Vowel merger in Australian English lateral-final rimes: /æɔ-æ/

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Abstract

Pre-lateral contrast reduction between Australian English /æɔ-æ/ (*howl-Hal*) compared to other environments might indicate an ongoing merger. Our apparent-time study explores this merger. Spectral and temporal characteristics of /æɔ-æ/ produced in pre-lateral and pre-obstruent contexts by 19 older and 15 younger speakers were compared. Acoustic vowel similarity was captured using random forest classification and hierarchical cluster analysis of dynamic formant properties and duration values. Consistent with a pre-lateral merger, younger speakers showed reduced pre-lateral vowel contrast than older speakers, and young male speakers produced /æɔl-æl/ similarly to pre-obstruent /æɔ/. Pre-lateral /æɔ-æ/ merger is attributed to younger speakers' changing $F2$ trajectories.

Index Terms: vowel change, Australian English, pre-lateral vowels, change by coarticulation

1. Introduction

Contrast reduction caused by systematic and directional coarticulatory variation is often implicated in the initiation of sound change, yet not all coarticulatory variation leads to sound change [1, 2, 3, 4]. In the Interactive-Phonetic (IP) model, sound change may be initiated when highly coarticulated realisations of one phoneme become acoustically similar to another phoneme, while other realisations remain distinct [4]. That is, sound change of this type has two important features: one phoneme must shift in the acoustic space according to its coarticulatory context, and another phoneme must already occupy the acoustic space that the coarticulated allophone is moving into. As listeners and speakers interact, coarticulated realisations are incorporated into listeners' representation, shifting them closer to the second phoneme, and potentially leading to a merger [4]. Such a merger is signalled by failed compensation for coarticulation in the IP model [4].

The Australian English (AusE) vowel pairs /iː-ɪ, ʉː-ʊ, æɔ-æ, əʉ-ɔ/ (e.g. *feel-fill, fool-full, howl-Hal, dole-doll*) may satisfy the necessary conditions of vowel change through coarticulation: members of the pairs show acoustic and perceptual contrast reduction in the pre-lateral position, while their pre-obstruent allophones remain distinct [5, 6, 7]. Decreased spectral contrast between pre-lateral /æɔ-æ/ is attributed to the $F2$ trajectory of /æl/ (Hal) becoming similar to that of /æɔl/ (*howl*) [6]. As the tongue transitions from the front vowel to dorsal dark /l/ in /æl/, a falling $F2$ transition is created, similar to that of the front-back transition in the diphthong /æɔ/ [6]. The spectral contrast reduction corresponds to perceptual contrast reduction as listeners are likely to confuse members of the /æɔ-æ/ vowel pair in the /l/ context [7]. In the pre-obstruent context, spectral and perceptual vowel contrast is preserved due to the maintenance of the high $F2$ of /æ/ [6, 7].

Contrast reduction between pre-lateral /æɔ-æ/ may be consistent with a contextual vowel merger in the IP model of sound change. Vowel-lateral coarticulation creates vowel realisations that potentially lead to overlapping formant trajectories and durations in separate phonemes. However, apparent-time studies have not examined pre-lateral merges in AusE, only in other varieties of English, such as American and British English [8, 9, 10]. Therefore, we examine if there is a pre-lateral vowel change and merger between /æɔ-æ/ (*howl-Hal*) in AusE. We hypothesised that younger speakers would (1) show smaller contrast between pre-lateral allophones of the members of the vowel pair /æɔ-æ/ than older speakers; (2) shift their production of /æl/ towards /æɔl/; and (3) younger and older speakers would preserve /æɔ-æ/ contrast in the pre-obstruent environment.

2. Methods

2.1. Speakers

Data were extracted from AusTalk, an AusE speech corpus recorded between 2011 to 2015 [11]. Speech recordings of 15 younger (F = 8, M = 7, ages = 20 – 29, mean = 23.5) and 19 older (F = 9, M = 10. ages = 51 – 80, mean = 60.5) native speakers of AusE were selected from the database. Speakers were born and educated in the Greater Sydney Metro Region with at least one of their parents born in Australia. The speakers did not report any reading, speaking, or hearing difficulties.

2.2. Material and procedure

The two stressed vowels /æɔ-æ/ were produced in two monosyllabic paradigms, /hVd/ and /hVl/ (*howd-had, howl-Hal*), in a single-word production task. Speakers read 322 isolated words, including the four target words, as they were presented orthographically on a computer monitor in a random order. The task was recorded on three separate occasions, each using a different order of words. Each speaker produced up to three repetitions of each lexical item; the number of repetitions differs between participants, as not all participants attended all three sessions.

2.3. Phonetic analysis

400 tokens were analysed (4 target words × 34 speakers × 3 maximal repetitions - 8 missing repetitions). Segment boundaries were automatically located using the MAUS forced aligner with the AusE grapheme-to-phoneme converter [13, 14, 15], and manually corrected in a Praat interface [16]. The vowel onset was determined on the basis of voicing onset and sudden increase in amplitude. Vowel offset in the /d/ context was determined on the basis of amplitude drop. Rime offset in the /l/ context was determined on the basis of voicing offset. Because there is no discernible boundary between the vowel and the fol-

lowing /l/ in /hVl/ words, the entire /hVl/ rime was analysed instead of selecting an arbitrary boundary in the vowel-lateral transition (Fig. 1). Automatic segmentation errors were corrected only when the boundary was judged to be misplaced by more than 20 ms [17]. Boundary correction was carried out by the first author and a phonetically trained research assistant with 15% of the data cross-marked by both. Boundary agreement, with a 20 ms agreement threshold was 99% for vowel onsets and 97% for vowel offset. /l/ offset boundaries were re-checked and corrected if necessary by the first author as agreement was 60%.

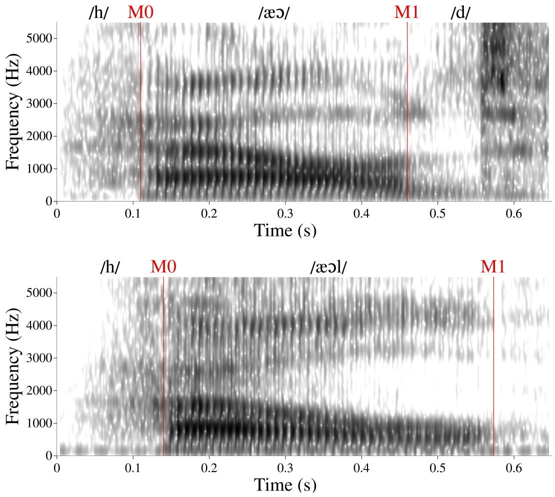

Figure 1: *Vowel (top) and rime (bottom) onset and offset.*

Formant trajectories in the pre-/d/ vowels and in the lateral-final rimes were extracted automatically and corrected manually in Praat [16]. Formant frequencies were estimated at every 5 ms throughout a 25 ms formant analysis window using a 50 ms Gaussian window with 75% overlap and with 50 dB dynamic range and a pre-emphasis filter increasing spectral slope above 100 Hz by 6 dB/octave. To optimise formant settings for each speaker, five to six formants were tracked up to 4500 ceiling for speakers who produced comparatively lower $F2$ and $F3$ or up to a maximum frequency of 7000 Hz for speakers who produced a comparatively higher $F2$ or $F3$ trajectory. Male speakers were typically analysed with lower and female speakers with higher formant ceiling. Formant trajectories were manually corrected using a Praat-based interface that superimposed formant estimates over a broadband spectrogram calculated over 5 ms windows with 40% overlap, allowing for corrections of estimates that did not align with the visible formants. Manual correction was carried out by the first author and a phonetically trained research assistant. After hand-correction, $F1$–$F3$ trajectories for every word were visually inspected by the first author; values 1.5 times above or below the interquartile range for each formant in each vowel × coda × age × gender group were rechecked by the first author.

Discrete cosine transformations (DCT) were used to model formant change over time using the first three DCT coefficients [18, 19, 20]. The 0th coefficient represents the mean of a formant trajectory multiplied by $\sqrt{2}$; the 1st coefficient represents the direction and magnitude of the curve of the trajectory; the 2nd coefficient represents the trajectory's curvature. Each token was represented parametrically by a total of 9 DCT coefficients (3 formants × 3 coefficients).

2.4. Statistical analysis

To test spectral similarity, we trained two random forest classification models to learn 2 (vowels) × 2 (coda) × 2 (age) = 8 categories for male and 8 categories for female speakers based on the DCT coefficients, duration values, and group labels using 75% of data produced by each gender [21, 23]. The training phase returned an out-of-bag error rate. A low out-of-bag error rate indicates that the algorithm was successful at learning the categories [22]. The remaining 25% of the tokens were used to test the classifier, by grouping unlabelled values based just on DCT coefficients and duration values. The testing phase returns two confusion matrices, separately for each gender. The confusion matrices were then fed into an agglomerative hierarchical cluster analysis using Ward's method [24] to measure between-group similarity based on the confusability rates. The results of hierarchical cluster analysis are represented on a dendrogram: elements that are clustered together are similar to each other, and the lower the cluster is split from the other elements, the higher the spectral similarity between the members of the cluster. That is, the location of nodes can be used for comparing between-cluster similarity. Approximately Unbiased p-value for each multi-element cluster were extracted by repeating the hierarchical cluster analysis on the same confusion matrices using multiscale bootstrap sampling [25, 26]. Approximately Unbiased p-value expresses the frequency with which a cluster appears in bootstrapping; the significant threshold is 95% or above. (For more details on the statistical analysis, see [6]).

Durational contrast reduction in lateral-final rimes compared to pre-/d/ vowels was further tested using generalised linear mixed models (GLMs) [27]. A GLM model was built with the dependent variable Duration, and the independent variables Coda, Vowel, Age, and Gender. Independent variables were contrast coded, giving pre-/d/ /æɔ/ produced by older female speakers as a baseline. Speaker was added as random intercept with Coda for random slope; random slope for Age and Gender was not added as the study had a between participant design. Convergence was estimated using the BOBYQA (Bound Optimization BY Quadratic Approximation) optimizer and an increased number of maximum iterations [28]. p-values were calculated using Satterthwaite's degrees of freedom method [29]. All statistical analyses were carried out in R [31].

3. Results

Two random forest classification models were trained on DCT coefficients, duration values, and group labels using 75% of the data for each genders. Out-of-bag error rate in the testing phase is 36.67% for male speakers and 40.67% for female speaker, indicating that DCT coefficients and duration values can classify vowels with comparable accuracy for both genders. Although out-of-bag error rates are high, they are in line with rates observed for classifying /l/-final rimes in AusE [6].

We used hierarchical cluster analysis to test whether confusion rates are statistically significant. Male speakers show five significantly frequently occurring clusters (Fig. 2). The two clusters of /d/-final rimes (100% frequency for both) are split by vowel and merged by age, indicating that the vowels /æ/ and /æɔ/ are produced similarly between age groups and differently from each other in the /d/ context. The clusters of /l/-final rimes are split by age (97% for older, and 100% for younger speakers) and merged by vowel, indicating that /l/-final rimes differ between the age groups but are similar between the vowels /æɔ/ and /æ/. In addition, there is a supercluster consisting of all male

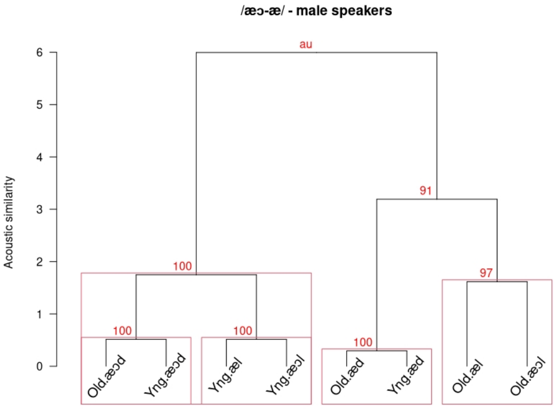

Figure 2: *Acoustic similarity in male speakers. Y-axis: similarity increases as the number decreases; similarity measured in arbitrary units. Au: approximately unbiased p-values.*

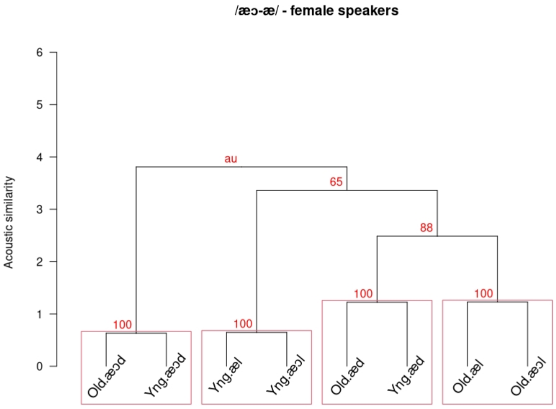

Figure 3: *Acoustic similarity in female speakers. Y-axis: similarity increases as the number decreases; similarity measured in arbitrary units. Au: approximately unbiased p-values.*

speakers' pre-/d/ diphthong and the younger speakers' /l/-final rimes (100% frequency), indicating that lateral-final /æɔ-æ/ shift toward the diphthong for young male speakers.

Female speakers show four clusters that occur with significant frequency (100% for each) (Fig. 3). The two /d/-final clusters are split by vowel and merged by age, indicating that the vowels /æ/ and /æɔ/ are produced similarly between age groups and differently from each other in the /d/ context. The two /l/-final clusters are split by age and merged by vowel, indicating that /l/-final rimes differ between the age groups but are similar between the vowels /æɔ/ and /æ/.

Younger speakers' pre-lateral clusters of /æɔ-æ/ branch at a lower point (below one) compared to older speakers (above one) for both genders, indicating higher higher similarity between members of the vowel pair in pre-lateral position (Figs. 2 – 3). As /l/-final rimes are inherently longer than pre-/d/ vowels, it is possible that /l/-final rimes formed separate clusters from pre-/d/ vowels only due to their different durational values. Therefore, we repeated random forest and hierarchical cluster analyses for both genders without duration values. For male speakers, /l/-final rimes formed separate clusters from pre-/d/ vowels for older speakers, but younger speakers' /l/-final rimes clustered with pre-/d/ /æɔ/ with and without duration values. For female speakers, /l/-final rimes formed separate clusters from pre-/d/ vowels for older and younger speakers with and without duration values. That is, the cluster of /l/-final rimes and the clusters of pre-/d/ vowels in Figs. 2–3 are not formed on the basis of duration values alone for any of the genders.

Our GLM shows that duration was not affected significantly by the main effect of Age and Gender, indicating no significant difference in /æɔ/ duration between the age groups and genders. The short vowel /æ/ was significantly shorter than the long vowel /æɔ/ ($\beta = -127.93, t_{9.84} = -13, p < 0.0001$). Coda /l/ resulted in a significant increase in duration for /æɔl/ compared to the vowel in the /d/-context ($\beta = 119.96, t_{15.81} = 7.59, p < 0.0001$) (Fig. 4).

An interaction between Coda /l/ and Vowel indicates that the rime containing the short vowel lengthens more in the /l/ context compared to the rime containing the diphthong ($\beta = 45.85, t_{13.92} = 3.29, p < 0.0011$). The remaining interactions, including the ones with Age, were not significant (Fig. 4).

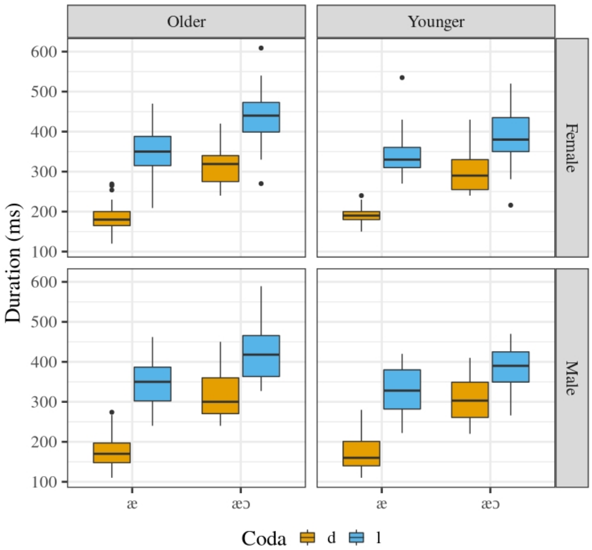

Figure 4: *Rime- and vowel duration.*

4. Discussion

Our first hypothesis stated that younger speakers would show smaller contrast between pre-lateral allophones of the members of the vowel pair /æɔ-æ/ compared to older speakers. Although this vowel contrast is reduced in pre-lateral environments compared to pre-obstruant contexts for both older and younger speakers, in line with our hypothesis, younger speakers show smaller contrast compared to older speakers. Smaller acoustic contrast between pre-lateral rimes for younger speakers compared to older speakers is consistent with an ongoing pre-lateral vowel merger.

The increased contrast reduction between pre-lateral /æɔ-æ/ for younger speakers might be driven by contrast reduction between the /æ/-/l/ transition and the second target of the diphthong /æɔ/ (120 - 300 ms, between vertical lines in the right panel of Fig. 5). Young speakers produce the /æ/-/l/ transition with a less steep $F2$ drop compared to older speakers, shifting their /æ/-/l/ transition closer to the second target of the diphthong /æɔ/. In contrast, older speakers preserve the $F2$ contrast between between the /æ/-/l/ transition and the second target of the diphthong /æɔ/ as they produce the /æ/-/l/ transition with a lower $F2$ compared to the second target of the diphthong. To explore at which point in time contrast reduction takes place in the rime, future research is required to examine formant trajectories using Generalised Additive Mixed Models.

Younger speakers appear to reduce duration contrast between lateral-final /æɔl/ and /æl/ compared to older speakers (Fig. 5), which might contribute to their increased contrast reduction. To address the role of duration contrast, future research is required to separate the vowel from the /l/.

Our second hypothesis stated that contrast reduction would be shown in the pre-lateral monophthong shifting toward the pre-lateral diphthong. In line with our hypothesis, contrast reduction between /æl/ and /æɔl/ is driven by the $F2$ transition from the monophthong /æ/ towards coda /l/: pre-obstruent /æ/ has a steady high $F2$ throughout the vowel (0-250 ms, left panel of Fig. 5), while pre-lateral /æ/ shows an $F2$ decline (from 25-50 ms onward, right panel of Fig. 5). As the tongue moves from the front vowel target to the dorsal target of dark coda /l/, it creates a back vowel-like transition, making /æl/ similar to /æɔ/ [32].

In addition, the vowel /æ/, when coarticulated with /l/, shows more similarities with pre-/l/ and pre-/d/ /æɔ/ for younger male speakers compared to older male speakers (Figs. 2 and 6). Increased similarity between lateral-final rimes and the pre-obstruent diphthong might be driven by the rising $F2$ at the end of the lateral-final rimes in young speakers' production (Figs. 5-6). This $F2$ increase is not consistent with the small $F1$-$F2$ of dark /l/ or with the low $F2$ of dark or vocalised /l/ [33, 34]. An increased $F2$ is consistent with young speakers vocalising *less* than older speakers (contrary to [35]). Alternatively, as the end of the analysis window was defined by the end of voicing, it may be caused by the tongue moving toward a neutral rest position. An articulatory study is required to address /l/-vocalisation.

Female speakers do not show acoustic similarities between lateral-final rimes and the pre-obstruent diphthong, despite showing similar $F2$ transitions from /æ/ towards coda /l/ as from [æ] to [ɔ] (Fig. 5). This difference might arise from timing differences: the duration of /l/-final rimes is longer than that of the pre-/d/ diphthong for female speakers (Figs. 4-5). For young male speakers, duration of /l/-final /æɔl/ and /æl/ are not too dissimilar from pre-/d/ /æɔ/. Coda /l/ lengthens rimes containing the short vowel more, indicating duration contrast reduction with no difference between genders; however, hierarchical cluster analysis might have been sensitive for small differences in duration contrast produced by male and female speakers.

Our third hypothesis stated that pre-/d/ allophones of the members of the vowel pair /æɔ-æ/ would remain distinct. We found no evidence of pre-obstruent contrast reduction for /æɔ/ and /æ/, as the vowels never clustered together in the pre-/d/ context due to their spectral and durational differences. Therefore, contrast reduction between /æɔl - æl/ is attributed to coarticulation with coda /l/ rather than across the board vowel contrast reduction. Across the board vowel change can be observed as younger speakers produce /æ/ with a higher $F1$ and lower $F2$ compared to older speakers (Fig. 5). However, in the pre-obstruent context, younger speakers' /æ/ shows spectral similarities to older speakers' /æ/, and younger speakers' /æɔ/ shows spectral similarities to older speakers' /æɔ/. Thus, as predicted by the IP model of sound change [4], AusE /æɔ-æ/ show an ongoing pre-lateral vowel merger caused by the coarticulatory influence of /l/, as the pre-lateral allophone of /æ/ moves through a similar acoustic space as /æɔ/, while the pre-obstruent allophones remain distinct. The shift of /æl/ to /æɔl/ in production is consistent with /æl/ being more likely to be misperceived as /æɔl/ than /æɔl/ as /æl/ [7]. Future research is required on the effect of speakers' and potentially listeners' age and gender on pre-lateral vowel contrast reduction.

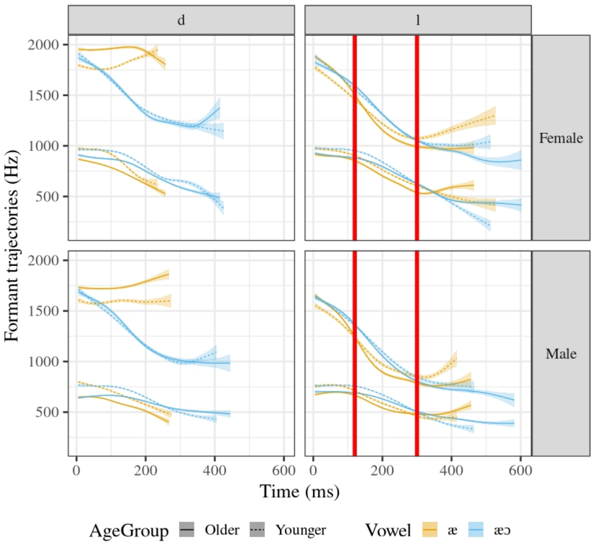

Figure 5: *$F1$-$F2$ trajectories. Vertical lines: areas of interest highlighting potential $F2$ contrast reduction in young speakers.*

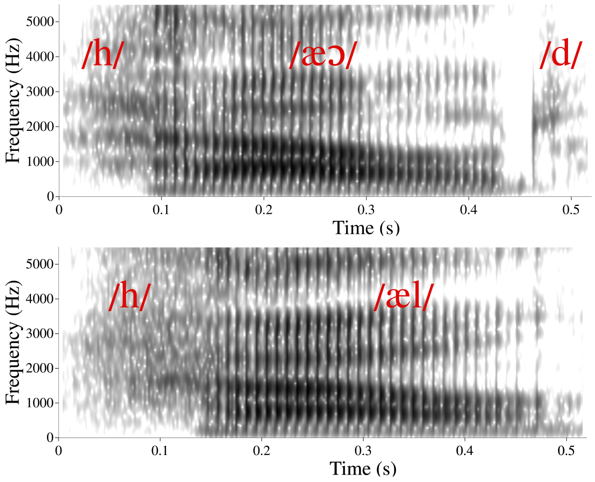

Figure 6: *Young male speaker's production. Top: Pre-obstruent /æɔ/ (howd) Bottom: Pre-lateral /æ/ (Hal). Colour on-line.*

5. Conclusions

Pre-lateral vowel merger between members of the vowel pair /æɔ-æ/ is shown, as younger speakers produce members of the pairs with smaller spectral contrast compared to older speakers. Pre-lateral /æ/ shifts toward /æɔ/ due to the coarticulatory influence of /l/. Male speakers' lateral-final rimes shift toward pre-obstruent /æɔ/, while female speakers only reduce contrast between the two lateral-final rimes. Decreased contrast may be carried by changes in young speakers' production of the /æ/-/l/ transition: while older speakers maintain a contrast between /æ/-/l/ transition and the second target of /æɔ/, younger speakers æ/-/l/ transition shifts towards [ɔ].

6. Acknowledgements

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7. References

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