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The influence of the dark /

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The influence of the dark /ɫ/ on the F1 and F2 of the preceding vowel in American English

1. Introduction

The English lateral phoneme /l/ has two major contextual variants known as the clear [l] and the dark [ɫ]. The distribution of these allophones varies ranging from the dialects in which the lateral approximant is either always dark, e.g. certain types of American English (Recasens and Espinosa 2005), or always clear, e.g. a number of southern Irish English dialects (Recasens and Espinosa 2005) to the ones in which the dark [ɫ] vocalised which can be heard "in the speech of many Londoners and South Australians, who may even fail to make the lateral occlusion. As a result, the raising of the back of the tongue virtually creates an [u] vowel" (Clark and Yallop 1990:97). However, there are accents (e.g. RP, Gimson 2001) in which the lateral is pronounced dark word-finally and preconsonantally (except for /j/) and clear elsewhere.

An additional point here can be also made in reference to the very concept of *phonetic darkness*, which does not seem to be based on a binary dark-clear opposition, but rather involves a number of intermediate points between the two positions understood as *extremely velarized* and *nonvelarized* (Recasens and Espinosa 2005).

The basic articulatory difference between the two variants of the lateral approximant lies in the fact that, in the dark allophone, there is an additional place of articulation at the back of the oral cavity, formed by the dorsum of the tongue rising towards the velum (Davenport and Hannahs 1998), which "can be considered as the addition of an [u]-like tongue position, but without the addition of the lip rounding (...)" (Ladefoged 1975:208). The articulation of the lateral is also influenced by the temporal ordering and extent of the apical and dorsal gestures, which might vary for different degrees of darkness (Recasens and Espinosa 2005, Recasens et al. 1996).[1]

The above-mentioned articulatory differences result in a number of acoustic characteristics: steady F1 at about 300-400Hz for both the velarized and nonvelarized lateral, F2 for the dark [ɫ] lower than for the clear [l] [2], a tight clustering of the formants F3, F4 and F5 (Jassem 1983, Jassem 1973) and the presence of an antiformant as a result of the lateral articulation (Jassem 1973). Additionally, the dark [ɫ] influences the quality (i.e. formant structure) of the preceding vowel (Cox and Palethorpe 2003). The scale of the influence may differ ranging from a slight shift to depriving the vowel of its phonemic identity and occasional disappearance of the phonemic contrast with other vowels in that position.

The aim of the current study is to analyze the influence that the velarized lateral exerts over the preceding English monophthongs in American English through the investigation of formant F1 and F2 changes in vowels in the [ˈhVd]and [ˈhVɫ] contexts.

2. Analyzed samples

[1] The subjective nature of the terms *dark* and *clear* has been very clearly expressed in Van Buuren (2005).

[2] In the clear [l], F2 is about 2200Hz whereas for the dark [ɫ] it is at around 800Hz (Jassem 1973).

The analyzed samples were produced by a native speaker of San Francisco American English, recorded and digitized at 44,1 kHz at the Pro-Media recording studio in Tarnobrzeg.

The speaker was asked to repeat each word four times[3]. Following the recording, values of formants were obtained from each of the samples for the purposes of a comparison and, subsequently, their means were used for the final analysis. In a pilot study, the number of vowels in the speaker's accent had been determined to be 8. The identified vowels were the following: /iː/, /ɪ/, /e/, /æ/, /ʌ/, /ɑː/, /ʊ/, /uː/ (see Table 1). As a result, 64 tokens were obtained (8 vowels x 4 readings x 2 contexts). The words which the speaker was asked to read were monosyllables containing three segments – the fricative [h], a vowel and the plosive [d].

Table 1. The two sets of vowels recorded for the analysis.

SET 1		SET 2	
[ˈh iː d]	[ˈh ʌ d]	[ˈh iː ɫ]	[ˈh ʌ ɫ]
[ˈh ɪ d]	[ˈh uː d]	[ˈh ɪ ɫ]	[ˈh uː ɫ]
[ˈh e d]	[ˈh ʊ d]	[ˈh e ɫ]	[ˈh ʊ ɫ]
[ˈh æ d]	[ˈh ɑː d]	[ˈh æ ɫ]	[ˈh ɑː ɫ]

There are three major reasons why a format like that is suitable for this kind of examination. Firstly, the initial fricative, apart from being articulated in the glottis, adopts the place of articulation of the following vowel (Ladefoged 1962). That very fact can be used in the

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3 A problem which was encountered during the recording was the speaker's tendency to *over-articulate* the dark [ɫ] word-finally, reducing the dorsal gesture and increasing the apical gesture. It was, however, was corrected *on site* through multiple repetitions in order to ensure that no instances of the coda clear [l] were present in the material.

precise measurement of formants F1 and F2 because they are level in [h] and in the vowel; thus, there is no transition. Secondly, [d] has a predictable locus of about 1800Hz (Hayward 2000), which makes it possible to adequately assess the range of the influence. Thirdly, the format is found in a number of similar studies (e.g. Peterson and Barney 1952, Ladefoged 1962, Cox and Palethorpe 2003) which makes it much easier to compare results.

Understandably, the first and the most natural choice for a set of words in which the influence of a consonant on other segments is studied is using /hV/words on the one hand, and /hVC/ on the other hand.[4] Unfortunately, this cannot be done for English because English phonotactic restrictions do not allow all monophthongs in syllable-final position (Gimson 2001).

The two acoustic parameters chosen to analyse the influence of the velarized lateral on the preceding vowel are F1 and F2. They constitute the crucial elements in the identification of vowel quality, F1 referring to the dimension of *height* and F2 intuitively referring to *backness*. In other words, listeners are able to identify vowels on the basis of their F1 and F2 values. It does not mean, however, that the two parametres are sufficient to describe any vowel. Vowels which have a more complex articulation, e.g nasalized or rhotacized, need other parametres as well (Hayward 2000, Stevens 1998, Davenport and Hannahs 1998).

Measuring F1 values did not present any problems because they were steady and clearly identifiable in all the cases. The procedure involved highliting the formant and reading the mean value calculated by Praat[5]. Obtaining F2 levels in set 1 was not problematic either because the beginning of [d] is easily recognizable from a spectrogram (a sudden drop in intensity) and the oscillogram (low energy of oscilations) (see Fig.1). The measurements of F2 have been conducted in the same manner. The mean value for F2 in set 2 has,

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4 C-consonant, V-vowel, [h]-glottal fricative

5 Praat 5.1.04

however, a different interpretation than the mean for F2 in set 1. The former might be just one of the many possible values of that formant but its calculation takes into account the two extremes i.e. much higher values (i.e. those close to [h]) and much lower values (those close to the dark [ɫ]). Due to the fact that F2 is stable in set 1, its mean values are much closer to the statistical notion of *mode* than for the mean in set 2, which is simply an arithmetic average of all the available values.

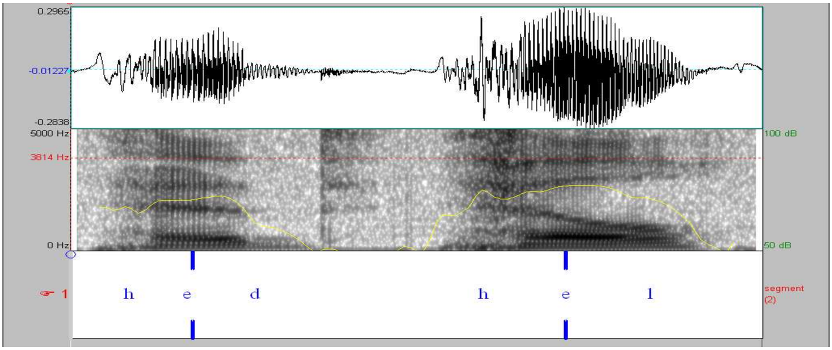

Figure 1. The oscillograms and spectrograms of the words *head* and *hell*

The reason why the mean of the values from the whole duration of the formant was taken into account is that, considering the continuous nature of the transition, in some cases it is very difficult to tell where the vowel ends and the dark [ɫ] begins. The only readily-available criterion here seems to be the auditory inspection i.e. looking for the point at which the vowel changes so much that it no longer retains its original quality and turns into the dark [ɫ]. The transition can be very clearly seen in Fig.1 and Fig.2.

There are at least two other methods of measuring formants whose values are not stable. One way is to identify the onset, medial and offset phase of a segment (Laver 1994) and read the formant values at those points. The other one involves looking at the temporal midpoint of the formant only and treating its value as characteristic of that formant. On the basis of Fig.1, it can be seen that, at least for [e], the first analysis would not describe the actual trajectory of F2 because none of the three separate stages of the formant are enough to express its overall resultant value. Additionally, the listener perceives only one vowel - not the onset, medial and offset phases separately. The problem with [e] results from the fact that its F2 does not have a steady - state phase. In other words, the vowel is not *resistant* to the influence of the following dark [ɫ] and its whole duration constitutes a transition. The other technique may bring misleading results if one tried to analyze the influence of the dark [ɫ] on the [i:] vowel.

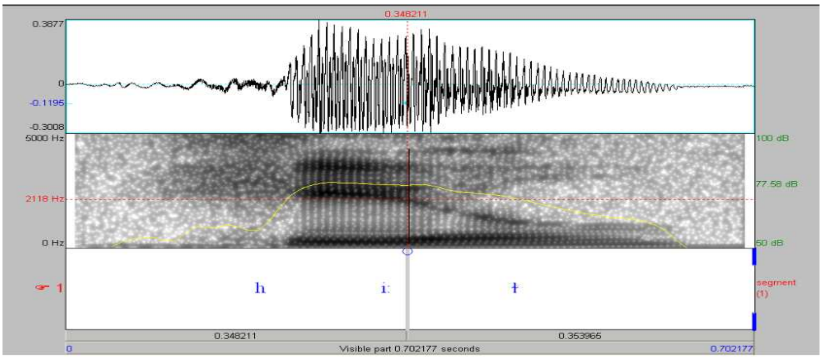

Figure 2. The oscillogram and spectrogram of the word *heal*.
The black vertical line marks the middle point of the vowel /i:/.

A vertical black line in Fig.2 shows the midpoint value of F2. That value should not be considered typical of F2 in this case for two reasons. Firstly, it is very close to the top value so it does not take into account the fact that, subsequently, F2 decreases quite rapidly. Secondly, it is calculated on the basis of the beginning and end of the vowel. However, with the starting point of the vowel easily identifiable either from the spectrogram or from the oscillogram, one does not actually know where the end of the vowel is. The decision about its location is to some extent arbitrary, which is a problem for both analyses. Hence, none of the two methods discussed above are able to sufficiently characterize all the eight vowels in the experimental sets.

The solution which has been chosen here (i.e. calculating the mean) is not perfect either, but it does have its merits. One of them is the fact that it can be used to characterize any vowel in the set and it is able to reflect the smooth change in the value of F2 throughout the length of the vowel. Due to that, it reflects the listener's intuition that we perceive only one vowel whose quality is the outcome of all the values of formants. Unfortunately, it suffers from the already mentioned theoretical weakness - similarly to the methods discussed above, it is arbitrary because it relies on the arbitrary calculation of the end of the vowel. Nonetheless, it seems to be the most adequate of the three presented approaches.

3. Statistical analysis.

Table 2 summarizes the final values of F1 and F2 in hertz for both sets. There are four variables, which, for reasons of convenience, we shall term Var1, Var2, Var3 and Var4. The first stage of the analysis consists in making sure that the differences between, firstly, Var1 and Var2, and secondly, Var3 and Var4 are due to the fact that the two elements of each pair come from different populations, not due to chance. Verifying the correctness of this assumption can be achieved using Student's t-test. In order to apply the t-test, however, the data must meet two mathematical conditions: the normality of the distribution and the homogeneity of variance (Clegg 1994). The normality of the distribution of values for each of the variables can be investigated using the Shapiro-Wilkinson Test (Baayen 2008). The homogeneity of variance in the Var1-Var2 and Var3-Var4 correlated pairs can be analysed via Morgan's Test (Juszczyk 2004).

The condition of the normality of the distribution is observed by the values of all the four variables and the requirement of the homogeneity of variance is met for both pairs of variables[6]. Student's t-test may provide the answer to the question whether the above mentioned pairs of variables come from different populations or from the same population. However, the data analysed here are correlated. Hence, the t-test for correlated pairs must be used.

Table 2. F1 and F2 values of the analyzed vowels.

VOWEL	[ˈhVd] F1 Var1	[ˈhVɫ] F1 Var2	[ˈhVd] F2 Var3	[ˈhVɫ] F2 Var4
iː	270	280	2378	2306
ɪ	379	449	1798	1558
e	487	533	1752	1265
æ	676	641	1723	1429
ʌ	486	498	1396	968
uː	338	364	1095	789
ʊ	424	343	1263	775
ɑː	625	541	1092	971

The t-test (see Table 3 in App.1) clearly shows that, statistically speaking, Var1 and Var2 come from the same population and the observable differences in the values for each vowel are due to chance. However, Var3 and Var4 differ significantly. Additionally, the t-test shows that it is highly unlikely that those differences are a result of chance.

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[6] Shapiro-Wilkinson test : Var1 ($W=0.9601$, $p=0.811$, $\alpha=0.05$), Var2 ($W = 0.9687$, $p = 0.8878$, $\alpha = 0.05$), Var3 ($W = 0.9108$, $p = 0.8878$, $\alpha = 0.05$), Var4($W = 0.8577$, $p = 0.0905$, $\alpha = 0.05$); Morgan's test: Var1-Var2($t = 1.165$, $t_{crit} = 1.943$, $\alpha = 0.05$), Var3-Var4($t = 1.874$, $t_{crit} = 1.943$, $\alpha = 0.05$)

The last element of the statistical analysis is an examination of the Pearson correlation coefficient *r* table. Table 4 (see App.1) shows the values of the *r*-coefficient calculated for all pairs of variables using the statistical online software BrightStat. The additional variables which have been included in the table are *height* (values: 0-close, 1-intermediate, 2-open), *backness* (values: 0-front, 1-intermediate, 2-back), Var3-Var4 and Var2-Var1.

A brief analysis of the contents of Table 4 reveals that there are significant correlations in the following pairs of variables: height – Var, height - Var2, backness - Var3, backness - Var4, Var1 - Var2, Var3 - Var4.

Surprisingly, there is no significant correlation between Var3-Var4 and either Var3 or Var4. Similarly, there is no correlation between Var2-Var1 and either Var2 or Var1. A high correlation between Var1 and Var2, and Var3 and Var4 at a very good level of significance can be interpreted as the expression of a regular and stable tendency which may describe the influence of the dark [ɫ] on the preceding vowel. The higher level of correlation and significance for variables Var3 and Var4 (0.957***) than for variables Var1 and Var2 (0.913**) results from bigger differences between the values of the formants and the fact that, for the former, the difference is always positive, whereas for the latter it is positive in 5 cases and negative in 3 cases.

4. Acoustic analysis

In order to analyze the influence of the velarized lateral on the preceding vowel, an F1-F2 plot generated by the formant table function of Praat was used. In Fig.3 (see App.2), F1 values are indicated on the ordinate and F2 values on the absissa. The monophthong to the left of the arrow is the one in the [ˈhVd]-context, whereas the one to the right of the arrow comes from the [ˈhVɫ]-context. The grey solid line connects all the segments in the [ˈhVd]-context, whilst the dashed line connects all the segments in the [ˈhVɫ]-context. Except for [iː], all the vowels have been considerably influenced by the following dark [ɫ] with [e] and [ʊ] being influenced the most, and [iː] the least. All the arrows are pointed to the right, which constitutes the graphical expression of the positive value of the Var3-Var4 variable in all the eight cases (the mean shift in F2 is 304.5Hz). The fact that some arrows are pointed upwards ([æ],[ɑː],[ʊ]) whereas others downwards ([iː], [ɪ], [e], [ʌ] and [uː]), corresponds to the various *starting points* of the monopthongs. The vertical direction of the pointing of the arrow reflects the sign of the Var2-Var1 variable - the positive sign corresponds to the arrow pointing downwards whereas the negative sign reflects the arrow which points upwards.

The two extreme ends of the vowel diagram at the fully close level, i.e. the back and the front, seem to display two divergent reactions to the presence of the dark [ɫ]. Firstly, the effect of the dark [ɫ] on [iː] is much smaller than for the other vowels[7]. Secondly, the influence of the velarized lateral on the two u-vowels not only causes a shift in the values of F1 and F2, but they also seem to *change places* in reference to their original F1 values. It remains for future research to investigate whether the phenomenon is significant or if it merely stems from the limited precision of the measurements.

In two of the cases shown in Fig. 3, the influence of the dark [ɫ] results in the complete or almost complete neutralisation of a phonemic contrast in the following two pairs of vowels: [ɑː] - [ʌ] and [uː] - [ʊ]. Both processes reflect the linguistic intuitions which the speaker expressed during the recording that, in his accent, those two pairs sound the same or almost the same. Hence, the number of possible vocalic contrasts in the [ˈhVd] - context can be calculated as 28, whereas in the [ˈhVɫ] - context it would be 15.

5. Conclusion

[7] Recasens et al. (1995) tried to explain a similar phenomenon in Catalan using the notion of *coarticulatory resistance*

The aim of the study was to examine the modifications that English monophthongs undergo when they precede the velarized lateral. The statistical and acoustical analyses allowed the author to demonstrate that the dark [ɫ] influences all monophthongs in American English. The extent of the change, however, varies depending on the vowel. For [iː], the shift is insignificant, whereas for the other vowels it is considerable. Additionally, the impact reaches its maximum for the two pairs [ɑː] - [ʌ] and [uː] - [ʊ] for which it results in the neutralisation of a phonemic contrast. The above conclusions seem to confirm neither the observations presented in Gimson (2001:203)[8], nor the views expressed in Jassem (1983:183)[9]. However, they corroborate most of the regularities reported in Swięciński (2000:122-127) for near RP English.

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8 "The velarization of [ɫ] often has the effect of retracting and lowering slightly the articulation of a preceding front vowel, e.g. feel, fill, fell, canal."

9 "The phonemes /iː, e, ɛ, a/ and /ə/are represented by special variants when followed by [ɫ] – the velarized allophone of the phoneme /l/."

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Appendix 1

Table 3. The results of the paired t-test.

correlated pairs t-test	H_0	t	Significance	Result
Var1-Var2	The values of Var1 and Var2 come from populations whose means are equal	0.2239	$\alpha = 0.05$ $_{theor} = 2.365$ $t < t_{theor}$ $p = 0.8292$	H_0 is not rejected
Var3-Var4	The values of Var3 and Var4 come from populations whose means are equal	5.459	$\alpha = 0.05$ $t_{theor} = 2.365$ $t > t_{theor}$ $p = 0.0009468$	H_0 is rejected

Table 4. The values of the Pearson correlation coefficient for pairs of variables analyzed in the study

	height	backness	Var3-Var4	Var2-Var1	Var1	Var2	Var3	Var4
height	1	0.018	-0.038	0.346	-0.871**	-0.839**	0.251	0.226
backness	0.018	1	0.116	-0.595	0.037	-0.238	-0.87**	-0.778*
Var3-Var4	-0.038	0.116	1	0.064	0.119	0.167	-0.335	-0.594
Var2-Var1	0.346	-0.595	0.064	1	-0.502	-0.106	0.444	0.36
Var1	-0.871**	0.037	0.119	-0.502	1	0.913**	-0.35	-0.336
Var2	-0.839**	-0.238	0.167	-0.106	0.913**	1	-0.193	-0.216
Var3	0.251	-0.87**	-0.335	0.444	-0.193	-0.193	1	0.957***
Var4	0.226	-0.778*	-0.594	0.36	-0.216	-0.216	0.957	1

- the minus sign denotes negative correlation

* $p < 0.05$

** $p < 0.01$

*** $p < 0.001$

Appendix 2

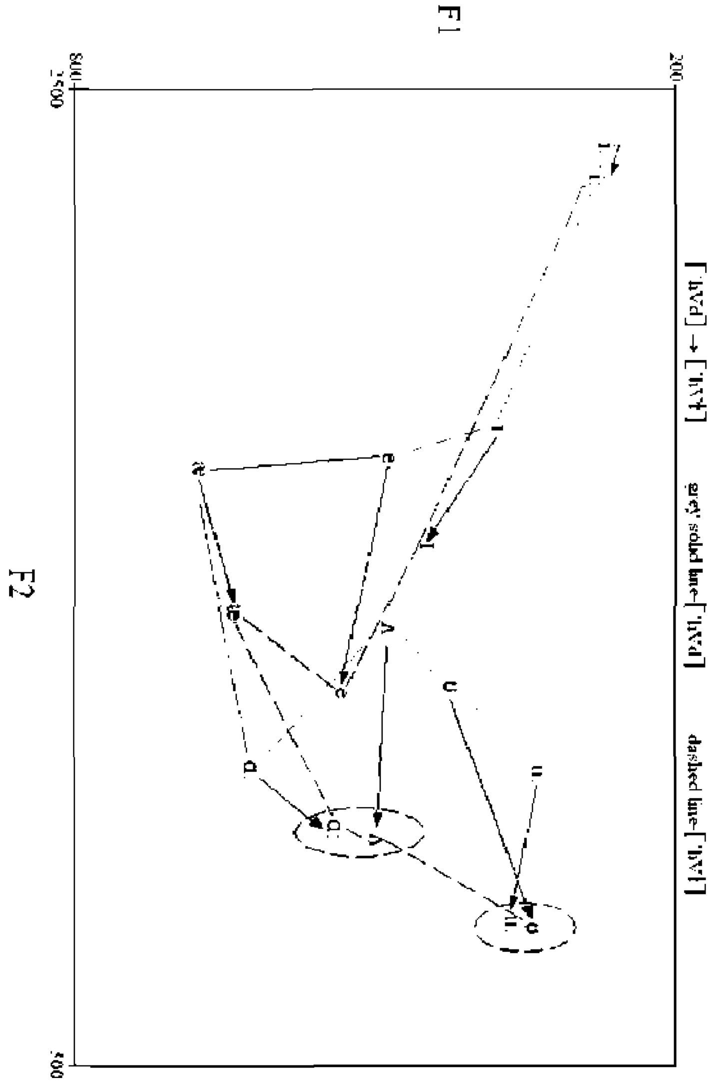

Figure 3. Vocalic shifts as a result of the following velarized lateral.