Harrington, J. (2012). The coarticulatory basis of diachronic high back vowel fronting. In M-J. Solé & D. Recasens (Eds). The Initiation of Sound Change. Perception, Production, and Social factors. John Benjamins Publishing Company. pp. 103-122.

The coarticulatory basis of diachronic high back vowel fronting*

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The study is concerned with the contribution of synchronic consonant-on-vowel coarticulation to the diachronic fronting of high back vowels. The first part of the paper makes use of an empirical analysis of German vowels to explain why high back vowels are more likely to front diachronically than high front vowels are to retract. This study is then linked to the changing coarticulatory relationships in the course of diachronic high back vowel fronting in the standard accent of England. The results show that this sound change in progress has resulted in a phonologization of the variants in a fronting context and a consequential realignment in perception of the back variants towards the front. The general conclusion is that the wide separation of phonetic variants induced by consonantal context provides the conditions for high back vowel fronting which can be fulfilled during a sound change in progress by their progressive approximation in perception and production.

1. Introduction

Coarticulation, or the way that sounds overlap with each other in time, is ubiquitous in languages and it is also a type of synchronic variation that is implicated in many kinds of diachronic change. In the direct realist model of speech perception and the related model of articulatory phonology, there is presumed to be a 'common currency' by which listeners parse the speech signal into the same sets of overlapping gestures that are produced by the speaker (Browman & Goldstein 1991, 1992; Fowler & Saltzman 1993). The finding that reaction to the perceptual

* My thanks to Keith Johnson, editor Maria-Josep Solé and an anonymous reviewer for many helpful comments on an earlier draft of this paper as well as to Felicitas Kleber and Ulrich Reubold who have made major contributions to the research reported here. This research was supported by German Research Council Grant No. HA 3512/3-2, "Sound change, lexical frequency, and variability: an experimental study of Southern British English, Received Pronunciation."

identification of V_2 in V_1CV_2 sequences is slowed when V_1 provides conflicting coarticulatory cues about V_2 (Martin & Bunnell 1982) shows that listeners are sensitive to coarticulation. Moreover, listeners factor out coarticulatory effects from the signal that can be attributed to a source. Thus, the acoustically very different schwa vowels in /əCi/ and /əCɒ/ have been shown to be perceived to be the same because listeners attribute this contextual variation in the schwa to the source that gives rise to it, the transconsonantal vowel (Fowler 2005). Analogously, identical acoustic signals can be perceived to be different in different contexts, as experiments on the compensation for coarticulation (Lindblom & Studdert-Kennedy 1967; Mann & Repp 1980) have shown.

The occasional mismatch between the way that speakers produce, and listeners perceive, coarticulation can give rise to sound change according to Ohala (1981, 1993). The development diachronically of a phonemic oral-nasal vowel contrast in French from a sequence of an oral vowel and following nasal consonant in Latin (Hajek 1993), the origin of various kinds of vowel harmony (Beddor et al. 2002), and the development of a tonal contrast from intrinsic pitch effects (Hombert et al. 1979) may come about if listeners do not attribute enough of the coarticulatory effect to the source that gives rise to it (see e.g. Fowler & Brown 2000, and Beddor this volume for further evidence that listeners do not compensate sufficiently for coarticulation). Ohala's (1993) model elegantly accounts for the dichotomy between sound change being non-teleological at the level of speaker-hearer interactions but at the same time systematic in the sense that similar types of sound change have been found to occur and shape the sound system in many languages: that is, sound change is non-teleological primarily because an unintended listener error cannot by definition be planned; and it is systematic because, if coarticulation is a driving source for sound change and since coarticulation is itself a lawful consequence of articulatory-auditory relationships, then so too are the types of sound change that it can give rise to.

The central theory that forms the background to the experiments reported here is that coarticulatory perception-production relationships are typically aligned in the sense that, as discussed above, the perception and production of coarticulation tend to be matched (Fowler 2005). However during a sound change in progress, the perceptual compensation for coarticulation wanes as a result of which listeners compensate insufficiently for contextual effects in production: it is in this sense that the production-perception modalities will be argued to be *misaligned* during a sound change in progress. The actual sound change involves shifting the context-dependent and context-independent variants closer together: as a result, coarticulation in perception and production are once again aligned since, following the sound change, both the perceptual compensation for context effects and the influences of coarticulation in production are reduced. Thus the proposed extension to Ohala's model sketched in this paper is that coarticulatory perception-production relationships in an entire speaking community (as opposed to in a single speaker-hearer, as in Ohala 1993) can become increasingly unstable and that sound change is a response to correcting these instabilities and realigning coarticulation in these modalities.

A more specific task in the present paper will be to explore the extent to which coarticulation plays a role in shaping diachronic high back vowel fronting which, as described in Section 2 below, has been found to occur in many different languages. There are two parts to this aim. The first is concerned with the physiological and auditory conditions that might predispose high back vowels to front diachronically: this part of the paper is concerned, therefore, with the origins of sound change. The focus of the analysis for this purpose is on the synchronic variation in German tense and lax vowels using as evidence a combination of physiological, acoustic, and auditory data. The second is concerned with establishing whether coarticulation has contributed to the diachronic fronting of high back vowels in the standard variety spoken in England. The principal type of analysis here draws upon a technique common in the sociolinguistics tradition of a so-called apparent time study (Labov 1972) in which the magnitude of sound change is inferred by comparing the spoken characteristics of older and younger members of the same speaking community (Section 3). However, in contrast to most studies in the sociolinguistic tradition, the focus will be on both the production and perception of coarticulation and whether the coarticulatory relationships either between or within the age groups have changed.

2. The physiological and perceptual basis of diachronic /u/-fronting

An idea that is central to most models of sound change is that categorical sound change has its origin in fine-grained synchronic variation. Consider then diachronic /u/-fronting: this is a sound change that has been reported to occur in structurally diverse languages including Akha (a Lolo-Burmese language), Albanian, and English; and it is also incorporated as one of Labov's (1994) general principles of chain-shifting in back vowels. Furthermore, although the backing of high front vowels is not unattested, as the diachronic retraction of /ɪ/ (hid) in New Zealand English in the last fifty years has shown (Maclagan & Hay, 2007), it seems to be much less common that the fronting of high back vowels. Certainly there is evidence synchronically that /u/ is fronted in the context of alveolar consonants (Flemming 2001, 2003; Öhman 1966) but there are also studies showing that /i/ and /ɪ/ are centralized in a context that induces lowering of the second formant frequency (e.g. Moon & Lindblom 1994).

A movement study by Harrington, Hoole, Kleber, and Reubold (2011a) of German tense and lax vowels produced by seven first language German speakers in a /ɡəCVCə/ context at two self-selected rates, where C was symmetrical /p, t, k/, sought to shed light on the predisposition for high back vowels to front. They showed that German tense /u/ and lax /ʊ/ were produced with a large tongue backing movement and high peak velocity from the C to the V in /ɡ|C[illegible]/ and that the confusion with high front /y, ʏ/ was asymmetric: that is, /u, ʊ/ w[illegible]e more likely to stray into the /y, ʏ/ space than the other way round. Some of these physiological data are summarized in the left column of Figure 1 which shows linearly time-normalized trajectories of the sensor positioned as far back on the tongue dorsum as the subject could tolerate averaged across all seven speakers. The trajectories were normalized relative to the same speakers' productions of sustained isolated /y/ and /u/ (henceforth T_y and T_u respectively) which can be thought of as context-free, idealized targets for these vowels (see also Moon & Lindblom 1994 for a similar approach): in this figure, a value of zero on the vertical axis represents a position in the tongue-dorsum space that is equidistant between T_y and T_u.[1]

The top left panel of Figure 1 shows that, whereas /y/ has positive values throughout the extent of the vowel – i.e. /y/ is closer to T_y in all three contexts – the onset and offset of /u/ in /tut/ and the onset of /u/ in /kuk/ extend well into the /y/ space (have values larger than zero). This pattern of differences is even more marked for lax vowels in the lower left column: notice in particular, how /ʊ/ in /tʊt/ is closer to T_y than it is to T_u throughout the entire extent of its trajectory. The left panels of Figure 1 show another difference between the high front and back vowels: the differences between tense and lax vowels for the same contextual place of articulation are far more dramatic for high back (e.g., /tut/ vs. /tʊt/) than for high front (e.g., /tyt/ vs. /tʏt/) vowels.

The second formant frequency trajectories show predictably that the labial context has the greatest influence on /y, ʏ/ and the alveolar context on /u, ʊ/.

1. The *y*-axis for both the tongue and formant data is a dimensionless normalized logarithmic space of increasing proximity to each speaker's steady-state productions of isolated /y/ and /u/. The value of zero on this axis represents a point equidistant between these steady-state positions. The articulatory data extend between the acoustic release of the stop and the offset of periodicity in the vowel, the formant data between the acoustic onset and offset of vowel periodicity. The vertical axes in Figure 1 and Figure 4 are dimensionless because they express a ratio of distances. More specifically, the values in Figure 1 on the vertical dimension are $\log(d_{u't}/d_{y't}) = \log(d_{u't}) - \log(d_{y't})$ in which $d_{u't}$ and $d_{y't}$ are the absolute distances from V_t, the TDX (or F2) value at time t, to the TDX (or F2) trajectory of steady-state /u/ (T_u) and steady-state /y/ (T_y) respectively. Thus when V_t is equidistant between T_u and T_y (i.e., $d_{u't} = d_{y't}$), then the value on the vertical axis is zero. See Harrington (2010, Chapter 6) and Harrington et al. (2008) for further details.

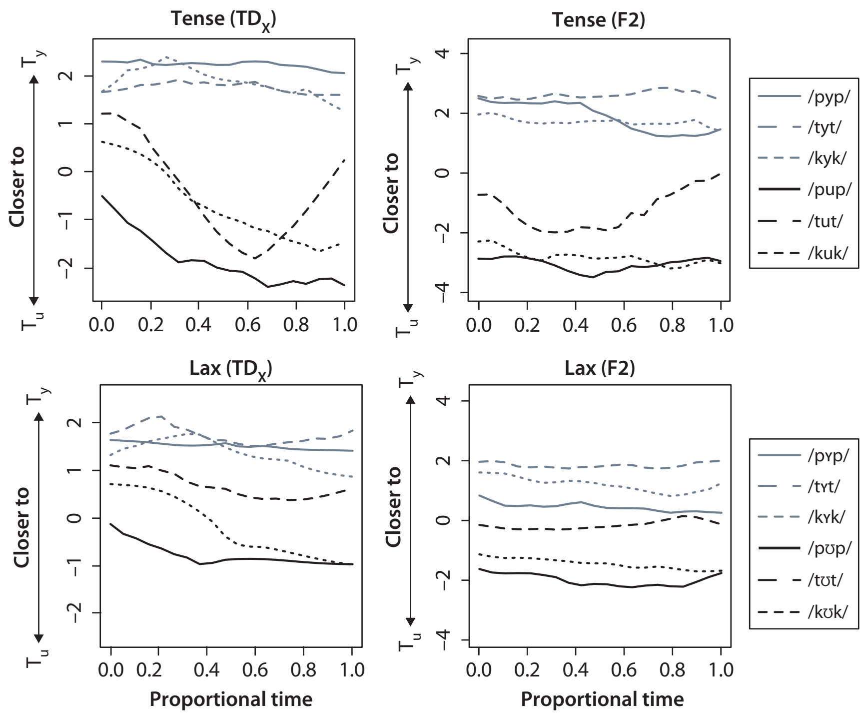

Figure 1. The horizontal position of the tongue dorsum (left) and of the second formant frequency (right) for tense /y, u/ (above) and lax /ʏ, ʊ/ (below) averaged and linearly time-normalized across seven speakers in three symmetrical contexts[1]

However, there is an asymmetry in that the extent of the shift is greater in the latter: that is, /u, ʊ/ in a /t_t/ context are closer to the steady-state front vowel than are /y, ʊ/ in a /p_p/ context to the steady-state back vowel. When 17 first language German listeners classified in a binary forced-choice task lax /ʊ/ and lax /ʏ/ spliced from their consonantal context and produced by the same speakers whose data are shown in Figure 1, there was a greater probability for /ʊ/ to be misclassified as /ʏ/ than the other way round. Thus in Figure 2, the number of /ʏ/→/ʊ/ mis-classifications in a labial context (top left) was much less than the number of /ʊ/→/ʏ/ misclassifications in an alveolar context whose classification was, as Figure 2 (bottom right) shows, close to chance level.

Finally, this asynchrony in the relative overlap and confusion between high front and high back vowels seems to be consistent with a slight bias against /u/ in the world's languages: for example, Maddieson (1984) shows that when a language's vowel system is asymmetrical along the front-back axis, then this is most

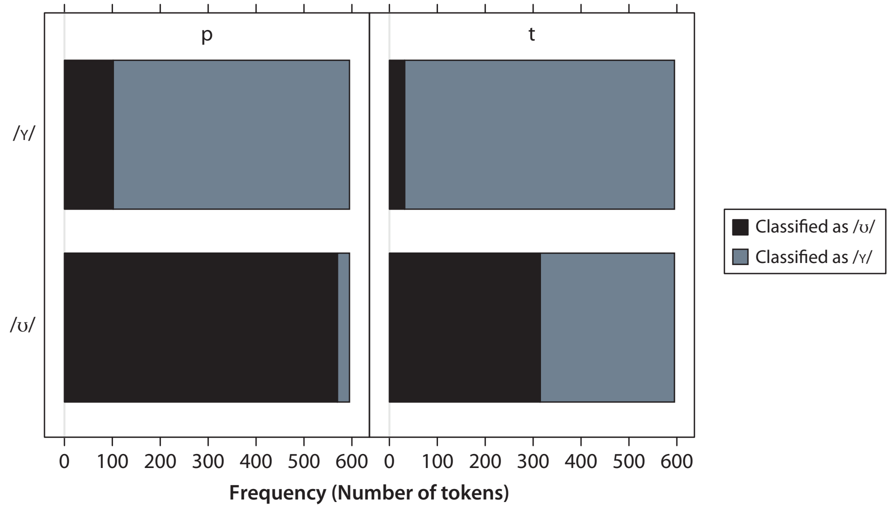

Figure 2. The distribution of the total number of /ʏ/ (row 1) and /ʊ/ vowels (row 2) classified by 17 listeners as /ʏ/ (black) and /ʊ/ (grey) in /p/ (left) and /t/ (right) contexts

likely to be occasioned by the absence of /u/ (see also Schwartz et al. 1997). Moreover, the more recent analysis of UPSID in Harrington et al. (2011a) showed that languages that have both high front and high back vowels have proportionately more consonants such as coronals that are likely to induce high back vowel fronting than consonants that induce the contextual backing of high front vowels. The distribution of segment inventories combined with the synchronic and diachronic evidence suggests that the effect of context skews probabilistically the vowel space towards the front and away from high back vowels.

3. Back-vowel fronting in standard Southern British

The previous section has been concerned with the physiological and perceptual conditions that might predispose /u/ to diachronic fronting. The focus in this section is on back vowel fronting that has been a sound change in progress in the last 50 years both in the standard accent of England, Standard Southern British (Hawkins & Midgley 2005; Henton 1983; McDougall & Nolan 2007) and in Australian (Cox & Palethorpe 2001), American (Fridland 2008) and New Zealand (Gordon et al. 2004) varieties of English.

The type of data in Figure 3, in which a comparison can be made between younger and older speakers on various vowels in an F1 × F2 formant space, is often

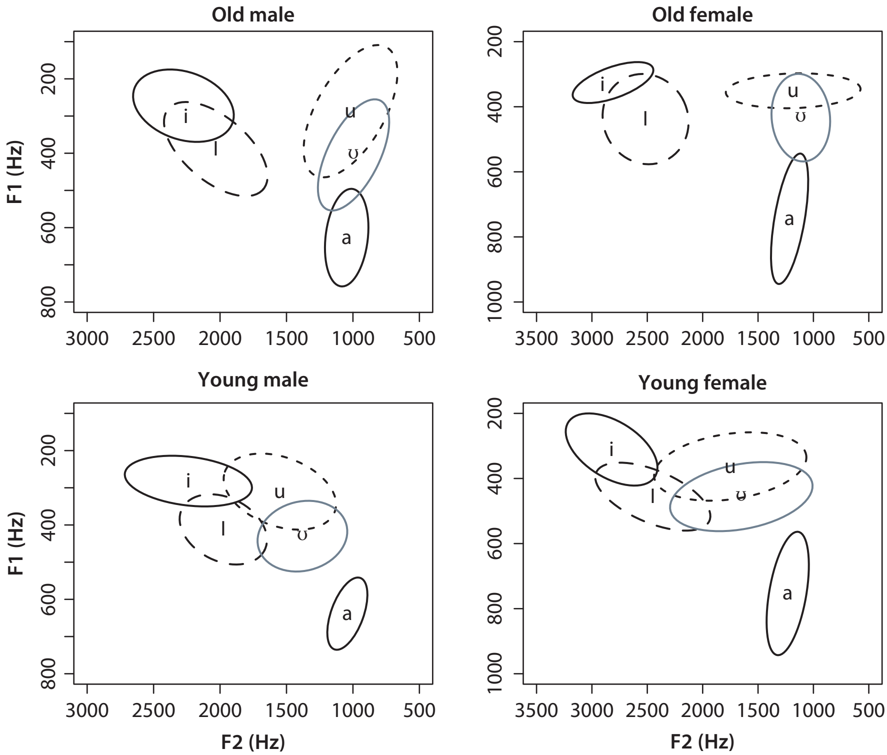

Figure 3. 95% confidence ellipses for five vowels produced by SSB speakers shown separately by age-group and gender. There were on average 10 tokens per vowel per speaker. The total number of tokens per vowel varied between 68 and 90

used as evidence in the sociolinguistics tradition for a sound change in progress. These data, which are taken from the same corpus as analyzed by Kleber, Harrington and Reubold (in press), show that Standard Southern British (SSB) /u, ʊ/ occupy an F2 region that is relatively much closer to /i, ɪ/ for younger (*n* = 18; mean age 20.2 years; 9 male, 9 female) vs. older (*n* = 15; mean age 75.4 years; 8 male, 7 female) speakers. Based on auditory impressions, Wells (1997) has suggested that age-dependent acoustic differences of the kind shown in Figure 3 could be due to unrounding of the lips in /u/ and in /ʊ/. However, a recent EMA study by Harrington, Kleber and Reubold (2011b) of five of the younger speakers whose data are included in Figure 3 provides little evidence to support this view. Some of their data are shown in Figure 4 which includes trajectories of the horizontal movement of sensors fixed to the tongue dorsum and to the lower lip averaged and linearly time-normalized across these five speakers.

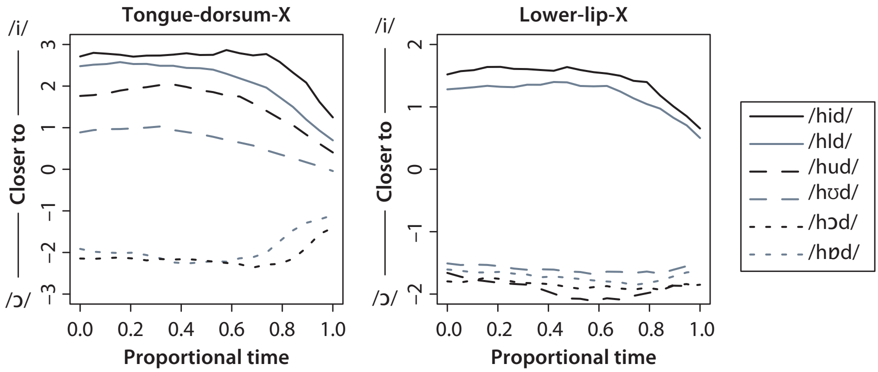

Figure 4. Linearly time-normalized trajectories of the horizontal movement of the tongue dorsum (left) and of the lower-lip (right) averaged across 10 tokens per category each produced by five young female SSB speakers in five /hVd/ words

The trajectories in Figure 4 extend from the onset to the offset of six /hVd/ words and the values on the vertical axis are defined relative to the same speaker's mean tongue or lip position in /i/ (*heed*) and /ɔ/ (*hoard*): thus zero on the vertical axis denotes a position that is equidistant between these two vowels[2]. The horizontal movement of the lower lip often indexes lip-rounding in vowels (Perkell et al. 1993) and that it does so in these data is evident by the clear separation between the unequivocally unrounded /i, ɪ/ and rounded /ɔ, ɒ/ (Figure 4, right panel). The same figure also shows that the lips are evidently rounded for these five young SSB speakers in /u, ʊ/ since their trajectories pattern with rounded /ɔ, ɒ/ and not with unrounded /i, ɪ/. As far as the tongue trajectories of /u, ʊ/ are concerned (Figure 4 left panel), they extend well beyond the point that is equidistant between /i/ and /ɔ/ and, while not as front, have a shape that is much more similar to front /i, ɪ/ than to back /ɔ, ɒ/. Overall, these data show that the tongue dorsum positions of young speakers' /u, ʊ/ are more advanced than the central position implied by the acoustic data of Figure 3. The general conclusion in Harrington et al. (2011b) is that the diachronic change in the last 50 years has involved a shift in the relative importance of the dorsal and labiality features that characterize these vowels: whereas 50 years ago, SSB /u, ʊ/ were distinguished from /i, ɪ/ based on both dorsal and labial features, the most reliable basis for their separation in present-day SSB is lip-rounding.

2. As in Figure 1, the vertical axis in Figure 4 is dimensionless because it expresses a ratio of distances.

4. The effects of context on diachronic /u, ʊ/ fronting in SSB

The evidence from Section 2 suggests that diachronic back vowel fronting is likely to have a phonetic basis in which contextual factors cause high back vowels to be shifted into a part of the vowel space which is close acoustically and perceptually to /y, ʏ/. The question to be considered here is whether such context effects have contributed to the diachronic fronting of SSB /u, ʊ/ discussed in the previous section.

The analysis in Harrington, Kleber & Reubold (2008) of SSB /u/ suggests that they have. Some of the production data in this apparent-time study comparing younger (mean age 18.9 years) and older (mean age 69.2 years) SSB speakers on a number of words in fronting and non-fronting contexts showed that the F2-differences in /u/ between non-fronting (*swoop*, *who'd*) and fronting (*used*, past tense) contexts was much greater for the older than for the younger speakers (Figure 5): the conclusion from data such as these was that the sound change has involved primarily a shifting of the variants of /u/ in a non-fronting context towards fronted

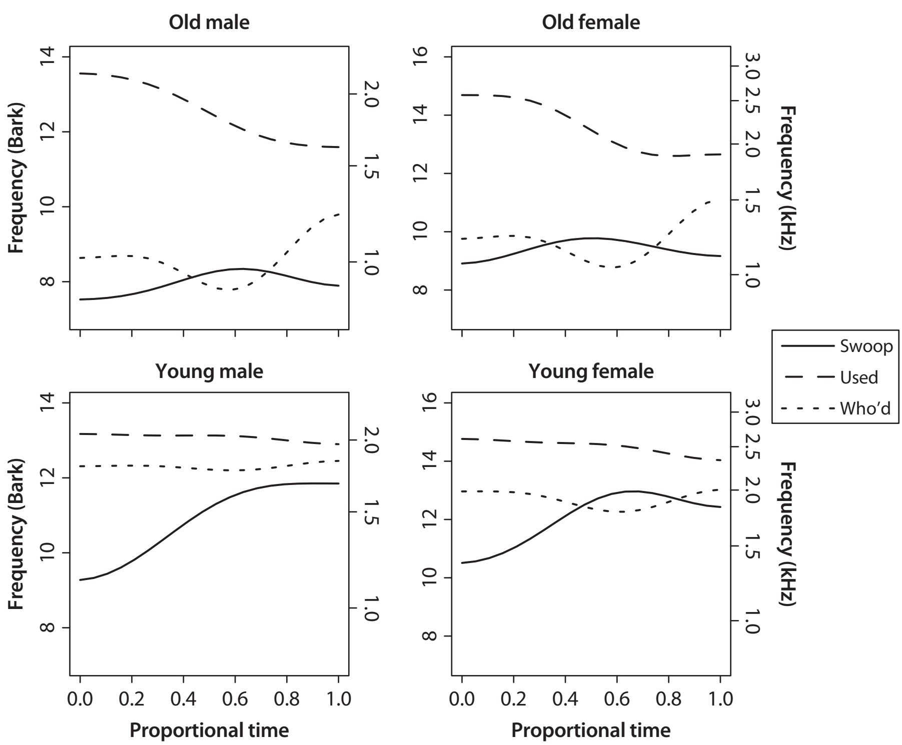

Figure 5. Linearly time-normalized F2 trajectories over the voiced interval of *used* (dashed), *swoop* (solid), and *who'd* (dotted) shown separately by age-group and gender

variants. This shift in Harrington et al. (2008) was shown not to be tied specifically to *swoop*, but was found for non-fronting /u/ in other words including *who'd* (see also Figure 5), *cooed*, and *food*.

Harrington et al. (2008) also investigated whether there were comparable differences between the age groups in perception. To do so, the same younger and older subjects participated in a forced-choice perception experiment in which they labeled an /i-u/ continuum that had been synthesized by shifting F2 downwards in 10 equal Bark steps and that was then embedded in minimal-pair fronting (*yeast-used*) and non-fronting (*sweep-swoop*) contexts. Based on their production data, the following two predictions were made. Firstly, the boundary between /i-u/ would be left-shifted (towards /i/, i.e. with more /u/-responses) for younger subjects, in accordance with their fronted /u/ in production. The second was that the perceptual responses would mirror production in showing a closer approximation between non-fronting and fronting contexts for younger listeners (for whom /u/ in non-fronting *swoop/who'd* and fronting *used* were closer together in production, as Figure 5 shows). The averaged psychometric response curves and 50% cross-over boundaries (vertical lines) – calculated using a generalized linear mixed model with the listener as a random factor – shown in Figure 6 were broadly consistent with these predictions: the curves were found to be significantly left-shifted and also closer together in the two contexts for younger than for older listeners[3]. Thus these data suggest that production and perception are matched but differently across the two age groups: for younger subjects, /u/ was fronted and the differences between the fronting and non-fronting variants were small in both production and perception; for the older subjects by contrast, /u/ was retracted with a wider spacing between the contexts in both modalities.

The further implication of the results in Figure 6 is that the older listeners compensated perceptually to a greater extent for the effects of context than did the younger listeners. Perceptual compensation for coarticulation essentially implies that some of the shift in F2 along the /i-u/ continuum is attributed to the coarticulatory effects of consonantal context. Overall, listeners evidently compensated for coarticulation because the psychometric curves for *yeast-used* are to the left of those for *sweep-swoop*. However, the finding in Harrington et al. (2008) of a significantly closer proximity between the responses curves in the two contexts for younger than older listeners suggests that younger listeners compensated less perceptually for the coarticulatory influence of consonantal context than did the older listeners.

3. In Figure 6 the *y*-axis is the proportion of /u/-responses, the *x*-axis shows the stimulus number extending in 10 equal decreasing Bark steps from 2311 Hz (stimulus 1) to 1269 Hz (stimulus 10).

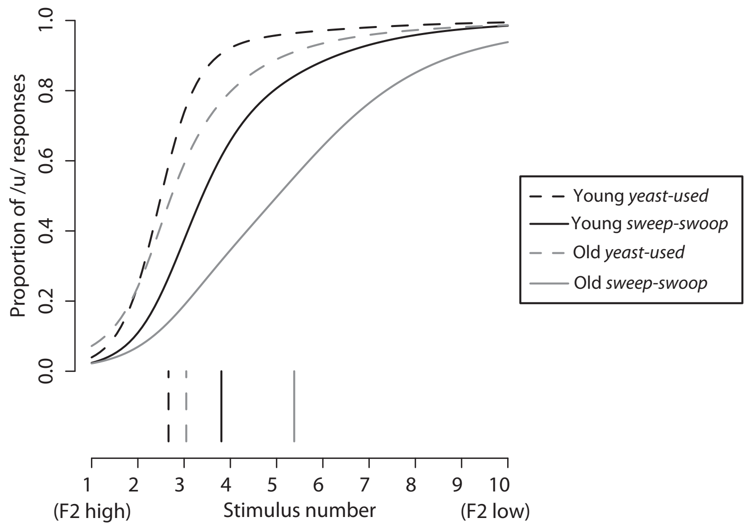

Figure 6. Averaged psychometric curves fitted to the responses of *yeast-used* (dashed) and *sweep-swoop* (solid) continua for the same older (grey) and younger (black) listeners whose production data are shown in Figure 5

More recently, Kleber et al. (in press) explored whether production and perception would be similarly matched for lax /ʊ/ (*hood*) that has also been undergoing diachronic fronting, as Figs. 3 and 4 suggest. For this apparent-time study, which included many of the same younger and older speakers from Harrington et al. (2008), /ʊ/ was once again analyzed for age-dependent acoustic and perceptual differences between fronting (*soot*) and non-fronting (*wool*) contexts. The averaged, time-normalized F2-trajectories in Figure 7 are consistent with those from the tense vowel data in Figure 5 in showing a raised F2 for the younger speakers and a closer approximation of /ʊ/ between their non-fronting *hood* and fronting *soot* contexts.

However, there was also a major difference: F2 of /ʊ/ in *wool* was only marginally raised for the younger compared with the older speakers. Consequently, the *soot-wool* distance was *greater* for the younger compared with the older speakers, whereas for the tense vowel data, the *swoop-used* distance was *less* for younger than for older speakers.

The question is now whether these differences in production between the tense and lax vowel data are also reflected in perception. That is, if the production and perception of coarticulation are matched, as they were for the tense /u/ (and differently so for the two age groups), then the influence of context in perception should, if anything, be greater for younger subjects who showed a larger distance between *soot* and *wool* than did older subjects in production (Figure 7). The averaged psychometric response curves resulting from a forced-choice perception

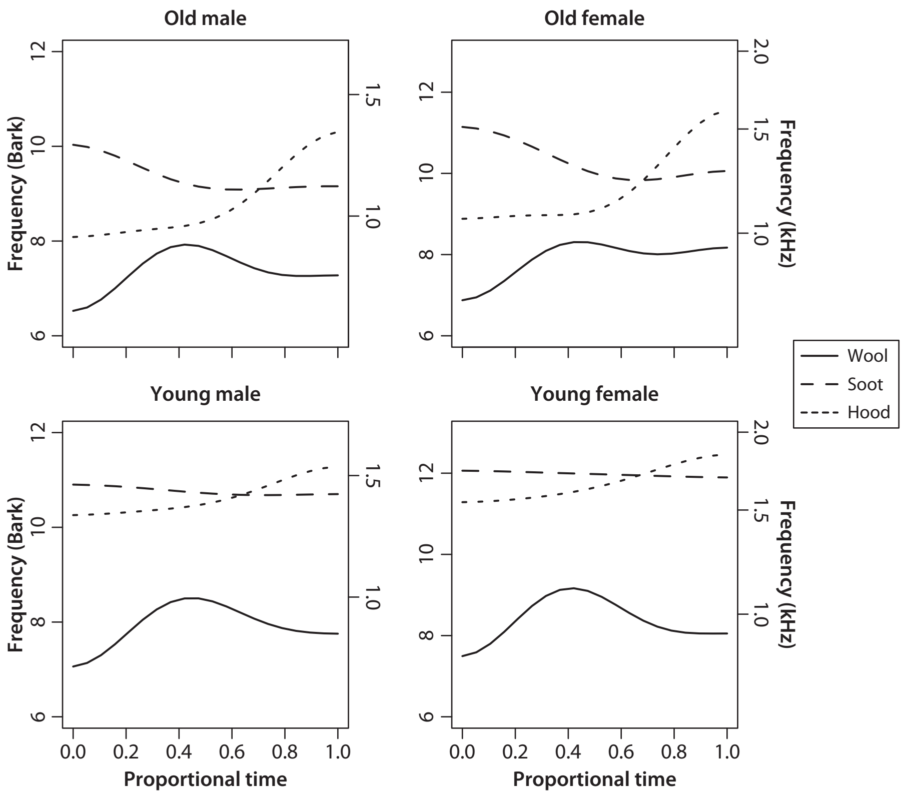

Figure 7. Linearly time-normalized F2 trajectories over the voiced interval of *soot* (dashed), *wool* (solid), and *hood* (dotted) shown separately by age-group and gender

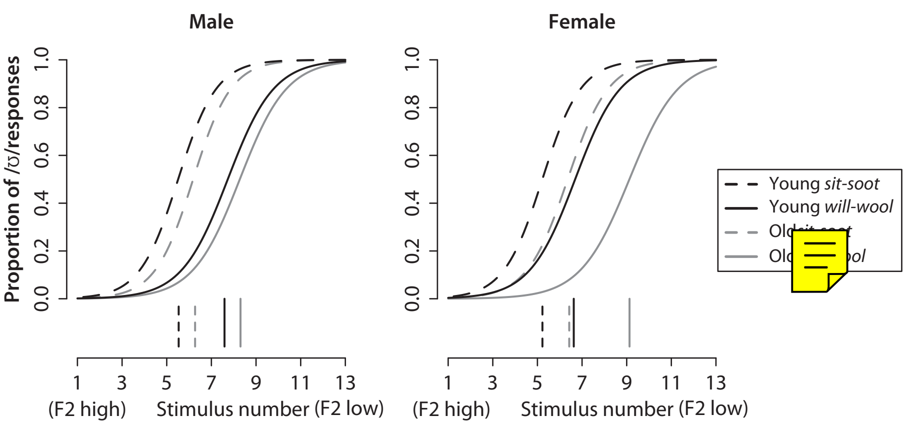

Figure 8. Averaged psychometric curves fitted to the responses of *sit-soot* (dashed) and *will-wool* (solid) continua for the same older (grey) and younger (black) male (left) and female (right) listeners whose production data are shown in Figure 6

experiment in which subjects labeled an /ɪ-ʊ/ continuum embedded in a non-fronting *will-wool* and fronting *sit-soot* contexts is shown in Figure 8 separately by age group and by gender. (The continuum was created by lowering F2 in the vowel in 13 equal Bark steps). The mean 50% cross-over boundary from /ɪ/ to /ʊ/ is shown for the four corresponding categories as vertical lines. The *y*-axis is the proportion of /ʊ/-responses, the *x*-axis shows the stimulus number extending in 13 equal decreasing Bark steps from 2100 Hz (stimulus 1) to 1100 Hz (stimulus 13). The data and cross-over boundaries in this figure show, as for the tense vowel data, that the continua are left-shifted for older than younger listeners in both men and women. These results are consistent with those from speech production: younger subjects have a fronted /ʊ/ in speech production and compatibly perceive a greater proportion of tokens from an /ɪ-ʊ/ continuum as /ʊ/. Secondly, the cross-over boundaries for *sit-soot* vs. *will-wool* were differently positioned (which means that listeners compensated perceptually for the effects of context). Finally, there was a discrepancy between production and perception as far as the differences between the front and back variants are concerned: it is certainly not the case that the younger listeners' perceptual boundaries in these contexts were further apart than those of older listeners, as would be expected if the perception and production of coarticulation were matched. Instead, the younger listeners' boundaries in these contexts were located at a similar position (for men) or closer together (for women) than those of the older listeners.

The further implication of these data is that a sound-change in progress may cause the association between the perception and production of coarticulation to become misaligned with each other. For the tense vowel data, the production and perception of coarticulation were in alignment (but differently so for the two age groups) because the /u/-variants due to context were widely spaced both in perception and production for the older subjects and narrowly spaced in the two modalities for the younger subjects. But although the /ʊ/-variants in *soot* and *wool* in the lax vowel data were further apart (widely spaced) for younger compared with older speakers in production, their perceptual boundaries were similarly or even more narrowly positioned than for the older subjects in the fronting (*sit-soot*) compared with non-fronting (*will-wool*) contexts.

5. Discussion

High back vowels are prone to diachronic fronting and more so than high front vowels are to retraction. The reasons for this are to do with the demands that are placed on the tongue dorsum in languages like German in which /u/ really is a peripheral vowel combined with the greater tendency for /u, ʊ/ than /y, ʏ/ to drift towards the central part of the vowel space. Although listeners have been shown to compensate for coarticulation, the consequences of not normalizing for the effects of contexts are more likely to lead to a misperception of high back as high front vowels than the other way round, as the perception experiment in which listeners classified the voiced part of lax vowels spliced from consonantal context has shown (Figure 2). The greater tendency for high back vowels to front than for high front vowels to retract diachronically combined with the slight skewing of vowel inventories in the world's languages away from the high back vowel space may have their origins in just this kind of perceptual ambiguity that can be brought about if the effects of tongue dorsum fronting are not attributed to context. Context also seems to be a contributory factor to diachronic /u/-fronting in Standard Southern British that has been taking place in the last 50 years. Moreover, as Figure 4 shows, the change has targeted the position of the tongue-dorsum and not the lips which is consistent with the view that diachronic /u/-fronting in SSB has originated due to forces acting on the tongue.

The apparent-time analyses in this paper have shown that young SSB subjects have fronted /u, ʊ/ boundaries relative to those of older SSB subjects in both production and perception. Thus younger subjects not only produce phonetically more advanced variants compared with those of older speakers, but they also cut up the high vowel continuum at a different point perceptually. Taking into account that context is a driving force in this sound change, the question is: what is the mechanism that has facilitated this fronting in both perception and production? According to Ohala (1993), a ~~hypoarticulation-induced~~ sound change can come about when a listener fails to compensate adequately for coarticulation. Under an extension of this model to these SSB data, listeners who used to filter out the effects of context from a fronted [ʉ] (and thereby recalibrate it perceptually as [u]) no longer do so: that is, they reconstruct perceptually not /tut/ but /tʉt/ from phonetic [tʉt]. The actual sound change would come about if the listener phonologized this change in other non-fronting contexts: thus /swup/ (*swoop*) changes to /swʉp/ with the consequence that the differences between the variants in *used* and *swoop* are reduced in both speech production and perception, as shown by the younger subjects' production (Figure 5) and perception (Figure 6) data. Such an extension of Ohala's (1993) model to this sound-change in progress is compatible with the observed differences in the production-perception relationships between the younger and older subjects. The simplest extension of Ohala's model (1993) to this apparent-time analysis also predicts that if the fronted /u/-variant has been phonologized, then the younger speakers' /u/ in non-fronting contexts should be located at approximately the position of the older speakers' fronted /u/-variant. This is because the sound change is assumed to involve a shift of variants in non-fronting towards those in fronting contexts. This is schematized in Figure 9 in which older subjects who compensate for coarticulation have widely separated boundaries between non-fronting and fronting contexts in perception (top left panel) and production (lower left panel). In the initial stages of the sound change in progress, compensation for coarticulation wanes and the perceptual boundary in the non-fronting context shifts towards the front (top middle panel). This perceptual waning of coarticulation is followed by a sound change that takes place in production in which /u/ in non-fronting contexts like *swoop* shifts towards the front (towards /u/ in *used*) as a result of which younger subjects have variants that are close together and in the front part of vowel space in both perception and production (right panels). The middle figures show the hypothesized misaligned perception-production relationships during the sound change in progress that may be characteristic of the SSB lax /ʊ/ reported in this paper. Thus in contrast to Ohala (1993), sound change in the model in Figure 9 does not consist of an abrupt change of one variant into another, but instead of a gradual approximation between the variants first in perception then in production (see Garrett & Johnson, in press for a further discussion and model of the relationship between coarticulatorily-induced synchronic variation, phonetic drift, and sound change).

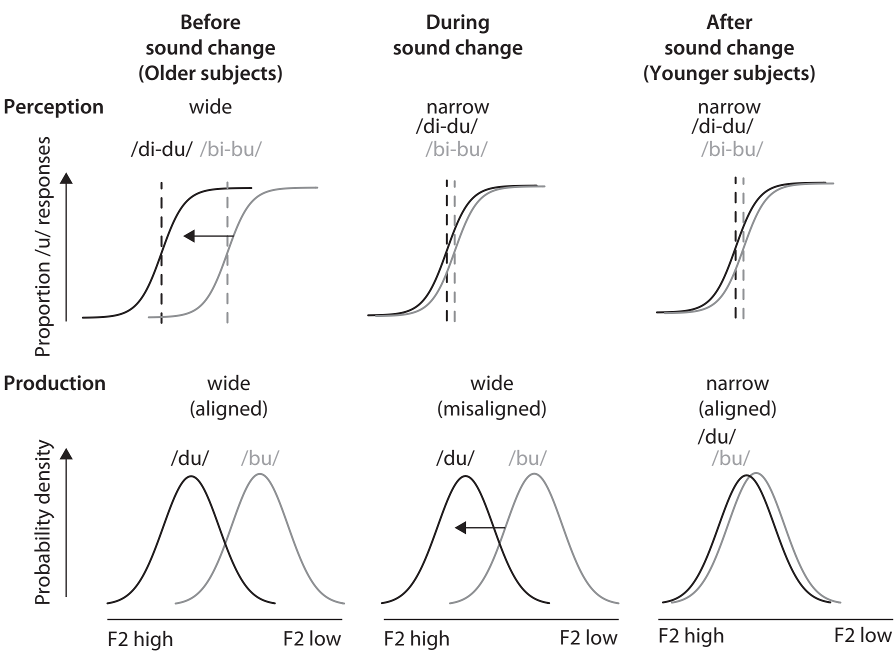

Figure 9. Proposed stages in the sound change of tense vowel /u/-fronting in SSB showing hypothetical cross-over boundaries (dotted lines) on an /i-u/ continuum in perception (above) and distributions of the second formant frequency in fronting (/du/) and non-fronting (/bu/) contexts

According to the model in Figure 9, younger subjects' non-fronted and older subjects' fronted variants should be similar (because the sound change has involved a shift of non-fronted towards fronted variants). Compatibly, Figure 5 shows that the young speakers' non-fronted variants in *who'd* and *swoop* are now positioned approximately in the same part of the space as the older speakers' variants in *used*.

To what extent is the diachronic shift of variants in the non-fronting towards those in the fronting context for tense /u/ compatible with the lax vowel data? The main similarity across the two sets of data is that there is a fronted boundary in both lax and tense vowels for younger relative to that of older subjects. On the other hand, it appears from Figure 7 as if F2 in the young speakers' *hood* is somewhat higher than F2 of the old speakers' *soot*. In fact, a comparison of F2-onset in *soot* produced by older speakers with F2 at the midpoint in *hood* produced by younger speakers with age and gender as the independent factors showed significant differences ($F[1,29] = 18.6$, $p < 0.001$) for gender (predictably because F2 is higher for women than men) but not for age. So there does seem to be a second consistency between the tense and lax vowel data: the tense and lax variants in younger speakers' /hVd/ (V = /u, ʊ/) are now located approximately at the position where the onglide (i.e., the point in the vowel at which C-on-V coarticulation is greatest) occurs in older speakers' variants in a fronting context.

The main discrepancy lies in the change that has taken place to tense /u/ in *swoop* on the one hand versus lax /ʊ/ in *wool* on the other. In production, the former has shifted almost as much as the /u/-variant in /hud/ (*who'd*) whereas younger speakers' F2 of /ʊ/ in *wool* is only marginally higher than for older speakers. Perceptually, the boundaries in the fronting and backing contexts are closer together for younger than for older listeners in the tense vowel (*used-yeast* vs. *sweep-swoop*) data, whereas in the lax vowel context they are only closer together for the female, but not the male listeners. What could account for these differences between the tense and lax vowel data? One possibility is that /w_l/ may have a much more marked influence on the target of /ʊ/ than does /w_p/ on /u/, given that the velarised /l/ in this variety, being resistant to coarticulation (Bladon & Al-Bamerni 1976; Recasens & Espinosa 2005) and produced with tongue-dorsum retraction, is likely to inhibit the fronting of the tongue-dorsum in /ʊ/ to a greater extent than the inconsequential articulatory influence of a labial consonant on /u/. In addition, /ʊ/, being shorter than /u/ in duration, is more prone to such coarticulatory influences. Another relevant factor may be that diachronic lax /ʊ/-fronting seems to have begun somewhat after the diachronic fronting of /u/ (Harrington, Kleber & Reubold 2011b; Hawkins & Midgley 2005): so it could be that /ʊ/ in *wool* is still evolving towards a stage in which it will be as close to the variant in *soot* as the /u/-variant in *swoop* is to that of *used*.

There are at least two further aspects of these data that require further investigation. The first is that the diachronic shift in perception in the lax vowel data is evidently ahead of its corresponding shift in production: whereas there has been a significant leftward shift in the *will-wool* boundary in younger compared with older listeners (Figure 8), this shift has not been accompanied by a corresponding shift in production (Figure 7). This discrepancy between the two modalities might follow from the model of sound change schematized in Figure 9 in which the variants are approximated diachronically in perception *before* they are in production. That is, whereas the sound change for the tense /u/ may be complete as a result of which both younger and older subjects have variants in perception and production that are aligned but differently (both widely space for older subjects, both narrowly spaced for younger subjects as shown in the left and rightmost panels of Figure 9 respectively), lax /ʊ/ may be subject to a sound change in progress in which younger subjects' variants in perception are more narrowly spaced than their variants in production (middle panel of Figure 9); some further data that addresses this point is presented in Kleber et al. (in press). The second implication of these findings is that listeners do not parse coarticulation from the signal in the same way. This is so in the tense vowel data because younger and older listeners differed in how much variation in /u/ they attributed to context perceptually; and in the lax vowel data, the extent of perceptual compensation for coarticulation in relation to the magnitude of coarticulatory influences in production was less for younger than for older subjects (i.e. for younger subjects, the distance between the *sit-soot* and *will-wool* boundaries in perception was smaller in comparison with the coarticulatory perturbation in production to /ʊ/ in *soot* and *wool* than for older subjects).While there is much evidence to suggest that there is a common currency between the way that gestures are overlaid in production and parsed in perception (Fowler & Thompson 2010), the results from the present study suggest that this association may also be overlaid by speaker-dependent characteristics. The idea that coarticulation may be learned differently by different speaker groups is consistent with the view that there are fine-grained coarticulatory differences across varieties and languages (Flemming 2001). In addition, many studies have shown that the production of coarticulation can vary substantially across speakers (Grosvald 2009) and that there is listener variation in the extent to which coarticulation is parsed from the speech signal (Fowler & Brown 2000; Beddor et al. 2007). The further interesting issue of whether subject-specific variation in the production and perception of coarticulation and the relationship between the two is a driving-force or a by-product of sound change is a subject for further investigation.

In summary, the main conclusions from this study are that high back vowels are prone to diachronic change because consonantal context can conflict with the demands placed on the retraction of the tongue dorsum causing it to shift into a front part of the vowel space. Context has played a part in the ongoing diachronic back-vowel fronting in SSB in which the variants in a non-fronting context have shifted towards those in a fronting context. The observed changes can be formulated in terms of an extension of Ohala's (1993) model of sound change. Under this proposed extension, the perceptual compensation for fronting effects of coarticulation has waned in younger listeners leading to a phonologization of the fronted variant and ultimately a shift towards it of the other variants in non-fronting contexts.

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The fonts are wrong for the schwa. It should be /gəCVə/. See also last page of this pdf file, in case the font in this note does not show up accurately.