SUB-REGIONAL VARIATION IN POSITIONING AND DEGREE OF NASALIZATION OF /æ/ ALLOPHONES IN CALIFORNIA

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ABSTRACT

We examined the phonetic realization of oral and pre-nasal /æ/ in speakers from three distinct sub-regions of California: Southern California, the Bay Area, and the Central Valley. Four acoustic variables were measured: two midpoint formant values (F1, F2), diphthongization, and acoustic nasality. Results show that speakers from the sub-regions exhibit distinct patterns: Bay Area speakers showed the largest differences in height, frontness, and diphthongization for oral and pre-nasal /æ/. Meanwhile, Central Valley and Bay Area speakers show differences in nasalization between oral and pre-nasal /æ/ productions, suggesting that nasalization is increasing in "ban" for these speakers relative to Southern Californians.

Keywords: California Vowel Shift, Intra-regional variation, Allophonic vowel split.

1. INTRODUCTION

The California Vowel Shift (CVS) is an ongoing sociolinguistic change in the vowel system of California English. The more salient aspects of the CVS include fronting of the back rounded vowels, which some consider to be a completed change [7]. Meanwhile, other vowel changes in the CVS seem to be in-progress and highly variable. For example, the splitting of /æ/ appears to be ongoing and particularly variable [3, 4]. Here, we focus on variation in the realization of the "nasal system" characterized by /æ/ raising before nasal consonant codas [12]. Often described as "tense" /æ/, this raised variant is produced with a higher and fronter tongue position. The nasal /æ/ system is exemplified in many Western US English dialects, including in California, where /æ/ lowering and backing in oral contexts is also reported to be a prominent feature [8, 4, 3].

While some studies focus on aspects of the CVS by treating California as a monolithic dialect region, without exploring intra-regional variation, e.g., [10], there appears to be significant variation in the vowel systems of the English spoken in the different sub-regions of California. Prior work has begun to describe differences in the vowel space positioning of the /æ/ allophones across speakers of different ages, from distinct sub-regions, and conveying varied social indexes. For example, in a study of the northern Central Valley, individuals who live in rural regions, or associate more strongly with rural identity, displayed less oral /æ/ backing, suggesting that the change is indexing affiliation with more urban and coastal regions of California [5]. In a follow-up study looking at the positioning of the pre-nasal /æ/ in the same Northern Central Valley region [16], it was found that younger speakers, regardless of "country", or rural, affiliation raise and front /æ/ more in nasal contexts. Meanwhile, Bay Area speakers have been shown to produce the frontest realizations of pre-nasal /æ/ compared to other regions [4, 9].

However, the variation in vowel quality associated with nasal codas, which leads to the /æ/ split in CVC and CVN contexts, actually involves changes in multiple acoustic properties: in addition to raising and fronting, pre-nasal /æ/ is becoming more diphthongal, e.g., [14]. Furthermore, there are reports of greater nasalization for pre-nasal /æ/ associated with raised CVN variants [19]. Co-variation of acoustic features in the context of a nasal coda would not be surprising: for example, [13] demonstrated that a varied opening of the nasopharyngeal passage also affects the oral formant frequencies even when the tongue position is the same. Yet, comparisons of *multiple* acoustic properties of these allophones across sub-regional varieties is understudied. In the current study, we ask whether there is sub-regional variation within California in the realization of the /æ/ split, in steady-state formant positioning, diphthongization, and coarticulatory characteristics.

2. METHODS

2.1. Data Collection

In the current study, we collected two productions of a CæC and CæN monosyllabic minimal pair containing /æ/ ("bad" and "ban"). Speakers also produced words containing the other monophthongal vowel phonemes of English in the same phonetic contexts. These words served as filler items for the experiment and were also used to collect data on each speakers' vowel space for formant-space normalization.

Native California English speakers from three regions were recruited: 34 Bay Area (1M, 33F), 18 Central Valley (3M, 15F), and 17 Southern California (2M, 15F) speakers. Our subjects predominantly consisted of women, which reflects the gender balance in the UC Davis Psychology subject pool they were recruited from. Nine subjects were also speakers of Spanish. The geographical distinctions between these regions is based on natural geographic boundaries and county borders. The Central Valley is defined as the valley bounded by the Sierra Nevada mountains to the east and the Coastal Ranges to the west, including Sacramento, San Joaquin, Tehama, Stanislaus, Butte, Colusa, Yolo, Merced, Placer, Madera, Kings, Kern, Fresno, Tulare, Shasta, and Yuba counties. The Bay Area is defined as the urban area surrounding the San Francisco Bay, including Alameda, Napa, San Mateo, Santa Clara, Sonoma, and San Francisco counties. Southern California is defined as the mostly urban area south and/or west of the Central Valley, including Santa Barbara, Ventura, Los Angeles, San Diego, Riverside, San Bernardino, Orange, and Imperial counties. In cases where subjects listed multiple cities of residence, the city where they spent their childhood and adolescence was selected as their region of origin.

Audio recordings were made using a Shure WH20 XLR head-mounted microphone and digitally sampled at 44-kHz in a sound-attenuated booth.

2.2. Acoustic Analyses

Recordings were hand-segmented by phonetically-trained coders. The onset and offset of the vowels were considered to be the points at which there was an abrupt increase or reduction in amplitude of higher frequency formants in the spectrograms; an abrupt change in amplitude in the waveform, along with simplification of waveform cycles, was used to corroborate these boundaries, especially in the case of words with nasal codas.

Three types of acoustic measurements were obtained from the vowels: midpoint F1-F2 values, spectral movement (i.e., diphthongization), and spectral nasality measurements.

<u>Acoustic vowel measurements</u> were extracted using FAVE-extract [17]. F1 and F2 measurements were taken at the midpoint (50% of vowel duration) for each target vowel and log mean normalized [15]. Formant values were log-mean normalized based on the average formant frequency values for all vowels in the system, excluding those that are the most established as being part of the California Vowel Shift (e.g., back vowels and /ʌ/). We additionally used FAVE-extract to measure F1 and F2 at 35% and 65% of the total vowel duration to calculate <u>spectral movement</u>. For each token, the relative spectral movement, or degree of diphthongization, was calculated based on the (log mean) Euclidean distance between F1 and F2 values at 35% and 65% of the overall vowel duration.

<u>Degree of nasalization</u> was measured acoustically as A1-P0, or the difference in the amplitudes of the first formant spectral peak (A1) and the lowest frequency nasal formant peak (P0) [2]. As nasalization increases, the amplitude (in dB) of nasal formant peaks increases, while oral formant peaks tend to be damped. The relative difference, then, of the oral and nasal formants (=A1-P0) provides a quantifiable measure which *decreases* as nasality increases. A1-P0 measurements were made automatically via script in Praat at vowel midpoints. The script locates the first 2 harmonic peaks, based on the fundamental frequency. The peak with the higher amplitude is selected as P0, since a raised peak in this frequency range is evidence of nasal amplification. A1 is selected as the highest harmonic peak within 2 harmonic peaks of F1, based on formant analysis. Values were checked and hand-corrected for pitch-errors. In order to compare relative differences in degree of vowel nasalization as realized in the oral and nasal contrast between vowels across different individuals, A1-P0 values were z-scored within speaker.

2.3. Statistical Analyses

Four separate linear mixed effects models were run on normalized F1, F2, diphthongization, and acoustic nasality values. The models were run in R using the *lmer* function with the *lme4* package [1]. Estimates for degrees of freedom, *t*-statistics, and *p*-values were computed using Satterthwaite approximation with the *lmerTest* package [11]. All models included fixed effects of Region (with three levels: Bay Area, Central Valley, Southern California), word Structure (CVC, CVN), the interaction between Region and Structure, and by-Subject random intercepts. For the acoustic nasality model, we additionally included the fixed effect of vowel Duration (z-scored), as nasality has been shown to vary by duration, e.g., [6]. Effects were contrast coded.

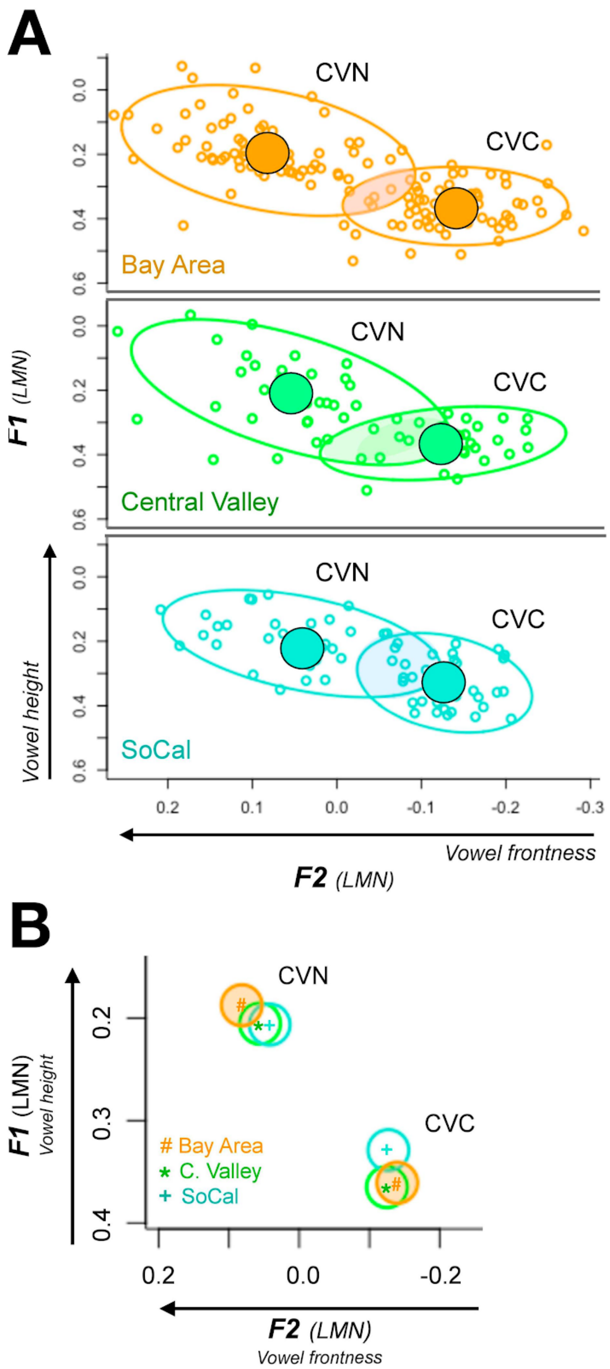
3. RESULTS

3.1. Midpoint Formant Values

Results show a significant main effect of CVN Structure for both F1 (F=280.6, p<0.001) and F2

(F=479.2, p<0.001): pre-nasal /æ/ vowels were higher and fronter than oral /æ/ vowels across all of our speakers (see Figures 1A and B).

Figure 1: (A) Log mean normalized (LMN) formant values for /æ/ in oral (CæC) and nasal (CæN) contexts by Region (Bay Area, Central Valley, Southern CA). Ellipses show 2 sd and solid circles show the means. **(B)** Mean (LMN) formant values for all Regions and Context (CæC, CæN).



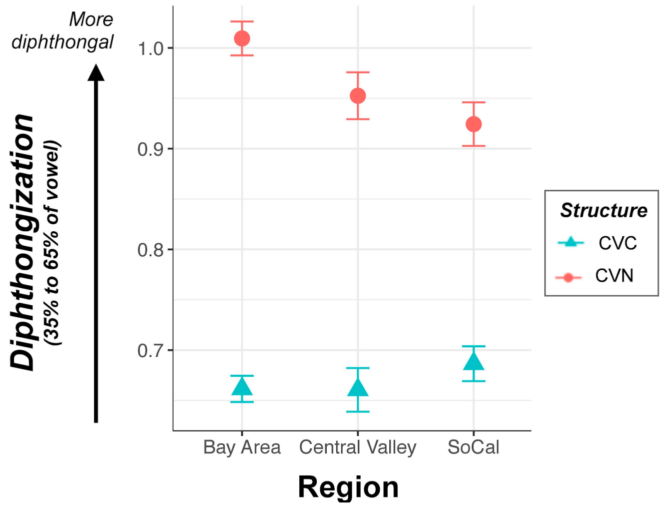
For the vowel height (F1) model, we additionally observe an interaction between Region and Structure (F=3.3, p=0.039): Bay Area speakers show more pre-nasal /æ/ raising (β=-0.053, p=0.011), compared to Southern California speakers as the reference level (see Figure 1B). No interaction for Central Valley*CVN is observed, compared to Southern Californians (β=-0.035, p=0.14). As seen in Figure 1B, Southern California speakers show greater raising in CVC contexts; a releveled post-hoc model (ref level=CVN) confirms the interaction between CVC*Southern California (β=-0.053, p=0.011).

In terms of vowel backness (F2), our model reveals an interaction between Structure and Region (F=4.27, p=0.015), where Bay Area speakers show more pre-nasal /æ/ fronting (β=0.054, p=0.008), relative to Southern Californian speakers (see Figures 1A and B). As with F1, no interaction between Region and Structure is observed for Central Valley speakers relative to Southern California speakers.

3.2. Diphthongization

For diphthongization, we observe a main effect of Structure (F=550.7, p<0.001): CVNs show more spectral movement, relative to CVCs, for all speaker groups. A main effect of Region was not significant. Results reveal an interaction between Structure and Region (F=7.01, p=0.001), where Bay Area speakers show greater spectral movement for CVN tokens (β=0.10, p<0.001), relative to Southern California speakers (see Figure 2). There was not a significant difference for Central Valley speakers by Structure.

Figure 2: Mean spectral movement (z-scored within speaker) by region.

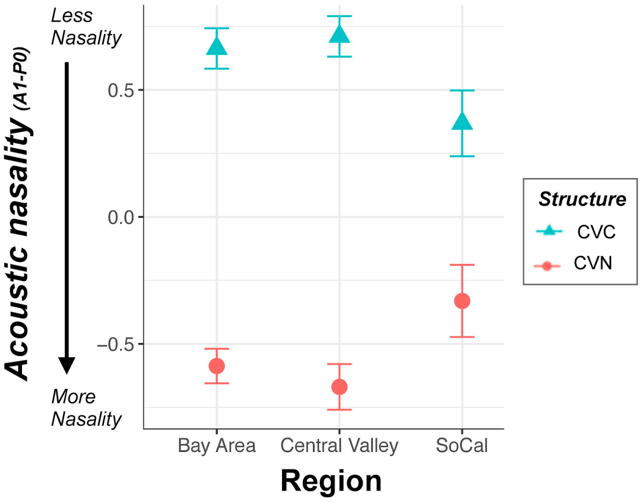


3.3. Acoustic Nasality

For acoustic nasality, the model reveals a main effect of Structure (F=189.4, p<0.001), where CVNs show greater nasalization than CVC words (i.e., lower A1-P0 values). While there was not a main effect of Region (F=0.93, p=0.9), vowel Duration does predict degree of nasality (β=-0.12, p<0.05), where shorter vowels showed greater nasalization.

Furthermore, the degree of nasalization in CæC vs. CæN words varies reliably across regions (Structure*Region, F=5.97, p<0.001): Bay Area and Central Valley speakers show larger differences in nasalization between CæC and CæN words, relative to Southern Californians' productions (Bay Area: β=-0.54, p=0.02; Central Valley: β=-0.67, p=0.01) (see Figure 3).

Figure 3: Mean acoustic nasality (A1-P0) (z-scored within speaker) at vowel midpoint by region.



4. GENERAL DISCUSSION

It is well-documented that /æ/ has a distinct allophonic realization in pre-nasal contexts, relative to other environments, in many American English dialects. Yet, in this study, we investigated *variation* in the realization of these multiple phonetic features associated with this allophonic split across speakers from three distinct sub-regions of California, who all have this nasal system. Table 1 summarizes the patterns we observe in the present study.

Table 1: Sub-regional variation patterns of the acoustic properties for CæC-CæN.

Feature	Pattern
F1	*CæN highest for Bay Area CæC highest in Southern California (i.e., lowering least advanced).*
F2	*CæN frontest for Bay Area*
Diphthongization	*CæN most diphthongal for Bay Area*
Acoustic nasality	*CæN most nasalized in Central Valley & Bay Area*

Distinct patterns of vowel height positioning and degree of vowel nasality in CæC-CæN across speakers indicate that there is significant variation in the realization of this CVS features across California sub-regions. One interpretation of these patterns is that they reflect differences in the weighting of the secondary features signaling the allophonic /æ/ distinction. Bay Area speakers rely more heavily on vowel height, frontness, and diphthongization as a cue to convey the oral vs. pre-nasal allophonic distinction, relative to Southern Californians (Central Valley speakers were not different from either of the other groups on this dimension). Meanwhile, Central Valley and Bay Area speakers weigh degree of nasalization as a stronger cue to the oral-nasal /æ/ contrast, relative to those from Southern California. These results indicate the importance of exploring variation of *multiple* acoustic features during sound change. Focusing solely on steady-state formants when investigating variation obscures the complexity of change in vowel systems.

Interestingly, we find that Southern California is not most advanced in the splitting of these allophones. This is somewhat surprising because, folk-linguistically, it has been observed that Southern Californian features appear to "stand in" for California as a whole, in perceptual dialectology work and broader stereotypes [18]. If this ideology were true, we might expect to find all CVS features are most advanced in Southern Californians. However, what we find is more nuanced: different sub-regions express this aspect of the CVS in distinct ways.

These findings open up avenues for future work. First, the perception of these multiple phonetic features of split /æ/ system should be investigated. In particular, one question is whether these differences across sub-regions are mirrored in listeners' perceptual cue weighting of these features. Another avenue is to investigate how each of the various acoustic features signal differences in social-indexicality. Previous work has suggested that an advanced split /æ/ system indexes an orientation toward urban, coastal, youthful, and white identities [16, 5, 4]. Further research can also explore how variation of these features within each of these geographical sub-regions realizes indexicality.

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