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Changing words and sounds: the roles of different cognitive units in sound change

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ABSTRACT

This study considers the role of different cognitive units in sound change: *phonemes*, *contextual variants* and *words*. We examine /u/-fronting and /j/-dropping in data from three generations of Derby English speakers. We analyse dynamic formant data and auditory judgments using mixed effects regression methods including generalised additive mixed models (GAMMs). /u/-fronting is reaching its end-point, showing complex conditioning by context and a frequency effect that weakens over time. /j/-dropping is declining, with low-frequency words showing more innovative variants with /j/ than high-frequency words. The two processes interact: words with variable /j/-dropping (*new*) exhibit more fronting than words that never have /j/ (*noodle*) even when the /j/ is deleted. These results support models of change that rely on phonetically detailed representations for both word- and sound-level cognitive units.

1. Introduction

The vowel /u/ (e.g. *goose*) is undergoing change in many English dialects, shifting from a back tongue position to a front one. This paper focuses on the cognitive aspects of sound changes such as /u/-fronting and asks: how are they reflected in speakers' cognitive representations? And, conversely, how do cognitive representations impact their unfolding? The nature of the cognitive units underlying sound change is one of the longest-standing debates in historical linguistics: the so-called *Neogrammarian controversy,* which asks: 'is it sounds or words that change?' (Labov, 2010: 260). The Neogrammarian view is that the fundamental units of change are phonemes and their contextually conditioned realisations (Labov, 2010). The alternative stance is that specific words can and do exempt themselves from general trends, leading to changes that diffuse gradually across the lexicon (Bybee, 2001; Phillips, 2006).

These views are associated with two different approaches to the nature of phonological representations. Modular approaches to phonology (Kiparsky, 1995; Bermúdez-Otero, 2007) assume that lexical representations consist of discrete abstract units (e.g. phonemes). When these units are passed on to phonetic implementation rules, information about their lexical identity is no longer available, and thus cannot influence their phonetic realisation. Modular approaches therefore predict that *gradient* sound changes (like /u/-fronting) cannot show lexical conditioning. This prediction does not extend to *categorical* changes, where a discrete phonological unit is replaced by a different one (e.g. *th*-fronting in English, where /θ/ is replaced by /f/). Categorical alternations can be represented solely via abstract units, and thus may show lexical conditioning.

The modular view is challenged by approaches that allow phonetic detail in lexical representations (Pierrehumbert, 2002), predicting that lexical conditioning can also arise in phonetically gradient changes. Such approaches are sometimes referred to as *episodic* or *exemplar-based*, since they often model phonetically detailed representations using collections of episodic memories. We refrain from using these terms: our focus is on how much phonetic detail is present in lexical and categorical representations, not how this detail is stored.

This study considers the roles of different cognitive units and their interactions in change: *phonemes*, *contextual variants* and *words*. The emphasis is on how these units manifest themselves in phonetically gradient change, though we also consider a change that may be categorical. We examine two phenomena in Derby English: /u/-*fronting* and /j/-*dropping* (variable deletion of /j/ before /u/ in e.g. *new*: /nu/ vs. /nju/). Our study builds on work that investigated these phenomena separately in relation to cognitive units (Labov, 2010; Phillips, 2006), but is unique in considering both their interaction and their unfolding over time. It is based on a set of nearly 3,000 acoustic measurements and auditory annotations representing three generations of speakers, and presents a dynamic analysis of vowel trajectories using generalised additive mixed models (GAMMs; Wood, 2006).

The rest of this section describes /u/-fronting and /j/-dropping (1.1), summarises work on cognitive units in change, and presents our predictions (1.2). Section 2 outlines our methodology. Section 3 presents an analysis of changes and structural/lexical influences in /u/-fronting, /j/-dropping and their interaction. Section 4 relates our findings to the issue of cognitive units in change.

1.1. /u/*-fronting,* /j/*-dropping and Derby English*

The vowel in English words like *goose* rarely has a phonetically back quality ([u]) for native speakers, instead showing fronted variants from [ʉ] to [y]. /u/-fronting is a widespread change found across the English-speaking world. Like most vowel shifts, /u/-fronting is phonetically gradient.

A /j/ before /u/ may be deleted after coronals. Deletion is found widely, but varies across dialects. Most British varieties have variable or categorical loss after /θ,s,z,l/ (*enthuse, suit, azure, lewd*), but retain /j/ after /t,d,n/ (*tune, duty, new*). In North America, /j/ deletion is the norm in all of these contexts. Most accounts of /j/-dropping treat it as a categorical process, though rarely with acoustic or articulatory support.

Derby English is a variety spoken in the north midlands of England. Like many other varieties, it exhibits /u/-fronting. However, it is fairly exceptional among British varieties in that it has variable /j/-dropping after /t,d,n/. This provides a unique opportunity to explore the interaction between these processes.

1.2. Phonemes, contexts and words in sound change

1.2.1 /u/-fronting

Figure 1 provides a visual summary of the intersecting levels of representation that are particularly relevant to /u/-fronting.

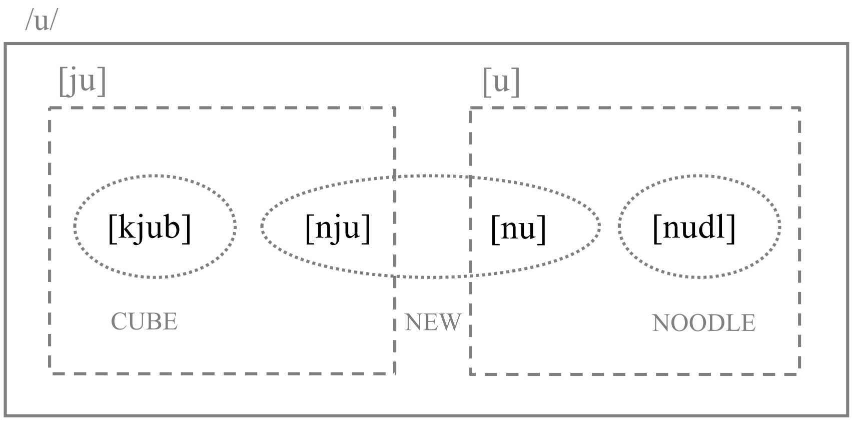

Figure 1: Three intersecting levels of representation relevant to /u/-fronting. See text for details.

The outermost solid box represents the phoneme /u/. The figure shows two contextual realisations of /u/ (dashed boxes): /u/ preceded by /j/ ([ju]) and /u/ in other contexts ([u]). The discussion below also highlights other important contexts such as a following /l/ in the same syllable. For the most part, specific words (dotted ellipses) are consistently realised with one of these contextual variants: for instance, *cube* is always [kjub], while *noodle* is always [nudl]. To streamline discussion we refer to words that always have /j/ as CUBE, and words that never have /j/ as NOODLE. Due to variation in /j/-dropping, a small set of words may be realised either with or without /j/. These words therefore span both contexts. We refer to variable words as N[j]EW when they contain /j/, and N[∅]EW when they do not.

Gradient sound changes provide ample evidence for the crucial role of phonemes and contextual variants, to the point where ‘the finding that a given change follows a regular Neogrammarian path is not a publishable result’ (Labov, 2010: 259). Changes that are complete usually affect all words with a given sound, and words with similar phonetic contexts tend to change in parallel, attesting to the ‘binding force of the phoneme’ (Labov, 2010). Such patterns can be accounted for by assuming that it is the phonetic details associated with abstract phonemic units that change. This account originates from modular approaches to sound change (Kiparsky, 1995), but has also been incorporated into a range of ‘hybrid models’, which propose that both abstract (e.g. phonemes) and less abstract units (e.g. words) are associated with phonetic detail (Pierrehumbert, 2002, 2016). Different contextual variants of a phoneme occasionally follow divergent paths, suggesting that such variants also have a degree of autonomy in phonetic realisation.

What role do phonemes and contextual variants play in /u/-fronting? /u/-fronting has been noted to display sensitivity to context. Words with preceding /j/ typically have the most front realisations of /u/, followed by words with preceding coronals/palatals (e.g. *noodle*, *June*). Conversely, a following /l/ in the same syllable (e.g. *school*) inhibits /u/-fronting. These patterns manifest both as synchronic variation and as long term change. Based on these contextual effects, we make the following predictions relating to the tension between phonemes and contextual variants:

> (P1) *Contextual effects in /u/-fronting*: different contexts will show different degrees of fronting, due to phonetic effects. They may develop in parallel in accordance with the notion of phoneme-level binding, or they may diverge over time. Contexts of particular interest are: (i) following /l/, (ii) preceding /j/, (iii) other preceding environments favouring fronting, and (iv) preceding environments that inhibit fronting.

Sound change can also be subject to lexical conditioning, proceeding at different rates in different words. For instance, /æ/-tensing in the US Mid-Atlantic region affects *bad*, *mad* but not *sad* (Labov, 2010). /t,d/ deletion in American English progresses faster in frequent words (Bybee, 2001); and the voicing of medial /t/ in New Zealand English is affected by a range of lexical factors, including word frequency and whether a word is typically used by younger or older speakers (Hay and Foulkes, 2016).

The possibility of lexical conditioning in phonetically gradual changes (like /u/-fronting) remains debated. This is partly due to the fact that studies investigating lexical effects rarely rely on continuous acoustic or articulatory measurements. Labov (2010), however, examines several vowel shifts in the US (including /u/-fronting) and fails to find robust lexical effects. This null finding seems to support modular approaches without phonetic details in lexical representations. However, Hay et al. (2015) do find lexical conditioning in vowel shifts in New Zealand English: low-frequency words change faster.

There is an additional complication regarding lexical effects in phonetically gradual changes. Certain online speech production processes are lexically specific: for instance, frequent and predictable words tend to be reduced (Bell et al., 2009). Since these processes apply online, they can also be accommodated in modular feedforward models where lexical representations are devoid of phonetic detail – reduction is not explicitly encoded in lexical representations, but is added in the course of word production. Importantly, the size of such purely online effects should stay stable in the context of a sound change, and frequency-related phonetic differences among words should therefore not increase or decrease over time. If, on the other hand, reduced variants are fed back into lexical representations, the phonetic targets for words experiencing different degrees of reduction will shift at different rates, leading to changes in the size of frequency effects (Hay & Foulkes, 2016).

Let us turn to our predictions about lexical effects in /u/-fronting. A recurring factor in word-specific changes is lexical frequency, though the direction of frequency effects is not always the same: high-frequency words lead certain changes (e.g. voicing of medial /t/; Hay & Foulkes, 2016), while low-frequency words lead others (e.g. vowel shifts; Hay et al., 2015). In the current case, the former scenario seems more likely. /u/-fronting is arguably a consequence of phonetically natural factors such as coarticulation with surrounding coronal/palatal consonants (Harrington et al., 2011), and the effects of such factors are likely to be exaggerated in high-frequency words that are produced in a reduced form. Therefore, we make the following prediction:

> (P2) *Frequency effects in* /u/-*fronting*: high-frequency words should lead. This effect may increase or decrease over time.

Figure 1 suggests an even more intriguing word-specific prediction. Words such as *new* show variable /j/-dropping. A preceding /j/ is a strong favouring environment for /u/-fronting, which means that N[j]EW should show more fronting than N[∅]EW. However, if phonetic details are stored in word-specific representations, the distribution underlying the production of /u/ in variable words will be based partly on fronted N[j]EW tokens and partly on less fronted N[∅]EW tokens. This may result in a 'regression to the mean', whereby N[∅]EW tokens show more fronting than non-alternating words without /j/ (NOODLE), while N[j]EW tokens show less fronting than non-alternating words with /j/ (CUBE). In other words, we may see a word-level binding force that acts against the differential phonetic pressures in N[j]EW *versus* N[∅]EW. Similar word-level binding effects have been reported for the retraction of /u/ before /l/, where alternating forms such as *fool~fooling* both show some retraction despite the fact that medial /l/ typically fails to cause retraction in other non-alternating words (e.g. *hula*; Strycharczuk and Scobbie, 2016).

> (P3) *Word-level binding in* /u/-*fronting*: N[j]EW will show less fronting than CUBE, while N[∅]EW will show more fronting than NOODLE.

1.2.2 /j/-dropping

The case of /j/-dropping is more complicated than that of /u/-fronting due to uncertainty around whether it is categorical or phonetically gradient. Previous work has analysed /j/-dropping categorically, coding for presence/absence of /j/, but there are claims that the phenomenon itself is gradient (Phillips, 2006). This is, of course, a crucial distinction: finding lexical effects for /j/-dropping would only constitute evidence for word-specific phonetic detail if the phenomenon is gradient. We cannot address this question, adopting here a categorical analysis for what may, in fact, be a gradient phenomenon. This decision is motivated partly by the difficulty of finding a quantitative measure of '/j/-fulness', and partly by a desire to make the analysis of the interaction between /j/-dropping and /u/-fronting more straightforward. Future work may determine whether /j/-dropping is gradient or categorical.

Phillips (2006) reports significant effects of word frequency on /j/-dropping in southern US English, with low-frequency items leading. Bybee (2000) argues that this effect follows from dialect borrowing from varieties without /j/: low-frequency items like *tunic* are less entrenched in memory than high-frequency items like *new*, and are therefore more vulnerable to influence from other varieties. Phillips (2006) provides a different account that also relies on the notion of memory entrenchment. She argues that the pressure to lose /j/ comes from the markedness of initial consonant sequences such as /tj,dj,nj/; low-frequency words with weaker representations are less resistant to this pressure.

Based on these findings, there are two possible predictions about the role of word-frequency in /j/-dropping in Derby English.

(P4a) */j/-dropping due to markedness*: If /j/-dropping is due to the markedness of clusters with /j/, Derby English should mirror southern US English, with low-frequency items leading the change.

(P4b) '*/j/-restoration*' *through dialect borrowing*: The standard dialect in England has no /j/-dropping after /t,d,n/ (Wells, 1982). If dialect borrowing affects low-frequency items first, we expect more /j/-dropping in high-frequency words, which should retain the local pattern due to their representational strength.

2. Methods

2.1. Materials

Our data come from recordings made in Derby in 1995 (Milroy et al., 1996) and 2010 (Haddican, 2014). They contain unscripted conversations and word-list data. There are three generations: *older* (19 speakers born 1913–50), *middle* (10 speakers born 1968–81) and *younger* (16 speakers born 1983–92).

2.2. Data processing

Using automatic methods (LaBB-CaT: Fromont & Hay, 2008; Penn Aligner: Yuan & Liberman, 2006), we extracted all /u/ words: 2,912 tokens after discarding high-frequency function words and problem cases. Words with preceding contexts that trigger near-categorical /j/-dropping such as *suit* and *enthuse* were excluded.

We used Formant Editor (Sóskuthy, 2014) to extract and manually correct F2 (second formant) trajectories. F2 is a reliable acoustic correlate of articulatory fronting. Each trajectory consists of 11 time-normalised measurements including the onset and offset points. /j/ was included in the trajectory where present. The first two authors made separate auditory judgments about the presence of /j/ for all words with variable /j/. We opted for auditory coding criteria in order to minimise artefacts in our acoustic analysis (i.e. using F2 alone to determine both the presence of /j/ and the degree of fronting in the vowel), and we also exploited auditory cues not embedded in the vocalic portion (e.g. affrication and palatalisation of the preceding consonant). Disagreements were resolved through discussion. A subset of 100 randomly chosen tokens were reanalysed blindly to estimate the reliability of our judgments. The raters agreed on 86% of tokens (Cohen's Kappa = 0.724), and the agreement between the original and new ratings was similarly high (84% for each rater, Cohen's Kappa = 0.673 and 0.682).

We normalised formant values to attenuate between-speaker differences (using Fabricius et al., 2002, implemented via Kendall & Thomas, 2009). Results are presented on a normalised scale, where a unit of one corresponds to the F2 difference between [i] and [u].

2.3. Data analysis

We fit three separate sets of statistical models to test our predictions. The first addresses P1 and P2, the second addresses P3 and the third addresses P4. Below is a brief summary of these models; more detail is provided in the results section.

M1. GAMMs that model F2 trajectories in /u/ as a function of age, context and frequency. (outcome variable: continuous F2 values)

M2. GAMMs that model F2 trajectories, looking at whether N[∅]EW differs from NOODLE, and whether N[j]EW differs from CUBE. (outcome variable: continuous F2 values)

M3. A mixed effects logistic regression model that predicts the presence of /j/ as a function of age and frequency. (outcome variable: binary presence/absence of /j/)

GAMMs extend mixed effects regression models by allowing the inclusion of *smooth terms* and *random smooths* in addition to linear terms (Wood, 2006; Winter and Wieling, 2016; Sóskuthy, 2016). Smooth terms capture non-linear effects without requiring pre-specification of the degree of non-linearity. Random smooths extend the same principle to random effects, fitting separate curves at each value of a grouping variable.

GAMMs are well suited to the analysis of time-varying speech data, as they can capture variation not only in trajectory *height* but also in trajectory *shape*. For example, **age** may affect average F2 (e.g. higher F2 for younger speakers across the entire trajectory), the shape of the trajectory (e.g. flatter trajectories for younger speakers), or both. Our GAMMs use separate terms to capture these two types of effects: parametric main terms for height effects, and smooth terms for shape effects. The latter are essentially interactions between position along the trajectory and one or several other variables such as **age** or **frequency**.

Since inspecting main and smooth terms separately may lead to false positives, we first evaluate their significance jointly using model comparisons between a full model and one that excludes both terms (the *overall* comparison; Sóskuthy, 2016). When the overall comparison is significant, we also perform more specific *shape* comparisons by excluding the shape term only.

The results are presented in the form of tables summarising the model comparisons, and model prediction plots. Since GAMMs cannot be interpreted solely using model summaries, the plots are not purely illustrative: they play a central role in the discussion. Space constraints prohibit a presentation of full model summaries. Instead, we focus on those terms that are directly relevant to our predictions.

3. Results

3.1. Overall trends in /u/-fronting

We first examine overall trends in /u/-fronting, with particular focus on the effects of age, frequency and preceding context (P1, P2). Only words that are consistently realised with or without /j/ are included (i.e. CUBE/NOODLE). Separate models were fit for tokens not followed by /l/ (2,213 tokens) and tokens followed by /l/ (291 tokens). Lateral contexts with a following vowel (e.g. *schooling*) were excluded.

The outcome variable for both models is normalised F2. The following predictors are included in the non-lateral model: **age** (*older*, *middle*, *young*), log wordform **frequency** from the British National Corpus (Burnard, 2007), **preceding** environment (/j/; *favouring*: coronal, palatal, velar;[1] *non-favouring*: all other consonants), **type** of recording (word list *vs.* conversation), **sex**, and trajectory **duration**. The lateral model includes the same predictors except **preceding** and **frequency**, as almost all pre-/l/ tokens are examples of the lexeme *school*. The non-lateral model includes height and shape effects for **age**, **frequency**, **preceding** and all their interactions. Therefore, it can capture changes in /u/, frequency effects on /u/, and also changes in the size of frequency effects. Both models include random smooths by **speaker**, **wordform** and **following** segment. They also include AR1 residual error models to control for autocorrelation within trajectories.

Table 1 shows the results of model comparisons for the non-lateral model. The comparisons always include the full model, incorporating all terms and interactions. The other model is a nested model. For ‘overall’ comparisons, the nested model excludes both the main term (height) and the smooth term (shape) corresponding to the predictor, as well as all

[1] Velars do not universally favour fronting, but they had a strong effect in our data.

higher order interactions containing these terms. For instance, the comparison in row 1a is between the full model and a model that excludes all terms with **preceding** (e.g. **age** × **preceding**, etc.). It tests whether **preceding** as a whole improves the model fit. For 'shape' comparisons, the nested model retains the main term but excludes the smooth term and all higher order interactions containing the smooth term. Such comparisons (e.g. row 1b) test whether the model is improved by including information about the effects of a predictor on trajectory shapes. Shape comparisons were only performed where the overall comparison was significant.

	COMPARISON	χ^2	DF	p (χ^2)
1a	overall: preceding	230.4	40	< 0.0001
1b	shape: preceding	119.7	30	< 0.0001
2a	overall: age	179.6	38	< 0.0001
2b	shape: age	96.4	21	< 0.0001
3a	overall: age × preceding	51.3	24	< 0.0001
3b	shape: age × preceding	27.7	14	< 0.0001
4a	overall: frequency	44.0	36	< 0.0001
4b	shape: frequency	20.3	21	< 0.0001
5a	overall: age × frequency	29.8	21	< 0.0001
5b	shape: age × frequency	8.1	12	0.18

Table 1: Model comparisons for the non-lateral model. First column: the type of comparison (cf. 2.3) and terms dropped in the nested model; second column: difference in log-likelihood; third column: difference in degrees of freedom; final column: *p*-value.

Table 1 provides evidence for age (2a,b), frequency (4a,b) and contextual effects (1a,b). /u/-fronting proceeds differently across contexts (3a), which is also manifested in trajectory shape (3b). The overall size (5a) but not the shape (5b) of the frequency effect changes significantly over time.

Figure 2 shows model predictions as a function of **age**, **frequency** and **preceding**.

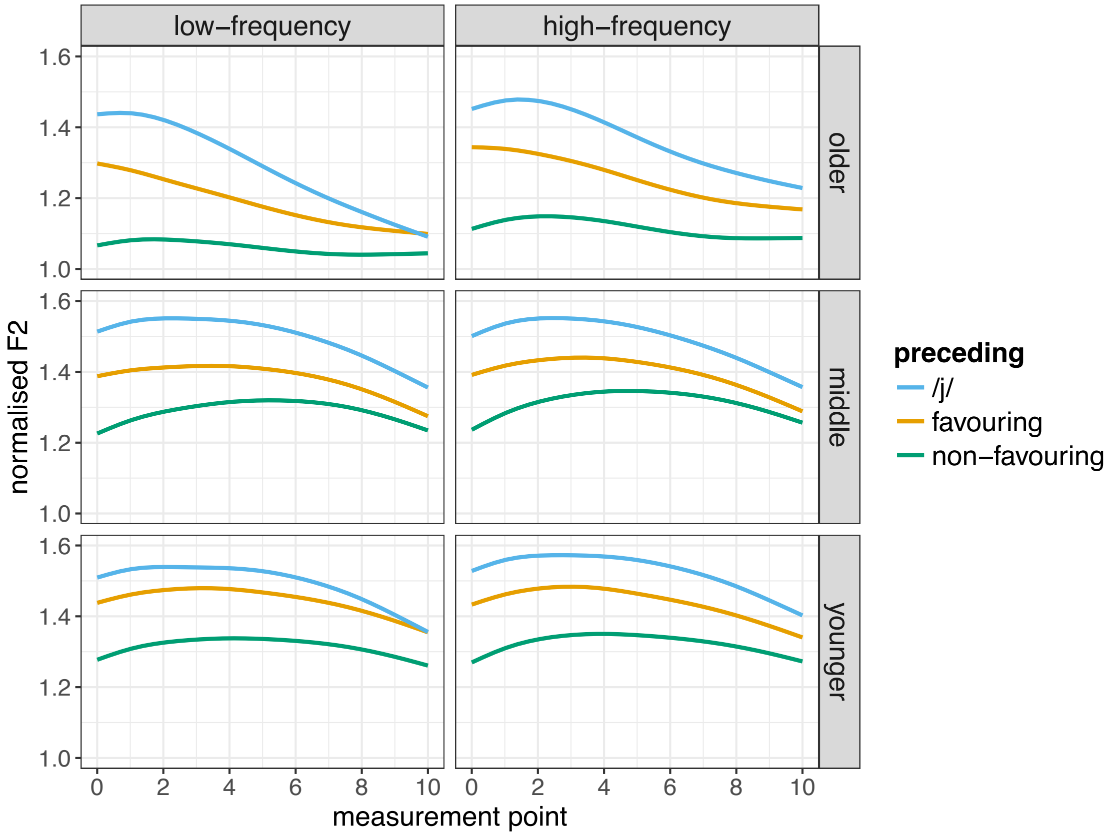

Figure 2: Prediction plot for the non-lateral model. Trajectories are shown for preceding /j/ (blue), favouring (orange) and non-favouring contexts (green). The panels show different combinations of **age** (rows) and **frequency** (columns). The low and high-frequency panels represent predictions at the 10th and 90th percentiles of **frequency**.

The plots show a flattening and raising of trajectories with /j/ (i.e. the change mainly affects the vocalic part of the sequence) and substantial overall raising in the favouring and non-favouring groups. These changes are slowing down, with greater differences between the older and middle generations than between the middle and younger generations. The older generation also exhibits a strong frequency effect across all environments, with frequent words showing the highest degree of fronting. The frequency effect mostly disappears in later generations ((5) in Table 1).

Table 2 summarises the lateral model.

	COMPARISON	χ^2	DF	p (χ^2)
1	overall: age	16.9	7	<0.0001
2	shape: age	16.4	3	<0.0001

Table 2: Model comparisons for the lateral model.

The comparisons suggest a significant **age** effect for pre-/l/ tokens (1), which manifests at least partly in the shape of the trajectories (2). Figure 3 illustrates this effect.

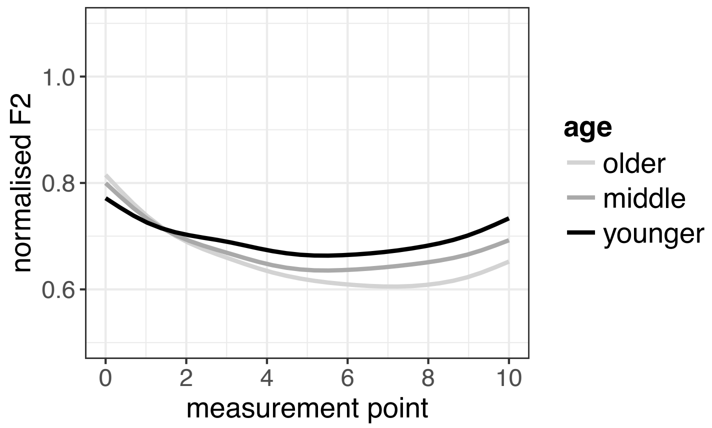

Figure 3: Prediction plot for the lateral model.

With normalised F2 between 0.6–0.8, /u/-fronting before laterals is far behind other contexts (cf. F2 of 1.0–1.6 in Figure 2). However, some fronting does occur, especially near the end of the trajectory. The size of the change is only a fraction of that seen in other positions.

3.2. The effect of /j/-variation on /u/-fronting

Our third prediction has two components: (i) words with variable /j/-dropping (e.g. *new*) may show more fronting than similar words without /j/ (NOODLE with preceding /t,d,n/) even when /j/ is not present (N[∅]EW); and (ii) they may show less fronting than words with an invariable /j/ (CUBE) when the /j/ is present (N[j]EW). We therefore fit separate GAMMs to compare (i) variable and invariable words without /j/ (665 tokens) and (ii) variable and invariable words with /j/ (598 tokens). The outcome variable for both models is normalised F2. The predictor that separates variable and invariable words is referred to as **/j/-variation**. The models test for height and shape effects of **/j/-variation** (differences between N[∅]EW vs. NOODLE and N[j]EW vs. CUBE), **age** and their interaction. They also include **type** of recording, **sex** and trajectory **duration** as control variables; random smooths by **speaker** × **/j/-variation** (separate random smooths for variable and invariable words within each speaker), **wordform** and **following** environment; and an AR1 error model.

Tables 3 and 4 show the model comparisons.

Words with [u] (N[∅]EW vs. NOODLE):

	COMPARISON	χ^2	DF	p (χ^2)
1	overall: /j/-variation	8.0	8	0.044
2	shape: /j/-variation	7.2	5	0.014
3	overall: /j/-variation × age	1.0	5	0.851

Table 3: Model comparisons for words with [u].

Words with [ju] (N[j]EW vs. CUBE):

	COMPARISON	χ^2	DF	p (χ^2)
1	overall: /j/-variation	0.4	8	0.999
2	overall: /j/-variation × age	0.1	5	0.999

Table 4: Model comparisons for words with [ju].

There are significant differences between variable and invariable words without /j/ (Table 3) but not between variable and invariable words with /j/ (Table 4). The models do not indicate any age effects, thus we only show model predictions for younger speakers (Figure 4).

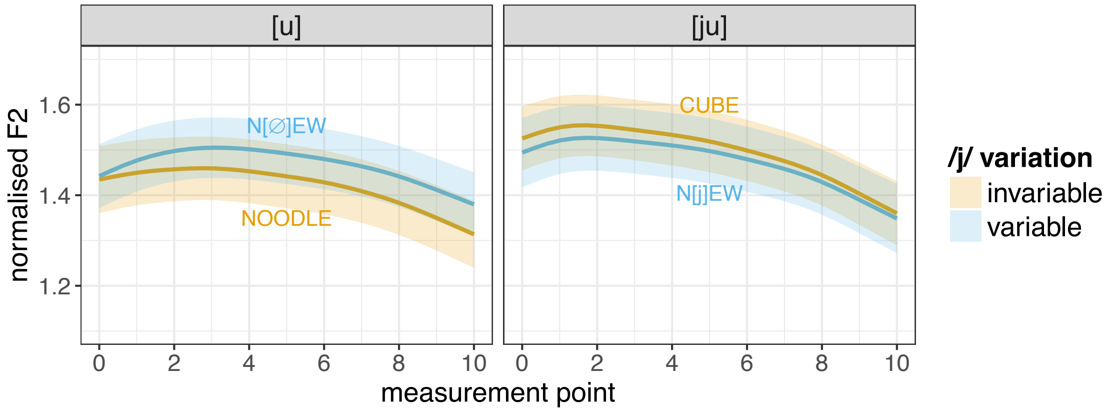

Figure 4: Prediction plot for young speakers for words with [u] (left) and words with [ju] (right).

The plots illustrate that variable words where /j/ is dropped (N[∅]EW) have higher F2 than words that never have /j/ (NOODLE). The difference manifests mainly near the end of the trajectory, which is supported by the significant shape effect in Table 4. In other words, the /j/ portion of the variable *versus* invariable trajectories has the same level of frontness, but the vowel itself is more fronted in variable words. There is no difference between variable words where /j/ is retained (N[j]EW) and words that always have /j/ (CUBE).

3.3. Overall trends in /j/-dropping

To test P4, we fit a mixed effects logistic regression model to words with variable /j/ (408 tokens). The outcome variable is the presence of /j/, while the main predictors are **age**, **frequency** and their interaction. The model also controls for **type**, **sex** and **preceding** context (/t,d,n/), and includes random intercepts by **speaker** and **wordform** and random slopes for the main predictors.

Table 5 shows model comparisons.

	COMPARISON	χ^2	DF	p (χ^2)
1	age	13.4	4	0.01
2	frequency	9.0	3	0.03
3	age × frequency	7.8	2	0.02

Table 5: Model comparisons for the /j/-dropping model.

All three model comparisons are significant, suggesting that **age** and **frequency** both play a role in /j/-dropping, and also that they interact. This is supported by Figure 5, which shows the predicted probabilities for the different age groups in low/high-frequency words. (The confidence intervals are asymmetrical since the predictions are transformed into probabilities from log-odds. This compresses distances around the top and bottom of the scale.)

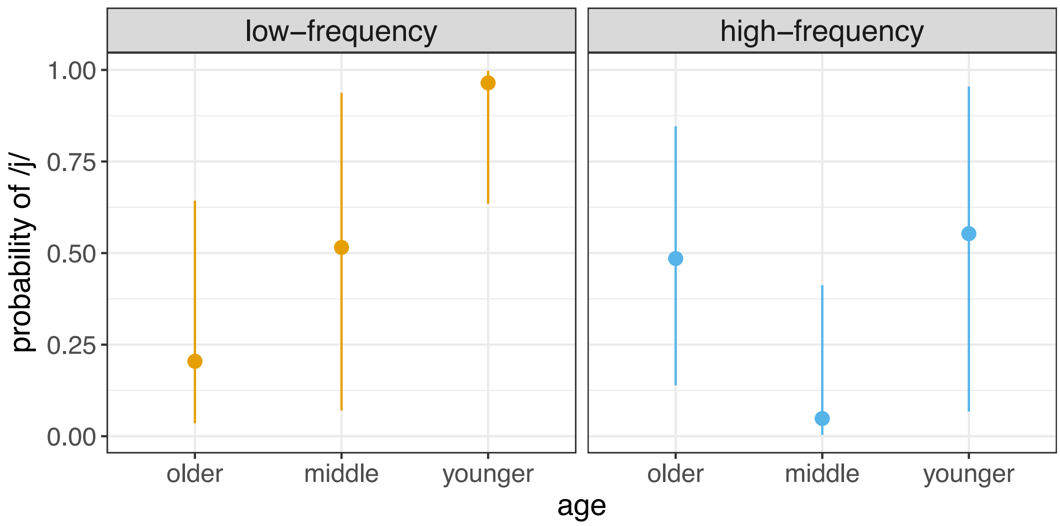

Figure 5: Predicted probabilities of /j/ by age group for words at the 10th (left) and 90th frequency percentiles (right). Dots = model predictions; lines = 95% confidence intervals.

The probability of /j/ increases in low-frequency words. For high-frequency words, we see fluctuations but no consistent change. The U-shaped pattern of change should be interpreted with caution, given the width of the confidence intervals.

4. Discussion and conclusions

Let us briefly summarise the findings. Where /u/ is not followed by /l/, fronting occurs in all contexts. Words with preceding /j/ lead the change. The change is reaching its end-point, with little change between the last two generations. Before /l/, /u/-fronting appears largely blocked, though there is some fronting in this context as well. We also found a frequency effect in /u/-fronting, with frequent words in the lead, though this effect is weaker than contextual effects and only present for older speakers. Variable words with deleted /j/ show more fronting than similar words that are never realised with /j/. This effect is also relatively weak. We predicted less fronting in variable words that retain /j/ compared to words that are always realised with /j/, but this prediction was not supported. Finally, /j/-dropping appears to be receding in low-frequency words, with no consistent changes among high-frequency words.

We now turn to P1. Looking at Figure 2, different contexts appear to change in parallel, supporting the notion of phoneme-level binding forces. A comparison between figures 2 and 3 also reveals that the pre-/l/ context breaks away from its original category, showing that contextual variants can indeed have some degree of independence. This, in itself, does not challenge modular approaches: it could easily be accommodated using separate phonetic implementation rules for the two contexts that change independently. However, the presence of fronting indicates that the pre-/l/ context has not yet fully separated from /u/, while the slower rate of change suggests that these tokens are less strongly bound to /u/ than tokens elsewhere. A possible interpretation of this effect is that category membership is gradient, with some contexts more strongly associated with a phoneme than others. This interpretation is easily accommodated by usage-based models that assume ‘fuzzy’ representations (e.g. Bybee, 2001; Scobbie & Stuart-Smith, 2008). It is also compatible with modular approaches, insofar as it does not bear on the issue of phonetic detail in lexical representations. However, the idea of gradient category membership would require a substantial reappraisal of the traditional generative view of categories.

The frequency effect for /u/-fronting supports P2: high-frequency words lead, and the size of the effect decreases over time. It is unclear whether this provides evidence for phonetically-detailed lexical representations. The observed decrease could also arise due to a ceiling effect: there is a high degree of overall fronting in the middle and younger groups, which leaves little scope for further fronting. Therefore, a simple online effect that applies to high-frequency words (e.g. vowel undershoot, which can lead to fronting for back vowels) could also, in principle, produce similar results.

P3 is partly supported: variable words without /j/ show more fronting than expected based on phonetic context alone, but variable words with /j/ do not show the expected reduction in fronting compared to words that always have /j/. Nonetheless, the net effect of these patterns is that tokens of /u/ in variable words with *versus* without /j/ are not as far apart as they should be based on the phonetic context. This is precisely what we expect if we assume that phonetic details can be part of lexical representations (section 1.2.1). We make two reservations about these findings. First, we did not find evidence that this pattern changes over time, which would provide a stronger argument against strictly modular approaches. Second, the intermediate degree of fronting in N[∅]EW words could potentially result from coding errors: if some tokens with /j/ are accidentally coded without one, they may artificially inflate the average F2 of the group. A similar effect could also arise from discretising a gradient process of /j/-dropping: some tokens with weakened /j/ would likely be coded as N[∅]EW, and have the same biasing the influence on F2. However, both of these biases would be expected to have a larger influence on the *initial* portion of the trajectory, where miscoded/weakened /j/ tokens would be located. This is not what we found: the differences are observed in the latter part of the trajectory; the initial portions are essentially identical for N[∅]EW and NOODLE, which suggests that the results are not due to coding errors.

The observed frequency effect on /j/-dropping goes against Phillips' (2006) markedness-based prediction (P4a), but is compatible with Bybee's (2000) proposal based on dialect levelling (P4b). It is plausible that variants with /j/ come from the standard variety, and first appear in low-frequency items with weaker lexical representations. We also observed an interaction between age and frequency. If /j/-dropping is gradient, this would support the idea that lexical representations can contain phonetic detail. If, however, /j/-dropping is categorical, modular approaches can also account for these results. Our data set does not allow us to distinguish between these two different scenarios.

In sum, our results include both lexical and more abstract categorical effects. Lexical effects were generally smaller than contextual ones (cf. Labov, 2010), but surfaced in several different aspects of /u/-fronting and /j/-dropping. These results do not support models that derive all aspects of sound change from a single level of cognitive representation. Instead, they call for models that treat phonemes, contextual variants and words as intersecting levels of phonetically detailed representation, each of which contribute to phonetic realisation (cf. Pierrehumbert, 2002, 2016). These results are not well accommodated by strictly modular feedforward models where the late stages of word production (where phonetic detail is added to an abstract categorical representation) can no longer refer to lexical information.

On a broader level, these findings also illustrate how observations about language change can inform us about the cognitive capabilities underlying language, and conversely, how cognitive factors constrain the space of potential changes. They attest to the fact that there is no such thing as a 'non-cognitive' approach to change, as language – and, by extension, language change – is inextricably bound up with cognition.

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