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This Pull's as Hot as Hal: A Quantitative Acoustic Study of Two Pre-Lateral Vowel Mergers

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This *Pull*'s as Hot as *Hal*: A Quantitative Acoustic Study of Two Pre-Lateral Vowel Mergers

Henry Leslie-O'Neill

This paper investigates mergers of the DRESS-TRAP and FOOT-GOOSE vowels in pre-lateral position for speakers of diverse varieties of English in Melbourne, Australia. A total of 35 participants were recorded producing 22 words from a list representing 11 monophthongs in pre-t and pre-l position. The vowels were measured for F1, F2, and duration, from which Pillai scores were calculated. Variation due to the speakers' variety of English was as predicted. Duration contrasts for both vowel pairs were present for most speakers as a way to differentiate the vowels when their formants overlapped. This was expected for FOOT-GOOSE but previously unreported for DRESS-TRAP.

1 Introduction and Literature Review

The phonetic realisations of vowels in every language are constantly in flux. Many of these changes are due to assimilation effects from the phonetic environment surrounding the vowels (Gick et al. 2013, Vigário et al. 2009). This study investigates two examples of this phenomenon in English, where the vowel pairs DRESS-TRAP and FOOT-GOOSE[1] acoustically merge in a pre-lateral environment such that the word pairs *hell-hal* and *pull-pool* become homophones or near homophones.

The pre-lateral context, especially the pre-[ɬ] context, is known to have an effect on all vowels. Cox and Palethorpe (2004) found that in Australian English vowels preceding [ɬ] are typically lowered and retracted, especially high-front vowels. This is in large part due to assimilation towards the velarised /l/ that is common in English syllable codas (Cox and Palethorpe 2007, Loakes et al. 2014, 2017). This effect has played a part in two mergers, among others, in the world's Englishes: first, the *hell-hal* merger, which has been documented in many parts of the world, including New Zealand (Hay et al. 2013), South Africa (Finn 2004), and Victoria (Loakes et al. 2017); second, the *pull-pool* merger, caused by backing of the GOOSE vowel pre-laterally, which is now common across Australia (Cox and Palethorpe 2007).

The *hell-hal* merger in Victoria has been attributed to the highly variable production of the DRESS and TRAP vowels, which occurs even in non-lateral contexts (Diskin et al. 2019). This results in a reduced perception of contrast between the vowels for many speakers which, combined with coarticulatory effects from the velarised lateral, leads them to produce the vowels with little or no differentiation (Diskin et al. 2019, Loakes et al. 2017). The merger is currently still in progress, as there are many Victorians who do not merge, or barely merge, the vowels. There is some conscious awareness of this merger among Victorians, although the speakers most aware of it are typically those without the merger from elsewhere in Australia (Loakes et al. 2017). The merger is often referred to by speakers as the tendency for Victorians to pronounce *Ally* and *Ellie* or *celery* and *salary* the same, or as the pronunciation of *Melbourne* as [mæɬbən] rather than [meɬbən]. In New Zealand, where the merger is almost complete, there is very little awareness of it within the community (Hay et al. 2013). This aligns with Labov's (1994) assertion that speakers rarely notice mergers, and when they do, it is usually in specific exemplars. Labov also argues that speakers almost never have positive or negative attitudes towards mergers, but there has been too little work on attitudes towards the *hell-hal* merger in Victoria to confirm or refute this. Bradley (1989) did, however, show that the merger was more frequent among speakers from lower socioeconomic backgrounds in Melbourne, and the same has been observed in New Zealand (Hay et al. 2013).

The *pull-pool* merger in Australian English is less often discussed in recent literature, perhaps because the merger is now widespread. Oasa (1989) documented this merger as an identifying feature of Adelaide English, but more recently Cox and Palethorpe (2007) state that the merger is now common for younger speakers across Australia. As with *hell-hal*, the *pull-pool* merger is largely due to a coarticulatory effect from the [ɬ] which causes the speaker to retract the GOOSE vowel in *pool*, bringing it closer to the already-back FOOT vowel in *pull* (Cox and Palethorpe 2007). This retraction may be more noticeable in Australian English, where GOOSE is produced with a central vowel /ʉː/ when it is not pre-lateral, compared to a variety such as American English where it is produced farther back in all contexts (Hayes 2000).

These mergers are typically measured in terms of vowel quality (F1 and F2), but an important feature often ignored is duration, which can maintain contrasts between vowels that have merged in terms of vowel quality (Di Paolo 1992, Fridland et al. 2014, Wade 2017). Gordon (2013:205) states that "it would be premature, however, for a researcher to suggest that two vowel phonemes are merged just because they show overlapping distributions in a two-dimensional vowel space defined by F1 and F2", and he proposes duration as an important parameter. In

[1] In Australian English, the most common variety in this study, these vowel pairs are transcribed as /e/-/æ/ and /ʊ/-/ʉː/, respectively (Harrington et al., 1997).

fact, duration contrasts have even been found to be enhanced by speakers in cases of merging, as a way to more clearly distinguish the spectrally merging vowels (Wade 2017). Thus, while completed or in-progress mergers of *hell-hal* and *pull-pool* exist regarding vowel quality, as documented in the studies above, they may still be distinguished by duration (Hay et al. 2006). Duration as a contrastive feature is well-established in the literature for *pull-pool* in Australian English, which is predictable given the FOOT and GOOSE vowels have a phonemic length contrast (Cox and Palethorpe 2007, Harrington et al. 1997). This has not been observed for *hell-hal*; in fact, Loakes et al. (2017:37) note that "impressionistically, duration does not appear to be a factor" for distinguishing *hell-hal*. However, while DRESS and TRAP are both phonemically short, Cox and Palethorpe (2014) note that TRAP is typically longer than the other short vowels. If this length is maintained pre-laterally, there may indeed be a duration contrast between *hell* and *hal*.

Along with not analysing duration, further gaps in the literature on these mergers result from many previous studies having been conducted with very few participants, mainly with female participants (Loakes et al. 2017), and often with speakers who have lived in the same area for most of their lives. This study contributes to research on the pre-lateral merging of the DRESS-TRAP (*hell-hal*) and FOOT-GOOSE (*pull-pool*) vowels, particularly with a larger pool of participants, including male speakers and speakers with diverse linguistic and geographical backgrounds. It also contributes novel data and discussion of the effect of duration on maintaining contrasts for these vowels in pre-lateral environments. The specific research questions are:

(1) How does *hell-hal* and *pull-pool* merging vary across the represented world varieties of English?
(2) How does *hell-hal* and *pull-pool* merging vary across the represented varieties of Australian English?
(3) How do duration contrasts interact with vowel quality mergers?

2 Methodology

2.1 Participants

The 35 participants, of whom 22 were female and 13 male, were a convenience sample of residents at a college on the University of Melbourne campus. Their age range is narrow, with 63% either 18 or 19 years old, and all but 1 under the age of 30. While they all live in the same place currently, the majority have only moved to Melbourne this year or last year. They speak diverse varieties of English, with 14 participants from Victoria (Australia), 9 from other Australian states, 5 from New Zealand, 2 from Singapore, and 1 from Canada, Dubai, Malaysia, South Africa, and Vietnam, respectively. A speaker's variety of English is defined in this study as that of the country they spent the most time in up to the age of 18. For Australian English speakers, their variety is also more narrowly defined as that of the Australian state they spent the most time in up to the age of 18. All participants are fluent, first-language English speakers, and 8 have a second first language. Of the participants, 5 have rhotic accents. (See Appendix table for participant information.)

2.2 Instruments and Procedures

Participants were asked to read out a list of 22 words, representing the 11 Australian English monophthongal vowels (Harrington et al. 1997) in pre-t and pre-l position (e.g., *hut* vs. *hull*). The words were chosen to provide consistent environments for the vowels: preferably being /h/-initial, monosyllabic, in line with previous literature, and easily understood by the participants. Participants were also asked for a pseudonym, by which I refer to them here, their age, their gender, and their geographical and linguistic history. They were asked to repeat each word three times to produce the words as naturally as possible, and they were only told that I was investigating differences in pronunciation. If they made any mistakes, they were given the opportunity to repeat sections.

In the varied Australian and non-Australian accents of the participants, the 11 vowels may or may not be phonologically contrastive. The pre-lateral position may also change the vowel for some participants, for example by adding an offglide such that *heat* [hi:t] becomes *heel* [hiəl] (Hayes 2000). Rhoticity affects production as well: for rhotic speakers the vowel in, for example, *hurl* is not pre-l but pre-r. Rhotic speakers were excluded from analysis in these cases in Section 3.1, where ['words with /r/' OR 'potentially rhotic vowels'] are analysed, but were included for the investigation of *hell-hal* and *pull-pool* as they are not rhotic.

The participants' speech was recorded with an iPhone 6. Each recording was then automatically segmented using WebMAUS trained on Australian English speech (Kisler et al. 2017). All 2,310 vowel segments were then manually checked and edited in Praat. The endpoint of pre-lateral vowels was identified using auditory and acoustic cues, such as drop in amplitude and the common drop in F2 of the velarised /l/ (Diskin et al. 2019). Midpoint F1, midpoint F2, and durations of each token were extracted using a modified version of the "Formant Logger" Praat script (Crosswhite n.d.). As this was a process with potential errors, two rounds of manual checks were undertaken. First, to fix outliers, I checked every measurement which had a formant value more than 20%

above or below the average for that word from that speaker. Of the 49 identified, 37 were fixed, and 12 were not errors. This process, however, would miss situations where all 3 productions of a word were measured equally incorrectly, so the final check was a visual inspection of each participant's vowel space. This led to me checking 22 more vowel sets, of which only 4 had to be changed.

2.3 Analyses

This study is based on calculations of Pillai scores, which have been effectively used as a measure of vowel mergers in previous literature, including with only few tokens of each vowel (Diskin et al. 2019, Hall-Lew 2009, Hay et al. 2006, Loakes et al. 2019). These were calculated using the *R* statistical analysis environment (R Core Team 2019), along with the *tidyverse* (Wickham et al. 2019) and *dplyr* (Wickham et al. 2019) packages.

Taking the measurements (F1/F2/Duration) as dependent variables and the words (e.g., *hell* and *hal*, or *pull* and *pool*) as independent variables, the MANOVA function outputs a Pillai score from 0 to 1 which represents the degree of overlap of the two clusters of produced tokens, with a lower Pillai score indicating a higher degree of overlap (Hall-Lew 2010). Pillai scores are useful because they take into account the Euclidean distance between the formants of each vowel as well as their distributional overlap (Hay et al. 2006).

Pillai scores were measured for each speaker for four combinations: *hell-hal* as independent variables with F1xF2 as dependent variables, *hell-hal* with F1xF2xDuration, *pull-pool* with F1xF2, and *pull-pool* with F1xF2xDuration. These were then formatted into a spreadsheet along with the sociolinguistic information collected for each speaker. Another spreadsheet was made that held the raw measurements for every vowel token. From these, SPSS was used to conduct a range of dependent and independent t-tests to find differences in merging across various factors such as phonetic context, variety of English, and whether duration was included in the Pillai calculation.

3 Results

3.1 The Overall Effect of Pre-lateral Contexts

Anticipatory coarticulatory differences between vowels in pre-t or pre-l contexts are clear in their formant values. Averaged across all speakers, F2 is lowered for every vowel in a pre-l context compared to a pre-t context ($t(1965.78) = 10.30$, $p < .001$, $d = 0.46$), as shown in Figure 1. This is especially true of the GOOSE vowel. On the whole, as shown in Figure 2, the F1 of all vowels is very slightly lower in a pre-lateral context ($t(1956.18) = 1.98$, $p < .05$, $d = 0.09$). However, splitting the vowels by where they are articulated reveals a clearer trend. Before /l/, back and low vowels have a slightly lower F1 than when these vowels precede /t/ ($t(1249.31) = 4.62$, $p < .001$, $d = 0.26$). The other vowels, FLEECE, KIT, DRESS, and GOOSE, are produced with a slightly higher F1 in pre-l compared to pre-t contexts ($t(795.52) = 3.08$, $p < .01$, $d = 0.22$). Articulatorily, this suggests that speakers use a higher tongue position for low and back vowels pre-laterally and a lower tongue position for high vowels pre-laterally. The fact that DRESS and GOOSE are lowered pre-laterally while TRAP and FOOT are raised is important for the mergers of these vowel pairs. This is discussed further in Sections 3.2 and 3.3.

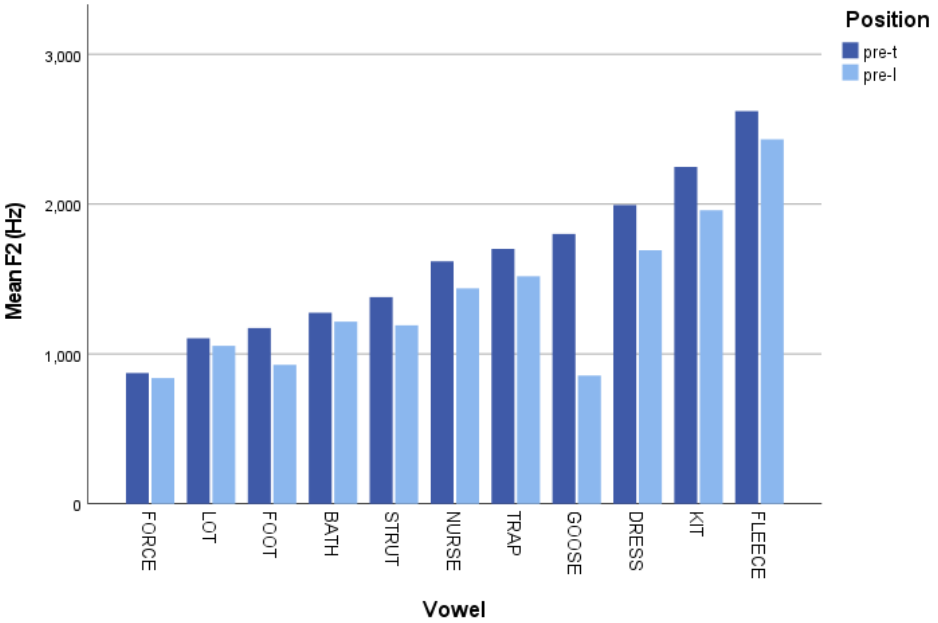

Figure 1: Mean F2 of all vowels pre-t and pre-l for all speakers.

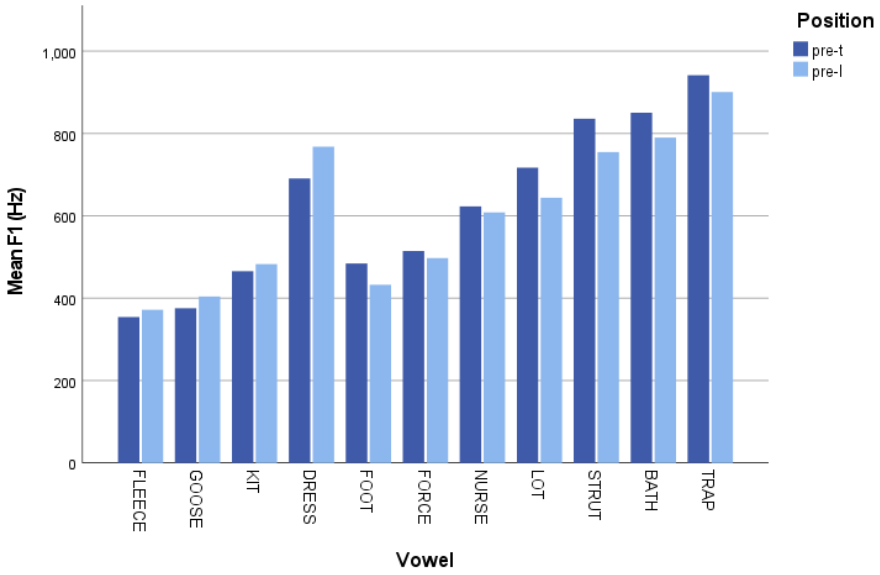

Figure 2: Mean F1 of all vowels pre-t and pre-l for all speakers.

3.2 The *hell-hal* Merger

3.2.1 An Overview of *hell-hal* Merging

There was wide variation in the merging of *hell-hal* across participants, though most participants produced the vowels with very little overlap (mean = .86, *sd* = .2, 83% above Pillai .8, see Appendix). There is no agreed point at which two vowels can be definitively said to be merged, as it depends on perception and other factors. As a guide, however, I do not produce the merger (Pillai = .94, not included in this study), and to my ears the *hell-hal* vowels produced by Foley (.14) or Acey (.26) are indistinguishable; May's, Susan's, and Jenna's vowels (.59-.66) sound very similar; and the vowels of the speakers with Pillai scores above .7 sound clearly distinct.

For those with at least some merging of *hell-hal* (Pillai < .8), the pre-lateral vowels were significantly more merged than the pre-t vowels in *het-hat* ($t(5) = 4.59$, $p < .01$, $d = 2.74$), as shown in Figure 3. However, across the whole group, the same difference is not significant ($t(34) = 1.97$, $p = .058$). Figure 4 depicts the vowel clusters of *het, hat, hell,* and *hal* for the 6 participants with Pillai scores below .8. The average distributions of *het-hat* are as expected: *het* is slightly higher and more forward than *hat,* and they do not overlap. Pre-laterally, both vowels are retracted into an overlapping distribution. The DRESS vowel is also typically slightly lowered, and the TRAP vowel sometimes slightly raised. The non-mergers of *hell-hal* typically showed pre-lateral vowel shifts in the same directions as the mergers, but not to the degree required to result in overlapping vowel clusters.

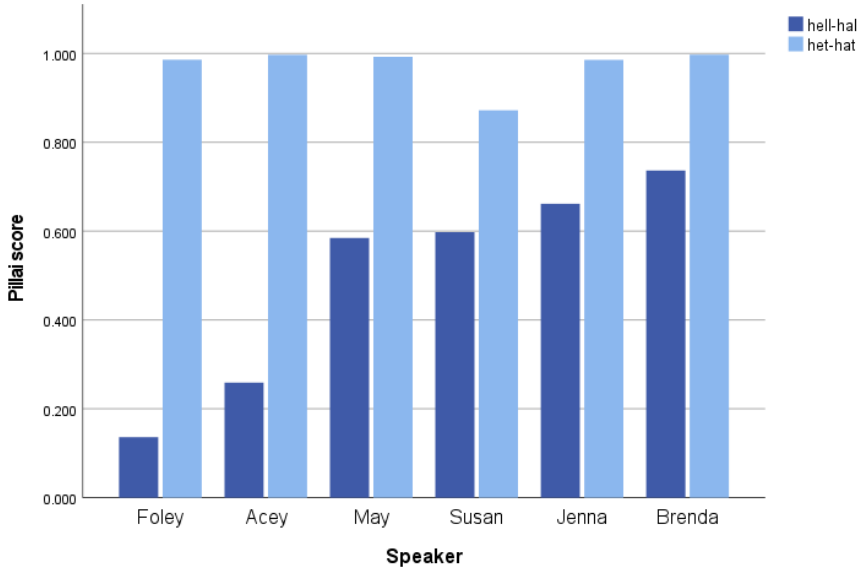

Figure 3: Pillai scores computed from vowel quality of *hell-hal* compared to *het-hat* for speakers with a Pillai score for *hell-hal* below .8.

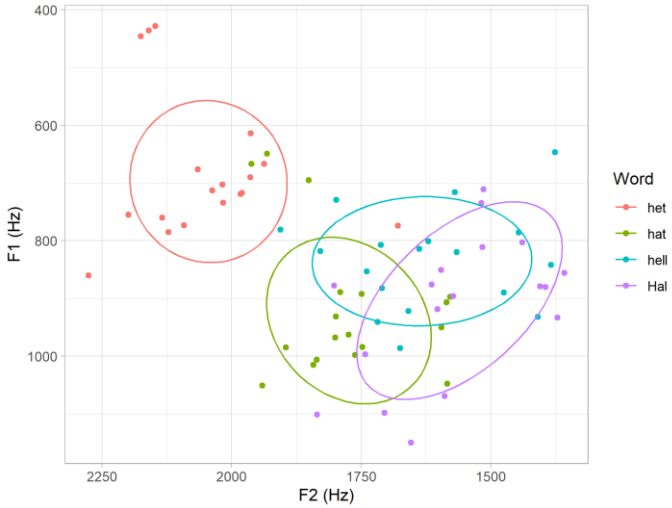

Figure 4: Vowel clusters of *het*, *hat*, *hell*, and *hal* for participants with Pillai below .8 for *hell-hal*.

3.2.2 The Effect of Duration on *hell-hal* Merging

When the formant values of a vowel are mostly or completely merged, the vowels may still be distinguished by duration. Adding duration as a dependent variable of the MANOVA along with F1 and F2 can elucidate how much it contributes to distinguishing the vowels. A way to understand what this Pillai score represents is: if the Pillai score with only F1 and F2 as dependent variables represents the overlap of the vowels' two-dimensional ellipses on a vowel plot, the Pillai score also including duration represents the overlap of the vowels' three-dimensional ellipsoids on a vowel plot with duration as a third axis.

Duration was a significant differentiating factor for *hell-hal*, with a small to medium effect size ($t(34) = 2.99$, $p < .01$, $d = 0.39$), as illustrated in Figure 5. Of the 6 speakers with a Pillai score below .8, 4 were raised above .8 when duration was added, and all Pillai scores increased. Note, however, that the Pillai score cannot be *reduced* by adding a variable. Therefore, for the speakers whose Pillai scores barely increased with the addition of the duration variable, duration is not an important factor in distinguishing the vowels. Average vowel lengths for *hell* and *hal* for each speaker are listed in Table 1. For all speakers except Dan, *hal* was produced with a longer vowel than *hell*. If duration were a completely irrelevant factor for some speakers, then one would expect *hell* to be longer than *hal* for around half of those speakers, or for the average durations to be almost identical. In line with Cox and Palethorpe (2014), the average length of the vowel in *hat* was longer than that in *het* for all but 2 speakers. This suggests that the pre-lateral duration contrast is not an innovation; rather, it is carried over from a general duration contrast between DRESS and TRAP. However, as shown in Figure 6, the average degree of difference in duration between DRESS and TRAP appears to be increased pre-l compared to pre-t. Foley and Acey also make for an interesting comparison, as duration is a large distinguishing feature for Acey's *hell-hal* but not for Foley's. Perhaps this is a difference between Victorian and New Zealand English, or perhaps it is due to individual variation not conditioned by variety.

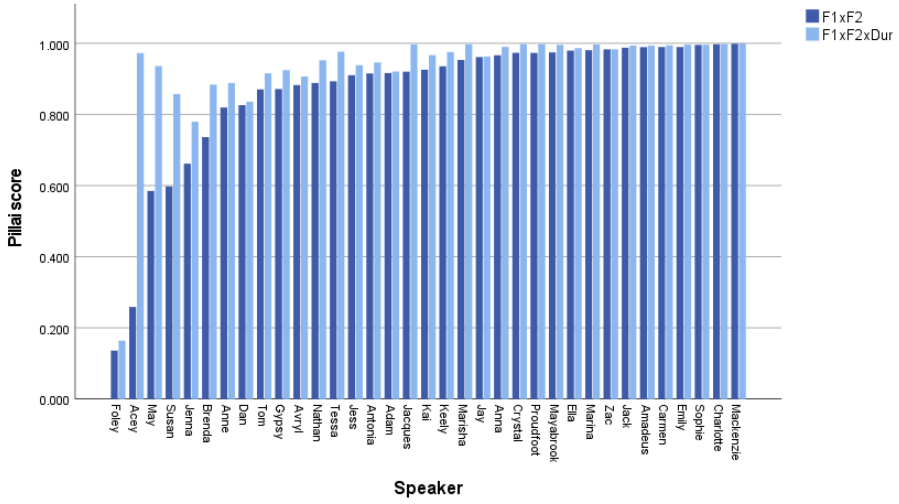

Figure 5: Pillai scores for *hell-hal* mergers computed from vowel quality alone compared to vowel quality and duration.

Table 1: Average duration (ms) of the vowel in *hell* and *hal* for each speaker

Speaker	*hal*	*hell*	Speaker	*hal*	*hell*	Speaker	*hal*	*hell*
Acey	100	40	Ella	117	77	Marina	308	93
Adam	89	47	Emily	125	88	Marisha	191	50
Amadeus	234	60	Foley	88	75	May	170	107
Anna	217	95	Gypsy	103	71	Mayabrook	194	93
Anne	156	111	Jack	95	40	Nathan	173	81
Antonia	100	78	Jacques	128	84	Proudfoot	192	65
Avryl	157	90	Jay	242	212	Sophie	244	120
Brenda	233	120	Jenna	125	89	Susan	153	70
Carmen	113	64	Jess	140	83	Tessa	145	95
Charlotte	210	108	Kai	205	58	Tom	93	50
Crystal	158	100	Keely	142	83	Zac	155	73
Dan	106	129	Mackenzie	211	59			

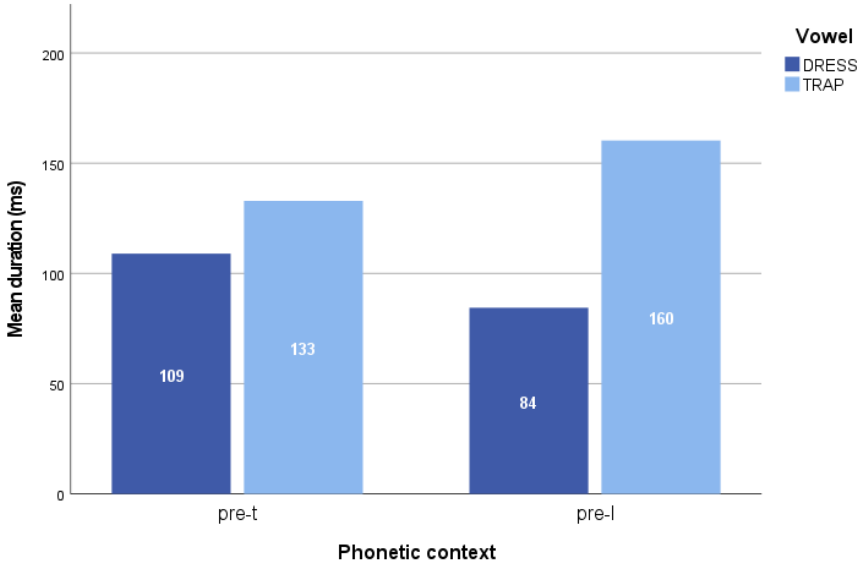

Figure 6: Duration contrasts between DRESS and TRAP vowels in a pre-t compared to a pre-l context.

3.2.3 The Relationship between Variety and *hell-hal* Merging

Trends according to variety of English can be seen in the data. Figure 7 shows that all of the speakers with a Pillai score below .7 come from Victoria, New Zealand (VIC/NZ), or South Africa, and this group has a significantly lower mean Pillai score compared to speakers from elsewhere ($t(23.707) = 2.13$, $p < .05$, $d = 0.68$). These varieties were selected as a group because they are the locations represented in the data which are said to exhibit this merger (Loakes et al. 2017). Note, however, that there are many speakers of varieties not from VIC/NZ/South Africa who have slightly stronger mergers than many of speakers from VIC/NZ/South Africa.

Looking just at participants from Australia or New Zealand, as shown in Table 2, those from New Zealand or Victoria tend to have the strongest mergers, though this distinction is statistically insignificant, and the single Tasmanian participant had a stronger merger than the average Auckland participant. The insignificance of these results suggest that while the varietal trends discussed in the literature probably exist, this sample size is too small to account for the interspeaker variation that exists within Victoria and New Zealand. This variation could be because the merger is still in progress or because the merger only occurs in specific areas of Victoria and New Zealand.

3.3 The *pull-pool* Merger

3.3.1 An Overview of *pull-pool* Merging

Merging *pull-pool* was a much more common feature for the participants than merging *hell-hal*. With F1 and F2 as dependent variables, there was a smooth grade from the most merged (.06) to the least merged (.97) (mean = .65, *sd* = .28), shown in Figure 8. For every speaker except Jay, who merged the vowels in *put* and *hoot*, the vowels of *pull-*

pool were far more merged than those in *put-hoot*. For those without the merger, the difference is of course minimal, but their *put-hoot* was never more merged than *pull-pool*. This contrasts with how speakers who barely merged *hell-hal* sometimes merged *het-hat* slightly more. This difference is likely because of how much farther forward the *hoot* vowel typically is than *put*, causing it to consistently be almost totally unmerged, whereas the means of the *het* and *hat* vowels are closer together and outliers in production are therefore more likely to cause overlap in their distributions.

Removing Jay as an outlier, differences between Pillai scores of *put-hoot* and *pull-pool* were significant and strong ($t(33) = 6.84$, $p < .001$, $d = 1.64$). Jay grew up in Singapore, and it is interesting to note his similarity to Jacques, who also grew up in Singapore. Jacques shows little overlap of *put-hoot* (.95), but this is due to his *hoot* vowel being farther back (lower F2) than *put*, whereas all speakers who grew up in Australia pronounce *hoot* farther forward (higher F2) than *put*.[2] Jay and Jacques may have a similar accent given their backgrounds, but Jay produces slightly higher F2 values for *hoot*, which leads to a *put-hoot* merger.

Figure 9 depicts the vowel clusters of *put*, *hoot*, *pull*, and *pool* for the 8 participants with a Pillai score below .4, indicating relatively strong mergers. The pattern is similar to the *hell-hal* merger. Pre-t, the GOOSE vowel is on average farther forward and slightly higher than the FOOT vowel. Pre-laterally, the GOOSE vowel is retracted and slightly lowered while the FOOT vowel is slightly retracted and raised, resulting in an overlapping distribution. Those who did not merge *pull-pool* still retracted the goose vowel pre-laterally to the same degree, but the resulting vowel cluster for *pool* remained higher than that of *pull*.

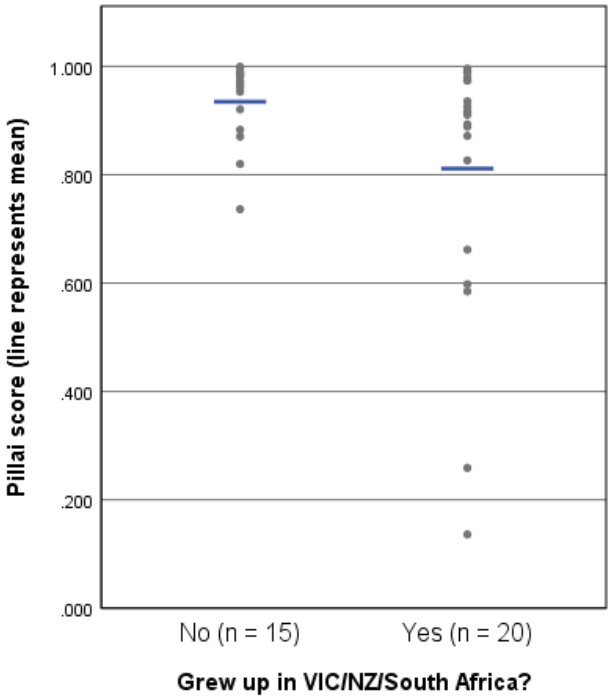

Figure 7: Pillai scores of vowel quality measuring degree of *hell-hal* merging for participants from VIC/NZ/ South Africa compared to elsewhere.

Table 2: Mean Pillai score of vowel quality for *hell-hal* merger by state (AUS) or city (NZ)

State/city	Pillai score
Cambridge (NZ)	0.14
Victoria (Aus)	0.85
Tasmania (Aus)	0.87
Auckland (NZ)	0.89
NSW (Aus)	0.92
Queensland (Aus)	0.98
ACT (Aus)	1.00

[2] This directionality distinction is not accounted for by Pillai scores.

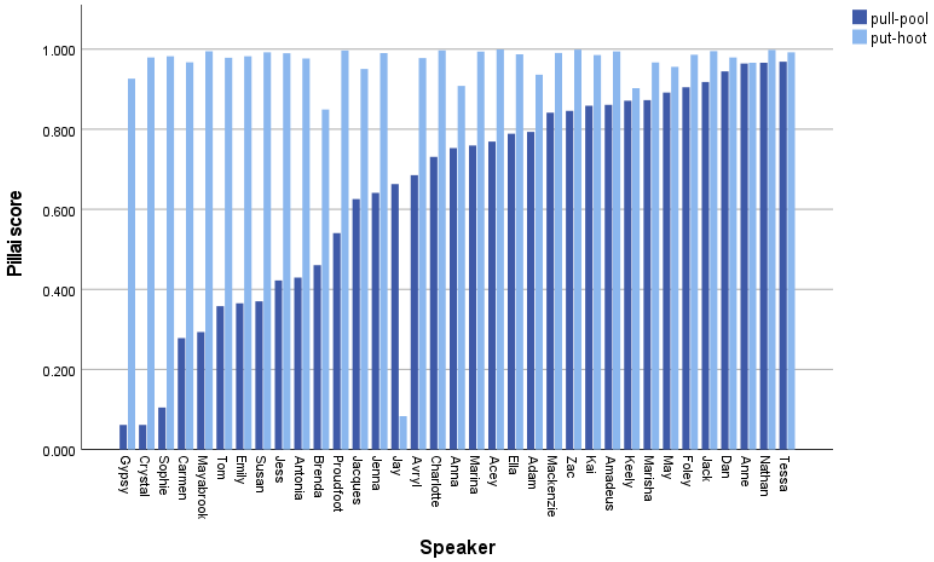

Figure 8: Pillai scores computed from vowel quality for *pull-pool* compared to *put-hoot*.

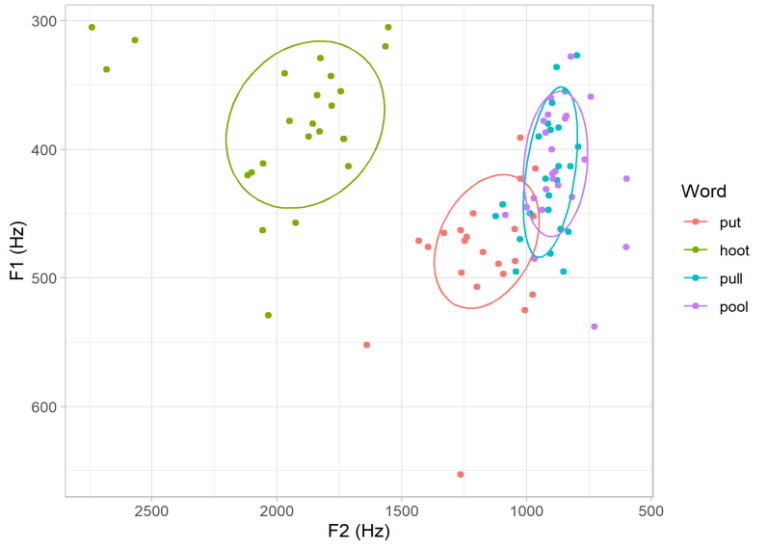

Figure 9: Vowel clusters of *put*, *hoot*, *pull*, and *pool* for participants with Pillai below .4 for *pull-pool*.

3.3.2 The Effect of Duration on *pull-pool* Merging

Including duration as well as F1 and F2 in the MANOVA increased the Pillai score for speakers as a whole ($t(34) = 5.85$, $p < .001$, $d = 0.88$), though the effect was far stronger for some speakers, such as Gypsy, than for others, such as Emily, who had similar durations for both, as shown in Figure 10. However, speakers for whom the Pillai score is already very high will inherently show a smaller increase in their score, as it is already closer to the limit. For example, Tessa's *pull* vowel is, on average, 135ms long, whereas her *pool* vowel is 220ms long, and both have small standard deviations. This is a large difference, but because her Pillai score is already nearing 1, adding duration as a dependent variable shows little increase. Similar to *hell-hal*, the vowel in *pool* was produced longer on average than that in *pull* by all but a single speaker. The *hoot* vowel also had a longer average duration than *put*, but unlike DRESS-TRAP, the degree of duration contrast between FOOT-GOOSE pre-t versus pre-l was roughly equal: GOOSE was roughly 50% longer than FOOT in both contexts.

3.3.3 The Relationship between Variety and *pull-pool* Merging

Participants who grew up in Australia had significantly stronger *pull-pool* mergers than those who grew up elsewhere ($t(32.03) = 3.93$, $p < .001$, $d = 1.24$). As shown in Figure 11, approximately half of those who grew up in Australia have a Pillai score less than .6, while all participants from elsewhere were above .6. Varietal

distributions of this merger within Australia were not investigated due to a lack of data from different regions of Australia.

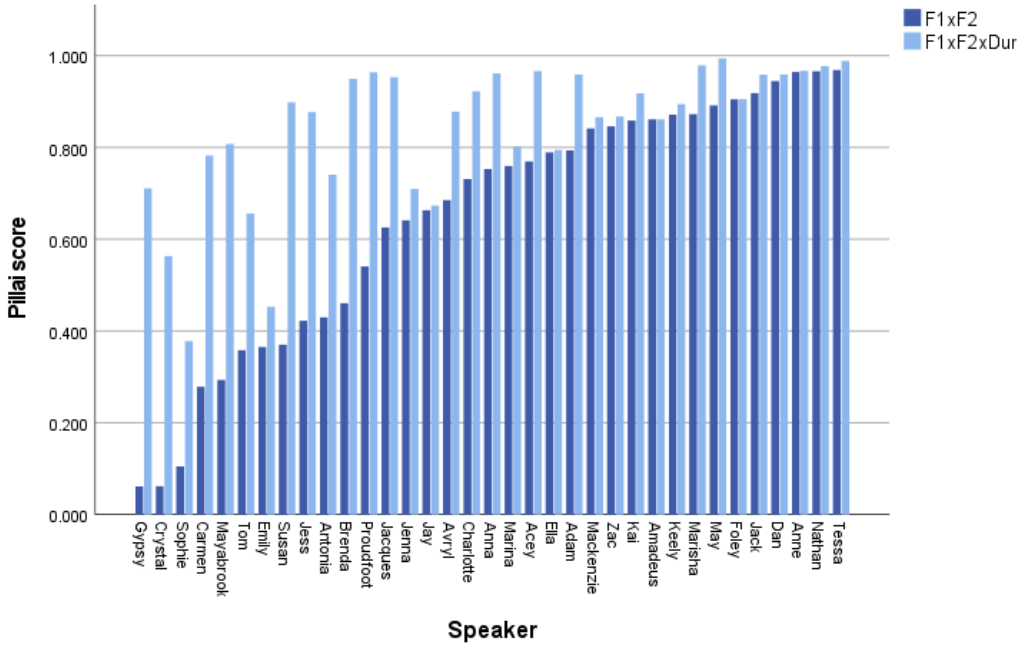

Figure 10: Pillai scores for *pull-pool* mergers computed from vowel quality alone compared to vowel quality and duration.

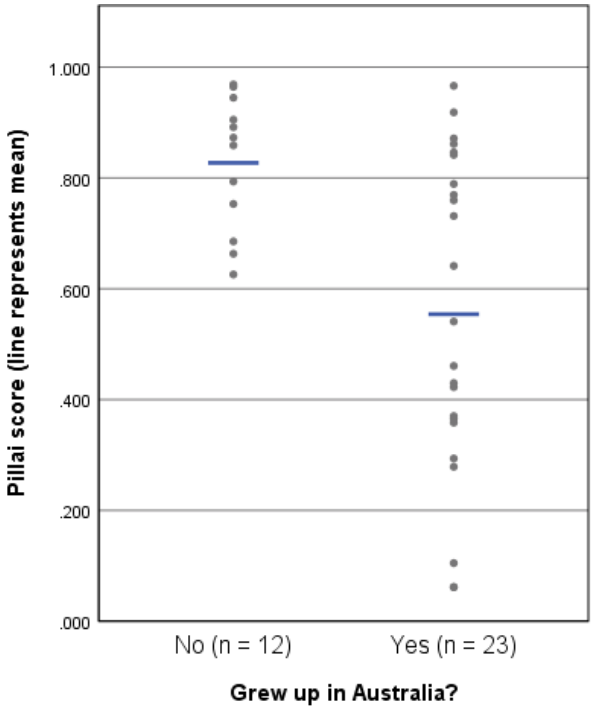

Figure 11: Pillai scores of vowel quality measuring degree of *Pull-pool* merging for speakers from Australia compared to elsewhere.

4 Discussion

4.1 Overall Effect of Pre-lateral Context on Mergers

The effect of /l/ on the preceding vowel mostly supports previous literature, with pre-lateral vowels produced farther back, especially high-front vowels (Cox and Palethorpe 2004). However, only the high-front vowels were

lowered; all others were slightly raised, which conflicts with the general understanding that it lowers all vowels (Cox and Palethorpe 2004). These effects are likely because of the velarisation of /l/ in coda position: the dorsum of the tongue is moved towards the velum, which draws the preceding vowel towards that position (Loakes et al. 2017). Thus, it makes sense that compared to their production in other contexts, high-front vowels were lowered and retracted pre-laterally, low vowels were raised and retracted, and high-back vowels were only slightly raised and retracted as they are already produced with the tongue close to the velum.

4.2 Effect of Duration Distinguishing Mergers

Research on vowel mergers tends to focus only on vowel quality, to the exclusion of duration. Duration has been shown to be important in distinguishing otherwise merged vowels (Fridland et al. 2014, Wade 2017), though Loakes et al. (2017) suggest that duration is non-differential in Victorians' *hell-hal* merger. Contrarily, this study found that duration was a significant differentiating feature for most speakers, and that *hal* was produced with a longer average vowel than *hell* by all but a single participant. For some speakers, such as Foley, who had the strongest merger, duration was indeed non-differential.

In line with Cox and Palethorpe (2014), the vowel in *hat* was typically longer than that in *het*, suggesting that a small duration contrast between DRESS and TRAP is present in other contexts as well as pre-laterally. The results also align with Grama et al. (2019), who found that the TRAP vowel was consistently longer than DRESS in a pre-nasal context. The duration contrast between these vowels, however, is increased pre-laterally. Before a /t/, TRAP is on average 22% longer than DRESS; before an /l/, TRAP is on average 90% longer than DRESS. Speakers may be emphasising this duration contrast pre-laterally in order to maintain a distinction between the vowels which are merged or merging in terms of vowel quality. Duration was also important for the *pull-pool* merger, as expected (Cox and Palethorpe 2007), though its importance also varied across individuals. The duration contrast was not found to be increased pre-laterally for this merger. It would be interesting to see if the duration contrasts between these vowel pairs are maintained or even increased in the future in order to distinguish the vowels, as observed for some other mergers (Labov and Baranowski 2006, Wade 2017), or if they will lose their importance as a distinguishing factor, perhaps as a result of the listeners' inability to perceptually distinguish the vowels even with the duration contrasts (cf. Loakes et al. 2012, 2019).

These results show that it is important to include measurements other than F1 and F2 when researching vowel mergers, as the vowels cannot be said to be merged if speakers and listeners are able to consistently differentiate them based on other features like duration, phonation, or trajectory (Di Paolo 1992, Gordon 2013).

4.3 Varietal Distribution of Mergers

The varietal distribution of *hell-hal* merging in this study reflects past research, with the Victorian, New Zealander, and South African participants producing the strongest mergers (Loakes et al. 2017). The amount of merging for Victorians closely resembles the results found in Diskin et al. (2019), with the Pillai score of about a quarter of participants below .8, going as low as .2. Hay et al. (2013:246) state that "most New Zealanders merge the vowels" in *hell-hal*, but this was not supported in this study, as all 4 participants from Auckland had Pillai scores above .8. This may be due to having only a small sample from NZ, or perhaps it reflects a lack of complete merging in Auckland compared to other areas of the country.

The *pull-pool* merger was found to be a strongly Australian phenomenon, though some participants from elsewhere had Pillai scores between .6 and .8. Loakes et. al. (2012) found that Australian listeners were not able to accurately distinguish *pull-pool*, which may be a factor driving the merging of the vowels in production, as in the *hell-hal* merger. Distributions of this merger within Australia could not be examined due to a lack of data.

4.4 Limitations and Future Research

The elicited nature of these data is likely not a fully accurate representation of how the participants pronounce these words (Hall-Lew and Boyd 2020). In some cases this clearly biased the results: for example, in one case, a participant mentioned that they thought they merge *hell-hal* very strongly in natural speech but, given the experimental context, they had tried to pronounce them as differently as possible. Contrastingly, some participants surprised themselves when they said *pull* three times then went on to *pool* and found that they pronounced them identically. This may suggest that they were not modifying their speech, because they were not even aware of the merger, unlike the participant purposefully differentiating *hell-hal* (cf. Labov 1994). However, it may also be that they do not merge the words in natural speech, which is why they were surprised by their merging in elicitation. Merging in minimal pairs but not spontaneous speech has been previously shown, for example, by Labov's (1994) participant Dan Jones, who merged *pull-pool* in elicitations but not in casual speech, or by several speakers in Pennsylvania, who merged *cot-caught* in elicitations but not in casual speech (Herold 1990). Analyses of naturalistic speech data are therefore an important supplement to these results. Alternatively, wordlist tasks with

several words for each target vowel may be a simpler way to strengthen the results. For example, some speakers' productions of *hal* were potentially affected because it is a name and/or because it was unfamiliar.

A more diverse sample in terms of age and socioeconomic status would allow for further connections to be made between mergers and these factors; for example, Hay et al. (2013) suggest that New Zealanders from a higher socioeconomic class do not merge *hell-hal* as often. A study of attitudes towards these mergers would also be interesting in light of Labov's (1994) suggestion that speakers almost never have attitudes towards mergers. Investigating other features of the vowel pairs, such as formant trajectory or phonation, would deepen our understanding of the degree to which they are merged, as suggested by Di Paolo (1992) and Gordon (2013). Further studies of perception in relation to Pillai scores could better define at what point of overlap a vowel is heard as merged. Finally, an analysis of merger variation across genders would also be productive and is possible with this data set.

5 Conclusion

This study has contributed to the literature on the pre-lateral DRESS-TRAP and FOOT-GOOSE mergers, incorporating the understudied factor of vowel duration. It has shown that coda /l/ has a significant coarticulatory effect on the preceding monophthong, backing and raising most vowels compared to those before a /t/. Duration was an important factor overall for maintaining a distinction between the word pairs, as indicated by the increased Pillai scores for many speakers when duration was included in the calculation. Furthermore, for almost all speakers the vowel in *hal* was longer than that in *hell*, and the vowel in *pool* was longer than that in *pull*. This duration distinction was greater pre-l than pre-t for DRESS-TRAP but not for FOOT-GOOSE. Differences in varieties of English had predictably strong effects on the extent of merging, with those from Victoria, New Zealand, and South Africa typically merging *hell-hal* more than others, and those from Australia merging *pull-pool* more than others.

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Appendix

Pseudonym	Variety of English	Age	Gender	Other Languages	Rhotic	Pillai *hell-hal*	Pillai *pull-pool*
Acey	Aus (VIC)	26	M			.26	.77
Adam	NZ (Auckland)	18	M	Japanese		.92	.79
Amadeus	Aus (NSW)	20	M			.99	.86
Anna	Dubai	22	F			.97	.75
Anne	Malaysia	18	F		Yes	.82	.96
Antonia	Aus (VIC)	19	F			.92	.43
Avryl	Canada	18	F		Yes	.88	.69
Brenda	Aus (NSW)	20	F			.74	.46
Carmen	Aus (VIC)	25	F			.99	.28
Charlotte	Aus (ACT)	19	F			1.00	.73
Crystal	Aus (VIC)	19	F			.97	.06
Dan	NZ (Auckland)	19	M	Mandarin	Yes	.83	.95
Ella	Aus (VIC)	18	F			.98	.79
Emily	Aus (VIC)	27	F			.99	.37
Foley	NZ (Cambridge)	18	M			.14	.91
Gypsy	Aus (VIC)	19	M			.87	.06
Jack	Aus (QLD)	20	M			.99	.92
Jacques	Singapore	38	M	Mandarin		.92	.63
Jay	Singapore	22	M	Mandarin		.96	.66
Jenna	Aus (VIC)	18	F			.66	.64
Jess	Aus (VIC)	19	F			.91	.42
Kai	NZ (Auckland)	18	M	Mandarin	Yes	.93	.86
Keely	Aus (VIC)	19	F			.94	.87
Mackenzie	Aus (NSW)	19	F			1.00	.84
Marina	Aus (QLD)	20	F			.98	.76
Marisha	Vietnam	23	F	Vietnamese		.95	.87
May	South Africa	18	F	French		.59	.89
Mayabrook	Aus (VIC)	18	F			.98	.29
Nathan	Aus (VIC)	19	M			.89	.97
Proudfoot	Aus (NSW)	21	M			.97	.54
Sophie	Aus (VIC)	18	F			1.00	.11
Susan	Aus (VIC)	23	F			.60	.37
Tessa	NZ (Auckland)	18	F	Mandarin	Yes	.89	.97
Tom	Aus (TAS)	19	F			.87	.36
Zac	Aus (QLD)	19	M			.98	.85