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HIGH DIPHTHONGS IN CANADIAN FRENCH: AN MRI INVESTIGATION

1. INTRODUCTION

The present paper concerns [+high] vowels in Canadian French (CF, henceforth) and their interaction with tautosyllabic voiced fricatives. It is hypothesised that the tense off-glide we find in [+high] diphthongs may be the result of pharyngeal expansion.

We will first describe the CF pattern and justify the grounds of our hypothesis. The hypothesis will then be supported by data from MRI scans done on a speaker of CF. A discussion of problems and possibilities will accompany the presentation of these preliminary results.

1.1. Pattern

One of the defining characteristics of CF versus its European counterparts is the "laxing" of high vowels in closed syllables. There is an apparent exception to this pattern however regarding the behaviour of high vowels in syllables closed by voiced fricatives. In this context, high vowels surface as diphthongs with a tense off-glide. The quality of the vowel in this case is different from that of high vowels in open syllables, which are short and tense.

(1) *vie*[1] 'life' = [vi]
vite 'fast' = [vɪt]
vive 'live' = [vɪⁱv]

The pattern is well attested in the literature (Gendron 1966; McLaughlin 1986), but has never been accounted for in terms of a co-articulation effect connected to voicing.

1.2. Hypothesis

The presence of +ATR vowels before voiced fricatives is the occurrence of a well-known phenomenon, which, in auto-segmental terms, is seen as the spreading of ATR values from obstruents to vowels. The phenomenon is described in Vaux (1992, 1994) for several languages including some Armenian dialects, Mon Khmer languages, Akan, and Madurese.

The distribution of the more advanced allophone [i] (as opposed to [ɪ]) is contingent on the following obstruent having a positive value for voice. In fact, the relevant feature for

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[1] CF has three high vowel phonemes /i, y, u/, which all behave like the data in (1). Space limitations has prevented me from providing data showing the other two phonemes. All behave identically however.

the obstruent is [ATR], as advancement of the tongue root is necessary for proper voicing of segments under certain conditions. In coarticulation with the following obstruent, the [ATR] feature manifests itself on the vowel as well.

Spreading of [ATR] values is the phonological expression of phonetic processes that are involved in the production of voicing. These are very well known, and their role in phonology has been discussed in literature dating back to Halle/Stevens (1971). As described in Shadle (1997) and Stevens (1998), production of voicing necessitates a pressure differential between the sub- and supra-glottal areas. Lowering of pressure in the supra-glottal area is done by means of expansion of the pharyngeal airway by forward movement of the tongue root. Advancement of the tongue root in such a way is responsible for the production of the preceding +ATR vowel.

Thinking only in terms of sub- and supra-glottal pressure, the hypothesis is problematic. Though all (voiced) obstruents involve a build-up of supra-glottal pressure, the pressure build-up involved in the production of plosives is presumably greater, given that their production requires complete closure of the vocal tract and total obstruction of airflow. There is thus an implicational hierarchy. The production of both plosives and fricatives involves the reduction of a pressure rise in the supra-glottal airway. Reduction may be implemented either passively, by compliance of the cavity’s walls, or actively, by articulatory movement (advancement of the tongue root, or lowering of the larynx). If the latter strategy is implemented by a given language to reduce pressure rise in the production of fricatives, we would expect the language to do the same for the production of plosives, as they involve a greater pressure build-up. If the implicational hierarchy were to be verified by CF, we would expect that tongue root advancement in the production of voiced stops, and the consequent realisation of the preceding vowel as a diphthong. The case of CF contradicts the hierarchy.

The case of CF is unexpected in this regard. Among the languages discussed in Vaux (1994) that exhibit this phenomenon, all verify the hierarchy. If [ATR] vowels are found adjacent to fricatives, they are also found adjacent to stops. What is more, most languages only show this behaviour for vowels adjacent to stops, not for fricatives. CF is therefore a contradictory case. The phenomenon occurs without exception in the case of voiced fricatives, but shows some variation in the case of stops.

However, CF is not so surprising if we consider Kohler (1984). Kohler (1984) provides finer-grained considerations of articulatory mechanisms, which offer insights into the matter. In the phonological literature, consonant classes such as `/p,t,k/` and `/b,d,g/` are traditionally differentiated with respect to [voice]. Though the distinction may suit the needs of most analyses, Kohler argues that phonological inquiry would gain much by considering the distinction between fortis and lenis consonants, and that the feature [+vce] should be reserved only for those consonants which exhibit actual glottal periodicity.

The fact is that scores of languages distinguish pairs of consonantal arrays such as `/p,t,k/` and `/b,d,g/`, but neither array need show any glottal periodicity at all. The standard example that comes to mind is Chinese, where the first array is made of aspirated consonants and the second of devoiced consonants. Kohler argues that these pairs should be distinguished using the feature [±fortis], where the former array is characterised by the positive value of the feature and the latter by the negative.[2] The positive value of the feature characterises those segments that show a greater auditory signal, which, in turn, is correlated with greater articulatory power.

Importantly, "[±fortis] is not proposed as an abstract feature, but it will be argued that degrees of articulatory power can provide its phonetic base" (Kohler 1984: 152). In abstraction, CF plosives and fricatives do belong to the same class, as they both involve obstructions of the vocal tract; in theory, they should behave similarly as a result of the pressure build-up that is involved in their articulation. Though the phonological prediction is phonetically grounded, we may gain something by grounding it further, so as to capture what sort of phonological generalisation is made by a child acquiring CF. It seems plausible that the child, in this case at least, may organise his system in terms of [±fortis], rather than [±vce].

How is [±fortis] characterised, articulatorily? In the articulation of any consonant, Kohler argues that one should consider the coordinated actions of the oral cavity's three valves: the oral, the velopharyngeal and the glottal. The articulation of a "quintessential" [+fortis] consonant, such as a voiceless fricative, involves the greater stricture of the oral and velopharyngeal valves, as well as the tightening or abduction of the vocal folds. In short, a [+fortis] consonant involves stricture, or tightening of at least one of the three valves. If a [+fortis] consonant is articulated with abduction of the vocal folds rather than tightening, greater stricture of the oral valve is necessary to ensure greater acoustic salience relative to lenis counterparts. This results in more energy being involved in the articulation of the release. Lenis consonants, on the other hand, involve a general slacking of a particular point in the oral tract. For instance, the articulation of a devoiced stop will involve abduction or tightening of the glottal valve, but slacking of the oral valve. The system entails that, if there is a general slacking of the valves (especially the glottal), voicing ensues. As Kohler himself points out: "owing to these physiological conditions, voicing is an extreme manisfestation of the lenis feature in stops and fricatives, since it greatly reduces the airstream power and the tension associated with powerful articulatory movements" (Kohler 1984: 163).

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[2] [+fortis] should not be correlated with aspiration, it is a happenstance of Chinese that only its [+fortis] consonants are aspirated. As pointed out by Kohler, Hindi has both aspirated and unaspirated [+fortis] stops that each have [-fortis] equivalents.

Not only is the force of stricture important, duration of stricture is also to be considered. The production of fortis stops involves more extensive movements with greater average velocity. This is confirmed by studies presented in Fujimura/Miller (1979). Fricatives on the other hand (fortis and lenis) involve greater muscle coordination that is sustained for a greater period of time "leading to longer vowels and consonants" (Kohler 1984: 155). This would explain the greater average length of CF vowels when preceding fricatives. What was accounted for by means of a phonological rule in past studies of this phenomenon can be reduced to a simple phonetic effect.

Kohler's dynamic perspective not only considers degrees of stricture in terms of location and duration, but also takes into account the timing of different articulations one relative to others. The articulatory movements involved in the production of a particular consonant variably affect the articulations of segments adjacent to it. This is, of course, the cause of co-articulation phenomena. It has been observed in Kohler (1981) that the articulatory movements necessary to ensure proper voicing of a coda obstruent are initiated during production of the preceding vowel (termed "preparation of voicing" (Kohler 1984: 163)). Kohler (1981) shows how this surfaces in the spectrographic representation of a relevant acoustic signal. Prior to the articulation of a fortis obstruent, first and second formants of a given vowel are closer together than prior to the articulation of a lenis. In fact, as was shown in Kohler's study of French in this respect, greater or lesser differences between F_2 and F_1 can be observed from the very beginning of the vowel. The results were established based on the comparison of French voiced (lenis) and voiceless (fortis) stops.

However, acoustic evidence is somewhat unsatisfying for it only provides information on movement of the body of the tongue. Basing ourselves on a cineradiographic study such as Perkell (1971), which shows that such movement is correlated with displacement of the tongue root, we can infer that differences between F_2 and F_1 must involve similar displacement of the tongue root. Going back to Perkell’s methods, but using MRI, we were able to investigate whether CF "lenis" consonants present the same characteristics as those of European French, as found by Kohler.

II. METHODOLOGY

Given what we know concerning the coordination of the vocal tract's different valves and given the study of relevant CF acoustic signals, we can infer that the successive production of a high vowel and a voiced fricative may necessitate pharyngeal compensation. Such an articulatory strategy, necessary for proper voicing of the fricative, may require anticipatory advancement of the tongue root, which, in turn, spurs advancement of the tongue body, causing the high vowel to be produced at a higher frequency. The hypothesis is perfectly justified, but not verified as of yet.

If one considers that the evidence gathered so far is only inferential, the question begs to be asked: what sort of evidence could confirm or disprove the hypothesis? Moving images of the interior of the vocal tract would of course be best suited to this purpose, but how does one obtain them?

The need of the study is this: to find if maximal pharyngeal expansion in the articulation of a [high V] + [vce, cont] sequence coincides with the articulatory gesture ensuring constriction of the vocal tract. For example, in the syllable [ɪ^{i}v], the experiment would seek to verify if maximal pharyngeal expansion coincides with retraction of the lower lip toward the teeth. A positive result would indicate two things: first, that tongue root advancement is an articulatory gesture aimed, not at producing a particular allophone of /i/, but aimed at ensuring proper voicing of the obstruent; second, because maximal advancement is timed with retraction of the lower lip, the tongue root is actually moved forward before retraction of the lip, that is, during production of the high vowel, thus leading the vowel to have a higher F_2.

Essentially, we are seeking to observe the hypothesised co-occurence of two articulatory gestures, which last only a few milliseconds. The observation of such a co-occurence requires imaging technology that is extremely precise, both in the quality and the capture timing of the image. Now, magnetic resonance imaging (MRI) may be the most promising technique, provided we get around one difficulty. MRI can provide the precise and total vocal tract imaging necessary for our objectives. MRI is a tomographic technique that provides very clear images of tissue contours with the added benefit of not exposing subjects to dangerous high-frequency radiation. As described in Stone (1997) tomographic techniques provide composite images made from scans of different planes of a subject's vocal tract. Scans are made by means of magnetic resonance, an advantage over computed tomography, which uses X-rays to the same ends. The subject is placed in the MRI machine, which surrounds the body with electromagnets creating a magnetic field of 1.5 Tesla. The effect of the magnetic field is to align the axes of hydrogen protons with the axis of the magnetic field. With each scan, a brief radio signal is emitted,[3] knocking hydrogen protons off their axes. As they realign, protons emit a radio signal that is received by the machine. Because hydrogen protons are found in watery tissues, the data collected essentially provides the location of watery tissues in the vocal tract. Essentially, these include all parts of the vocal tract that are not made of bone or oxygen-filled space. Once a composite image of scans is prepared by a computer, we are able to see images that contrast watery tissue (in

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[3] The radio signal is emitted at the resonance frequency of hydrogen in a 1.5 Tesla field: 6300 Hz.

white) with other elements (in black). The technology thus provides very precise imaging of tissue contours, however, as I have mentioned previously, there is one difficulty one must get around. The process of capturing images through magnetic resonance scans is overly slow, while articulation of different sounds is extremely rapid. While transition from one articulator to another can take 80 to 300ms, some consonantal articulations can take as little as 20–40ms to complete (Stevens 1998: 38 ff.). In order to produce a moving image of an articulation, an image capture rate of 100 frames per second (fps) is needed (Nissenbaum et al. 2002). Though newer scanners are able to capture one image every 50ms (Stone 1997), the frame rate of technology that is typically available can be up to 1fps or more (Nissenbaum et al. 2002). The frame rate is much too slow to study the interaction of articulators over a time span.

The challenge of accelarating MRI scans, as presented in Nissenbaum et al. (2002), has been overcome by the work of several researchers in the field (cf. Masaki et al 1997; Mathiak et al. 2000; Mohammad et al. 1997). The thing to understand is that an MRI magnet does not capture images, but magnetic resonance data. A still MRI of a patient's brain say is formed by means of an inverse 2-D Fourier transformation of the sample signals. A multi-slice image acquisition protocol yields a three-dimensional data matrix, which can be pictured as a loaf of bread, each slice being a two-dimensional array of data. The two-dimensional array is a rectangular table of magnetic resonance data with 256 rows. With each scan of the machine, a single row of data is collected for each "slice" of bread. Each data collecting event corresponds to one row of the array being filled. In the case of a still MRI, each two-dimensional array of the matrix corresponds to one cut of the object being filled. By combining different cuts together, we get a complete image of the object under investigation. To make moving images, we proceed entirely differently. Where each two-dimensional array corresponded to a cut of an object for a still MRI, in the case of moving images, each array corresponds to a point in time during an utterance (there are 128 slices in the protocol used for this study). In the case of a still image, with each scan, one array was filled. In the case of a moving image, a particular row of each slice is filled. So, with the first scan, we fill the first row of 128 arrays, with the second scan, we fill the second row, and so on. To fill the 256 rows of data, the subject is asked to repeat the same utterance 256 times. The first slice of the matrix will then correspond to a mid-sagittal view of the subject at the beginning of the utterance, while the last slice will correspond to the same mid-sagittal view of the subject at the end of the utterance. Slices in between correspond to intermediary points. Each slice of the matrix is then converted into images that are minimally different as positions of the various articulators shift over time.

I have applied the technique to the study of tongue root advancement in CF. At the time of writing the experiments have not been fully controlled, and only provide partial results.

The hypothesis to test is this: production of a high vowel requires greater stricture of the oral valve of the vocal tract leading to an increase of pressure in the supra-glottal cavity; voicing of a fricative requires reduction of supra-glottal pressure; given the observations of Kohler (1984), we would expect pharyngeal expansion by means of tongue root advancement to occur so as to insure pressure reduction. In the case of a mid vowel however, there is much less stricture of the vocal tract; because less stricture leads to less pressure, no pharyngeal expansion will be necessary. Because there will be no tongue root advancement in the production of a fricative following a mid vowel, the vowel will not be affected.

The first results I present were based on two MRI scans of a CF speaker, each scan corresponding to a different utterance. In the first utterance, a word containing a high vowel and a voiced fricative was placed in a carrier sentence in which it had phonological prominence. For the second scan, the same carrier sentence was used, but the target word was changed to one containing a mid unrounded vowel and a voiced fricative. During the collection of data, each carrier sentence was uttered 256 times, each of which had to be synchronised with the scanner. To do this, the following strategy was used. A very short question-answer dialog was recorded, where the question prompted the carrier sentence as an answer. The dialog was repeated 256 times into headphones worn by the subject. The subject uttered the carrier sentence in synchrony with the answer to the question he was hearing. Utterances were recorded into a microphone placed in front of the speaker's mouth.

For each carrier sentence, two frames of the scan were isolated. The first of each corresponds to the first frame of the film, at a point in the utterance when there is no tongue root advancement, corresponding to a beginning point in the vowel. The second frame corresponds to the frame where there is maximal lower lip retraction:

Figure 2a: high vowel + vce fricative

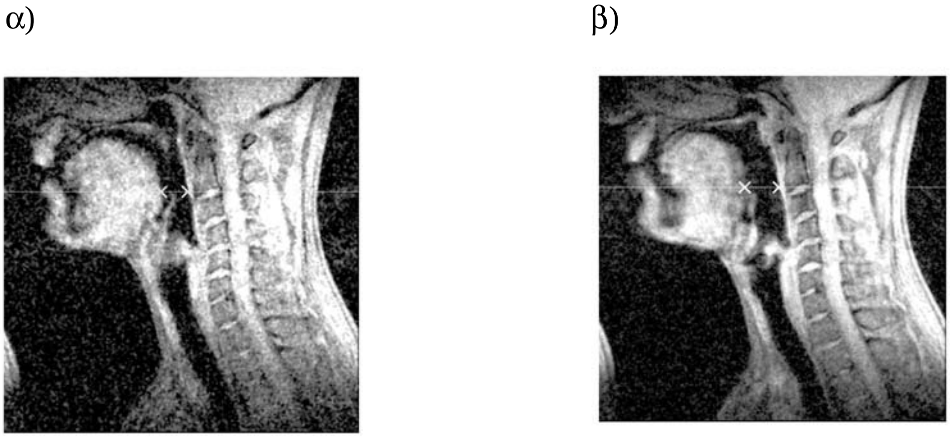
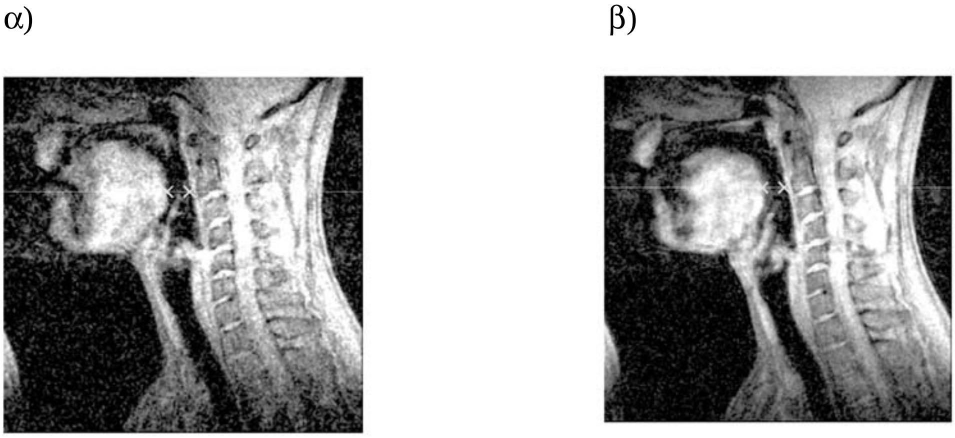


Figure 2b: mid unrounded vowel + vce fricative



α)

β)

Image analysis using Matlab software proceeded as follows. A script was written so as to allow a point to be chosen on the pharyngeal wall, and a line parallel to the abscissa drawn through it. Another script was then written for a point with identical co-ordinates to be chosen in all three remaining images (point A). Then, for each image, another point on the line was chosen, one corresponding approximately to the intersection of the line with the outermost edge of the tongue root (point B). Distance between point A and B was then measured for every frame between the 1st and 81st frames.[4] Given that the tongue root has a somewhat curved shape, distance between the pharyngeal wall and the tongue root may vary, depending on which area of the pharynx is being measured. Two pairs of points were therefore chosen. The line linking the first pair of points (A_1 and B_1) also intersected with the tip of the epiglottis. The line linking the second pair of points (A_2 and B_2) ran through a point located one 10 mm above the tip of the epiglottis.

The hypothesis is this: in the case of a high vowel, we expect an inverse correlation between the degree of tongue root advancement, and the degree of stricture necessary to produce turbulence in the vocal tract. Stricture, in the case of voiced labial fricative, is measured by looking at the distance between the upper and lower lip. Technically, turbulence is produced by contact of the lower lip with the upper teeth, however, because teeth do not contain any watery tissue, they do not appear on the images at all. The distance between the upper and lower lips is therefore only an indicator of what articulatory movements may be occurring and when. Distance between the lips was measured much in the same way de-

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[4] Essentially, measurement is done by counting the number of pixels between each point with the help of the software, which then converts the number of pixels into measurements in millimeters; each pixel is equal to 0.86 mm.

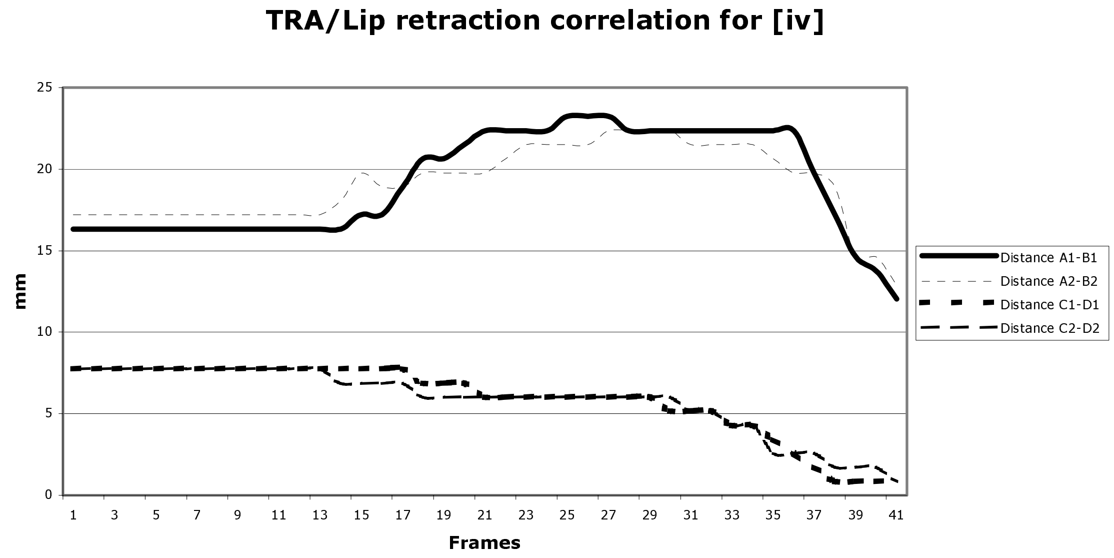
scribed above. A point was chosen on the upper lip which remained constant throughout all frames (C_1), and a line parallel to the ordinate axis was drawn through it. For each frame, another point was chosen on the lower lip (D_1). This point corresponded to the approximate intersection of the line parallel to the ordinate axis and the inner edge of the lower lip. Another pair of points on the lips was also chosen a few millimeters to the left.

III. RESULTS

We notice in *Figure 2a* (α) that lack of lip retraction is correlated with the lack of tongue root advancement. In *2b* (β) however, lip retraction for production of the voiced fricative is accompanied by tongue root advancement. By examining trends in tongue root advancement versus articulator constriction, we will see how we find overlap between these two phenomena.

Measuring the varying distances over time, we expect to find the following trends in the case of a high vowel: maximal distance between the tongue root and the pharyngeal wall should coincide with a marked reduction in the distance between the two lips. The expected trend is indeed observed in the following graph depicting the measured distances:

Chart 1

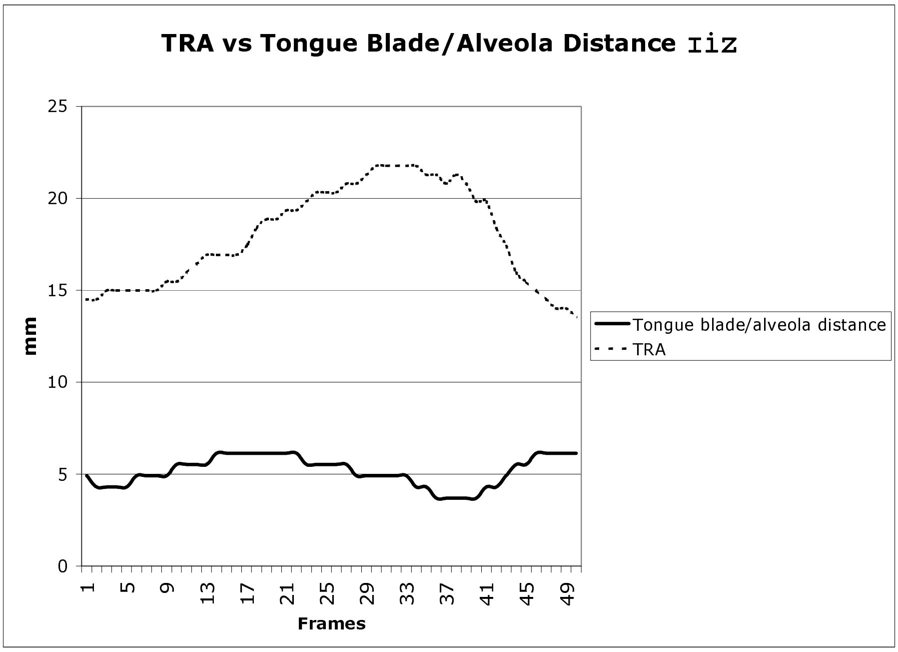


The chart above shows tongue root advancement (distances A1-B1, A2-B2), and lip retraction (distances C1-D1, and C2-D2) as a function of the number of frames included in a section of the film containing the target word. Given the number of frames, we can calculate the number of milliseconds into the utterance at which they were taken, allowing us, using the recordings made during scanning, of telling which sound was uttered during which frame.

The utterance *Yves attend* (of which the target is *Yves*) lasts approximately 700 ms. Over these 700 ms, 128 MRI frames were taken. There is therefore 1 frame for every 5.46 ms.

The chart reveals that lip retraction begins at approximately the 29th frame, that is, given our values, 158 ms into the utterance. That is not to say that frication necessarily starts at that point. We see that at the 29th frame, distance between the two lips is still well over 5 mm. When we consider a recording of the utterance, we can see that frication starts approximately 191 ms into the utterance. Doing the reverse calculation (dividing 191 ms by 5.46), reveals that frication should start around the 35th frame. Now, considering the above chart, we see that, at the 35th frame, tongue root advancement is still in its maximal range of values. At that point in time (i. e. when frication begins), the tongue root is at 22.6 mm from the pharyngeal wall.[5] The chart also reveals that tongue root advancement over 20 mm is maintained until frame 38, that is, until 207 ms into the utterance. Tongue root advancement is thus maintained for approximately 16 ms into articulation of the fricative. Length of the fricative in this case is 127 ms. Maximal tongue root advancement is thus held for the first 12.5% of the fricative's articulation. The same sort of measurements were done for the utterance *Lise attend* for which the target word was *Lise* ([lɪ^{i}z]):

Chart 2



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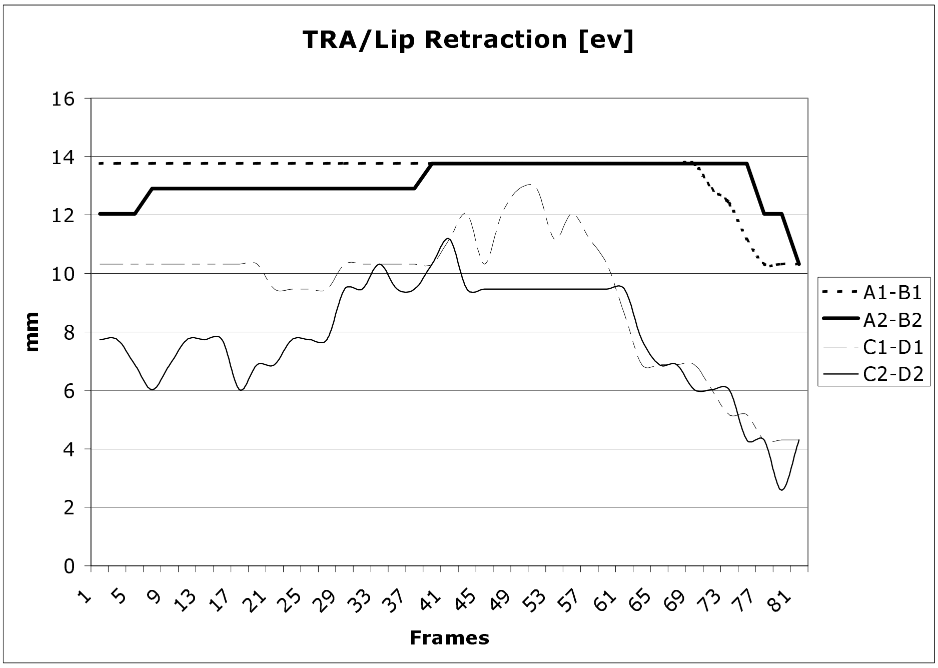
[5] As opposed to approx. 16 mm, which appears to be the value of TRA when at rest.

Chart 3 reveals that maximal tongue root advancement (>20 mm) lasts from frames 22 to 38 , while minimal distance between the tongue blade and the alveola (< 5 mm) lasts between frames 33 and 43. There is thus an overlap of 5 frames during which tongue root advancement is held during frication. In this case, the utterance was approximatel 760 ms in length. Again, 128 frames were scanned; there is thus an interval of approx. 5.9 ms between each frame. An overlap of 5 frames therefore represents 29.5 ms during which tongue root advancement and frication are maintained. The total length of the voiced fricative in this case is 120 ms. Maximal tongue root advancement values are thus maintained for 25% of the fricative's articulation. The results contrast with those collected in the case of a mid vowel followed by a voiced fricative. These are illustrated in *Chart 3*:

Chart 3

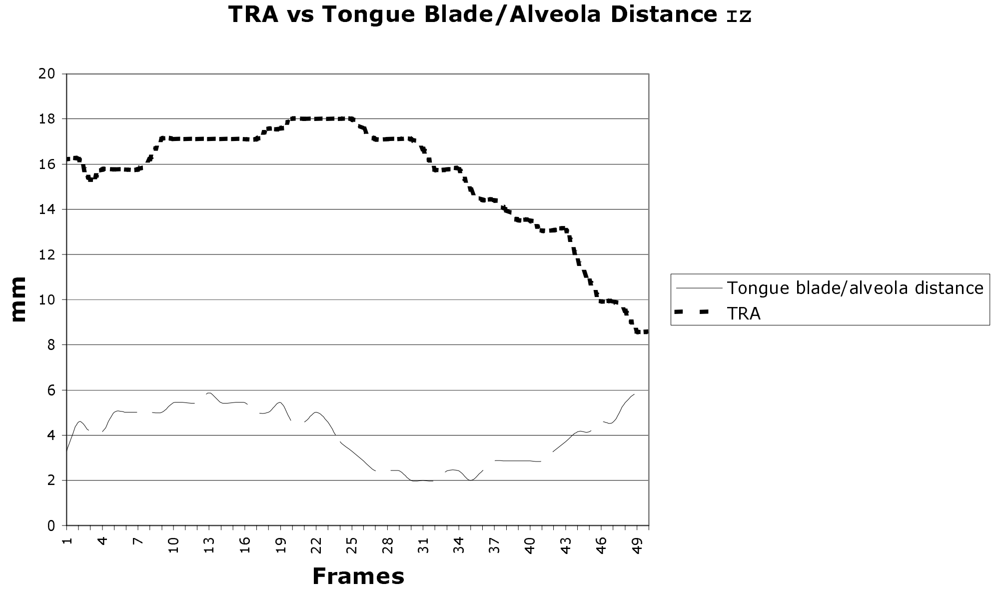


Considering the distance between the tongue root and the pharyngeal wall (A_1-B_1 and A_2-B_2), it is clear from *Chart 3* that it remains constant almost throughout the selected range of frames, even at the point where distance between the lips begins to diminish significantly (between frames 61–65). Moreover, the distance between the tongue root and the pharyngeal wall is kept much below 20 mm. Basing ourselves on *Chart 3*, at the beginning of the utterance, when, presumably, there is no tongue root advancement, the tongue root is at an average of 16.77 mm from the pharyngeal wall. The chart shows that at the beginning of the utterance, the tongue root is at an average of 13.33 mm from the pharyngeal wall. The tongue root is therefore even less advanced, and what is more, the average value is maintained throughout the first 81 frames indicating that there is no advancement of the tongue root at all in this case.

The predictions formulated with the help of Kohler (1984) hold. When there is less stricture in the oral valve, pharyngeal expansion is unnecessary to produce voicing. In the opposite case however, pharyngeal expansion becomes a probable occurrence. In the case of CF, the occurrence is observed, and may well explain the peculiar production of high vowels before voiced fricatives.

The results need to be controlled further however, as we have to eliminate all possibilities. For example, we must see what happens in syllables that are closed by a voiced fricative, but where there is no impact on the preceding vowel. Such cases exist in the inventory of English loan words in CF. The word *fizz* for instance was borrowed without any major changes: `[fɪz]`. There are one of two possibilities. According to the hypothesis, because the voiced fricative is preceded by a high vowel, we should see tongue root advancement, which is necessary for its proper voicing. However, there is no co-articulation on the preceding effect in this case. There are two possibilities: either, tongue root advancement is simply timed in such a way that maximal pharyngeal expansion does not correspond with stricture, or, full voicing is ensured by another articulatory strategy, namely, passive expansion of the pharyngeal airway. A subject was scanned uttering the sentence *Du fizz en masse*. *Chart 4* compares tongue root advancement with the distance between the tongue blade and the alveolar ridge:

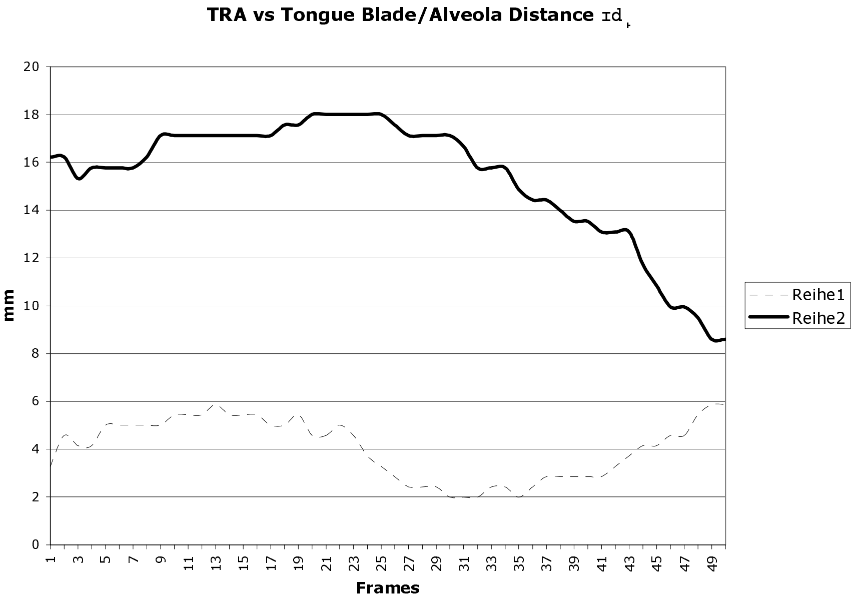
Chart 4



In *Charts 1* and *2*, we saw that tongue root advancement was held over 20 mm for an appreciable amount of time, which overlapped with the time during which the articulators responsible for turbulence in the airflow were constricted. This suggested that tongue root advancement was not necessarily linked only to articulation of the vowel, but that pharyngeal expansion may in fact be linked to voicing of the fricative.

In *Chart 4* however, we see that a decrease in tongue root advancement is timed exactly with a decrease in the distance separating the tongue blade from the alveolar ridge. *Chart 5* shows results of a scan of the speaker uttering the word *Gide* ([ʒɪd]). Again, we see the same pattern as in the chart following the articulation of *fizz* ([fɪz]) :

Chart 5



Again, we see that the distance separating the tongue root from the pharyngeal wall is only 18 mm, which is not suprising, given that *fizz* and *Gide* share the same lax vowel. The key thing however, is that we see no overlap between narrowing of the constriction between the tongue blade and the alveola, and maximal advancement of the tongue root. *Chart 5* suggests that no tongue root advancement is involved in the articulation of voiced stops. The difference in quality between vowels found before voiced fricatives and voiced stops is not the result of a difference in timing of tongue root advancement, but rather, is a function of the presence or absence of tongue root advancement during constriction.

We might wonder then how voicing is ensured during production of a CF voiced obstruent or during a voiced fricative found in a loan word. In the former case we could hypothesise, in line with Kohler (1981, 1984), that CF voiced obstruents are "[+fortis]", however, how that might be characterised articulatorily remains to be investigated. So far, we have no clear answers regarding that question. As for the latter case (*fizz*), it is always possible that, because there is a conflict between the articulatory gestures involved in voicing of the loan fricative and preservation of the loan vowel, that speakers opt for another articulatory strategy to ensure voicing, namely, through compliance of the vocal tract walls. Many further hypotheses are raised by these results, and no clear answer has been found as of yet in this research project.

IV. CONCLUSION

This paper has presented preliminary results obtained from pilot experiments used to investigate the possibility that tensing of CF high vowels before voiced fricatives may be the result of co-articulation. So far, results suggest that this is a clear possibility. However, some questions remain which will be the object of further investigation into this matter. Such an investigation should include a look at the behaviour of more loan words in CF. For example, some loan words include diphthongs with a tense off-glide followed by segments that are not voiced fricatives (e.g. *shoot* [ʃʊᵘt]). It would be interesting to find out in this case if we do have an overlap between tongue root advancement and articulation of the coronal stop. If we do, then we would have difficulty saying whether or not the overlap we find in the case of voiced fricatives is significant at all. Another example of an important control would be to measure tongue root advancement in the case of the short tense vowels we find in open syllables. In this case, it would interesting to find out whether they involve raising of the body of the tongue with or without secondary tongue root advancement. This would help us rule out the possibility that much of the tongue root advancement we have observed in the case of *Yves* ([ɪⁱv]) is simply due to the fact that the off-glide is a high tense front vowel which may involve this sort of advancement as a secondary gesture. In the same line of thought, another possible test would be to observe the behaviour of the high back vowel (/u/), which behaves on a par with high front vowels regarding diphthongisation. We would expect that the articulation of this vowel might include less secondary advancement of the tongue root. If we do find such advancement before a voiced fricative, then there is a chance that we are not dealing with an articulation that is secondary to fronting of the tongue, but secondary to voicing of the fricative.

Finally, it would also be useful to compare the intraoral pressure in the case of voiced fricative and voiced stops. If our hypothesis holds, we would expect a greater overall pressure in the case of a fricative compared to a stop. If that is the case, we can understand why articulation of a voiced fricative might involve pharyngeal expansion when articulation of a voiced stop does not.

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