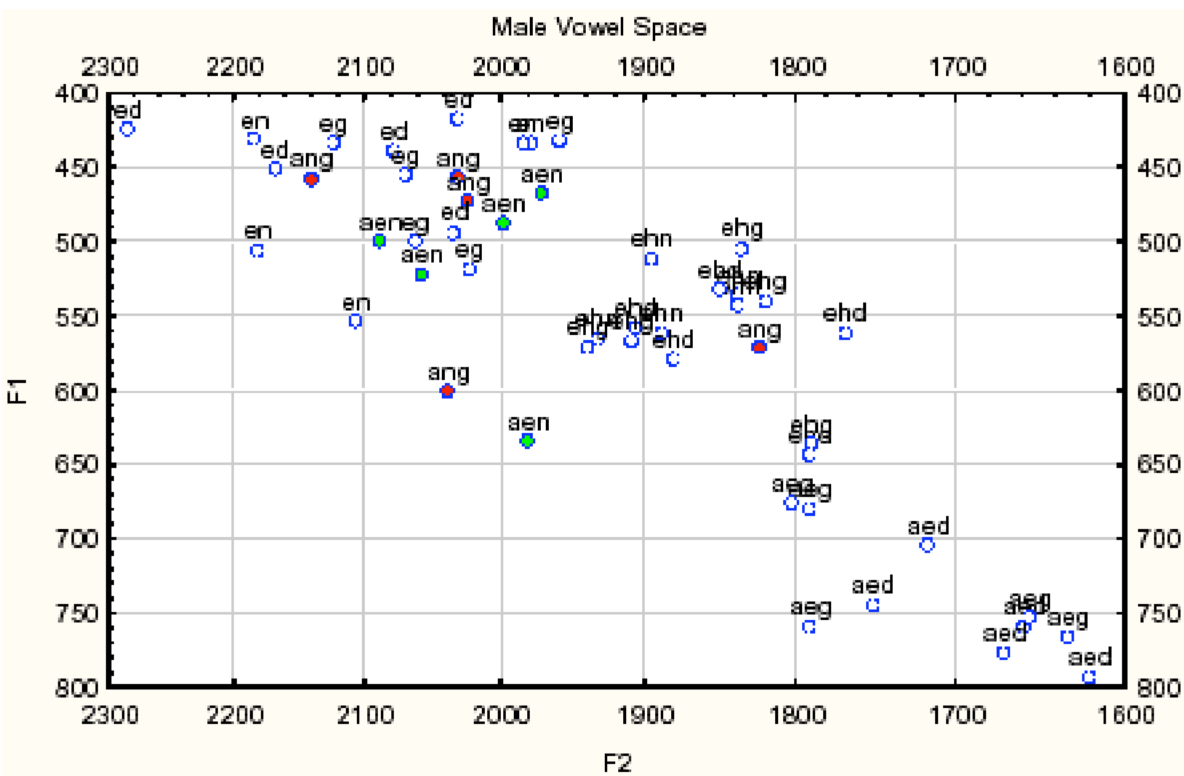


Figure 19: Vowel space showing the location of the non-high vowels of the male speakers.

In figure 19, there are three general clusters: One in the upper left-hand corner, which corresponds to the tense [e] vowels; one in the middle which corresponds to the lax [ɛ] vowels; and one in the lower right-hand corner which corresponds to the vowel [æ]. Upon closer inspection, though, the vowel [æ] vowel in "ban" by and large appears to cluster with the tense [e] vowels, and the vowel in "ang" clusters somewhere in between the tense [e] vowels and the lax [ɛ] vowels.

In figure 20 below, a shorthand is used to refer to the vowels rather than using the IPA. The vowel correspondencies are as follows: (a) "e" = [e]; (b) "eh" = [ɛ]; and (c) "ae" = [æ]. Additionally, "ang" is used to represent the vowel in "bang".

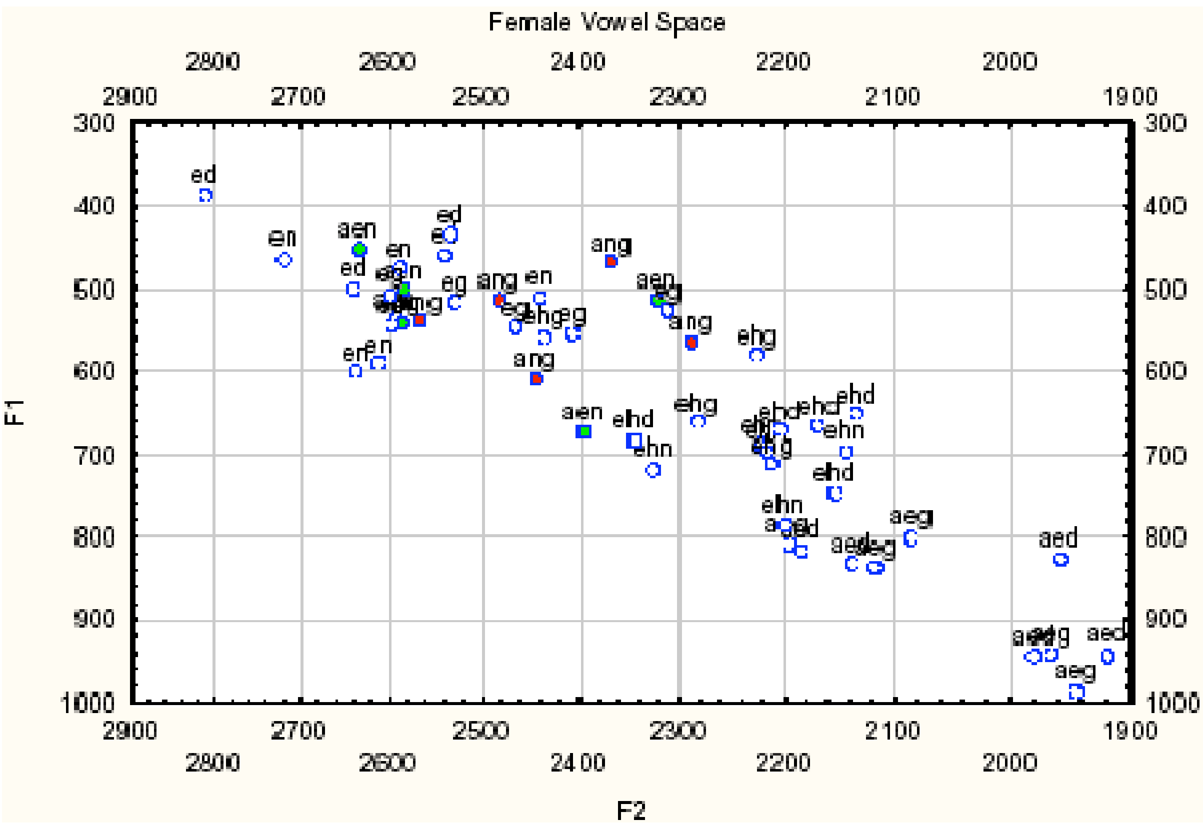


Figure 20: Vowel space showing the location of the non-high vowels of the female speakers.

The same clusters can be seen with the female speakers as can be with the male speakers (cf. figure 19). The vowels in "bang" and "ban", however, appear to be intermediate to a greater degree than with the male speakers. Additionally, while the male speakers have a large cluster in the upper left-hand corner, the vowels of the female speakers are spread more evenly from the lower right-hand corner to the upper left-hand corner. In other words, the female vowel space, as a whole, looks a bit more like one would expect.

In figures 21, 22 and 23 below, a shorthand is used to refer to the vowels rather than using the IPA. The vowel correspondencies are as follows: (a) "e" = [e]; (b) "eh" = [ɛ]; and (c) "ae" = [æ]. Additionally, "ang" is used to represent the vowel in "bang".

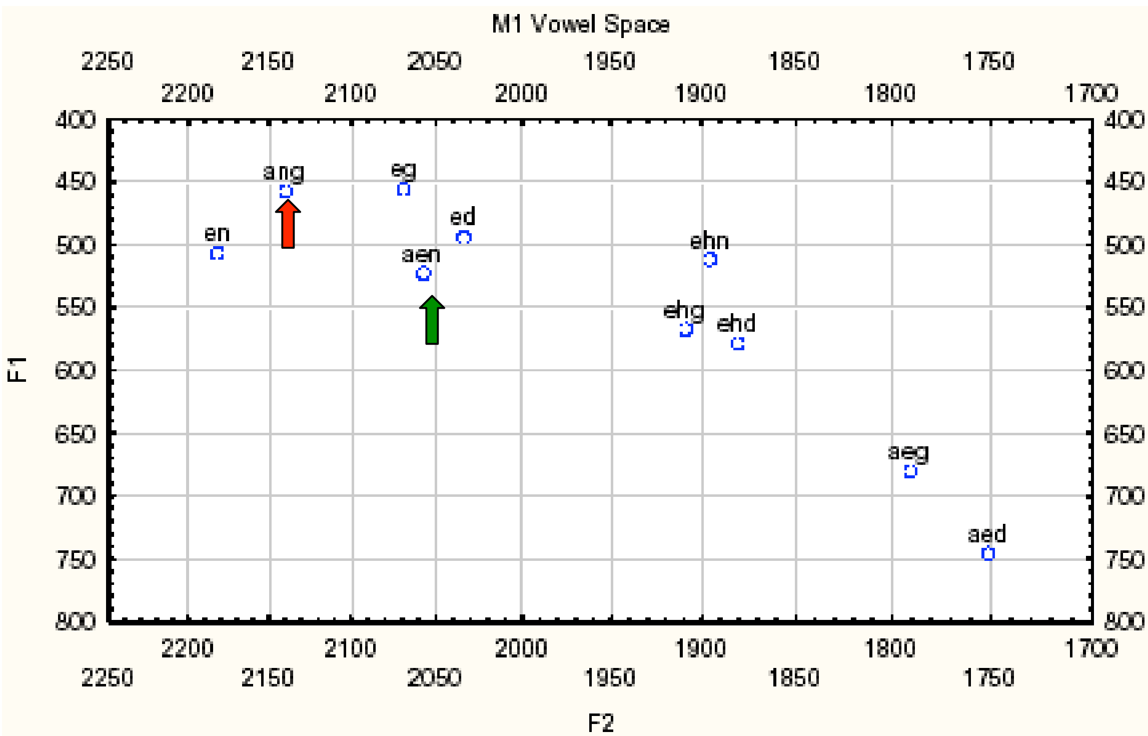


Figure 21: Vowel space showing the location of the non-high vowels of M1.

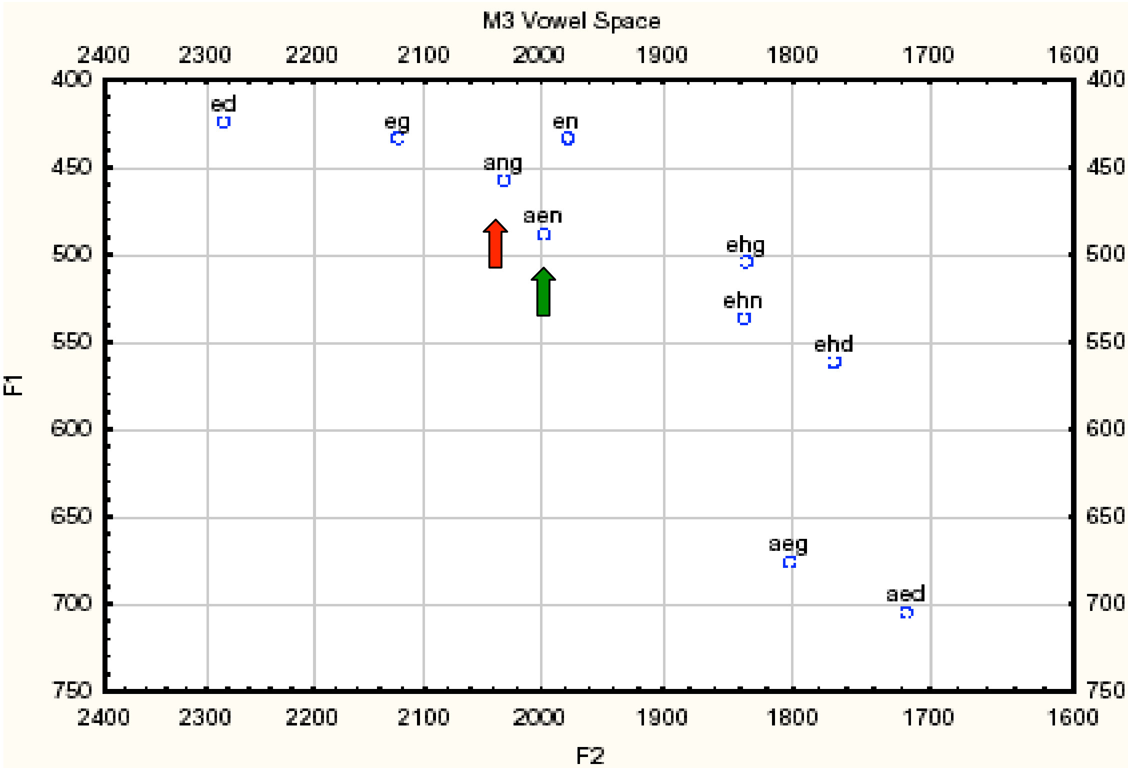


Figure 22: Vowel space showing the location of the non-high vowels of M3.

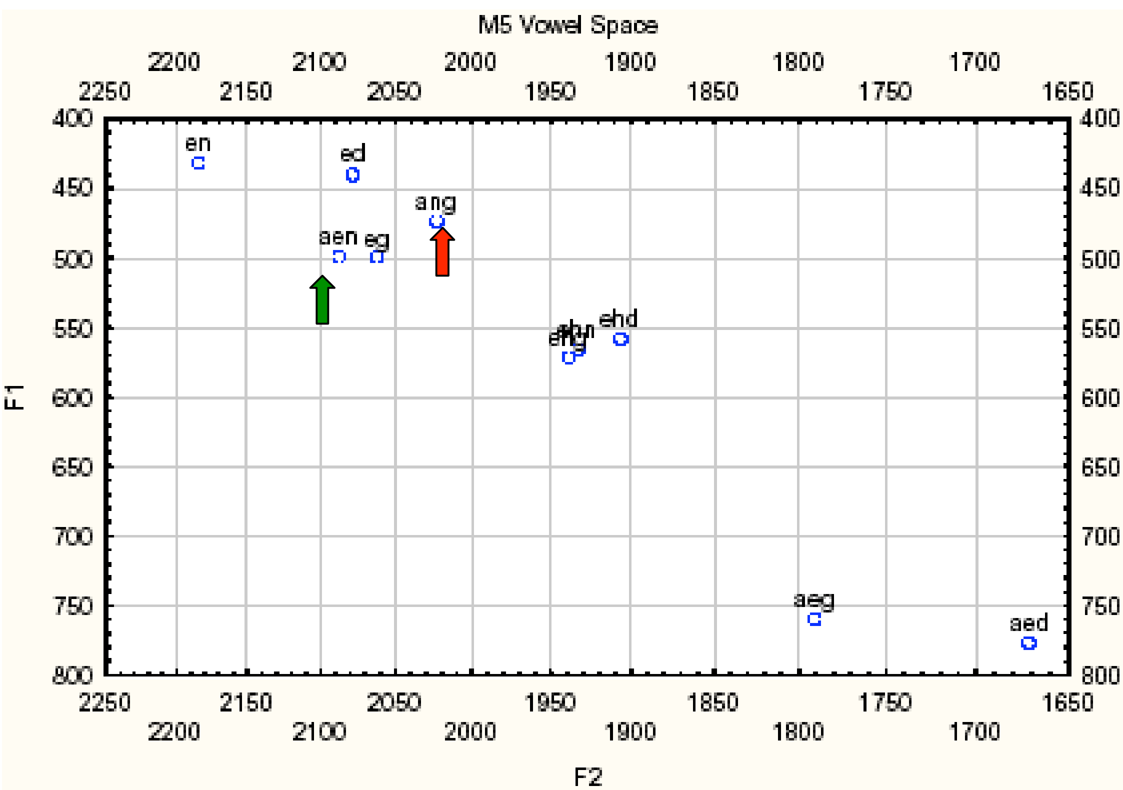


Figure 23: Vowel space showing the location of the non-high vowels of M5.

In figures 21 through 23, the vowels in "bang" and "ban" appear to cluster closely with the tense [e] vowels. The three clusters are seen most clearly in M1's vowel space, but instead of the vowels for "bang" and "ban" clustering with the [æ] vowels in "bad" and "bag", they cluster with the tense [e] vowels. In M3's vowel space, "bang" and "ban" cluster close to the tense [e] vowels, but don't form as tight a cluster as in M1's vowel space. However, if one includes the nasal vowel in "bane", these three form a rather tight cluster in between the non-nasal tense [e] vowels and the lax [ɛ] vowels. In M5's vowel space, "ban" and "bang" again cluster with the tense [e] vowels.

In figures 24 and 25 below, a shorthand is used to refer to the vowels rather than using the IPA. The vowel correspondencies are as follows: (a) "e" = [e]; (b) "eh" = [ɛ]; and (c) "ae" = [æ]. Additionally, "ang" is used to represent the vowel in "bang".

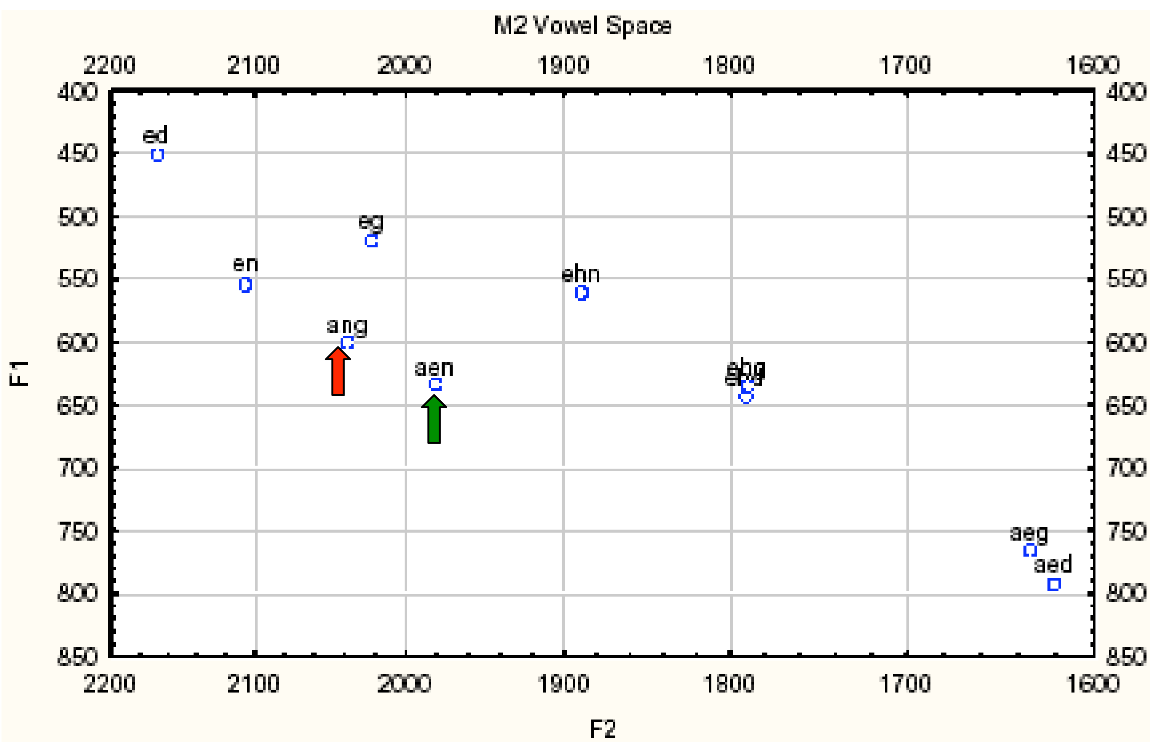


Figure 24: Vowel space showing the location of the non-high vowels of M2.

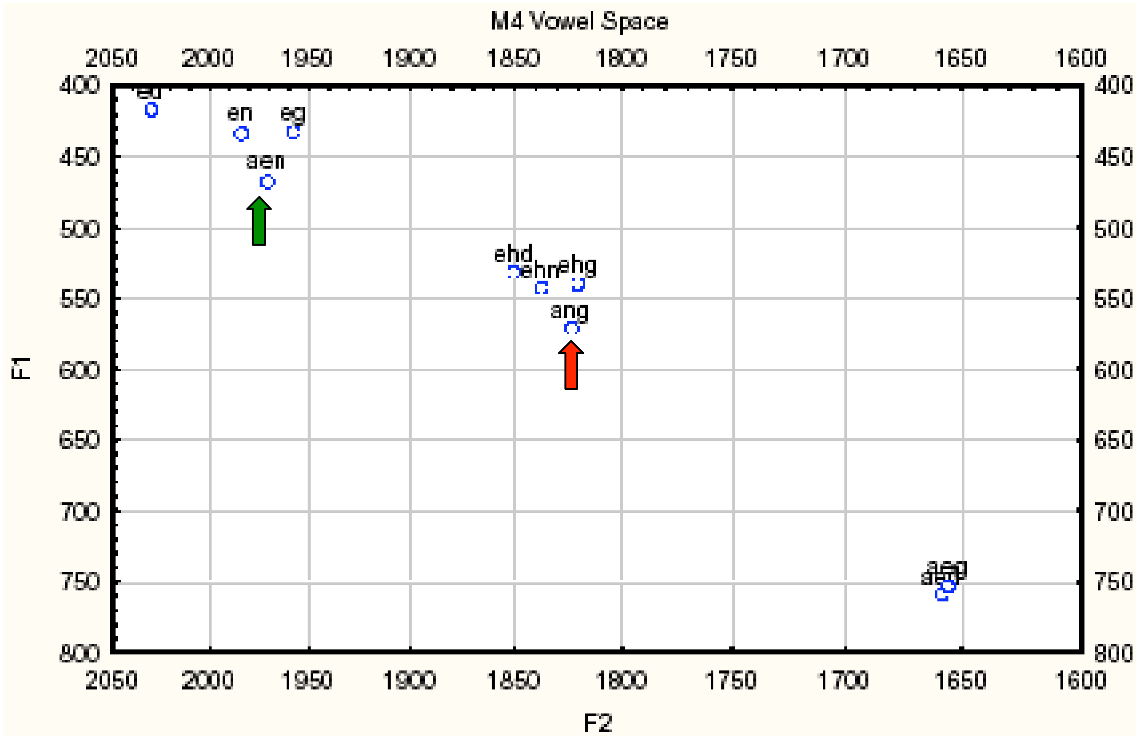


Figure 25: Vowel space showing the location of the non-high vowels of M4.

The vowel spaces in figures 24 and 25 are rather different. Though the same basic pattern can be seen in M2's vowel space (the vowels in "bang" and "ban" cluster somewhat with the tense [e] vowels), their F1 values are much, much higher (corresponding to a lower vowel) than the F1 values of the first three male speakers. The same is true for the lax [ɛ] vowels. M4's vowel space is a more traditional one. That is, there are three tight clusters, each one where one might expect. The difference from the first three vowel spaces is that the vowel in "ban" clusters with the tense [e] vowels, but the vowel in "bang" clusters with the lax [ɛ] vowels.

In figures 26 and 27 below, a shorthand is used to refer to the vowels rather than using the IPA. The vowel correspondencies are as follows: (a) "e" = [e]; (b) "eh" = [ɛ]; and (c) "ae" = [æ]. Additionally, "ang" is used to represent the vowel in "bang".

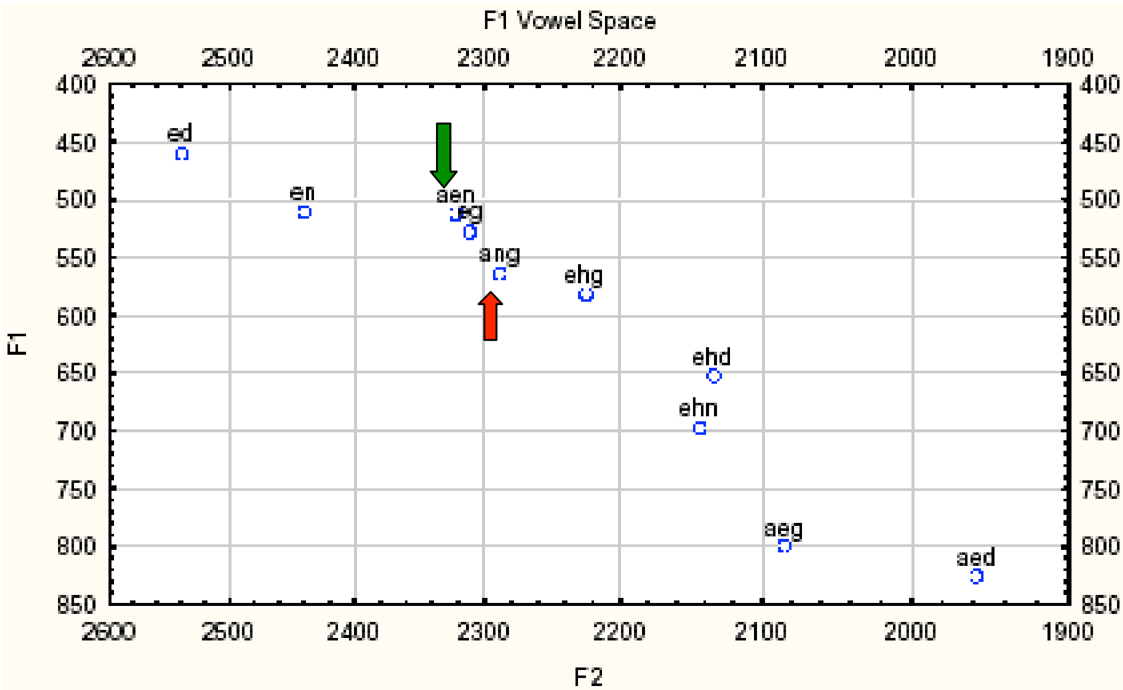


Figure 26: Vowel space showing the location of the non-high vowels of F1.

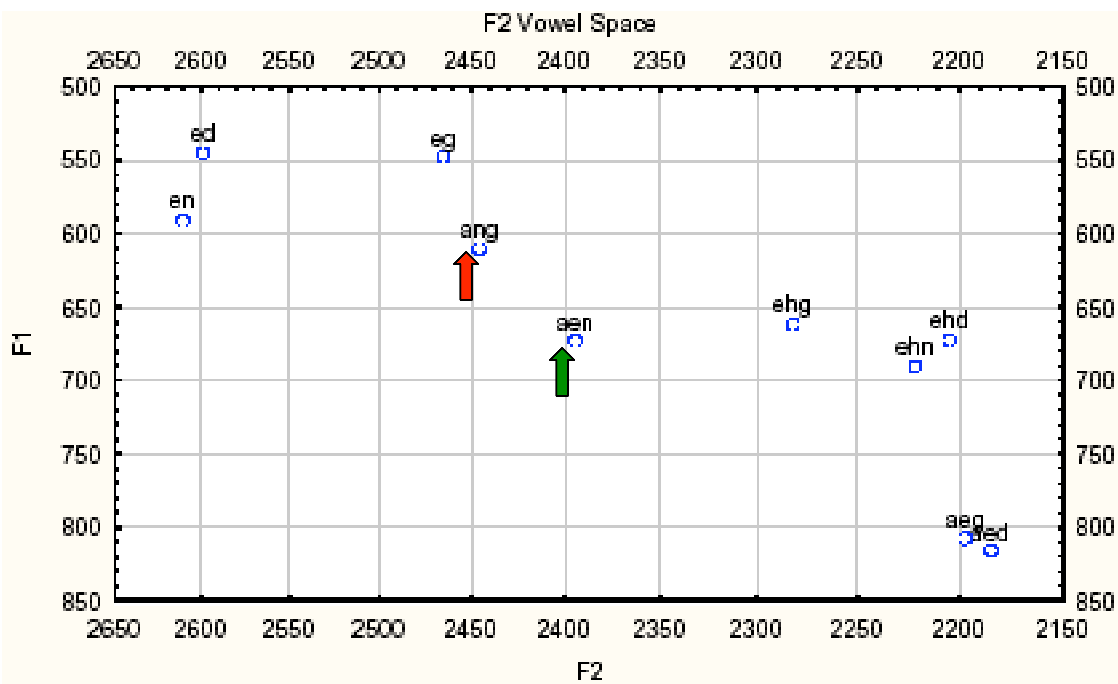


Figure 27: Vowel space showing the location of the non-high vowels of F2.

Regarding the female vowel spaces, it can be observed that in these first two vowel spaces (figures 26 and 27), it's clear that the vowels in "bang" and "ban" cluster together, but aside from that, it's difficult to conclude anything definitive. They don't cluster with the other [æ] vowels, but they also don't appear to cluster with the [e] vowels or the [ɛ] vowels. Rather, they appear to be somewhere in between these two groups.

In figures 28, 29 and 30 below, a shorthand is used to refer to the vowels rather than using the IPA. The vowel correspondencies are as follows: (a) "e" = [e]; (b) "eh" = [ɛ]; and (c) "ae" = [æ]. Additionally, "ang" is used to represent the vowel in "bang".

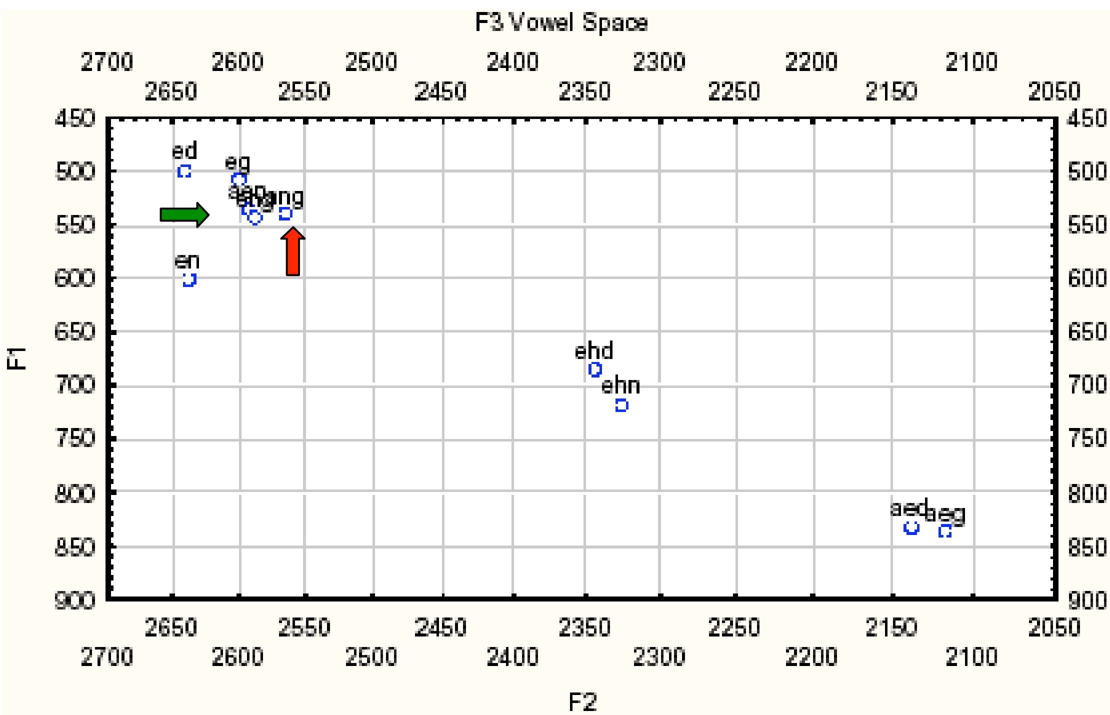


Figure 28: Vowel space showing the location of the non-high vowels of F3.

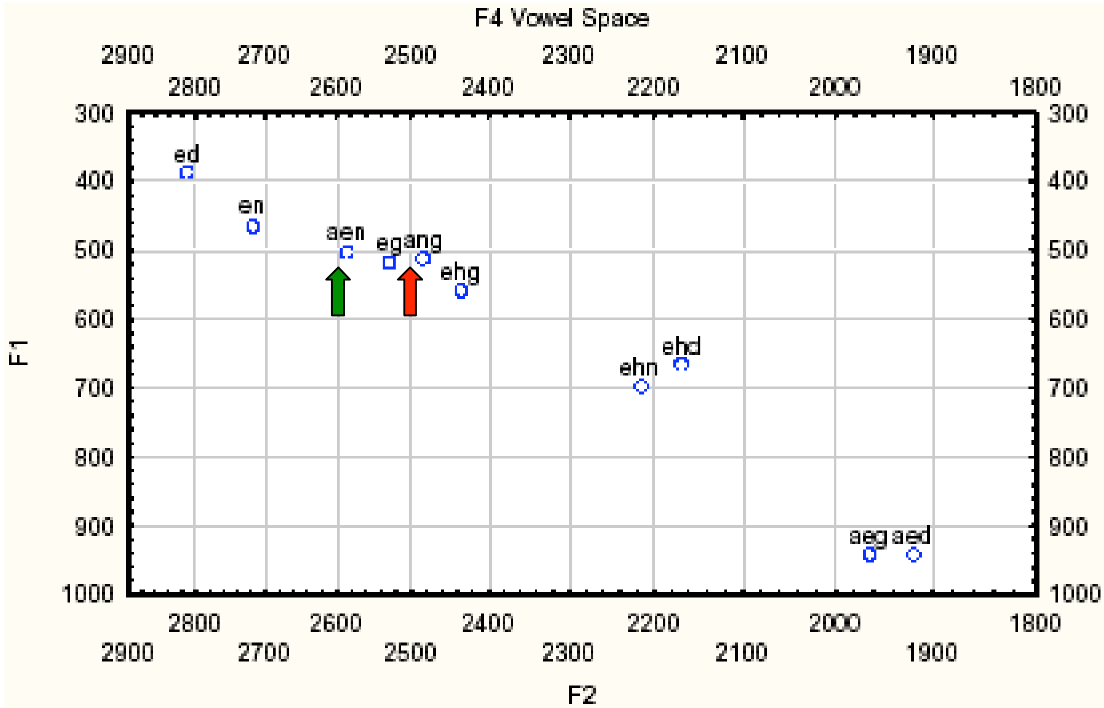


Figure 29: Vowel space showing the location of the non-high vowels of F4.

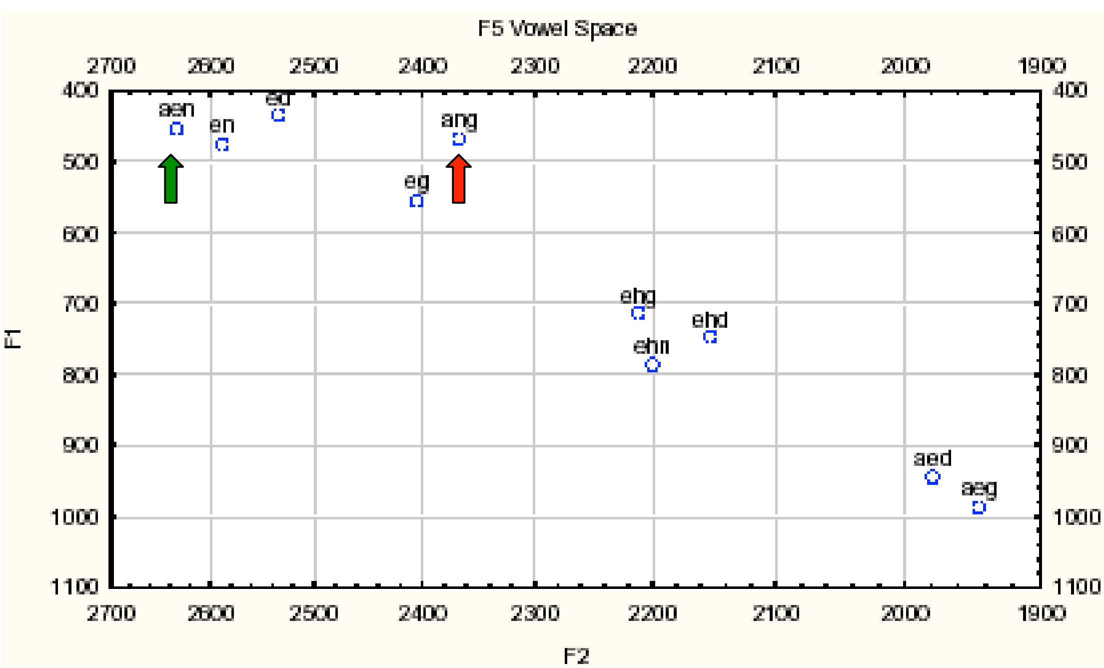


Figure 30: Vowel space showing the location of the non-high vowels of F5.

In the final three female vowel spaces, the vowels in "ban" and "bang" cluster with the tense [e] vowels, and each vowel space shows three tight clusters for [æ], [ɛ] and [e]. An interesting point to note about F3 and F4's vowel spaces is that the vowel in "beg" also clusters rather clearly with the tense [e] vowels.

3.7 Duration, High Vowels

There was no significant interaction between gender and vowel type [$F(6, 48)=0.61$, n.s.] (see figure 31 below), so the female and male data were grouped together. A planned comparison showed that the duration of the vowel in "ing" was shorter than the duration of the vowel in test words with [i] [$F(1,8)=85.72$, $p < 0.001$], and also shorter than the duration of the vowel in test words with [ɪ] [$F(1,8)=8.96$, $p < 0.018$].

Additionally, in a general comparison between coda types, the duration of the vowels in words with nasal codas (including "ing") proved to be shorter than the duration of the vowels in words with non-nasal codas [$F(1,8)=23.20$, $p < 0.002$]. On the other hand, the duration of the vowels in words with velar codas (including "ing") were not significantly different from the duration of the vowels in words with non-velar codas [$F(1,8)=2.79$, n.s.].

In pair-wise comparisons with specific vowel/coda contexts, the duration of the vowel in "ing" proved to be shorter than the duration of the vowel in words with [in] [$F(1,8)=41.11$, $p < 0.001$], [id] [$F(1,8)=101.98$, $p < 0.001$], [ig] [$F(1,8)=30.34$, $p < 0.001$], [ɪd] [$F(1,8)=13.21$, $p < 0.007$], and [ɪg] [$F(1,8)=10.54$, $p < 0.012$]. There was no significant difference between the duration of the vowel in "ing" and the duration of the vowel in words with [ɪn] [$F(1,8)=0.06$, n.s.].

In figure 31 below, a shorthand is used to refer to the vowels rather than using the IPA. The vowel correspondencies are as follows: (a) "i" = [i]; (b) "ih" = [ɪ]. Additionally, "ing" is used to represent the vowel in "bing".

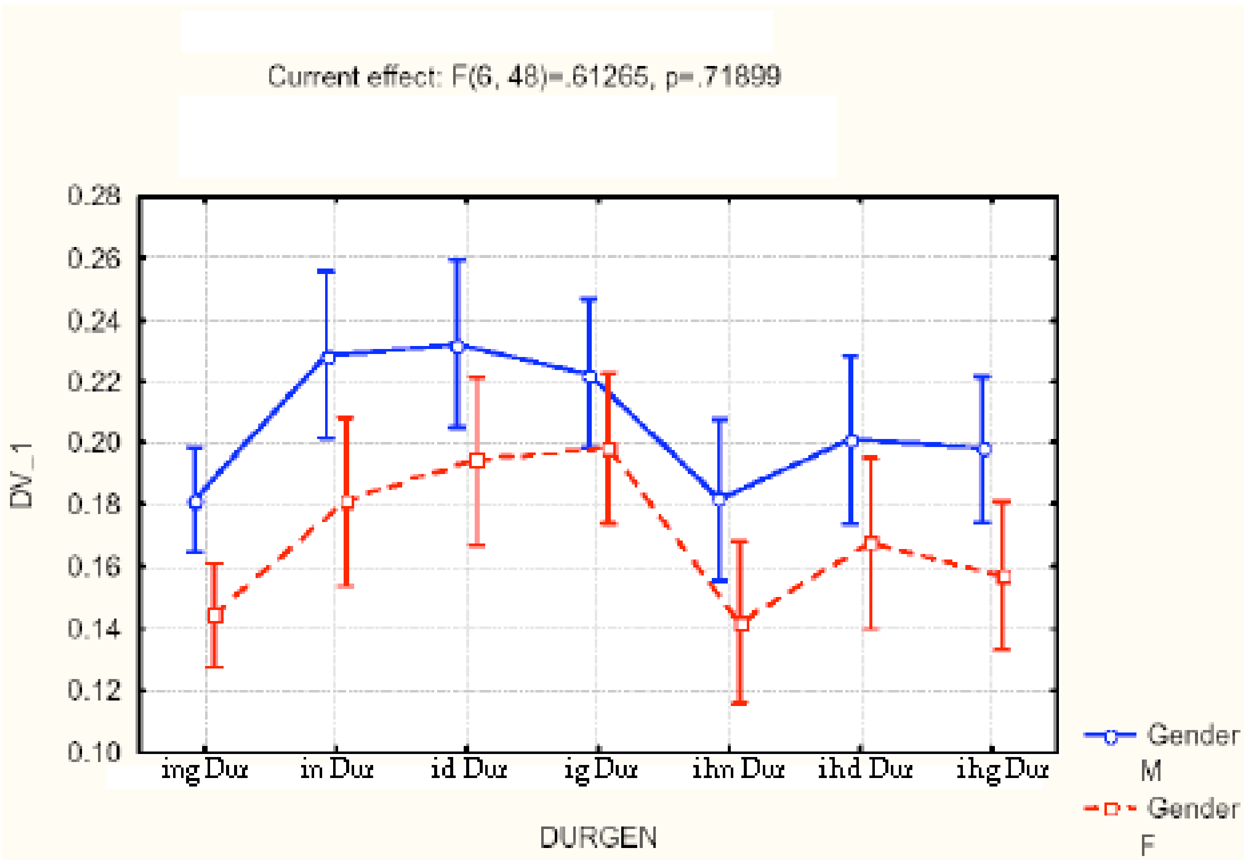


Figure 31: Mean value and standard errors of duration (in seconds), separately for the male and female subjects.

The table below summarizes the results of the planned comparisons detailed above.

"ing" compared to…	In comparison, duration of "ing" is…	F(1, 8)	p Value
[iC]	*shorter*	85.72	< 0.001
[ɪC]	*shorter*	8.96	< 0.018
[in]	*shorter*	41.11	< 0.001
[id]	*shorter*	101.98	< 0.001
[ig]	*shorter*	30.34	< 0.001
[ɪn]	*not different*	0.06	*not significant*
[ɪd]	*shorter*	13.21	< 0.007

[ɪg]	*shorter*	10.54	< 0.012

Table 8: A summary of the results of the planned comparisons run on the duration of the vowel in "ing".

3.8 Duration, Non-High Vowels

There was no significant interaction between gender and vowel type [F(9, 72)=1.78, n.s.] (see figure 32 below), so the female and male data were grouped together. A planned comparison showed that the duration of the vowel in "ang" was shorter than the duration of the vowel in test words with [e] [F(1,8)=8.11, p < 0.022], and also shorter than the duration of the vowel in test words with [æ] [F(1,8)=41.14, p < 0.001]. The duration of the vowel in "ang" was longer, though, than the duration of the vowel in test words with [ɛ] [F(1,8)=26.35, p < 0.001].

Additionally, in a general comparison between coda types, the duration of the vowels in words with nasal codas (including "ang") proved to be shorter than the duration of the vowels in words with non-nasal codas [F(1,8)=6.30, p < 0.036]. On the other hand, the duration of the vowels in words with velar codas (including "ang") were not significantly different from the duration of the vowels in words with non-velar codas [F(1,8)=0.35, n.s.].

In pair-wise comparisons with specific vowel/coda contexts, the duration of the vowel in "ang" proved to be longer than the duration of the vowels in words with [ɛn] [F(1,8)=250.40, p < 0.001], [ɛd] [F(1,8)=15.25, p < 0.005], but shorter than the duration of the vowels in words with [en] [F(1,8)=6.71, p < 0.032], [ed] [F(1,8)=12.82, p < 0.008], [æn] [F(1,8)=14.97, p < 0.005], [æd] [F(1,8)=43.03, p < 0.001], and [æg] [F(1,8)=43.63, p < 0.001]. There proved, however, to be no significant difference between the duration of the vowel in "ang" and the duration of the vowels in words with [eg] [F(1,8)=2.44, n.s.] and [ɛg] [F(1,8)=4.00, n.s.].

In figure 32 below, a shorthand is used to refer to the vowels rather than using the IPA. The vowel correspondencies are as follows: (a) "e" = [e]; (b) "eh" = [ɛ]; and (c) "ae" = [æ]. Additionally, "ang" is used to represent the vowel in "bang".

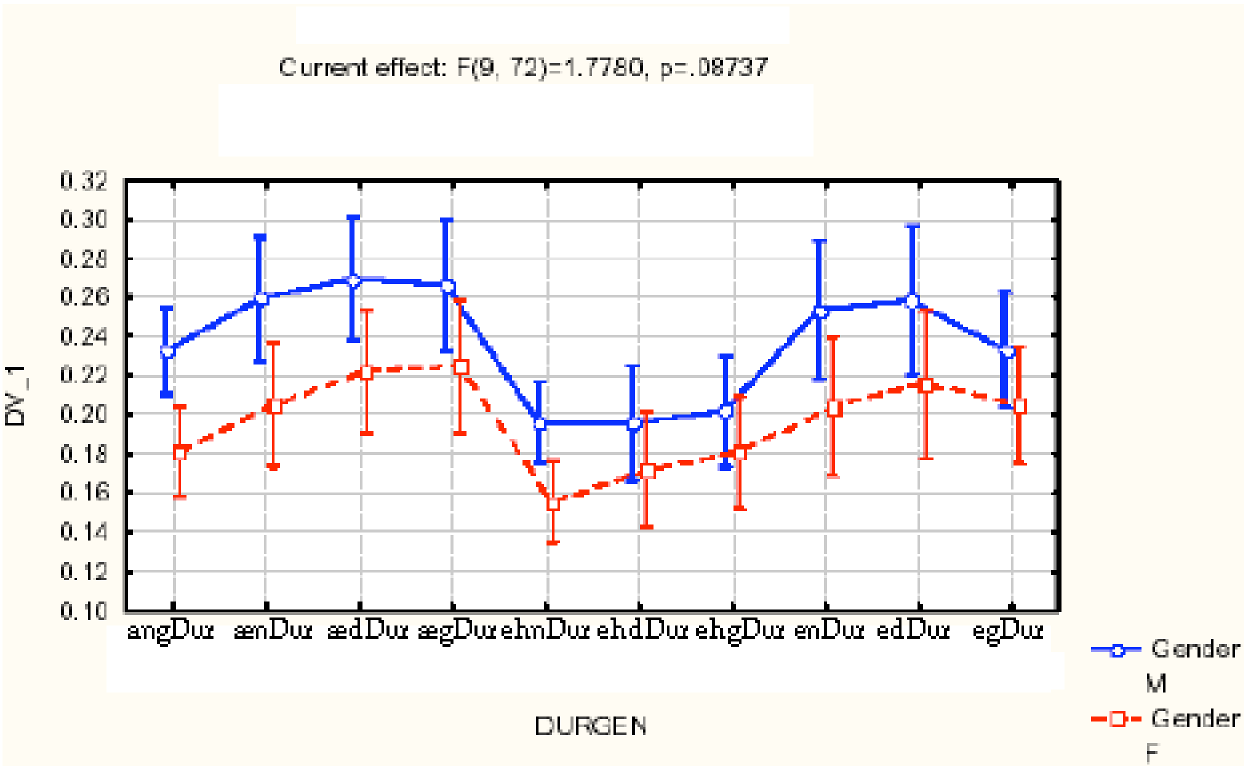


Figure 32: Mean value and standard errors of duration (in seconds), separately for the male and female subjects.

The table below summarizes the results of the planned comparisons detailed above.

"ang" compared to…	**In comparison, duration of "ang" is…**	**F(1, 8)**	**p Value**
[eC]	*shorter*	8.11	< 0.022
[ɛC]	*longer*	26.35	< 0.001
[æC]	*shorter*	41.14	< 0.001
[en]	*shorter*	6.71	< 0.032
[ed]	*shorter*	12.82	< 0.008
[eg]	*not different*	2.44	*not significant*
[ɛn]	*longer*	250.40	< 0.001
[ɛd]	*longer*	15.25	< 0.005
[ɛg]	*not different*	4.00	*not significant*
[æn]	*shorter*	14.97	< 0.005

[æd]	*shorter*	43.03	< 0.001
[æg]	*shorter*	43.63	< 0.001

Table 9: A summary of the results of the planned comparisons run on the duration of the vowel in "ang".

4.0 Discussion

4.1 Summary of Results

The results of the analysis of the high vowels showed that the vowel in “bing” is equal in height to the vowel in “bean”. Both of these are lower in height to the vowels in “bean” and “beag”, and higher than the vowels in “bin”, “bid” and “big”. Looking at F2, the same distribution can be seen, save that the vowel in “bean” is more fronted than the vowel in “bing”. Looking at duration measurements, the vowel in “bing” is as long as the vowel in “bin”, but these as a pair are shorter in duration than all the other test words investigated. These results are summarized in table 10 below:

F1 (High to Low)	[id], [ig] > [in], “ing” > [ɪn], [ɪd], [ɪg]
F2 (Front to Back)	[id], [ig], [in] > “ing” > [ɪn], [ɪd], [ɪg]
Duration (Long to Short)	[in], [id], [ig], [ɪd], [ɪg] > [ɪn], “ing”

Table 10: A summary of the results of the tests on the high vowels.

No independent rankings were made between the non-engma vowels of the same quality, with respect to F1 and F2. This table simply summarizes the relation each VC element bears to the engma coda in question—in this case, the “ing” test word.

The results of the analysis of the non-high vowels showed that, for males, the vowel in “bang” is equal in height to every test vowel, except that it is higher than the vowels in “bad” and “bag”. For females, the vowel in “bang” is higher than the vowels in “bed”, “Ben”, “bad” and “bag”, but is equal in height to the vowels of all other test words. Regarding F2, the F2 of "bang" for males was higher than the F2 in "bad" and "bag", but not equal to all other vowels, as with the F1 measurement. For females, the vowel in "bang" was not as far forward as the vowel in "bade", but was further forward than the vowel in "bed", "Ben", "bad" and "bag". The F2 measurement for "bang" for females was equivalent to the vowels in all other test words. Finally, the duration of the vowel in "bang" was equal to the duration of the vowels in "vague" and "beg". As a group, these vowels were longer than the vowels in "Ben" and "bed", but shorter than all other test vowels. These results are summarized in table 11 below:

F1 (High to Low)	**Males**	[en], [ed], [eg], [ɛn], [ɛd], [ɛg], [æn], "ang" > [æd], [æg]
	Females	[en], [ed], [eg], [ɛg], [æn], "ang" > [ɛn], [ɛd] > [æd], [æg]
F2 (Front to Back)	**Males**	[en], [ed], [eg], [ɛn], [ɛd], [ɛg], [æn], "ang" > [æd], [æg]
	Females	[ed] > [en], [eg], [ɛg], [æn], "ang" > [ɛn], [ɛd], [æd], [æg]
Dur. (Long to Short)	**Both**	[en], [ed], [æn], [æd], [æg] > [eg], [ɛg], "ang" > [ɛn], [ɛd]

Table 11: A summary of the results of the tests on the non-high vowels.

Overall, it appears that raising is present in Southern Californian American English. For the high vowels, the vowel in "bing" has raised to a level just below that of the tense vowels, though it retains the length of a lax vowel (i.e., it's length is not significantly different from the length of the vowel in "bin"). For the non-high vowels, the vowel in "bang" has raised to an even greater degree. The vowel has raised to a level equivalent to the tense vowel [e] for nearly all speakers, and has at least raised to an intermediate level for the rest of the speakers. Additionally, the vowel in "ban" has raised to a level equivalent with the vowel in "bang" for all but one speaker. In summary, raising was found for all speakers but two with "bing", and for all speakers with "bang". Somewhat surprisingly, raising was also found with "ban", suggesting that nasality may play some role in the raising seen in Southern Californian American

English. No significant raising effect was found with words with voiced velar codas, however, suggesting that place of articulation does not play a significant role in the raising seen in Southern Californian American English.

4.2 Comparison to Other Work

Before discussing the specific results for the vowels in "bang" and "bing", the present study's results will be compared to the results of the previous studies mentioned in section 1.0:

Vowel Type	**Study**	**F1**		**F2**	
		M	**F**	**M**	**F**
[i]	Peterson and Barney	270	310	2290	2790
	Hillenbrand, et al.	342	437	2322	2761
	Hagiwara	291	362	2338	2897
	Present Study	272	323	2379	2874
[ɪ]	Peterson and Barney	390	430	1990	2480
	Hillenbrand, et al.	427	483	2034	2365
	Hagiwara	467	418	1807	2400
	Present Study	427	472	2008	2413
[e]	Peterson and Barney	—	—	—	—
	Hillenbrand, et al.	476	536	2089	2530
	Hagiwara	403	440	2059	2655
	Present Study	445	465	2119	2625
[ɛ]	Peterson and Barney	530	610	1840	2330
	Hillenbrand, et al.	580	731	1799	2058
	Hagiwara	529	808	1670	2163
	Present Study	575	685	1839	2201
[æ]	Peterson and Barney	660	860	1720	2050
	Hillenbrand, et al.	588	669	1952	2349
	Hagiwara	685	1017	1601	1810
	Present Study	756	872	1685	2036

Table 12: A summary of the F1 and F2 results in Herz for male and female adults of three studies of American English vowels (front vowels only), accompanied by the results of the same measurements in the present study in the contexts [b_d].

By comparing the various studies in table 11, it can be seen that the results of the present study match up fairly closely with the results of Hagiwara. For F1, the male results are all within 75 Hz of each other, and the female results are all within about 50

Hz of each other, save the two lowest vowels, for which the female speakers of the present study have values which are about 150 Hz lower. Nevertheless, by combining the results of the present study with Hagiwara's, it seems reasonable to conclude that the two lowest vowels are lower for Southern Californian speakers than for non-Southern Californian speakers. Also, by looking at the F2 measurements, each pair of measurements is fairly close, save two: The pair of [æ] F2 measurements for females (the difference is about 200 Hz), and the pair of [ɛ] F2 measurements for males (the difference is about 150 Hz). Collectively, though, the results are rather similar, suggesting that the speech of the speakers of the present study, as indicated by their vowel formants, is a fair representation of Southern Californian English.

Having seen the general results of the vowels in the present study before a coda [d], let us now turn our attention to the three vowels that showed raising—specifically, the vowels in "bing", "bang" and "ban". As mentioned before, these words are traditionally transcribed with the vowels [ɪ], [æ] and [æ], respectively. Below is a table which shows the results from table 12 combined with the averages for the vowels in "bing", "bang" and "ban" from the present study:

Vowel Type	**Study**	**F1**		**F2**	
		M	**F**	**M**	**F**
[i]	Peterson and Barney	270	310	2290	2790
	Hillenbrand, et al.	342	437	2322	2761
	Hagiwara	291	362	2338	2897
	Present Study	272	323	2379	2874
[ɪ]	Peterson and Barney	390	430	1990	2480
	Hillenbrand, et al.	427	483	2034	2365
	Hagiwara	467	418	1807	2400
	Present Study	427	472	2008	2413
"bing"	Present Study	360	397	2253	2630
[e]	Peterson and Barney	—	—	—	—
	Hillenbrand, et al.	476	536	2089	2530
	Hagiwara	403	440	2059	2655
	Present Study	445	465	2119	2625
	Peterson and Barney	530	610	1840	2330

[ɛ]	Peterson and Barney	530	610	1840	2330
[ɛ]	Hagiwara	529	808	1670	2163
	Present Study	575	685	1839	2201
[æ]	Peterson and Barney	660	860	1720	2050
	Hillenbrand, et al.	588	669	1952	2349
	Hagiwara	685	1017	1601	1810
	Present Study	756	872	1685	2036
"bang"	Present Study	512	539	2011	2430
"ban"	Present Study	522	536	2019	2505

Table 13: A summary of the F1 and F2 results in Herz for male and female adults of three studies of American English vowels (front vowels only), accompanied by the results of the same measurements in the present study in the contexts [b_d].

In table 13, we can see that the F1 measure for "bing" is in between the values for [i] and [ɪ] for all four studies (including the present study). The F2 values, on the other hand, group more closely with the F2 values for [i] than the F2 values for [ɪ]. Comparing the F1 and F2 values for "bang" to the F1 and F2 values for "ban", it can be seen that "ban" and "bang" are nearly identical, the largest difference being a difference of 75 Hz in the female F2 values. As a group, "bang" and "ban" looking nothing like the other [æ] vowels. For males, the F1 of "bang" and "ban" are in between the values for [e] and [ɛ] shown above. For females, they appear to be quite a bit closer to the [e] values. It is worth noting that, as a whole, the male values for [ɛ] are rather close to the male values for [e], when compared to their female counterparts. In F2 measurements, both male and female speakers in the present study have values for "bang" and "ban" that are closer to the values for [e] in the other studies than to anything else. Thus, when compared to other American dialects (or to the same dialect before a non-nasal coda), the Southern Californian values for "bing", "bang" and "ban" stand apart.

The results of the current study suggest, as described above, that the lax vowels of Southern Californian English found before velar nasals are different in quality than previously reported for other varieties of American English. Presumably, since there are no minimal pairs before velar nasals in English[8], this should pose no problem for phonologists who wish to describe the vowel system of English. When classifying the vowels of their own language, however, it is unclear how native speakers would classify the vowels before velar nasals.

Looking at the individual speakers, we can examine Liu's (2004) claim about the connection between the tensing of [ɪ] and the tensing of [æ] before [ŋ]. Liu asserts that if raising is seen in the high vowels, it will also be seen in the non-high vowels. Most of the speakers in the present study seem to confirm this. In speakers M1, M3, M5 and F5, raising is seen with both the high and non-high vowels. Conversely, speakers F1 and F2 show raising in neither the high nor non-high vowels. Thus, in six of the ten speakers, the two versions of raising can be seen. With the others, the correlation is less clear. In speakers M2 and F4, the vowel in "bang" has raised to a tense position, but the vowel in "bing" has raised only to an intermediate position between the tense and lax vowel clusters. The same basic pattern can be seen with F3, though the vowel in "bing" has raised less. And in speaker M4, one of the more conservative speakers, the vowel in "bang" has raised to an intermediate position, while the vowel in "bing" hasn't raised.

One unexpected result of the present study is that female speakers, as a group, appeared to be more conservative than the male speakers with respect to the sound changes in question (the raising of the vowels in "bing", "bang" and "ban"). F1 and F2 were the only speakers who didn't have a fully raised vowel (i.e., a vowel equivalent to a corresponding tense vowel) in "ban", and they were also the only speakers with no fully raised vowels, whatsoever. Only F5 showed fully raised vowels in each of the three areas. Three out of the five male speakers, however, showed full raising in each of

[8] There does seem to be at least one minimal pair, for those whose non-high vowel before a velar nasal is [æ]. A professional basketball player originally from Sudan named Luol Deng has a last name which is pronounced as [dɛŋ] by those who would pronounce the interjection "dang" as [dæŋ].

the three areas, with M2 showing two fully raised vowels (the non-high vowels), and M4 one (the vowel in “ban”).

This difference between male and female speakers could explain an apparent incongruity between the results of the present study and Liu’s (2004) results. Liu concludes that there is a “merger” in Southern Californian English before velar nasal codas for both the high and non-high vowels. That is, he concludes that the vowels in “bing” and “bang” are “different from both the tense and lax vowels of a given speaker” (Liu, 2004). While this looks to be the case for the high vowels of speaker F1, for example, the results of the present study suggest that the vowels in “bing” and “bang” tend not to be very different from the tense vowels. That is, they haven’t raised to a position intermediate between the tense and lax vowels, but have raised to the level of tense vowels, or very nearly so. The speakers that least conformed with this tendency were the female speakers, who, on the whole, were more conservative, as mentioned. An examination of Liu’s study shows that seven out of his nine speakers were, in fact, female. Thus, his conclusions may result from the fact that a majority of his speakers were speaking a more conservative version of Southern Californian English[9]. If an equal number of male speakers were examined, a pattern similar to the one found in the present study may have been discovered.

4.3 General Discussion

Based on the results of the current study, there seems to be evidence of a possible sound change, the upshot of which is that the lax vowel [ɪ] is in the process of moving from a lax position to a tense position (that is, so it looks more like [i]) before velar

[9] It would be ideal to examine Liu’s results to see if the his male speakers conformed to the general trend of the male speakers examined in the present study, but Liu didn’t mention the gender of each subject.

nasals. Additionally, the lax vowel [æ] is in the process of moving from a lax position to a tense position (that is, so it looks more like [e]) before velar and alveolar nasals. Finally, given the direction of both sound changes, it appears that male Southern Californian English speakers are in the vanguard with respect to these sound changes, as the individual female speakers show more conservative realizations of the vowels in "bing", "bang" and "ban", in many cases.

Outside of the vowels followed by a coda engma, another interesting correlation can be found. That is, in every case but one, those that have a raised vowel in "bang" also have a raised vowel in "ban". Speakers F1 and F2 have an intermediate vowel for both "bang" and "ban", while speakers M1, M2, M3, M5, F3, F4, and F5 all have a raised vowel in "ban" and "bang". Speaker M4 has a raised vowel in "ban" but an intermediate vowel in "bang". In fact, looking at the group as a whole, the vowel in "bang" isn't significantly different in quality from the vowel in "ban", but both differ greatly from words with [æ] as their main vowel. Though the two remain distinct in length (the vowel in "ban" was significantly longer than the vowel in "bang" for both male and female speakers), this could suggest that a nasal coda is what's causing the previous vowel to raise. Place of articulation, however, doesn't seem to play much of a factor at all in the variety of raising seen in the present study. If it did, we would expect to see all the vowels with velar codas patterning together to the exclusion of the vowels with alveolar codas, but this doesn't seem to be the case.

Though there is individual variation, it appears that the raising of the vowel in "bing" lags behind the raising of the vowel in "bang"—that is, where the vowel in "bing" has raised, one can predict, based on the present results, that the vowel in "bang" will have also raised, though the opposite prediction cannot be made. Thus, it appears that the raising of "bang" occurs before the raising of "bing". Further, there is no case where "bang" has raised and "ban" hasn't. For the speakers in the present study, then, if "bing" has raised, one can predict that "bang" will have raised, and, if "bang" has raised, then "ban" will also have raised.

Concerning the nature of the raising itself, it appears that the lax vowels [ɪ] and [æ] are moving from a lax to a tense position. That is, it presumably would be easier for [æ] to raise to [ɛ] rather than [e]. Instead, it seems that [æ] is raising directly to [e], with perhaps only a brief stopover in the [ɛ] region. Additionally, though many speakers don't have a fully raised vowel in "bing", the vowel is closer to the tense vowel than the lax vowel. This could suggest that what's taking place in Southern Californian American English is not raising, but tensing. That is, it's not the case that the vowels before a velar nasal and/or an alveolar nasal are raising a bit, but they're moving (and, in the case of the non-high vowels, quite some distance) from a lax position to the nearest tense position. The present study doesn't lend strong support for tensing before nasal codas, since the lax vowel in "bin" does not raise at all, and, for female speakers, the vowel in "Ben" also clusters with the other [ɛ] vowels, but the trend is nevertheless interesting, and worthy of future study.

One final interesting and unexpected result that this study uncovered was the difference between male and female Southern Californian English speakers. Though many of the vowel space graphs above appear to show a three-way contrast for most speakers, as a group, it appears that males only have two height distinctions amongst the non-high vowels, whereas females have three. That is, for males, the vowels in "bad" and "bag" had F1 and F2 measures which were not significantly different. These two, then, were significantly lower than all the other non-high vowels measured. The rest of these vowels, though, were not significantly different from each other. That is, the vowels in "bang", "bane", "bade", "vague", "Ben", "bed", "beg" and "ban" all had

F1 and F2 measures which were not significantly different from one another. Females, on the other hand, maintained three different levels, where "bad" and "bag" were the lowest; "Ben" and "bed" were in between, and "bang", "bane", "bade", "vague", "beg" and "ban" were the highest. This picture is what one would expect to see for all speakers (aside from the height of "beg").

4.3 Further Research

In order to determine what speakers think of the vowels in words like "bing", a perceptual experiment should be done. The goal of this experiment would be to give subjects a forced choice between a tense and a lax vowel—[i] and [ɪ] for "bing", for example—when hearing a CV- segment from a word like "bing". With the high vowels, the possible results are that all speakers would classify the vowel as lax; all as tense; some as lax and some as tense; or that none (or very few) would be able to consistently classify it as either tense or lax. For the non-high vowels, there are three options—[e], [ɛ] and [æ]—but the most interesting comparison will probably be between [e] and [ɛ]—especially since there seem to be contexts in which males make few distinctions between these two vowels. In addition to a word like "bang", though, words with [æn] codas like "ban" should also be tested, as the vowel formants in these two words have not proved significantly different.

If it turns out that a nasal coda is causing a preceding [æ] to raise (and, to reiterate, this is a claim that needs to be tested; the results of the present study merely suggest that the possibility might exist), then there are a few questions which should be raised. First, why is it that a coda nasal is causing the vowel to raise? Previous studies have reported some interesting results with respect to this question. Labov (1981) makes the observation that "nasals…appear to be the most favoring environment for the tensing of English low vowels in general". He reports that the low vowels—both front [æ] and back [ɑ]—appear to be tensing in several American dialects before final "front" nasals (i.e., [n] and [m]). Specifically, Labov cites evidence from dialects where [ɑ] raises to [ɔ] before [m], [n] and [ŋ], and [æ] raises to [e] before [m] and [n]. What he lacks is evidence for the raising of [æ] before [ŋ]. Zeller (1997) reports such evidence. In her study on Midwestern American English, Zeller finds that for all ten of her speakers a following velar nasal had a "significant raising effect" on [æ]. This fills in the gap in Labov's findings. What is lacking, though, is a single dialect where all six varieties of raising can be seen. A complete study of the quality of vowels before nasals in Southern Californian English might prove to be relevant to the work of Zeller and Labov. Informal tests conducted by the experimenter in fact suggest the vowel [æ] in "bam" raises to the extent that the [æ] in "ban" does, but the claim must be tested—perhaps with an experiment similar to the one conducted in the present study, but with a series of words with a bilabial nasal coda (i.e., "beam", "bim", "bame", "bem" and "bam", plus possibly "bomb"), and another series with a voiced bilabial stop coda, to match (i.e., "beeb", "bib", "babe", "beb", and "bab" and also "Bob").

Given the results of the present study, which show that [æ] has raised in the context of a nasal coda to be very near to, if not indistinguishable from, [e], a question arises as to the phonemic status of the [æ] vowel in both "bang" and "ban". In predicting how subjects will classify the vowels in "bang" phonemically, Zeller (1997) used the F1 measurement only. Using that measurement, one might predict that the speakers in the present study would classify the vowels in both "bang" and "ban" as [e]. Judging by the survey that subjects of the present study filled out, this prediction seems to hold, as nine of ten speakers indicated that they thought the vowel in "bang" was [e] (the lone detractor indicated that the vowel was [æ]). Subjects were not asked about the identity of the vowel in "ban", however, so it remains to be seen how speakers classify this raised vowel.

Though it remains to be seen, it seems unlikely that speakers who easily classify the vowel in "bang" as [e] would classify the vowel in "ban" as [e] as well. There are two main reasons for this. First, there are phonetic differences between the vowel in "ban" and the vowel in, for example, "bane". Though the vowel in "ban" is indistinguishable from the vowel in "bane" in its main F1 and F2 measurement, and in duration, the vowel in "ban" is characterized by an offglide for many speakers, represented by a sharp rise in F1 and/or drop in F2 right before the nasal closure. This accounts for less than a sixth of the duration of the vowel, whose F1 and F2 measures are otherwise level and steady. This is an example of the vowel in "ban":

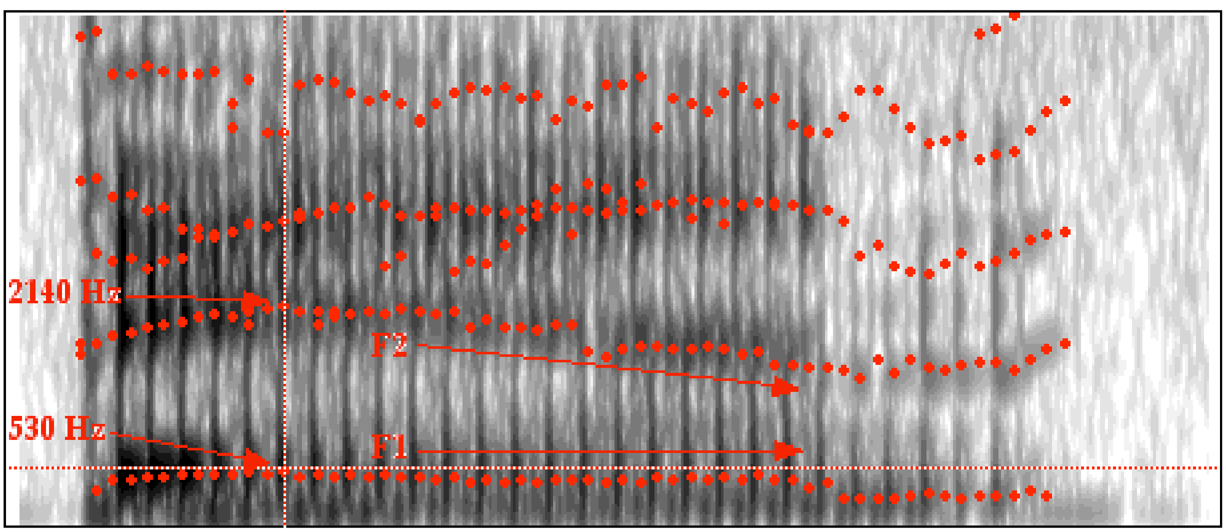


Figure 33: Sample measurement of the word "ban" using PRAAT.

The vowel in "bane", on the other hand, is characterized by either a monophthong (surprisingly common for a large number of subjects in the present study), or a gradual lowering of F1 and rising of F2, corresponding to a diphthong, which is a way the vowel [e] is frequently transcribed (see section 1.0). This is an example of the vowel in "bane":

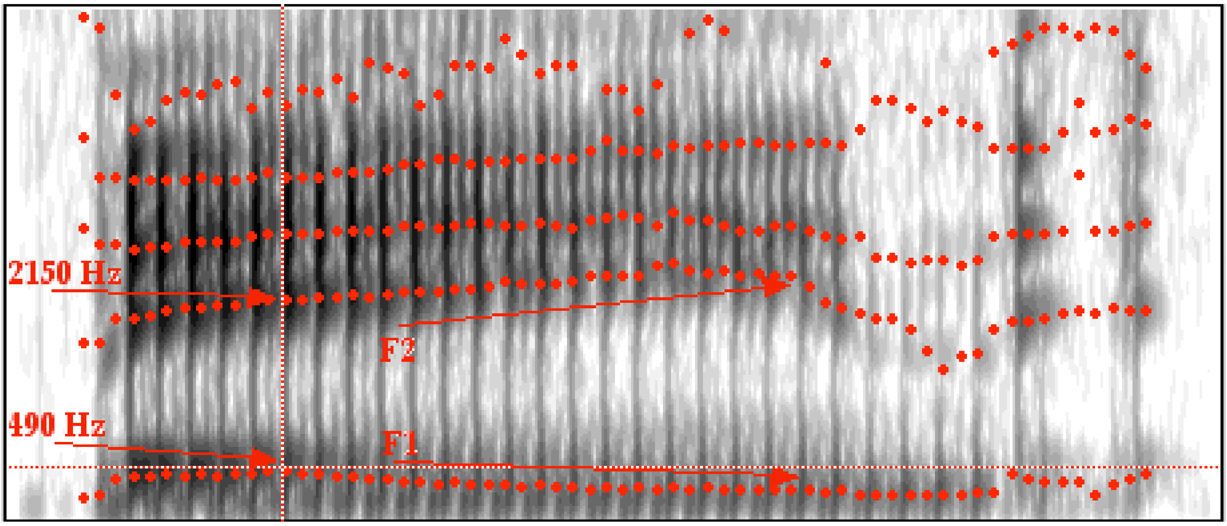


Figure 34: Sample measurement of the word "bane" using PRAAT[10].

Additionally, the vowel [ɛ] is never realized as a diphthong, and is consistently shorter than the vowels in both "bane" and "ban". So even though the vowel in "ban" and the vowel in "bad", for example, are different (a difference of nearly 300 Hz on average, for the F1 measurement), the vowel in "bane" is different enough from the vowels in "ban" and "Ben" as not to be classified with them.

The logic of this last claim is circular, though. If it were the case that "ban" is different from the vowels in both "bane" and "bad", why would there be a preference for classifying it with one vowel over the other? One might guess that the vowel to which it was closer phonetically—in this case, the vowel in "bane"—would be the one with which it would be classified. In this case, though, the opposite is predicted. Why? Additionally, the vowel in "bang" has a greater number of differences from the vowel in "bane" than does the vowel in "ban" (the three are alike in their formant

[10] Both this and the last measure come from the same speaker.

measurements, but the vowel in "bang" is shorter than the other two), yet 90% of the subjects in the present study classified the vowel in "bang" as [e]. Why, then, would the same not be true of the vowel in "ban"? Zeller (1997) brings up a simple yet important point. In English, there is no reason for children to maintain a distinction between [æ] and [e] before a velar nasal, because there are no lexical contrasts between [æ] and [e] before a velar nasal[11]. Therefore, if raising has occurred before a velar nasal, there's no pressure on speakers to think of the vowel as [æ], or to classify it as such. The opposite case holds for a low vowel before an alveolar nasal. English maintains a large number of lexical contrasts before an alveolar nasal that differ simply in the quality of a non-high front vowel (e.g., "bane", "Ben" and "ban", from the present study). Therefore, if raising has occurred, it would *not* be useful to think of the vowels in "ban" and "bane" as indistinguishable, because the difference is still maintained lexically. Compounded with this is the fact that speakers maintain a phonetic difference between these two vowels, though the difference is slight (e.g., compared to the difference between the vowels [e] and [æ] before a voiced alveolar stop).

5.0 Conclusion

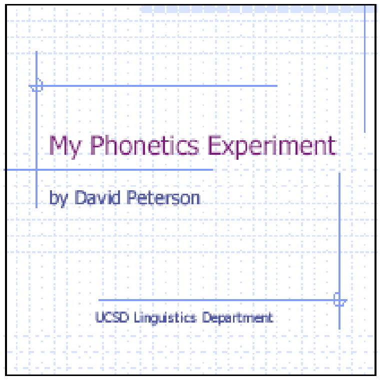
The results of the present study suggest that a sound change is in the process of taking place in Southern Californian English. Based on the results of the present study, the vowels in "bing" and "bang" have raised to the level of tense vowels (or very nearly so), as has the vowel in "ban". With respect to these three sound changes, the female speakers proved to be more conservative than the male speakers. Additionally, the raising of the vowel in "bing" seems to presuppose the raising of the vowel in "bang",

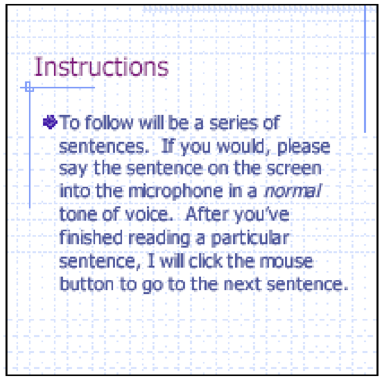
[11] The lone exception of Luol Deng is negligible.

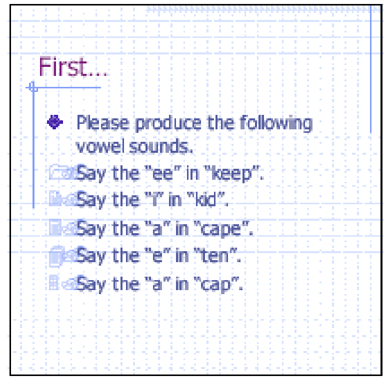
suggesting that there is a correlation between the raising of the two vowels, as predicted by Liu (2004). Place of articulation turned out not to be a crucial factor in the raising found in the present study. Additionally, the results suggest that the raising seen in Southern Californian English may actually be tensing, and not a case of simple raising. No conclusions can be made about the phonemic status of the vowels in "bing", "bang" and "ban", nor can anything be said about the cause of the raising. Nevertheless, it appears that a coda nasal is causing the preceding lax vowel to raise.

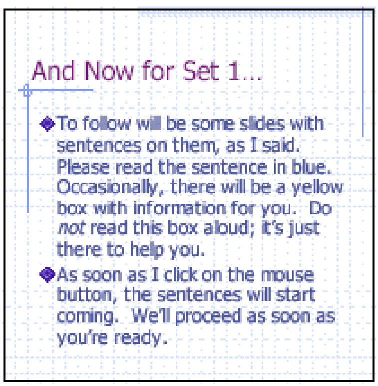
6.0 Appendix

6.1 Examples of PowerPoint Slides Used









6.2 Survey:

(1) Where are you from? ____

(2) Where are you parents from? ____

(3) Do you speak any language other than English fluently? If so, which? And for how long have you spoken this/these language(s)? ______________________
____
____

(4) In linguistics we use a different alphabet in order to phonetically transcribe speech sounds. Here are some examples:

(a)

—The vowel (underlined) in the following words is transcribed by linguists with this symbol [i]: "f<u>ee</u>t", "b<u>ea</u>d", "l<u>ea</u>n", "s<u>ee</u>".
—The vowel (underlined) in the following words is transcribed by linguists with this symbol [ɪ]: "f<u>i</u>t", "b<u>i</u>d", "s<u>i</u>n".

—Question: Which symbol would *you* use for the underlined vowel here: "s<u>i</u>ng"?__

(b)

—The vowel (underlined) in the following words is transcribed by linguists with this symbol [e]: "f<u>a</u>te", "m<u>a</u>de", "l<u>a</u>ne", "s<u>ay</u>".
—The vowel (underlined) in the following words is transcribed by linguists with this symbol [ɛ]: "g<u>e</u>t", "b<u>e</u>d", "p<u>e</u>n".
—The vowel (underlined) in the following words is transcribed by linguists with this symbol [æ]: "c<u>a</u>t", "b<u>a</u>d", "p<u>a</u>n".

—Question: Which symbol would *you* use for the underlined vowel here: "s<u>a</u>ng"?__

Thank you for completing this survey!

7.0 References

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