# Discerning the sub-phonemic identity of pre-nasal /æ/ in British Columbia English

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There are two features of /æ/ in British Columbia (BC) English that are widely attested in the literature: it is undergoing retraction and lowering and it is sensitive to the influence of certain following consonants. The present study aims to utilize both features to evaluate the phonological status of /æ/ before nasal consonants in BC English by examining the progression of sound change and the phonemic organization of /æ/ in different environments. Specifically, production and perception results are taken together to evaluate the phonetic position of pre-nasal /æ/ relative to other environments. These results are interpreted within a modular feedforward architecture of phonology to establish the phonological (*allophonic*) and phonetic (*shallowphonic*) rules that govern the internal relationships between the subphonemic elements of /æ/ in BC English. Further, the findings of this study provide evidence for the allophone being the target of sound change, rather than the phoneme.

## 1 Introduction

The sub-phonemic organization of a vowel can have important consequences for the direction and structure of sound change. However, many studies do not consider the actual phonological organization beneath the level of the phoneme and how it interacts with ongoing sound change, even if they consider the behavior of the vowel in specific conditioning environments. Although this approach is widespread in sociophonetic work, it presents a limited description of sub-phonemic elements as it can ignore the role of sub-phonemic conditioning. Alternately, it may entail the discussion of the conditioning effects of phonetic and phonological environments without distinguishing whether these effects are part of the phonetic or phonological structure of the dialect. This lack of attention to the organization of the phoneme also bypasses the opportunity to gain deeper insight into the motivation and mechanisms of sound changes, such as chain shifts. By paying careful attention to the difference between phonetic and phonological conditioning, Dinkin (2011), Fruehwald (2013), and Bermúdez-Otero (2007) have successfully been able to draw conclusions about the structure of sound change. This focus highlights a challenge for most present sociophonetic work, as it requires a way to differentiate between the roles of the phonetics and the phonology in conditioning the realization of an underlying phoneme.

The natural first step in descriptive sociophonetic work is to focus on the description of the acoustic correlates, such as formant measurements or segment duration, of particular dialect features. It is this scholarly interest that has generated a significant wealth of knowledge about Canadian English and how it patterns across the country, particularly in relation to the progression of the lowering and/or backing of front lax vowels in the Canadian Shift (Clarke, Elms & Youssef 1995; Labov, Ash & Boberg 2006; Boberg 2008; Sadlier-Brown & Tamminga 2008; Boberg 2010; Roeder 2012). However, the actual phonological organization of these regional varieties of a language tends to be under-described in the literature, particularly beneath the level of the phoneme. Despite this gap, the description of the variation across dialects can inform phonological theories and provide insight into the possible interaction between sub-phonemic entities. The logical next step in understanding the mechanisms of sound change is to interpret the phonetic descriptions of dialect features in relation to their phonological structure.

The examination of a variety of English spoken in Canada's westernmost province, British Columbia (BC), can offer insight into these relationships among sub-phonemic elements, as there

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is a solid base of sociophonetic literature describing the front lax vowels and the progression of /æ/-retraction (Esling & Warkentyne 1993, Pappas & Jeffrey 2013). While scholars note conditioning effects of phonetic or phonological environment on the realization of a phoneme (Hall 2000, Boberg 2008, Boberg 2010), such as before a nasal or a velar consonant, the implications of these patterns have not been fully explored from a phonological perspective. Specifically, very little attention has been paid in sociophonetic research to discerning the actual identity of sub-phonemic elements and how they interact with the overall trajectory of active sound changes.

The present paper adopts a generative model of phonology and uses it to evaluate the phoneme-internal organization of /æ/ in BC English. As part of a larger consideration of the front vowels in the dialect, the present paper aims to discern the phonological status of /æ/ before nasal consonants as it pertains to the phoneme overall. The goal of this paper is threefold: to describe changes in progress within a phoneme, to discern the phonological status of different phoneme-internal elements, and to test the predictions of a modular feedforward architecture of phonology.

## 2 Modular feedforward architecture of phonology

The present analysis works within the theory of a modular feedforward phonology, as first defined by Pierrehumbert (2002) and further developed by Bermúdez-Otero (2007). This approach is an explicit formalization of generative, rule-based, phonology. It is composed of discrete levels, which include lexical, phonological, and phonetic echelons. Rules are applied at the interface between two different levels and create outputs that are then fed into the derivation as the input at the next stage. This establishes a strict order whereby phonological rules are applied to lexical representations to yield the phonological representation, which is then the input to the next stage of derivation. At the following step, rules act upon abstract and discrete phonological objects, such as features. Following this, phonetic implementation rules act upon the output of these phonological rules by converting the abstract, discrete phonological representations into articulatory implementations in continuous phonetic space, resulting in the actual realization of a sound. Crucially, the application of phonetic rules is only sensitive to the output of the phonological rules and cannot access the underlying lexical representations or the identity of the phoneme.

Bermúdez-Otero (2007) argued that phonetic implementation rules result in gradient patterns in phonetic space while phonological rules yield discrete patterns. Dinkin (2011) used this model of phonology to investigate pre-nasal /æ/ in different New York dialects, as guided by the descriptions of nasal and continuous systems in Labov, Ash, and Boberg (2006). He examined their participation in the Northern Cities Shift and found evidence for both continuous and discrete patterns for /æ/ across participants. Both sub-phonemic organizations of /æ/ have a higher and more front /æ/ in the pre-nasal environment, relative to other environments. However, one system has the pre-nasal /æ/ as part of a gradient continuum with the pre-nasal and elsewhere tokens situated at opposite ends, without a discrete separation between them. For the other system, there is a discrete separation, which suggests that the vowel in each environment is a different phonological entity under the phoneme. The phonological structure of the phoneme, having a continuous or discrete pre-nasal /æ/, was found to be related to the progression of the Northern Cities Shift. Specifically, it is argued the New York dialects with a discrete nasal allophone are resistant to the /æ/-raising process because phonologically discrete entities act independently of each other in chain-shift situations, even if they are allophones of the same phoneme, and the phonologically discrete status of the pre-nasal /æ/ is able to block the raising of the rest of the phoneme.

The two systems that Dinkin (2011) described illustrate the differences between phonological and phonetic rules. Almost all speakers showed evidence for pre-nasal /æ/ being associated with lower F1 values than other /æ/ tokens, regardless of whether this process created a discrete allophone. For those that have a continuous pattern, this raised position is a result of phonetic implementation rules. For those with a discrete pattern, the raising is initiated by a phonological rule. The modular feedforward architecture of phonology thus predicts two distinct sub-phonemic levels: that which is the output of phonological rules and that which is the output of the phonetic implementation rules.

### 2.1 Sub-phonemic elements

Figure 1 shows the productions of /æ/ by an individual speaker, a twenty-two-year-old female speaker from North Vancouver, and depicts the difference between the application of rules at the levels of the phonetics and the phonology. There are two discrete groupings of tokens of /æ/ that show no overlap. One of these clusters includes productions where the vowel precedes a voiced velar sound (/g/ or /ŋ/), being higher and more front in the vowel space, and the other contains tokens of /æ/ in other pre-nasal environments (/m/ and /n/) and elsewhere.[1] This suggests that these two conditions differ on the level of phonological features, as they "occupy discrete, largely nonoverlapping regions in phonetic space" (Bermúdez-Otero 2007:499), and so the clear separation between the groups is indicative of a rule that operates in the phonology. Within the pre-velar cluster, there appears to be some difference between /æŋ/ and /æg/ productions where the former is generally higher. However, these tokens form an "unbroken phonetic continuum" (Bermúdez-Otero 2007:499), which suggests that /æŋ/ and /æg/ may be a part of the same phonological entity, meaning that they are only distinguished by a phonetic implementation rule.

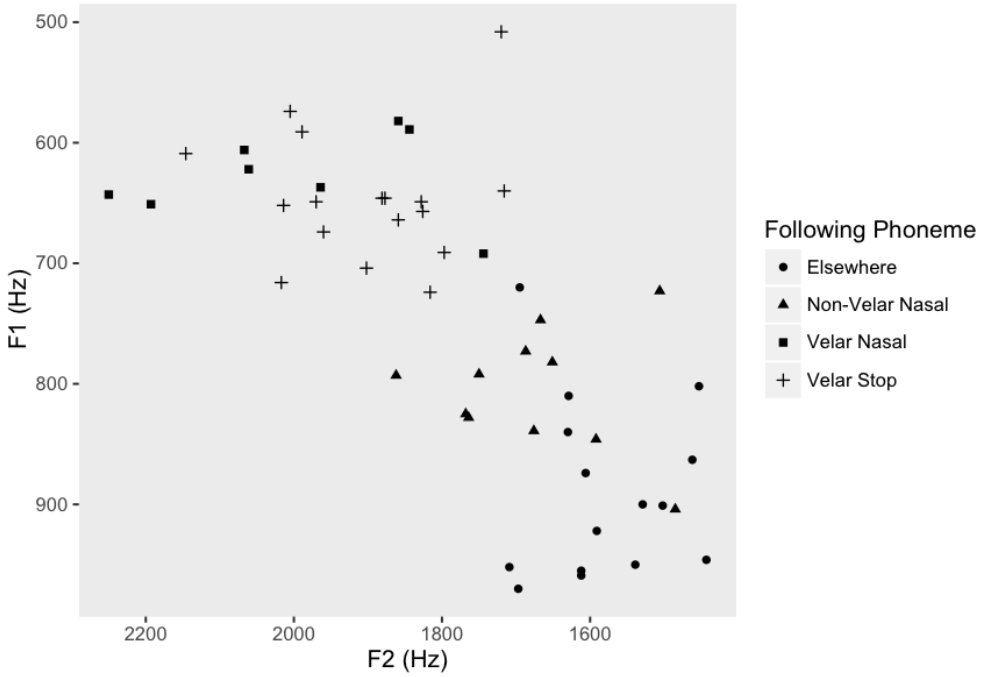


Figure 1. F1 and F2 values for /æ/ in different environments, as produced by a speaker of BC English

The term "allophone" is traditionally used in sociophonetics to refer to environmentally conditioned effects on the realization of a phoneme without discriminating between whether the conditioning takes place at the level of the phonetics or the phonology. However, the modular feedforward architecture of phonology distinguishes between them and therefore it is not sufficient to rely upon this usage. Instead, I propose the use of the term "allophone" to refer strictly to the output of the phonological rules. Allophones are discrete phonological entities, such as the pre-velar cluster in Figure 1. However, there is no common term to capture the contextually-conditioned output of the gradient phonetic rules, such as the difference between the vowel before /g/ and /ŋ/ in Figure 1. In order to address this dearth, I propose the term *shallowphone* to refer to the sub-allophonic distributions that are the product of rules that create the differences between particular phonetic environments. This term is derived from the common term *allophone*, which represents the level above it, and implies a less substantial depth. This lack of depth can be

[1] "Elsewhere" refers to /æ/ before obstruents, including /k/, but with the exclusion of /g/.

understood in the present context to refer to structural abstraction. This yields a phonological organization where the phoneme is composed of allophones, which are the output of phonological rules, and these in turn consist of a continuous distribution of shallowphones, which are the output of phonetic rules.

While it is possible to assess the phonological status of the environments in the given figure by determining whether there is a visible discrete separation at the nucleus, an additional method would be to observe behavior in apparent time, as shallowphonic "trajectories over time are yoked together, and are not independent" (Fruehwald 2013:3). In contrast, allophonic units should be able to move autonomously because they are phonologically discrete and therefore may be sensitive to different rules. Overall, the internal conditioning of the phoneme, whether it is allophonic or shallowphonic, is predicted to impact how it will behave in sound change.

## 3 British Columbia (BC) English

The phonetic properties of the low front vowel, /æ/, in BC English have been examined in great detail since Esling and Warkentyne's (1993) seminal description of the retraction of /æ/ in Vancouver English. This variable has a relatively long history of undergoing change in this dialect, as well as patterning with Canada-wide changes attested across the country.[2] In particular, the lowering and backing of /æ/ is a productive element of the Canadian Shift which describes a chain shift affecting the front vowels where /ɪ/ lowers toward /ɛ/, /ɛ/ to /æ/, and /æ/ moves back toward /ɑ/ (Clarke, Elms & Youssef 1995). Speakers of BC English have been found to participate in this change (Boberg 2008, Boberg 2010). Two decades after the initial description, Pappas and Jeffrey (2013) evaluated the status of the retraction of /æ/ in Vancouver English and concluded that it is still progressing, with male speakers lagging behind by a generation and young female speakers being the most advanced. However, they did not make reference to specific environments in relation to the retraction pattern.

Boberg (2008, 2010) examined the relative height of /æ/ before a front nasal and before /g/ in a synchronic consideration of English across Canada, including in BC. He reported a "continuous" short-*a* pattern, in which /æ/ is raised more before front nasals than before /g/ (Boberg 2010:207), though this varies across the country. Raising was found in both conditions with twelve speakers of BC English, and a considerably smaller Cartesian distance between /æN/[3] and /æg/ from the general phoneme than other regional dialects. Swan (2015) considered English spoken in Vancouver and Seattle, finding less raising for /æN/ than /æg/ across nineteen speakers between the ages of eighteen and thirty-six from BC. She further found that the male speakers were more prone to raising /æ/ in the pre-front nasal condition. Therefore, since Boberg (2008, 2010) described greater raising preceding a front nasal and Swan (2015) found less raising in this condition than expected, there is evidence for a change in progress that is affecting the pre-front nasal /æ/. However, this conclusion is limited in the consideration of previous work due to a limited number of participants or a relatively small age range considered.

Previous work on BC English, when considered as a whole, suggests that there is a change in progress. In particular, the general /æ/ phoneme is reported to be undergoing retraction as expected within the Canadian Shift. However, this retraction does not seem to be reflected across all the environments where /æ/ appears. Specifically, /æ/ before /g/, in words like *bag*, is described in the literature as high while there are different reports of the pre-nasal variant before /n/ in words like *ban*, ranging from being realized with a similar F1 to /æg/ or produced lower in the vowel space. The present study aims to expand upon the previous work by providing a detailed description of the phonetic changes and discerning the phoneme-internal phonological status of the different allophones and shallowphones within /æ/. This, in turn, will then be used to test the predictions of the modular feedforward architecture of phonology, which suggest the presence of distinct

[2] Of course, it is important to recognize that this variable is of interest in many regions aside from British Columbian and Canadian English. Though discussing these is outside the scope of the present paper, I suggest that readers examine Zeller (1997); Labov, Ash, and Boberg (2006); Bauer and Parker (2008); Purnell (2008); Freeman (2014); and Wassink (2015), among others, for further discussion of the behavior of /æ/ in different environments in additional dialects.

[3] The notation /æN/ refers to /æn/ and /æm/, at the exclusion of /æŋ/.

phonetic and phonological rules. On a phonetic level, this paper aims to clarify whether /æ/ is lowering before front nasal consonants and whether this patterns with either /æg/ or the general phoneme. On a phonological level, I aim to discern whether /æ/ before the voiced velar /g/ and /æ/ before a front nasal are categorically distinct allophones, whether /æ/ before /ŋ/ is a shallowphone of the velar or the nasal condition, and if the pre-front nasal /æ/ is continuous with the general phoneme or a phonologically discrete entity.

# 4 Methodology

## 4.1 Participants

Sixty-five speakers of BC English were participants in this task, thirty-six female and twenty-nine male.[4] The ages ranged between thirteen and sixty-two, with a mean of thirty. A breakdown of number of speakers by gender and decade of birth is shown in Table 1. All speakers had lived in BC for at least a decade before age eighteen. Only four of the speakers were not monolingual, though English was a native language for all participants.

| Decade of Birth | Male | Female |
|---|---|---|
| 1950-1959 | 0 | 3 |
| 1960-1969 | 3 | 4 |
| 1970-1979 | 2 | 5 |
| 1980-1989 | 9 | 9 |
| 1990-1999 | 14 | 13 |
| 2000-2009 | 1 | 2 |

Table 1. Participant gender and decade of birth

## 4.2 Procedure

### 4.2.1 Production

Participants were instructed to read a list of 218 words that included all the vowels in Canadian English across several environments with attention to following phoneme, including before nasal and velar consonants. The wordlist can be found in the appendix. Sound files were recorded on a Blue Tiki USB Microphone in a .wav format. The maximum amplitude was normalized to -1.0dB and DC offset was removed. FAVE was used for forced alignment and vowel extraction (Rosenfelder, Fruehwald, Evanini & Yuan 2011). The vowel measurements were taken from the nucleus, at about 35% of vowel duration, and the offglide, at 80% of vowel duration and normalized using FAVE's default function. This resulted in 3397 tokens of /æ/ produced by 65 speakers that include the environment before a front nasal, /æŋ/, /æg/, and an elsewhere condition, which is comprised of /æ/ before other obstruents.

### 4.2.2 Perception

There was a brief perceptual task that was akin to syntactic grammaticality judgments and meant to assess the perceptual inclination of the participant regarding /æ/ with attention to their own production. Participants were shown flashcards with words printed on them in five distinct trials, such as *tag*, *tap*, and *tan*. They were instructed to first read the words out loud. Following each set, composed of two to three words, participants were asked a question related to the vowels. The stimuli words and questions are shown in Table 2, though only the results from the first three trials are reported in the current analysis. These questions were structured such that the researcher pointed at the relevant card in the question in lieu of pronouncing the target word, meaning that the question was phrased as "Does this word sound more like this one or this one?" This protected

[4] There were initially sixty-seven participants, but acoustic data from two of the speakers was excluded in the current analysis due to poor audio quality that hindered reliable acoustic measurement.

against any bias that the researcher's pronunciation might have on the task and further brought the participants' attention to their own speech as they were encouraged to repeat the words if it helped. If the participant could not make a judgment call, this was noted as *neither*.

1. Does the vowel in (TAN) sound more like the one in (TAP) or in (TAG)?
2. Does this vowel in (RAN) sound more like the one in (RANG) or in (RAG)?
3. Does this vowel in (BANG) sound more like the one in (BAG) or in (BAN)?
4. Does this word (BAG) rhyme with this one (VAGUE)?
5. Does the first syllable of this word (MAGAZINE) sound like this one (MEG)?

Table 2. Perceptual stimuli and questions

# 5 Results

## 5.1 Production

The measurements taken at the nucleus across all participants, shown in Figure 2, reveal raising for the front nasal condition and the two velar conditions relative to the elsewhere condition, which excludes sonorant consonants in the present analysis. As in Boberg (2010), there is a considerable amount of individual variation regarding the articulation of /æ/. The mean F1 values, shown in Table 3, across all tokens are 737 Hz for /æN/, 718 Hz for /æg/, 706 Hz for /æŋ/, and 854 Hz for /æ/ in the elsewhere condition. At the nucleus, there is substantial overlap between /æg/, /æŋ/, and before a front nasal consonant, while the elsewhere articulations are, on average, over 100 Hz higher on the F1 dimension. Additionally, the F1 of /æŋ/ appears to be closer to the F1 of /æg/ than the other nasal consonants. Though Figure 2 suggests similar values for the vowel height of these three environments, which exclude the elsewhere environment, a regression shows that the following phoneme is a significant predictor of F1 ($p$ = 3.29 x $10^{-12}$). The results of individual *t*-tests between each of the environments, including the elsewhere condition, are shown in Table 4.

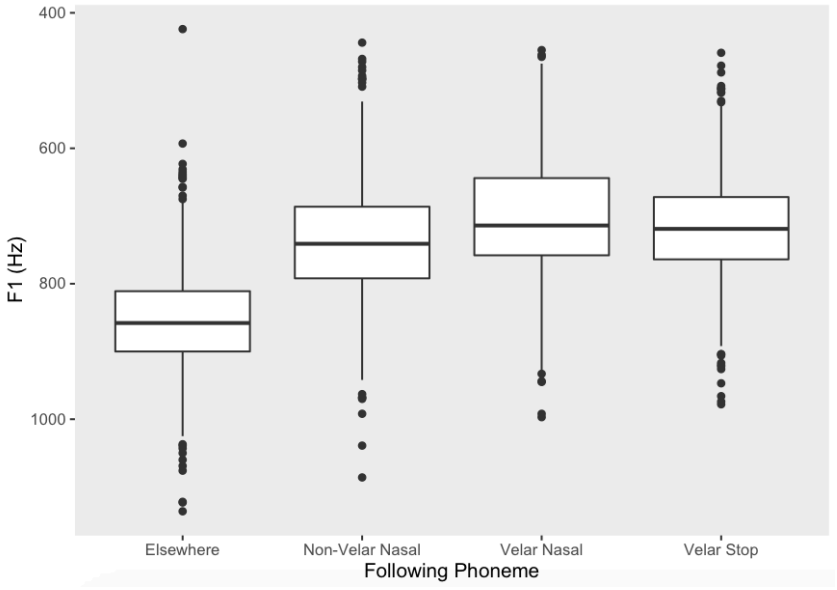


Figure 2. F1 of /æ/ at nucleus by following phoneme

| | Elsewhere | Non-velar nasal | /ŋ/ | /g/ |
|---|---|---|---|---|
| Nucleus F1 (Hz) | 854 (74) | 737 (87) | 706 (86) | 718 (73) |
| Offglide F1 (Hz) | 826 (96) | 774 (101) | 683 (93) | 638 (79) |

Table 3. Mean F1 with SD at nucleus and offglide, by following phoneme

| Following Consonant | /g/ | /ŋ/ | Elsewhere |
|---|---|---|---|
| Non-velar nasal | $9.90 \times 10^{-7}$ | $1.30 \times 10^{-9}$ | $1.56 \times 10^{-150}$ |
| /g/ | | 0.0084 | $1.98 \times 10^{-271}$ |
| /ŋ/ | | | $1.98 \times 10^{-152}$ |

Table 4. *p*-values for *t*-tests between nucleus F1 by following consonant

Though there is a pattern of overlap for mean vowel height at the nucleus across three of the conditions, this is not mirrored in the measurements at the offglide. As shown in Figure 3, at 80% of total vowel duration, the average height of the pre-front nasal /æ/ lowers toward the values found for the elsewhere condition, as demonstrated in the spectrograms in Figure 4 and Figure 5, while the height of the vowel before /g/ rises to surpass its counterpart before /ŋ/, as shown in Figure 6. The mean value for the first formant across all participants for /æN/ at the offglide is 775 Hz, 638 Hz for /æg/, 683 Hz for /æŋ/, and 826 Hz for the elsewhere condition. These are shown in Table 3, along with the corresponding mean values at the nucleus. Both /æg/ and /æŋ/ have upward trajectories at the offglide that show some amount of overlap, while the pre-nasal and elsewhere /æ/ are articulated relatively low at the end of the vowel. Table 5 shows the results of *t*-tests at the offglide, where each yields a significant *p*-value.

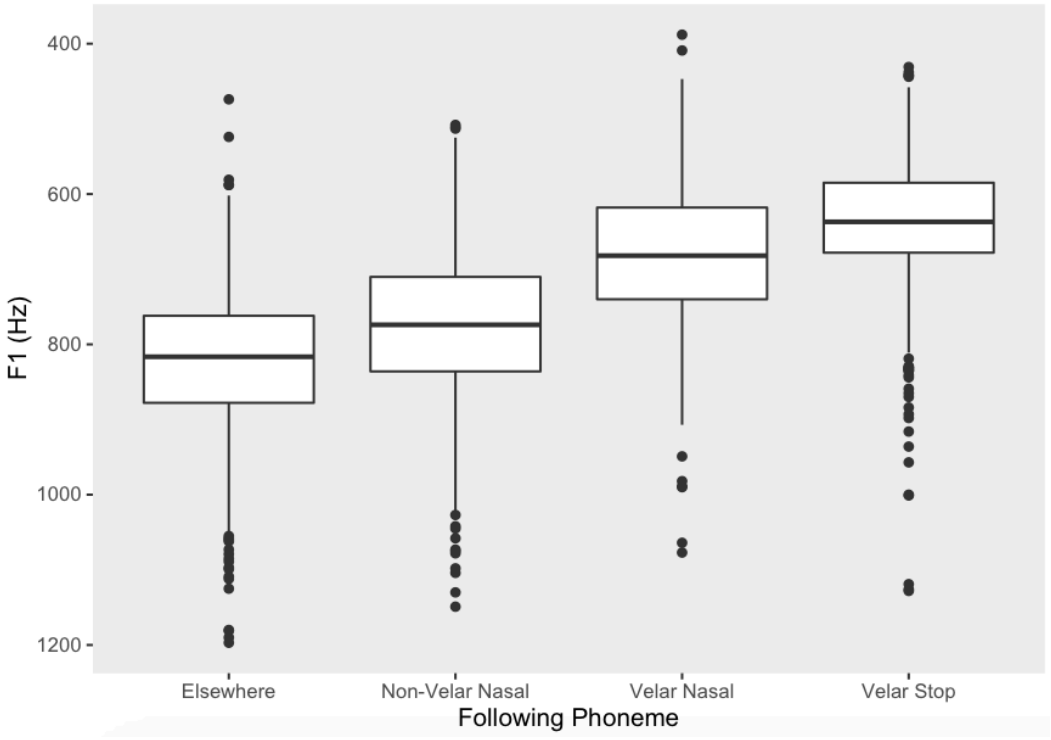


Figure 3. F1 of /æ/ at offglide by following phoneme

| Following Phoneme | /g/ | /ŋ/ | Elsewhere |
|---|---|---|---|
| Non-velar nasal | $4.03 \times 10^{-158}$ | $1.30 \times 10^{-53}$ | $2.03 \times 10^{-25}$ |
| /g/ | | $7.58 \times 10^{-20}$ | $4.27 \times 10^{-220}$ |
| /ŋ/ | | | $1.80 \times 10^{-123}$ |

Table 5. *p*-values for *t*-tests between offglide F1 measurements, by following phoneme

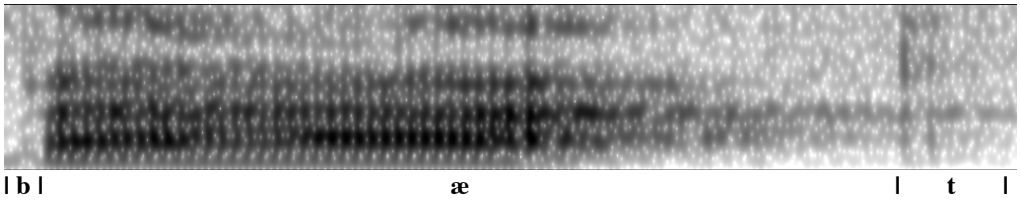


Figure 4. "bat" as produced by a 46F speaker

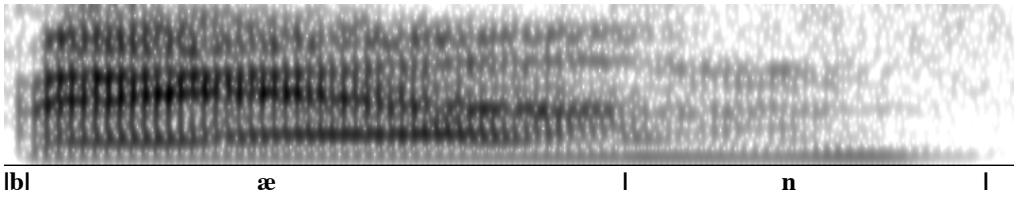


Figure 5. "ban" as produced by a 46F speaker

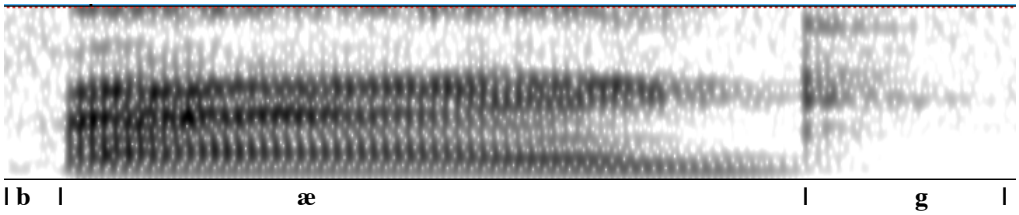


Figure 6. "bag" as produced by a 46F speaker

Overall, there are significant differences between F1 measurements at the offglide in each paired test, which are represented in two key patterns found in individual productions. For about 54% of speakers, there is little to no overlap at the offglide between /æ/ before a velar consonant (/ŋ / or /g/) and before a front nasal. The remaining 46% have a more continuous pattern between the two conditions. Individual productions for two female speakers from Maple Ridge are shown in Figure 7, where the forty-four-year-old, on the left, has a discrete pattern, and the fifty-three-year-old, on the right, has a continuous pattern.

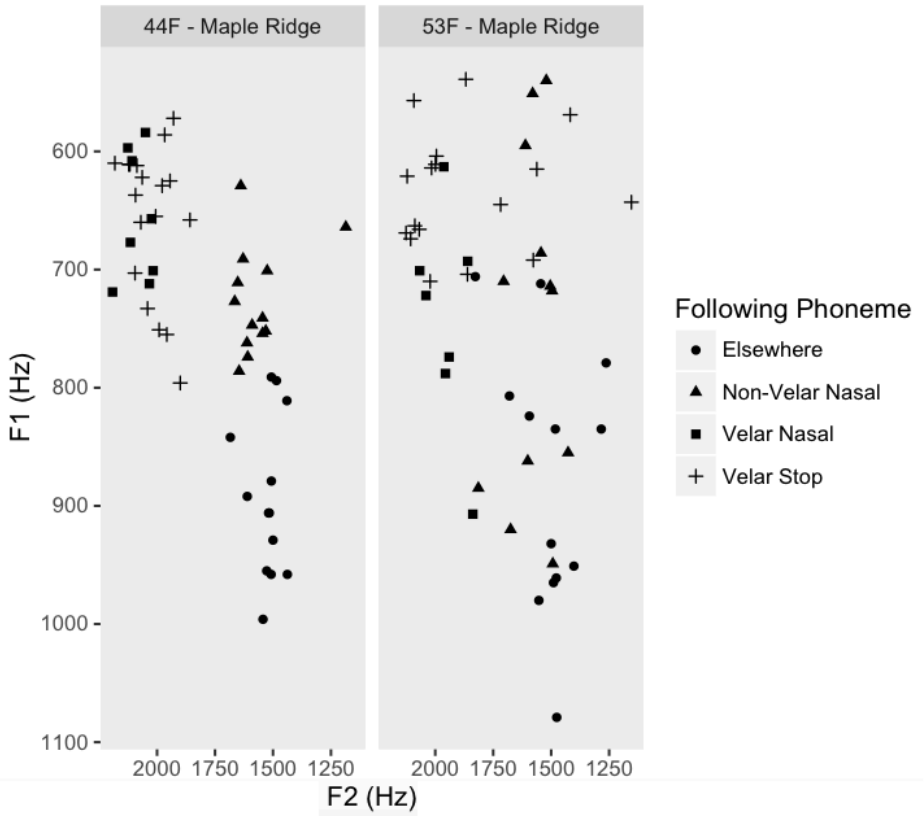


Figure 7. /æ/ at the offglide for two speakers, by following phoneme

Further, the height of /æ/ at the offglide appears to be changing in apparent time, as shown in Figure 8. A multiple linear regression with the elsewhere condition as the reference level, shown in Table 6, reveals that the interaction between age and following phoneme is a significant predictor of offglide F1, while gender is not. Individually, age is a significant predictor of offglide F1 for the elsewhere condition, as shown in Table 7. The young speakers, of both genders, have lower F1 values at the offglide, suggesting that the offglide of /æ/ in these environments is raising in apparent time. The correlation between age and offglide height is significant before /g/, indicating raising, or a front nasal, indicating lowering. However, the same relationship is not significant for the vowel before /ŋ/. Despite offglide height being significant for /æg/ and highly insignificant for /æŋ/, the interaction between age and following phoneme on vowel height is not significant, as shown in Table 8. This indicates that the offglides of /æ/ before the two velar consonants do not appear to be moving in substantially different directions, despite having some significant height distinctions at the offglide.

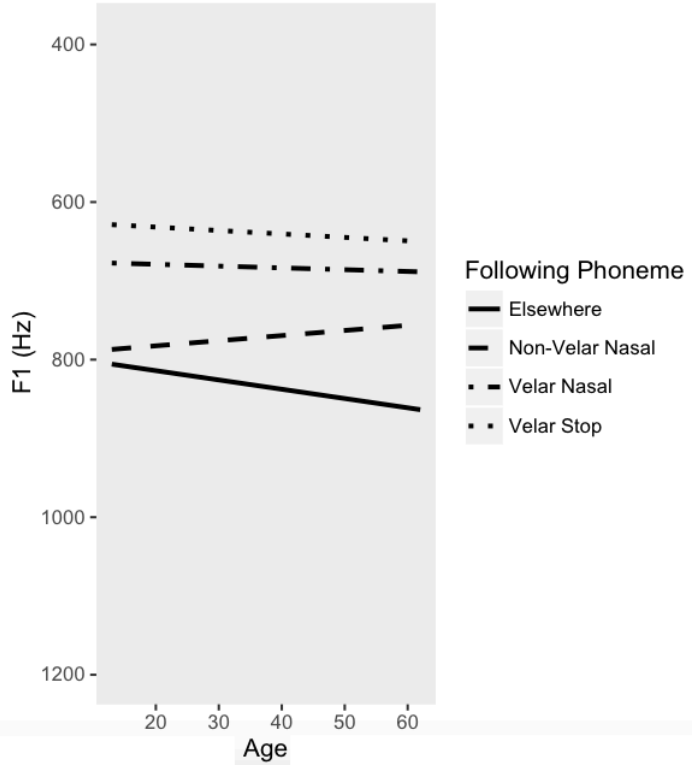


Figure 8. /æ/ F1 at offglide in apparent time, by following phoneme

| | Coefficient | *t*-value | *p*-value |
|---|---|---|---|
| Non-velar nasal | 5.0787 | 0.398 | 0.6910 |
| /ŋ/ | –115.9212 | –8.134 | $5.84 \times 10^{-16}$ |
| /g/ | –167.3996 | –14.693 | $< 2 \times 10^{-16}$ |
| Age | 1.1960 | 4.568 | $5.11 \times 10^{-6}$ |
| Male | 2.6323 | 0.809 | 0.4187 |
| /g/:Age | –0.7419 | –2.121 | 0.0340 |
| /ŋ/:Age | –0.9522 | –2.172 | 0.0299 |
| Non-velar nasal:Age | –1.8297 | –4.661 | $3.28 \times 10^{-6}$ |

Table 6. Effect of age, gender, and following phoneme on offglide F1

| | Coefficient | *t*-value | *p*-value |
|---|---|---|---|
| Elsewhere | 1.1788 | 4.326 | $1.68 \times 10^{-5}$ |
| /g/ | 0.4366 | 2.176 | 0.0298 |
| /ŋ/ | 0.2271 | 0.633 | 0.527 |
| Non-velar nasal | -0.6500 | -1.976 | 0.0485 |

Table 7. Correlations for environment (age as predictor of offglide F1)

| | Coefficient | *t*-value | *p*-value |
|---|---|---|---|
| Age | 1.1788 | 4.326 | $1.68 \times 10^{-5}$ |
| /g/ | -0.6500 | -1.976 | 0.0485 |
| Age: /g/ | 0.2271 | 0.633 | 0.527 |

Table 8. Age and following phoneme as predictor of offglide F1 for pre-velar (/ŋ/ and /g/) /æ/

Examining the patterns at the nucleus within each condition, by age and gender, reveals sound change in apparent time. Multiple linear regressions, shown in Table 9 and Table 10, yield a significant interaction between age and gender on vowel height and backness in the elsewhere condition.

| | Coefficient | *t*-value | *p*-value |
|---|---|---|---|
| Age | 0.1660 | 0.673 | 0.5012 |
| Male | 12.0066 | 0.816 | 0.4149 |
| Age:Male | –1.0753 | –2.279 | 0.0229 |

Table 9. Age and gender as predictor of nucleus F1 for elsewhere /æ/

| | Coefficient | *t*-value | *p*-value |
|---|---|---|---|
| Age | 1.6473 | 4.065 | $5.23 \times 10^{-5}$ |
| Male | 110.671 | 4.577 | $5.37 \times 10^{-6}$ |
| Age:Male | –1.6759 | –2.162 | 0.0309 |

Table 10. Age and gender as predictor of nucleus F2 for elsewhere /æ/

Figure 9 shows the vowel height (F1) and Figure 10 shows the frontness (F2) of /æ/ at the nucleus in the elsewhere condition. This reveals two changes in apparent time, represented by the correlations reported in Table 11. This includes the lowering of /æ/ for male speakers and the backing of /æ/ for the female speakers over apparent time. The increase of F1 by age for male speakers is slightly significant and the decrease of F2 by age for female speakers is highly significant. The two other measures, F1 of female speakers and F2 of male speakers, show no evidence of change in progress. Therefore, the ongoing retraction and lowering of /æ/ in the Canadian Shift is reflected in lowering for male speakers and retraction for female speakers. Further, Figure 9 shows that the male speakers are catching up to the female speakers in regard to vowel height, while Figure 10 reveals that female speakers are leading in the backing process.

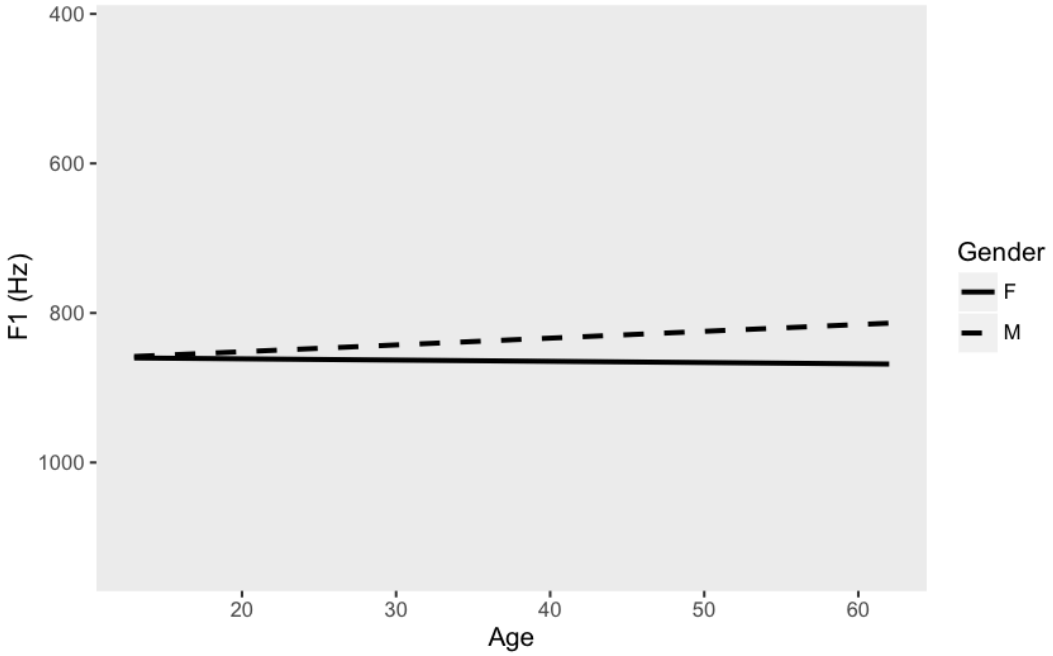


Figure 9. Nucleus F1 of elsewhere /æ/ by age and gender

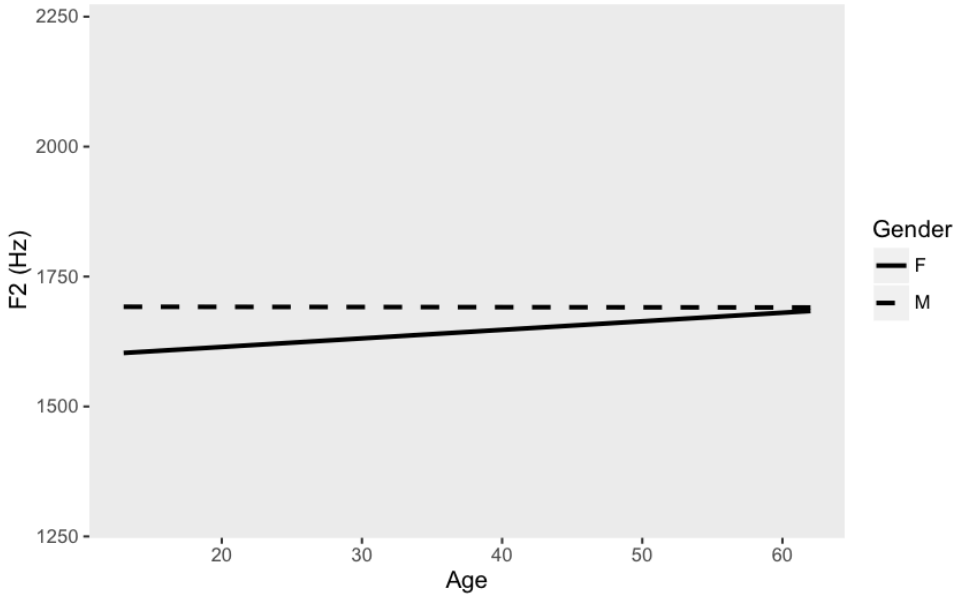


Figure 10. Nucleus F2 of elsewhere /æ/ by age and gender

| | Coefficient | *t*-value | *p*-value |
|---|---|---|---|
| Female – Nucleus F1 | 0.1660 | 0.2482 | 0.504 |
| Male – Nucleus F1 | –0.9093 | –2.277 | 0.0233 |
| Female – Nucleus F2 | 1.6473 | 4.029 | $6.48 \times 10^{-5}$ |
| Male – Nucleus F2 | –0.02853 | –0.044 | 0.965 |

Table 11. Correlations for elsewhere /æ/ formants with age as predictor, by gender

The interaction of age and gender also proves to significantly influence vowel height before a nasal consonant in a mixed linear regression model, as shown in Table 12.[5] Therefore, the height of pre-front nasal /æ/, shown in Figure 11, is undergoing change, as demonstrated by the tokens produced by female speakers. The regression line for the women shows substantial lowering, reflected in increasing F1 values for the younger speakers, over apparent time. As demonstrated with the correlations in Table 13, this is highly significant for the female speakers, while there is no apparent trend for the males. This depicts lowering of pre-front nasal /æ/ for female speakers of BC English that does not appear to be affecting the male speakers at this time.

| | Coefficient | *t*-value | *p*-value |
|---|---|---|---|
| Age | –1.5628 | –4.852 | $1.49 \times 10^{-6}$ |
| Male | –60.1441 | –3.160 | 0.00164 |
| Age:Male | 1.3034 | 2.146 | 0.03221 |

Table 12. Age and gender as predictor of nucleus F1 for elsewhere /æ/

| | Coefficient | *t*-value | *p*-value |
|---|---|---|---|
| Male | –0.2594 | –0.524 | 0.601 |
| Female | –1.5628 | –4.71 | $3.4 \times 10^{-6}$ |

Table 13. Correlations for /æ/ before a front nasal nucleus F1 with age as predictor, by gender

[5] There was no significant change in apparent time on the F2 dimension for the non-velar nasal or voiced velar obstruent environments and these measurements are not relevant to the present analysis.

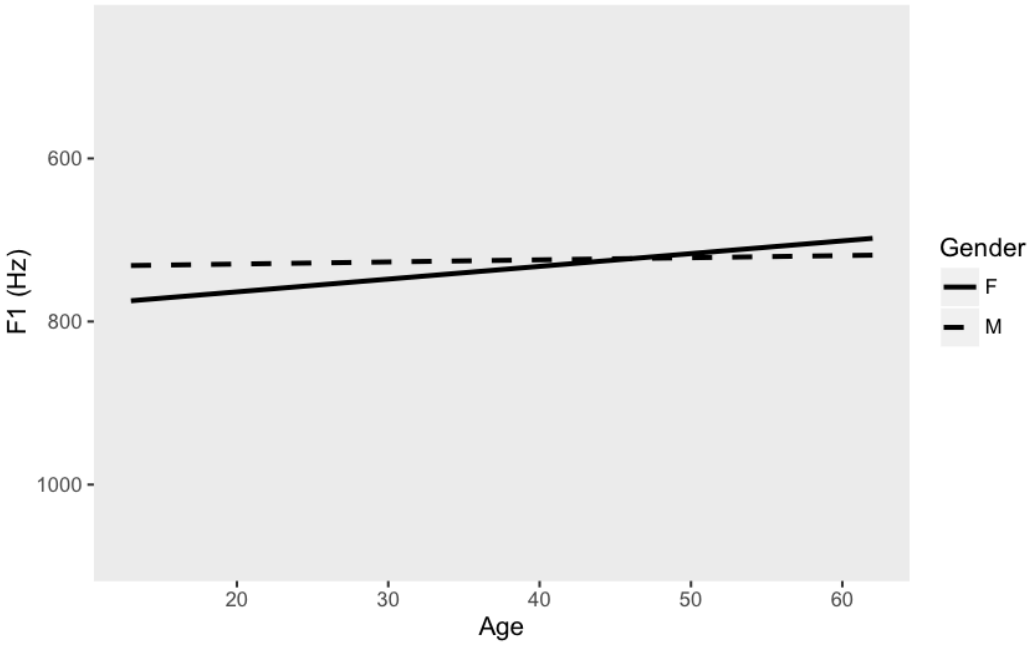


Figure 11. Pre-front nasal nucleus F1 (Hz) by age and gender

In a mixed linear regression that considers the interaction between age and following phoneme for the two velar conditions, there is no significant difference in apparent time between the vowel height of /æŋ/ and /æg/ at the nucleus, as shown in Table 14. The vowel height for /æ/ before the velar consonants over time shows a general trend toward raising across both conditions. Across all speakers, age has a significant effect on the F1 of /æ/ before the velar consonants, as shown in Table 15. However, there is no significant interaction between gender and age on F1 measurements at the nucleus. This is shown in Figure 12, broken up by gender, with female participants on the top and age represented along the x-axis. Both genders show a tendency for younger speakers to articulate /æ/ higher before a voiced velar consonant.

| | Coefficient | *t*-value | *p*-value |
|---|---|---|---|
| Age | 0.75598 | 2.542 | 0.0111 |
| Following Phoneme | 11.20732 | 0.967 | 0.3339 |
| Age:Following Phoneme | 0.05443 | 0.153 | 0.8787 |

Table 14. Age and following phoneme as predictors of nucleus F1 for /æ/ before a velar (/ŋ/ or /g/)

| | Coefficient | *t*-value | *p*-value |
|---|---|---|---|
| Age | 0.9453 | 4.847 | $1.37 \times 10^{-6}$ |
| Male | 17.8301 | 1.528 | 0.127 |
| Age:Male | –0.4137 | –1.105 | 0.269 |

Table 15. Age and gender as predictor of nucleus F1 for /æ/ before a velar (/ŋ/ or /g/)

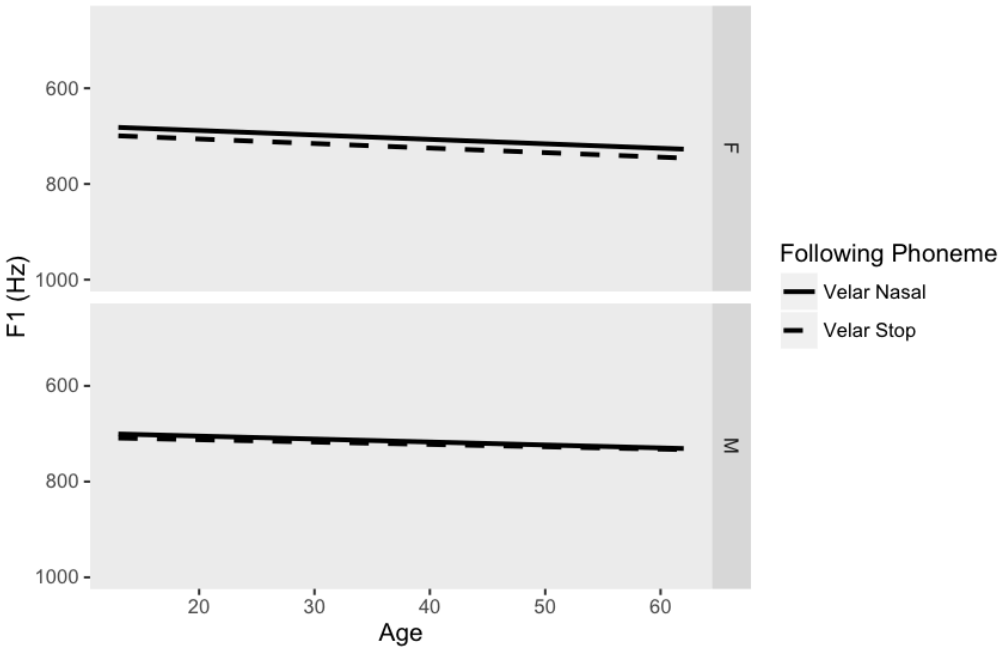


Figure 12. Pre–velar nucleus F1 by gender and following phoneme

The fact that the F1 of /æg/ has the same apparent-time slope as the F1 of /æŋ/ suggests that the two environments are moving in unison. As the two velar conditions appear to be moving as a unit, they may be shallowphones of the same allophone. Examining the productions of individual speakers to determine if they are part of a single continuous distribution provides evidence for this. Figure 13 shows the productions of /æg/ and /æŋ/ for four female speakers, matched for age. In the two panels on the left, a thirty-year-old from New Westminster and a forty-four-year-old from Maple Ridge show a more continuous pattern that is typical of most speakers. This provides evidence for a shallowphonic interpretation of these two environments. In the panels on the right, a forty-six-year-old from Coquitlam and a thirty-year-old from Surrey, have the least continuous patterns of all the speakers. However, even for these more discrete speakers, there is still overlap between the two conditions suggesting that, for all speakers in the present study, /æg/ and /æŋ/ are shallowphones of the same allophone.

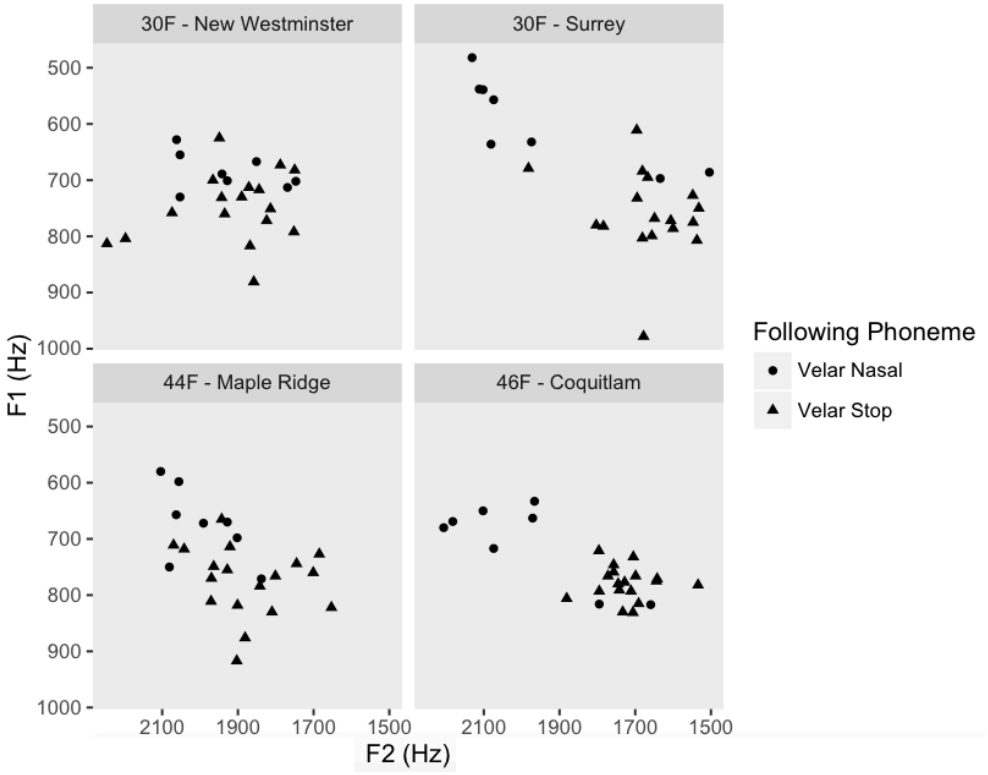


Figure 13. /æ/ before velar consonants for four speakers

Finally, the mean Cartesian (Euclidean) distances for each speaker were calculated between the mean nucleus position (F1 and F2) in the elsewhere condition and the pre-front nasal condition, and between the elsewhere condition and the pre-velar obstruent condition, as in Boberg (2008). The formula for this is to first calculate the Cartesian distance between /æN/ and /æ/ and then calculate the distance between /æg/ and /æ/ before subtracting these two values from each other. If the pre-front nasal /æ/ and the pre-velar obstruent /æ/ are moving in the same direction or at the same rate as the general phoneme, stability would be expected with no correlation to age. However, this is not the case, as is shown in Figure 14, where the difference between the two Cartesian distances is charted by age with circles denoting females and triangles for males. This yields a slightly significant correlation for male speakers ($p = 0.0254$) and an almost significant one for the female speakers ($p = 0.0554$), denoting a greater difference for younger speakers. This confirms that the two allophones are categorically distinct as they are moving apart over time.

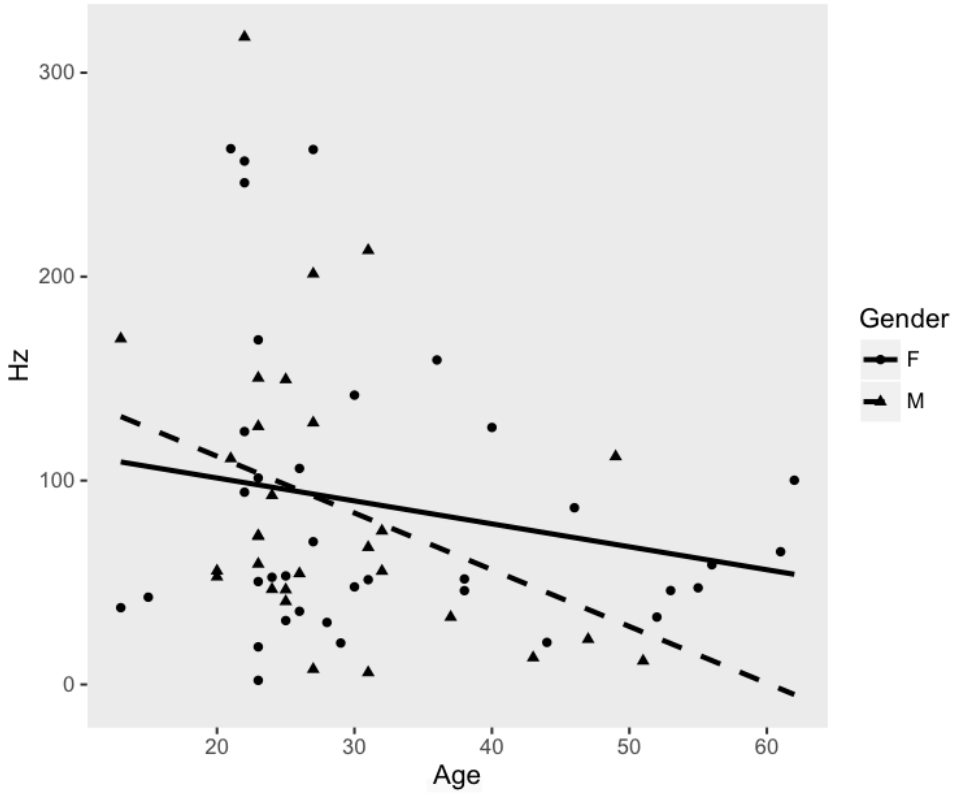


Figure 14. Difference between Cartesian distances of /æN/-/æ/ and /æg/-/æ/

### 5.2 Perception

The perceptual responses largely mirror the production results. Table 16 shows that 64% of speakers believe that *BANG* is more similar to *BAG* than to *BAN*. Conversely, 28% think that *BANG* should be paired with *BAN* and a further 8% were unable to match the vowel in *BANG* to one of the given words. While productions of the vowel before /n/, /ŋ/, and /g/ are all overwhelmingly similar at the nucleus in production across all speakers, only the latter two show substantial overlap at the offglide. Further, /æ/ was found to be continuous in both velar environments, which were found to move in unison. Therefore, the shallowphonic relationship between the /æg/ and /æŋ/ suggested by the production data is mirrored in the tendency to pair the two velars in the perceptual task.

| Response | Percentage |
|---|---|
| BAG | 64% |
| BAN | 28% |
| Neither | 8% |

Table 16. Responses to question: *Does the vowel in BANG sound more like BAG or BAN?*

The responses given for whether *RAN* sounded more like *RANG* or *RAG*, shown in Table 17, are slightly less decisive with a small majority (56%) of participants pairing /æn/ with /æg/. 31% paired *RAN* with *RANG*, choosing to group the two nasal sounds together, and a remaining 12% were unable to make a judgment call. The variation and indecision within this particular task is reflective of the phonetic data, as /æŋ/ and /æg/ tend to pattern together at both the nucleus and the offglide, meaning that these two are seen to be more similar to each other than to the vowel before a front nasal, which only shows similar vowel height at the nucleus. Therefore, it is not unexpected

that participants would have a harder time choosing between the two velar environments when categorizing *RAN*.

| Response | Percentage |
|---|---|
| RANG | 31% |
| RAG | 56% |
| Neither | 12% |

Table 17. Responses to question: *Does the vowel in RAN sound more like RANG or RAG?*

The most overwhelming tendency toward a particular pairing was found when participants were asked whether /æ/ before /n/ sounded more similar to its counterpart before /p/, which is part of the elsewhere condition, or /g/. As shown in Table 18, 75% of participants decided that *TAP* should be paired with *TAN*. The remaining 25% was comprised of either the pairing of *TAN* and *TAG* (22%) or participants who were unable to provide a judgment (3%). While this does not reflect the vowel height as measured at the nucleus, it does reflect both the patterns observed at 80% of vowel duration and the lowering of pre-front nasal /æ/ toward elsewhere /æ/ over apparent time observed in female speakers. Therefore, the perceptual responses are all concurrent with some element of the actual productions observed across all participants.

| Response | Percentage |
|---|---|
| TAG | 22% |
| TAP | 75% |
| Neither | 3% |

Table 18. Responses to question: *Does the vowel in TAN sound more like TAG or TAP?*

## 6 Discussion

Establishing the relative phonetic positions of and changes affecting /æ/ in different environments informs the sketch of the phonological organization of the vowel in BC English. First and foremost, the measurements reported in this analysis provide overwhelming evidence for /æ/ having an allophone before voiced velar sounds (/ŋ/ and /g/) that is categorically discrete from its other allophones. The results from the nucleus, offglide, direction of change, and perceptual responses support this conclusion, as the two velar conditions overwhelmingly pattern together, generally to the exclusion of the front nasals and elsewhere condition. While /æ/ before /ŋ/ and before /g/ did appear to be significantly different at the nucleus in terms of vowel height, this does not challenge the conclusion that they are part of the same allophone. Instead, it suggests that there is a shallowphonic relationship between the two environments such that /æ/ before /ŋ/ is produced slightly higher than before /g/.

The fact that /æ/ in these velar environments is moving upwards in the vowel space while /æ/ in the pre-front nasal environment is lowering, in the opposite direction, provides evidence that they may be categorically distinct. This movement in apparent time is observed at both the nucleus and the offglide. Given Fruehwald's (2013) argument that phonetic sub-phonemic units should move in tandem, while phonologically discrete ones can behave independently over time, the simultaneous movement in opposite directions suggests that these two conditions represent separate allophones. This is also somewhat supported in the examination of individual vowel productions that shows that approximately half of the speakers (54%) have visibly discrete patterns at the offglide, such that /æ/ before front nasals and before voiced velar consonants is non-overlapping. However, given the close proximity between the two conditions, it is plausible that all speakers have phonologically distinct allophones for the pre-front nasal and pre-velar obstruent /æ/ that happen to overlap as they move in separate directions. Therefore, it appears that pre-velar obstruent /æ/ must be a categorically distinct allophone from pre-front nasal /æ/, despite substantial overlap at the nucleus and some at the offglide.

The similarity of /æ/ before /g/ and /ŋ/ at the nucleus, at the offglide, and in trajectory of change support the inference that /æŋ/ is a shallowphone of the velar condition, rather than the nasal one. Further, participant variation and indecision in the perceptual task that asked whether *RAN* sounded more like *RANG* or *RAG* corroborate the conclusion that /æ/ before a voiced velar consonant is a cohesive allophone, as this choice reflects less confidence in a certain pairing across the speech community.[6] However, when asked to match /æŋ/ with either /æg/ or /æn/, participants were more confident in their choice to select the former. This supports the conclusion that /æŋ/ and /æg/ are part of the same allophone. Though vowel height for the two different environments is significantly different, this is not necessarily an argument for allophony. Specifically, the phonetic distribution of shallowphones can show continuous patterns such that the height of the vowel in one environment is generally higher than the others. In this case, /æŋ/ tends to be higher, while still being continuous and moving with /æg/ in apparent time. Statistical tests that determine whether two conditions are significantly different at one acoustic measure are clearly not reliable as sole indicators of sub-phonemic classification. The slight, though significant, differences between the two are reflective of the two conditions being shallowphones of the same allophone such that there are slight differences in the phonetic implementation that are not phonologically encoded.

The remaining step in the analysis of the sub-phonemic organization of /æ/ in BC English is to determine the relationship of pre-front nasal /æ/ to the elsewhere allophone. There is evidence that supports both a shallowphonic and an allophonic interpretation of this relationship. The vowel heights at 80% duration are similar, and participants are perceptually inclined to pair the words *TAP* and *TAN*. However, even though this similarity might suggest that pre-nasal /æ/ could justifiably be a shallowphone of the elsewhere allophone, in opposition to the allophone consisting of the pre-velar /æ/, the differences in vowel height at the nucleus, as shown in Figure 2, and movement in different directions make this highly implausible. Therefore, at the level of phonology, there are three categorically distinct allophones, which occur before voiced velar consonants, front nasals, and elsewhere.

The retraction of /æ/, as described previously in the literature, is confirmed to be still progressing in BC English. The results for /æ/ generally suggest that the phoneme is undergoing lowering for male speakers and backing for female speakers. While Pappas and Jeffrey (2013) report female speakers being a generation ahead in this change, the present data suggests that males are not yet participating in the change on the F2 dimension but that this is likely an impending next step. In the meantime, the male speakers are still demonstrating change over time on the F1 dimension that is bringing their height closer to the values reported for female speakers, who do not show any evidence of lowering the elsewhere /æ/ allophone.

The female speakers show evidence for the lowering of pre-front nasal /æ/, as predicted by the juxtaposition of Boberg (2008, 2010) and Swan (2015), while this change is not significant in apparent time for male speakers. The vowel in this environment is moving in an opposite direction, relative to the pre-voiced velar condition. It further patterns in a similar manner to the elsewhere condition but maintains a distinct nucleus. This discrete pattern supports that the pre-front nasal /æ/ is a separate allophone. Additionally, if pre-front nasal /æ/ were a shallowphone of the elsewhere allophone, the vowel in both environments would be expected to lower and back along the same trajectory simultaneously. However, this is not the case as the female speakers have higher F1 values for the elsewhere /æ/ than their male counterparts, suggesting that the lowering of /æ/ was a previous step in the general retraction pattern. It seems that the lowering of pre-front nasal /æ/ in female participants follows the path of this preliminary change, thus mirroring the current lowering of the elsewhere /æ/ described for the male speakers. Women are leading in the general retraction of /æ/ in Vancouver by a generation (Pappas & Jeffrey 2013) and so the subsequent lowering of pre-front nasal /æ/ appears to be a novel innovation following the

[6] An anonymous reviewer aptly pointed out that "untrained speakers aren't supposed to 'hear' allophonic differences". I concede this may be true when "allophone" is used to mean the product of both phonological and phonetic conditioning, but I believe that these results, at the very least, suggest that speakers are more able to perceive phonological (allophonic) than phonetic (shallowphonic) differences. However, the results in the present paper merely provide further support for the other conclusions and justify speaker perception of allophonic/shallowphonic differences as an avenue of research that I will explore in future work.

same trajectory of the /æ/-retraction in the elsewhere environment. The gender asymmetry and delay in movement along the same path are evidence for the pre-front nasal /æ/ and the elsewhere /æ/ being separate allophones, rather than shallowphones of the same allophone. However, the two allophones are participating in suspiciously similar sound changes with some amount of delay, which could be indicative of a chain-shift pattern.

The lowering and subsequent backing of /æ/ is cohesive with the allophone being the target of chain shifts, as argued in Dinkin and Dodsworth (2014), as it appears that allophones of the same phoneme are able to put pressure upon each other in a chain shift, as phonemes are purported to do. Though the modular feedforward architecture of phonology does predict this, it has not been discussed previously. The movement of the /æ/ allophones in BC English provides empirical proof to support this prediction. This also provides further evidence for the pre-front nasal /æ/ being phonologically discrete because it operates as an independent link in the sub-phonemic chain-shift, moving at a separate rate than the rest of the phoneme. The lowering of the elsewhere /æ/ allophone for male speakers, which is ongoing, does not seem to have progressed enough to trigger the lowering of pre-front nasal /æ/. This delay in movement, which is dependent on the lowering and retraction of the elsewhere allophone, provides convincing evidence for a sub-phonemic chain shift. These changes are not happening simultaneously as those who are lowering /æ/ in the elsewhere condition have not yet backed it. This suggests a sub-phonemic chain shift where elsewhere /æ/ must lower far enough to trigger the movement of pre-front nasal /æ/. Following the lowering of the elsewhere allophone, the backing of /æ/ creates a clear space for the pre-front nasal allophone to move into.

Therefore, if pre-front nasal and elsewhere /æ/ are separate allophones, then the systematic delay of the pre-front nasal condition lowering, following the retraction pattern of the elsewhere /æ/, suggests that the movement of the elsewhere /æ/ is triggering a chain shift below the level of the phoneme. This movement resembles the pull-shift pattern described in Clarke, Elms, and Youssef's (1995) description of the Canadian Shift, in which /æ/ lowers and retracts towards the merged vowel. However, instead of /æ/ causing /ɛ/ to move, it triggers the lowering of one of its own discrete allophones.

While the pre-front nasal /æ/ is lowering, the higher pre-voiced velar condition appears to remain immune to the overall chain shift, as the phonological rules create an output which is not subject to the same chain-shift pressures that affect pre-front nasal /æ/. This inapplicability follows from Labov, Yaeger, and Steiner's (1972) observation that chain shifts target offglide subsystems. In the present analysis, the pre-voiced velar offglide is categorically distinct from the other allophones and therefore may belong to a different subsystem than the other allophones of /æ/, which is not sensitive to the chain-shift pressure which motivates the movement of the others. Therefore, the sub-phonemic chain shift is likely targeting a subsystem which includes both the pre-front nasal and elsewhere allophones, to the exclusion of the pre-voiced velar one, which is part of a different subsystem and consequently not subjected to the chain shift pressure.

The combination of perception and production data, showing evidence for /æ/ moving in three separate directions, provides evidence for the phonological organization of this vowel being made up of three distinct allophones, /æ/ before a front nasal, /æ/ before a voiced velar consonant, and /æ/ before other obstruents. Phonological rules act upon the underlying lexical representation to create these discrete entities. Following this, synchronic phonetic rules are applied to two shallowphones, which represent the voiced oral and the nasal variants of the velar allophone, which results in /æŋ/ having slightly lower F1 at the nucleus than /æg/. The pre-front nasal and the elsewhere conditions are further lowered, which constitutes the pull-chain shift pattern. This ultimately fits with the modular feedforward architecture of phonology, which predicts that phonologically discrete allophones of the same phoneme can move in different directions and participate in chain-shift systems.

An interesting implication that follows from the categorization of these sub-phonemic elements and the divergent direction of the voiced velar allophone is that chain shifts must target the level of the allophone, rather than that of the phoneme which follows from Dinkin's (2011) definitions of phonological and phonetic rules and supports the empirical predictions of the modular feedforward architecture of phonology. Further, this analysis suggests that the vowel quality at the offglide is an important factor to consider in dialectal work as it appears to be more perceptually salient and reflects the patterns of ongoing sound changes in a way that is less

apparent at the nucleus, which supports Labov, Yaeger, and Steiner's (1972) finding that chain shifts appear to target vowels grouped by a similar offglide trajectory.

## 7 Conclusion

The present analysis examines the phonological structure of /æ/ in British Columbia English from the perspective of a modular feedforward architecture of phonology. The data supports a three-way phonological distinction between pre-front nasal, pre-voiced velar, and elsewhere allophones as well as a shallowphonic pairing of /æŋ/ and /æg/ within the same allophone. Further, the sub-phonemic organization of /æ/ in BC English provides empirical support for Dinkin's (2011) hypotheses regarding phonological rules which predict the allophone is the target of chain shifts, rather than the phoneme. Taken in isolation, this paper provides a phonetic and phonological examination of the subphonemic elements of /æ/ in BC English. However, in the context of the larger project, the present description of /æ/ will be a crucial piece in understanding how this phoneme is interacting with the larger sound changes occurring in the dialect, such as the Canadian Shift.

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## Appendix
## Wordlist for recording task

| | | | | |
|---|---|---|---|---|
| jest | house | wig | dew | choice |
| dance | length | fair | drag | gang |
| near | fig | goat | soul | mass |
| trap | her | eve | kiss | brag |
| hearse | mouth | bug | scared | hang |
| cool | nurse | flag | tar | pad |
| boing | pain | sleek | raid | toss |
| said | herb | dung | eight | scarce |
| tune | sag | tote | bagel | beard |
| square | bus | pill | say | bow |
| kid | mat | stag | loud | fad |
| beagle | dose | lot | pang | find |
| peace | beer | doll | league | buy |
| big | rad | wool | team | bowl |
| can | goo | boy | caught | ski |
| tall | fan | thought | dead | tin |
| strength | sass | coin | lag | pet |
| fleece | nag | town | hood | math |
| handbag | fright | mat | cage | Vancouver |
| ban | north | Langara | start | droid |
| dent | man | belay | pal | strut |
| moon | gag | snag | scene | meek |
| owl | beat | set | woman | shell |
| dress | mud | dice | car | peg |
| palm | wit | ale | card | odd |
| dang | rag | mess | fang | vague |
| beg | out | clang | keg | |
| fog | zig-zag | Kent | craft | |
| see | swag | magazine | brood | |
| bane | aisle | penguin | but | |
| foot | aim | at | kit | |
| dawn | cart | plague | hag | |
| limb | flayed | face | dread | |
| horse | game | bang | tea | |
| seed | cull | oil | choice | |
| data | phone | pen | win | |
| big | sleep | go | meh | |
| Meg | cure | sing | price | |
| case | seal | force | law | |
| don | Granville | cord | tag | |
| drama | track | cot | slang | |
| bite | pun | hoarse | bam | |
| tight | foot | pan | lamb | |
| ode | Kim | spa | boot | |
| fade | goose | drain | goose | |
| frugal | bat | Stan | pit | |
| wag | Sam | fair | mad | |
| bag | long | awed | core | |