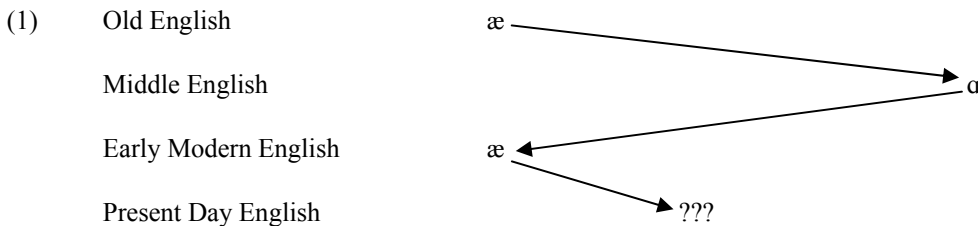


More Velar than /g/: Consonant Coarticulation as a Cause of Diphthongization

Adam Baker¹, Jeff Mielke², and Diana Archangeli¹

¹University of Arizona and ²University of Ottawa

Short-*a* is a short vowel with a long history. The present-day reflexes of short-*a* are arguably the best studied vowels in the world. As illustrated in (1), in the course of history its phonetic realization has shifted from front to back to front, and has recently shifted again in the pre-nasal context.



Present Day English exhibits a variety of short-*a* realizations, varying by dialect (cf. Labov, Ash, and Boberg 2006). In this paper we examine the realizations of short-*a* before voiced stops and nasals in Western American English. In this dialect, short-*a* is generally contrastive with neighboring vowels, with the only exception being before the velar nasal.

(2)

	<u>b</u>	<u>d</u>	<u>g</u>	<u>m</u>	<u>n</u>	<u>ŋ</u>
short- <i>a</i>	ab	bad	hag/bag	lamb	LAN	bang (?)
long- <i>a</i>	Abe	bade	Hague	lame	lane	--
short- <i>e</i>	ebb	bed	beg	LEM	Len	--

Impressionistically there are (at least) three allophones of short-*a* in Western American speech: before oral voiced stops, before [m] and [n], and before the velar nasal [ŋ]. Compare the “normal” short-*a* of *bad*, the “nasal” vowel of *bam* or *ban*, and the long-*a* ([eɪ]) of *bang*.¹ We provide acoustic data and statistical analysis that confirm these impressions.

The change of short-*a* to long-*a* in words like *bang* is similar to a change that occurs in Wisconsin English. Here the same change ([æ] to [eɪ]) is found before [g] as well: [beɪg] for *bag* (Zeller 1997; Labov et al. (2006) document an even broader geographic distribution of this change).

(3)

	West	Wisconsin
[æ]	<u>[g]</u> & <i>elsewhere</i>	<i>elsewhere</i>
[eɪ]	<u>[ŋ]</u>	<u>[g], [ŋ]</u>

There is reason to suspect a phonetic motivation for these changes. The formants of pre-velar vowels exhibit “velar pinch.” A velar pinch both raises F2 and lowers F1: precisely the changes in formants involved in a shift from [æ] to [eɪ]. The fact that short-*a* goes to long-*a* before [ŋ] and [g], or only before [ŋ], but not only before [g], can be represented with the implicational statement below.

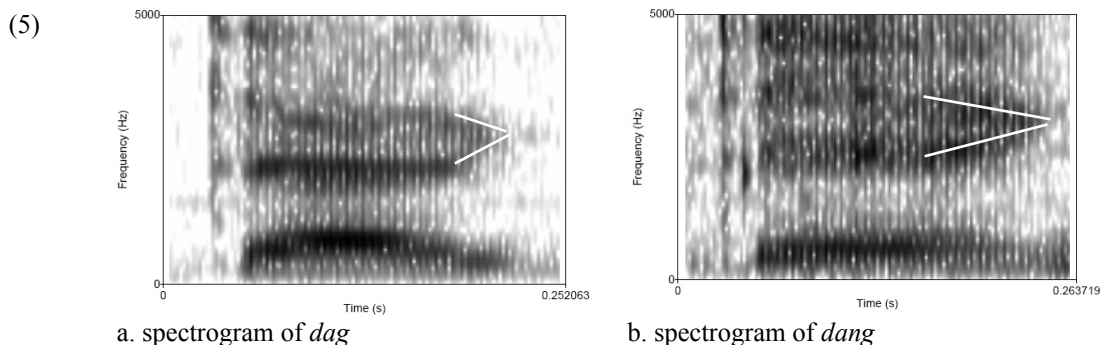
¹ Although this pattern appears not to be limited to the American West, it does not hold for all speakers of English: the *Survey of English Dialects* reports that most British dialects have a single version of short-*a*.

- (4) If [æ] → [eɪ]/ __ [g], then [æ] → [eɪ]/ __ [ŋ]

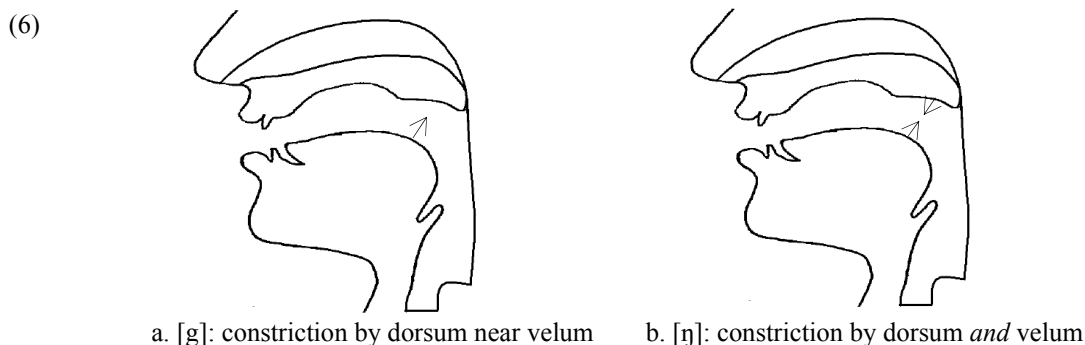
The implicational statement suggests that the velar nasal is somehow “more velar” than the velar plosive. In this paper we explore why this seems to be the case.

1. Hypotheses: How [ŋ] is more velar than [g]

Inspection of spectrogram (5a) shows the classic velar pinch in the formant trajectories of short-*a* right before [g] while, as seen in (5b), before [ŋ] the velar pinch is elongated, starting at about the midpoint of the vowel. Pre-velar long-*a* looks like short-*a* with an exaggerated velar pinch.



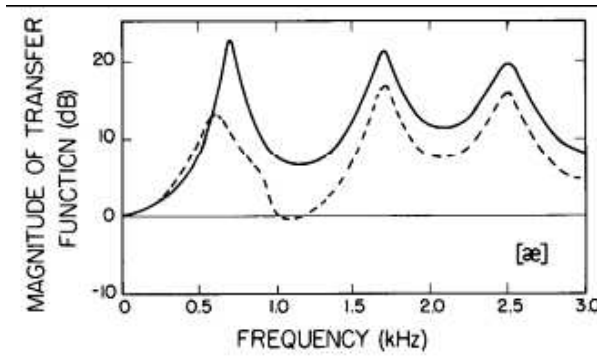
If we accept that the shift from short-*a* to long-*a* is an exaggeration of velar pinch, we must ask: why does [ŋ] have a more velarizing effect than [g]? A brief consideration of the articulations involved suggests an explanation. In the case of the velar stop, there is one factor contributing to the velar pinch, the raising of the tongue dorsum shown by the single arrow in (6a). In the case of the velar nasal, there are two factors, both the raised tongue dorsum and the lowered velum, shown by the two arrows in (6b) (images adapted from <http://www.asel.udel.edu/speech/tutorials/production/cavity.htm>).



We hypothesize that the perceived diphthongization is the result of the coarticulatory effect, not only of the raised dorsum, but also of the lowered velum. This hypothesis predicts that vowel quality changes in F1 and F2 should increase as velum lowering increases. Velum lowering can be measured indirectly by degree of nasal airflow.

Note that this hypothesis is distinct from another acoustic effect of lowering the velum: the antiresonance introduced by coupling the nasal and the oral cavities. Stevens (1999:311) predicts that for [æ] there will be a lowering of the frequency of F1, and a small decrease in amplitudes of the higher formants, shown in (7). That effect does not predict any change in the frequencies of F1 and F2.

(7)



To test the hypothesis, we recorded the speech of native speakers of English, and attempted to determine whether lowering of the velum – measured indirectly through nasal flow – indeed has an effect on F1 and F2.

2. The test

2.1. Subjects

For this study, subjects were 18 University of Arizona undergraduates from the American West. Of the eighteen subjects, twelve successfully completed the experiment. Data from the others were not included due to technical problems or inability to read stimuli. Each completed a language background questionnaire used to determine that they were from the American West.

2.2. Procedure

As subjects read the prompts, acoustic data (44,100 Hz), nasal airflow data (1375 Hz), and ultrasound data (~40 Hz) were simultaneously recorded. Oral airflow was not recorded because the oral airflow equipment is unfortunately not compatible with the ultrasound equipment.

2.3. Stimuli

Target words were “CVC” words starting with a voiced stop (b,d,g) and ending with a voiced stop or with a nasal (b,d,g,m,n,ŋ). Five front vowels were used, [æ, ε, eɪ, i, ɪ]. Where no English word existed, nonce words were substituted using standard English spelling conventions. The nonce words included sequences like “beng” in an effort to elicit [bɛŋ] (corresponding to the vowel in *length*). These efforts were unsuccessful.

Prior to recording, subjects read the prompt list aloud. Difficulties with prompts that were not attributable to dialectal variation were corrected. Data from subjects with an excessive number of mistakes that were not attributable to dialectal variation were simply discarded. In the experiment, subjects read the prompts from a computer screen, clicking to advance to the next prompt at their own pace.

2.4. Measurements

The aerodynamic data were converted to Praat format with the Crackquirer program (Baker 2006). A low pass filter at 50 Hz eliminated fluctuations attributable to voicing. This is a common procedure in analyzing airflow data (cf. Fougeron 2001, Solé 2002).

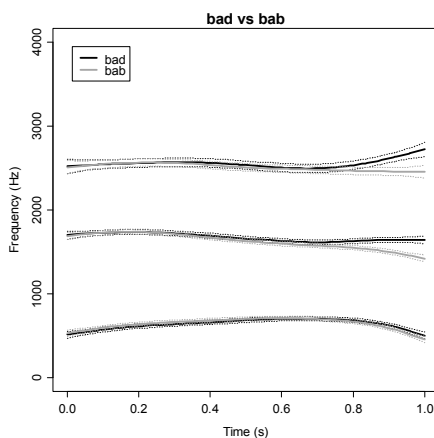
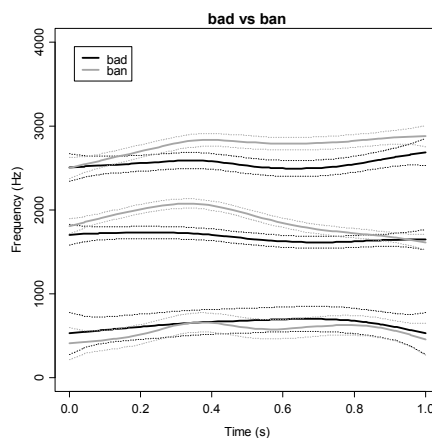
Vowel portions of the waveform were manually annotated. The first three formants were identified using LPC formant tracking, with manual adjustment of the tracking parameters for each subject. Both vowel formants and nasal airflow were extracted at 75 ms intervals with linear interpolation when necessary. The ultrasound data were not measured for this study.

The formant values were subjected to a Smoothing Spline ANOVA analysis (see Davidson 2006 and references therein). The figures below show formants during short-*a* with different following contexts for one representative speaker. Similar data obtain for all speakers (with the exception of one speaker of African American English, who had diphthongization in different contexts).

Each plot represents five tokens of two words differing in the final consonant, with time normalized. The dotted lines above and below each dark line show “confidence intervals”, indicating where there is 95% certainty about the mean. By convention, for regions where the confidence intervals of two vowels do not overlap, there is a statistically significant difference in that region.

The plot in (8a) shows the tracings for F1, F2, and F3 of the vowels for *bad* and *bab*. In this pair, the confidence intervals align except for the last fraction of a second at the very end of each vowel, where coarticulation from the following consonant accounts for the higher formants in *bad*. This high degree of similarity contrasts sharply with the distinct patterns found when the vowels of *bad* and *ban* are compared, (8b).

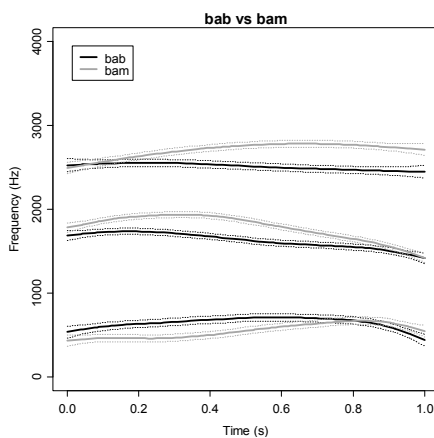
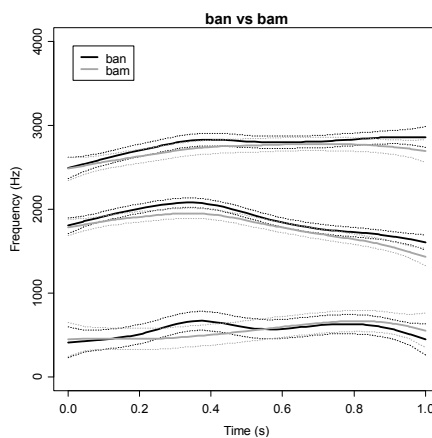
(8)

a. *bad* vs. *bab*b. *bad* vs. *ban*

With *ban* vs. *bad* the confidence intervals of both F2 and F3 overlap only at the very beginning and the very end of each vowel; even with F1 the overlap varies throughout the duration of the vowel.

Similar differences are found when the vowels of *bab* and *bam* are compared, (9a): there is virtually no overlap between confidence intervals for the three formants, except at the very beginning and the very end of each vowel. Comparison of the vowels of *ban* and *bam* (9b) shows something quite different: overlap throughout the vowel except at the very end, attributable to coarticulation with the following (different) consonants.

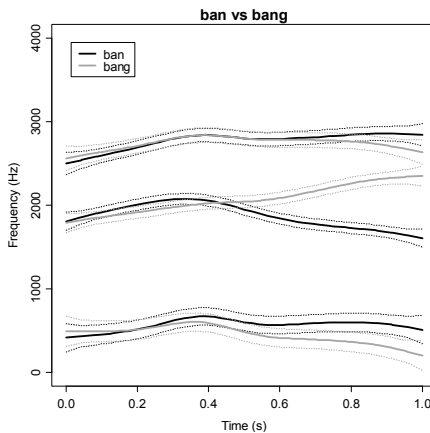
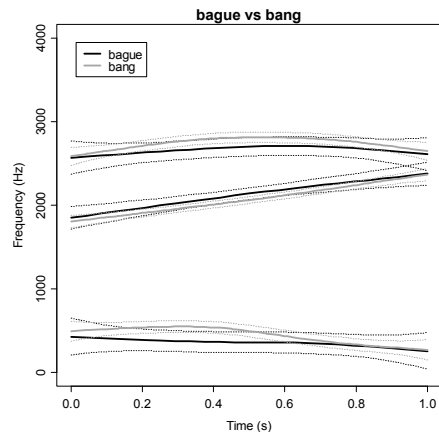
(9)

a. *bab* vs. *bam*b. *ban* vs. *bam*

These figures show that the vowels of *bad* and *bab* are distinct from those in *ban* and *bam*. Two conclusions can be drawn. First, where similarity occurs, it can be attributed to (i) same initial consonant, (ii) “same” vowel, and (iii) same final consonant. The differences follow from whether or not the final consonant is nasal. Second, the pre-nasal vowels show diphthongal tendencies, particularly noticeable in the contour of F2, which contrasts with the very flat contour of the oral F2 vowels.

The vowels of *bam* and *ban* have not merged with the vowel of *bang*, however. The plot in (10a) contrasts the formants of *ban* and *bang*. The formants diverge after the first third of the vowel, with *bang* revealing its characteristic exaggerated velar pinch, true diphthongization rather than a diphthongal tendency. A further interesting comparison is between the vowel of *bang* and that of *bague*, a nonce word that rhymes with (*The Hague*). As (10b) demonstrates, the vowel formants of *bang* and *bague* are statistically indistinguishable.

(10)

a. *ban* vs. *bang*b. “*bague*” vs. *bang*

To determine whether nasal airflow (our indirect measure of a lowered velum) contributes to velar pinch effect, we used a linear regression, with F1 and F2 as dependent variables. Shift from [æ] to [ɛɪ] is characterized by a lower F1 and a higher F2. The independent variables are explained here and summarized in (11).

Time is relevant because the formant trajectories change over time. The formant trajectory changes are nonlinear, so Time, Time², Time³ are all included, in order for the regression to fit as nearly as possible. The place of articulation of the following consonant is critical since coarticulation to that place affects the vowel formants; interaction of place with time is included too because we expect formant trajectories to be different for different places of articulation. Finally, nasal airflow is included because we are testing whether the patterns of F1 and F2 can be correlated to nasal airflow.

- (11)
- a. Time, Time², Time³
 - b. Following place of articulation (only Labial, Coronal; see below)
 - c. Interaction of Time with Place of Articulation
 - d. Nasal airflow

For the linear regression, we include words with short-*a*, including only data points from the second half of the vowel; we do not expect the preceding context to matter. The data are further restricted to include only forms with following Labial or Coronal consonants. We already know that an increase of nasal flow is correlated with a change in the vowel quality in the pre-velar context: this is the sound pattern under investigation. Thus, only tokens with final [b,d,m,n] are included.

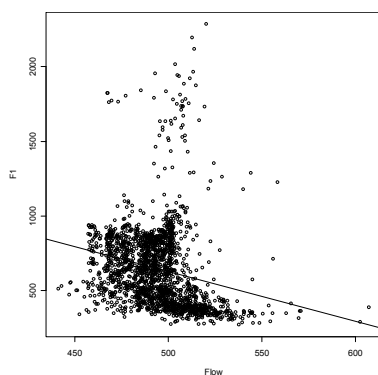
2.5. Results

The effect of nasal airflow on F2 was significant for 9 of the 12 subjects; there was a positive correlation for all subjects such that F2 becomes higher as nasal airflow increases (indicating a lower velum). Since a higher F2 correlates to a more front vowel, we can conclude that as the velum lowers, the preceding vowel becomes more front.

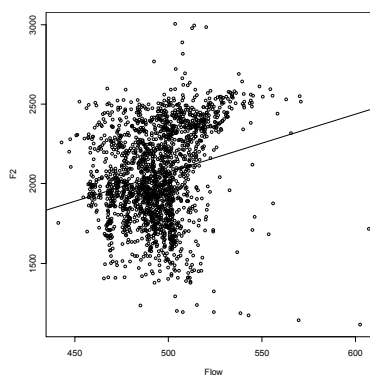
The effect of nasal airflow on F1 was significant for 10 of the 12 subjects.² This correlation was negative for 8 subjects, meaning that as the velum lowered, F1 also lowered, giving the effect of a higher vowel. For two subjects, this correlation was positive, meaning that as the velum lowered, F2 raised, indicating a lower vowel.

The correlations of nasal airflow with F1 and F2 are shown in (12), showing the negative correlation between nasal airflow and F1 in (12a) and the positive correlation between nasal airflow and F2 in (12b). There is, as expected, a great deal of variation in both F1 and F2 that does not correlate with nasal airflow. We expect variation to fall out from other factors such as the following consonant.

(12)



a. F1 (Hz) vs. Nasal airflow (ml/s)

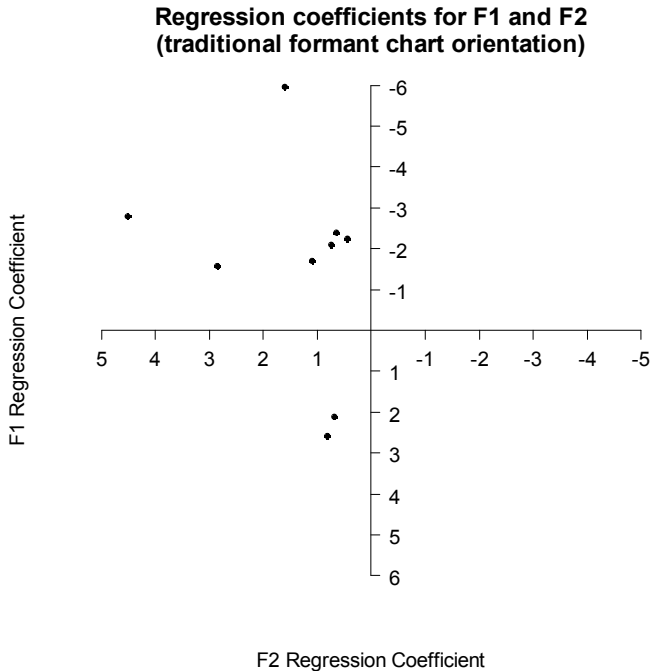


b. F2 (Hz) vs. Nasal airflow (ml/s)

Another way to view these results is by comparing the regression coefficients for F1 and F2 for each subject; these coefficients are plotted in (13). These values can be interpreted as each individual's bias towards a lowered F1 and a raised F2: in two cases the bias towards lowering F1 is negative, resulting in a raised F1. In all other cases, biases for both F1 and F2 go in the expected direction, with a lowered F1 and a raised F2 indicative of a higher, more fronted vowel.

² There were no significant effects of nasal airflow on either F1 or F2 for two subjects.

(13)



3. Discussion

The hypothesis being tested is that velum lowering for a nasal consonant both raises F2 and lowers F1 in the preceding vowel in English. The data presented here generally support this hypothesis. Lowering of the velum, as measured by nasal airflow, is associated with raising of F2, itself correlated with a more “front” vowel, an effect typically achieved by tongue body fronting. Velum lowering is also associated (usually) with lowering of F1, itself correlated with a more “high” vowel, an effect typically achieved by tongue body lowering. These two patterns together are consistent with the change of [æ] to [eɪ], the latter being the articulation of [æ] before a velar nasal [ŋ] (recall (10b), showing the formant patterns for *bang* and “*bague*”).

In this context it is interesting to compare MRI images of oral and nasal consonants. Figure (14a) shows [s] while (14b) shows [n]. Note the constriction in the velar region due to the lowered velum, found with [n] and absent in [s]. Comparing these two images also suggests that the front tube is shortened due to the constriction in the region of the velum. (For comparison, MRIs of both [ŋ] and [æ] are also included.)³

³ One point of interest is the relaxed velum position for the vowel [æ] in (14d), despite its being articulated in isolation. This may be an effect of the subject having been asked to hold the articulation position for 10 seconds in order to secure the image. Note however that there is no velum opening with [s] in (14a), suggesting in fact that the lowered velum is simply part of this subject’s general articulation of [æ]. We thank the University of Arizona’s Cognition & Neuroimaging Labs for assistance in producing the MRI images.

(14)



a. [s]



b. [n]



c. [ŋ]



d. [æ]

There are a few remaining questions. First, how do we account for the two speakers with raised F1 rather than a lowered F1? At this point, we can only offer speculation that perhaps this difference has to do with differences in velum shapes – an anatomical solution rather than a grammatical one.

A further question is why the raising of F1 in the two “anomalous” speakers does not seem to affect the sound change. There are at least two explanations. First, the tendency of the population as a whole is certainly toward lowering of F1. The mean point in the graph in (13) could be taken to represent the tendency of the population, and it would be a tendency to lower F1 and raise F2. Second, it is important to note that the tendency for increased nasal flow to raise F1 in the two speakers does not mean that these speakers’ F1 was raising during their productions of the vowel. As is well-known, a following consonant *depresses* F1. Thus, while their F1 may have been higher than it would otherwise have been, they would still be producing a vowel with a falling F1.

4. Summary and conclusion

To review the findings presented here, there is an asymmetry in short-*a* allophones across dialects, such that the pre-[ŋ] environment is the most conducive to diphthongization.

(15)

		Phonetic Context		
		___[ŋ]	___[g], ___[ŋ]	___[g]
Change	[æ] → [eɪ]	West	Wisconsin	unattested

We hypothesized that the [æ] → [eɪ] change is an exaggeration of velar coarticulation due to the confluence of the raised tongue dorsum (for the velar articulation) and the lowered velum (to allow nasal airflow). We tested this hypothesis by comparing speakers’ short-*a* formant values with their nasal airflow. The results supported the hypothesis: nasal airflow increases, F2 raises and F1 drops.

These results identify a phonetic motivation for the [æ] → [eɪ] sound change because lowering the velum encourages both fronting and raising of the preceding vowel, which in this case results in diphthongization. This result is particularly interesting because prior work on nasalization of vowels

has focused on the consequence of coupling the nasal and oral resonating cavities (e.g. Stevens 1999), not on the influence of the velum on the shape of the vocal tract.

As with most work of this type, in some ways more questions are raised than are answered. Directions we see for future research include the following. First, acoustically the vowel of *bang* and “*bague*” are identical despite possibly having different abstract vowels, /æ/ and /e/ respectively. Are the articulations the same, or are they different? If different, is the difference consistent with the abstract source vowels? Second, the hypothesis of the paper predicts that the voiceless velar [k] will have the same effect on the preceding short-*a* as does the voiced [g, ŋ]. Is this borne out? Third, the hypothesis predicts that other vowels will show the same diphthongizing effect. Is this borne out, or is [æ] special? Fourth, the results showed inter-speaker variability in the F1 effect. What is the source of this variability and what are its impacts? Finally, another pre-nasal allophony pattern in English is the merger of [ɪ] and [ɛ], e.g. in *pin/pen*. Is this merger explained by the same effects noted for short-*a*?

References

- Baker, Adam. 2006. Crackquirer (software). Available: <http://dingo.sbs.arizona.edu/~apilab/pmwiki/pmwiki.php?n=Procedures.ConvertingFlowAndPressureDataToPraatFormat>
- Davidson, Lisa. 2006. Comparing tongue shapes from ultrasound imaging using smoothing spline analysis of variance. *Journal of the Acoustical Society of America* 120(1): 407-415.
- Fougeron, Cécile. 2001. Articulatory properties of initial segments in several prosodic constituents in French. *Journal of Phonetics* 29: 109-135.
<http://www.asel.udel.edu/speech/tutorials/production/cavity.htm>
- Labov, William, Sharon Ash, and Charles Boberg. 2006. *Atlas of North American English*. Berlin: Mouton de Gruyter.
- Orton, H., E. Dieth, and the University of Leeds Department of English Language and Medieval English Literature. 1971. *Survey of English Dialects*. E.J. Arnold for the University of Leeds.
- Solé, Maria-Josep. 2002. Aerodynamic characteristics of trills and phonological patterning. *Journal of Phonetics* 30: 655-688.
- Stevens, Kenneth N. 1999. *Acoustic Phonetics*. The MIT Press.
- Zeller, Christine. 1997. The Investigation of a Sound Change in Progress: /ae/ to /e/ in Midwestern American English. *Journal of English Linguistics* 25(2): 142-155.

Proceedings of the 26th West Coast Conference on Formal Linguistics

edited by Charles B. Chang
and Hannah J. Haynie

Cascadilla Proceedings Project Somerville, MA 2008

Copyright information

Proceedings of the 26th West Coast Conference on Formal Linguistics
© 2008 Cascadilla Proceedings Project, Somerville, MA. All rights reserved

ISBN 1-57473-423-2 library binding

A copyright notice for each paper is located at the bottom of the first page of the paper.
Reprints for course packs can be authorized by Cascadilla Proceedings Project.

Ordering information

Orders for the library binding edition are handled by Cascadilla Press.
To place an order, go to www.lingref.com or contact:

Cascadilla Press, P.O. Box 440355, Somerville, MA 02144, USA
phone: 1-617-776-2370, fax: 1-617-776-2271, e-mail: sales@cascadilla.com

Web access and citation information

This entire proceedings can also be viewed on the web at www.lingref.com. Each paper has a unique document # which can be added to citations to facilitate access. The document # should not replace the full citation.

This paper can be cited as:

Baker, Adam, Jeff Mielke, and Diana Archangeli. 2008. More Velar than /g/: Consonant Coarticulation as a Cause of Diphthongization. In *Proceedings of the 26th West Coast Conference on Formal Linguistics*, ed. Charles B. Chang and Hannah J. Haynie, 60-68. Somerville, MA: Cascadilla Proceedings Project.

or:

Baker, Adam, Jeff Mielke, and Diana Archangeli. 2008. More Velar than /g/: Consonant Coarticulation as a Cause of Diphthongization. In *Proceedings of the 26th West Coast Conference on Formal Linguistics*, ed. Charles B. Chang and Hannah J. Haynie, 60-68. Somerville, MA: Cascadilla Proceedings Project. www.lingref.com, document #1656.