A perceptual analysis of the articulatory and acoustic factors triggering dark /l/ vocalization

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Abstract

This paper investigates whether the vocalization of dark /l/ into [w] results from contact loss at the alveolar place of articulation and/or should be attributed to spectral similarity between the two consonant sounds, which share a low F2 about 800-1000 Hz. A series of /l/ stimuli ranging from moderately dark to strongly dark were presented to Catalan informants for identification as /l/ or as /w/ in /VlbV, VldV, VlsV, VlkV/ sequences excised from Majorcan Catalan real speech sentences. The stimuli were specified for different degrees of F2 frequency height and of alveolar contact as measured with electropalatography. Identification results indicate that /l/ vocalization may be triggered by both alveolar contact loss and acoustic equivalence (e.g., percentages of /w/ identification were highest for realizations of /l/ before /b/ involving at the same time a low alveolar contact degree and a low F2), or by alveolar contact loss alone (e.g., practically no /w/ responses were obtained for realizations of /l/ before /d/ exhibiting much alveolar contact and a low F2). Perception data reported in this paper suggest that both articulatory and acoustic cues, whether in combination or in isolation, may play a role in sound change.

1 Introduction

While a good deal of research has been carried out on the causes of sound change, little is still known about the strategies that speakers use when replacing one phonetic sound with another. One of these replacements is consonant vocalization and, more specifically, the vocalization of dark /l/ into /w/. This sound change has been attributed to either articulatory factors, i.e., apical contact loss at the place of articulation, or to acoustic factors, i.e., the acoustic equivalence between the two input and output consonants. This paper will test the articulation-based and acoustic equivalence hypotheses through analysis and perceptual evaluation of those articulatory and acoustic cues which may contribute to the vocalization of dark /l/.

1.1 Phonetic characteristics of dark /l/

There is general agreement among phoneticians and phonologists that languages and dialects may exhibit either a clear variety of /l/ (e.g., Spanish, German, French) or a dark variety of the consonant (e.g., Russian, British or American English dialects).

Dark /l/ is produced with an apical closure at the dental, dentoalveolar or alveolar zone, and with considerable predorsum and jaw lowering and postdorsal retraction towards the pharyngeal or velar region (Koneczna & Zawadowski 1951; 1956; Straka 1968; Keating et al. 1994; Browman & Goldstein 1995; Lindblad & Lundqvist 2003; Martins et al. 2008). An increase in darkness degree for this consonant variety is associated with an enlargement of the medial cavity located between the front apical closure and the back postdorsal constriction (Fant 1960).

Dark /l/ presents a grave acoustic spectrum with a low F2 about 1000 Hz, reaching frequencies 300 Hz below or above that frequency depending on whether degree of darkness increases or decreases, respectively (Recasens & Espinosa 2005). F2 decreases and F1 increases with darkness degree in the alveolar lateral consonant: F2 varies inversely with degree of predorsum lowering and postdorsal constriction narrowing, while F1 increases with tongue dorsum-to-palate distance and with jaw lowering and oral opening. Another acoustic measure relating these two formants, i.e., F2-F1, has also been proposed as a darkness index. F3 for dark /l/ increases with a reduction in front cavity size.

1.2 Explanatory hypotheses for dark /l/ vocalization

The vocalization of dark /l/ into /w/ in Romance and other language families appears to be conditioned by syllable position and segmental context (Recasens 1996). It applies syllable finally rather than syllable initially, preferably after low or back rounded vowels, and before labial or velar consonants and, less frequently, before dentals or alveolars (Catalan [ˈawβə] ALBARU, Majorcan Catalan *Aucadena* for the place name *Alcadena*, Old Occitan [faws] FALSU, [mowt] MULTU, Italian dialects [ˈsawtu] SALTU; Grandgent 1905: 70; Rohlfs 1966: 343). Based on these positional and contextual conditioning factors, the present paper tests whether the vocalization of dark /l/ into /w/ should be attributed to articulatory variations or to the acoustic characteristics of the lateral consonant.

1.2.1 Articulation-based hypothesis

It has been argued that the change /l/ > /w/ should be triggered by the failure of the primary tongue tip articulator to reach the dental, dentoalveolar or alveolar target (Straka 1968; Grammont 1971). According to this articulation-based hypothesis, closure undershoot would give rise to an /w/-like lingual configuration thus rendering dark /l/ vocalization possible.

Evidence for contact loss at closure location during the production of dark /l/ is documented in the literature. Cinefluorographic data show instances of closure undershoot for American English /l/ in prepausal position at fast speech rates (Giles & Moll 1975). EPG data for /lC/ sequences produced by British and Australian English speakers reveal instances of complete or partial undershoot after back vowels (/ɔ, ʌ/) and before velars (/k/, as for *milk*) rather than after front vowels (/ɪ, ɛ/) and before alveolars and palatoalveolars (/t, d, s, z, dʒ/) (Hardcastle & Barry 1985). According to another EPG study, /l/ vocalization in British and American English takes place more frequently prepausally and before labial consonants than prevocalically (Scobbie & Wrench 2003). EPG has also been used for investigating alveolar contact loss in three Catalan dialects where the alveolar lateral is either maximally dark (Majorcan), moderately dark (Eastern) or clear (Valencian) (Recasens 2009). In agreement with dialect-dependent differences in degree of darkness, the consonant exhibited complete and partial contact loss in Majorcan, instances of partial contact loss in Eastern, and always complete closure in Valencian. Alveolar contact loss occurred preconsonantally rather than intervocalically, mostly after back vowels and before labials and, less so, before velars or /s/. It was also found to operate more frequently in spontaneous speech than in oral reading of a written text.

EPG contact configurations for five Majorcan speakers presented in Figure 1 exemplify different degrees of alveolar contact loss for dark /l/ before consonants of different places of articulation. In the linguopalatal contact configurations of the figure, electrodes are arranged in eight rows and in four columns on each half of the artificial palate. The frontmost row 1 just behind the upper teeth is displayed at the top of the EPG graphs and the backmost row 8 just in front of the soft palate appears at the bottom. The palate surface has been subdivided into four articulatory zones for data interpretation, i.e., front alveolar (rows 1 and 2), postalveolar (rows 3 and 4), prepalatal (rows 5 and 6), mediopalatal (row 7) and postpalatal (row 8). Electrodes appear in black, grey or white depending on frequency of activation across repetitions, i.e., 80–100% (black), 40–80% (grey) and less than 40% (white).

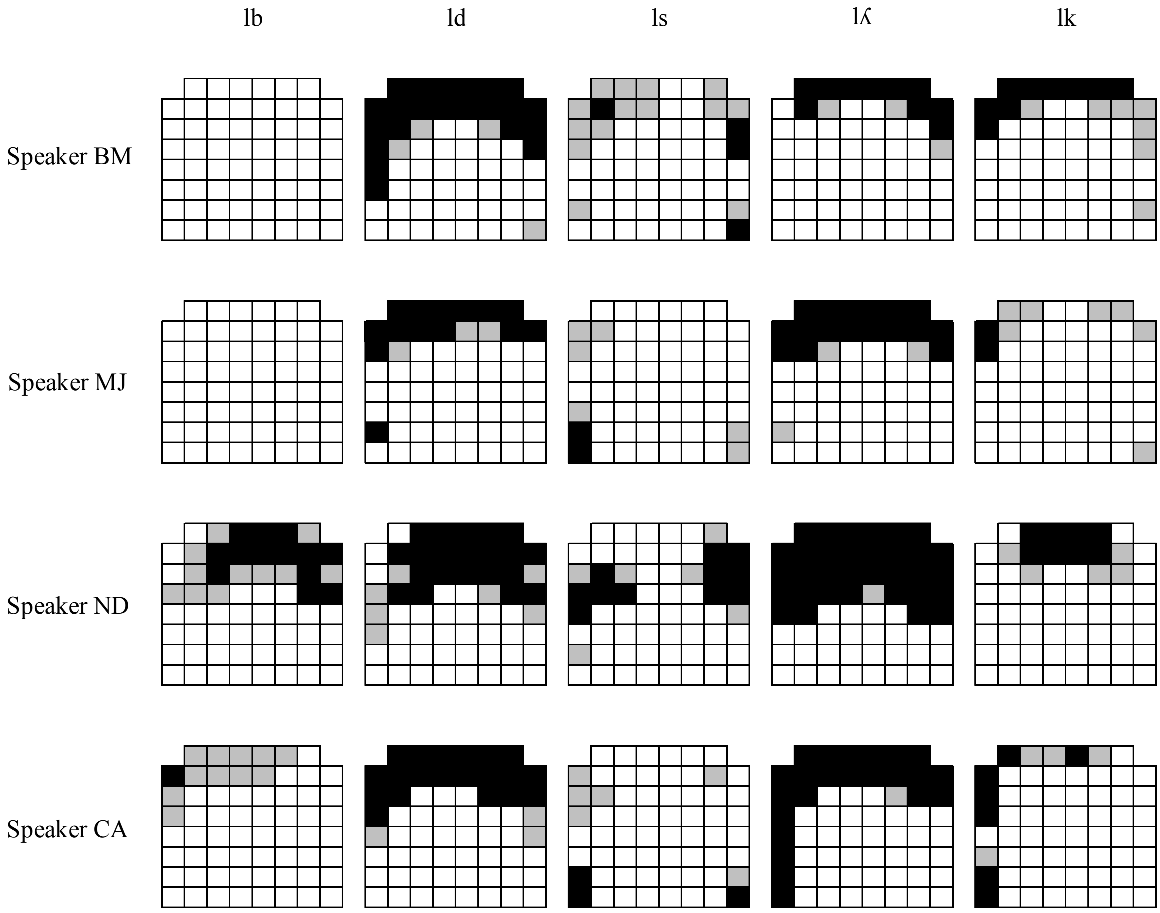

Figure 1. Average linguopalatal contact configurations sampled at /l/ closure midpoint in the sequences /lb, ld, ls, lʎ, lk/. Data belong to the Majorcan speakers BM, MJ, ND and CA. See text for details.

These data are consistent with the prediction that the change /l/ > /w/ should be based on articulation. Indeed, vocalization is most prone to operate in positions and contexts favoring undershoot, i.e., syllable finally where consonants become especially reduced through a decrease in dorsopalatal contact (Giles & Moll 1975; Sproat & Fujimura 1993; Recasens 2004), and also next to phonetic segments involving no tongue front raising.

1.2.2 Acoustic equivalence hypothesis

According to an alternative hypothesis, the vocalization of dark /l/ into /w/ is associated with the lateral and the glide sharing a grave spectral configuration with a low F2 frequency about 1000 Hz (von Essen 1964; Ohala 1981). Dark /l/ vocalization could also be triggered by the categorization of the vowel formant transitions as /w/ through the stages /Vl(C)/ > /Vwl(C)/ > /Vw(C)/. This perceptual categorization process accounts for the insertion of other glides before /l/ ([peə̯l, pee̯l, peɛ̯l] PILU in Occitan; Ronjat 1930: 134).

The acoustic equivalence hypothesis predicts that the vocalization of dark /l/ is prone to apply in positional and contextual conditions causing the consonant to undergo considerable predorsum lowering and postdorsum backing and F2 lowering, namely, syllable finally after back vowels and before labials, velars, dentals or /s/ (Dart 1991; Recasens 2004). Indeed, strongly dark /l/ in Majorcan Catalan, and to a large extent moderately dark /l/ in Eastern Catalan, have been found to exhibit a minimal degree of dorsopalatal contact before labials, and F2 frequency values that vary with the following consonant in the progression alveolopalatals (1100 Hz) > velars, alveolars > dentals, labials (850-900 Hz) (Recasens 1986; 1996; 2009).

1.2.3 The two hypothesis compared

In the light of the articulatory and acoustic data just referred to, the vocalization of syllable-final dark /l/ after back vowels and before labials and velars may be accounted for by both articulation-based and acoustic-based hypotheses. Only the acoustic-based hypothesis predicts, however, that the sound change of interest may also apply before /t, d/ where /l/ is articulated with a full dentoalveolar closure while exhibiting a considerably low F2 frequency.

Specific articulatory and acoustic characteristics render dark /l/ different from /w/ and, therefore, are at odds with the two testing hypotheses. Thus, F2 and, to a large extent, F3 are lower for /w/ than for dark /l/, as revealed by American English data for both consonants in word initial position across vowel contexts (/w/: 305 Hz, 630 Hz and 2180 Hz; /l/: 295 Hz, 950 Hz and 2610 Hz) and in word final position after low and mid back rounded vowels ([ʊ]: 410/545 Hz, 740/870 Hz and 2330 Hz; /l/: 415/435 Hz, 870/905 Hz and 2225/2435 Hz) (Lehiste 1964). This spectral difference is related to more lip rounding and a narrower dorsovelar constriction for the glide than for the lateral. Moreover, the formant transitions exhibit a faster rate of change for dark /l/ than for /w/, and only the lateral shows spectral zeroes associated with the branching cavity behind closure location (Fant 1960).

2 Method

A perception test with natural speech stimuli was designed in order to investigate whether the change of dark /l/ into /w/ is better accounted for on the basis of articulatory undershoot or of acoustic equivalence. The heterosyllabic clusters /lb, ld, ls, lk/ were recorded seven times by the four Majorcan Catalan speakers BM, MJ, ND and CA with an artificial palate in place. As stated in the Introduction, Majorcan Catalan /l/ is strongly dark and may exhibit alveolar contact loss. Those four clusters were produced after a central or a back vowel in the sentences *laca molt bona* ‘very good varnish’ (/olb/), *deu ser el dotzè* ‘it must be the twelfth’ (/əld/), *trec el suc últim* ‘he/she pulls out the last juice’ (/əls/) and *menja’t el cranc* ‘eat the crab’ (/əlk/). The rationale for selecting the second consonant in the /lC/ clusters of interest is as follows:

(a) /l/ vocalization before a labial consonant (/lb/) may be accounted for by both the articulation-based and the acoustic equivalence hypotheses since the lateral often exhibits alveolar contact loss and a low F2 in this context.

(b) The scenario for the clusters /ls, lk/ is similar to that for /lb/ though less extreme: /l/ before /s, k/ may undergo vocalization, and shows different degrees of closure undershoot and a relatively low F2.

(c) /l/ vocalization before /d/ should be associated with acoustic equivalence alone since the lateral is articulated with a full closure and its F2 frequency may be considerably low in this case.

Clusters with an alveolopalatal C2 were excluded from analysis since palatalized /l/ does not undergo vocalization, and lacks the appropriate articulatory and acoustic cues for being confused with /w/.

All sequences were sampled at 10 kHz. The articulatory and acoustic characteristics of /l/ were measured at closure midpoint, namely, halfway between the temporal frames showing activation and deactivation of one or more central electrodes at the alveolar place of articulation. The offset of /l/ generally coincided with the offset of a period of formant structure, and with the onset of closure for /b, d, k/ and of frication for /s/. The number of «on» electrodes at closure location was measured on the EPG contact patterns. F1, F2 and F3 frequency values were also obtained at closure midpoint using LPC with a 16 filter order and a 20 ms analysis window. Unsatisfactory LPC values were corrected by hand.

The perception stimuli were specified for two extreme articulatory and acoustic characteristics, i.e., maximal and minimal tongue contact at the place of articulation, and highest and lowest F2 frequency. F1 and F3 values were not subject to manipulation since they turned out to be much less variable than F2 values across contexts, speakers and tokens. For each /lC/ cluster, stimuli were classified according to the following EPG contact-F2 combinations:

low alveolar contact degree - high F2 (Lco-HF2),
high alveolar contact degree - low F2 (Hco-LF2),
low alveolar contact degree - low F2 (Lco-LoF2),
high alveolar contact degree - high F2 (Hco-HF2).

It was hypothesized that the change /l/ > /w/ would be based on articulation if triggered by the Lco-HF2 condition (a low alveolar contact degree favors vocalization while a high F2 frequency does not), and on acoustic equivalence if triggered by the Hco-LF2 condition (vocalization is favored by a low F2 but not by a high alveolar contact degree). The other two combinations Lco-LF2 and Hco-HF2 should provide no crucial information about whether vocalization depends on alveolar contact loss or on acoustic equivalence. This should be so since both articulatory and acoustic cues favor vocalization for the Lco-LF2 condition, while neither a high degree of alveolar contact nor a high F2 frequency favors vocalization in the case of the Hco-HF2 condition.

The acoustic and articulatory characteristics of the perception stimuli were determined as follows. Tokens exhibiting the highest and lowest F2 frequency values were selected for the high and low F2 conditions (HF2, LF2), and tokens showing the highest and lowest alveolar contact values at closure location were selected for the high and low contact conditions (Hco, Lco). The maximal contact condition (Hco) was taken to occur when contact activation amounted to 6 to 8 «on» electrodes at the alveolar zone, and the minimal contact condition (Lco) when tongue contact occurred on 3 alveolar electrodes or less.

The perception test included two tokens for each articulatory-acoustic combination and for each of the clusters /lb, ls, lk/. The cluster /ld/ contributed values to the Hco-LF2 and Hco-HF2 conditions only since /l/ is always articulated with a full closure before dentals. The number of tokens was 28, i.e., 24 tokens of /lb, ls, lk/ (2 tokens x 4 conditions x 3 clusters) and 4 tokens of /ld/ (2 tokens x 2 conditions x 1 cluster). They were sampled from productions by speakers MJ (10), BM (8), and ND and CA (5 each). Table 1 presents information about the number of «on» electrodes at the place of articulation and the F2 frequency values for all 28 tokens chosen for perceptual evaluation. The number of «on» electrodes for the low contact condition was mostly 0 (7 times) but also 1 (3 times), 2 and 3 (once); F2 ranged between 650 Hz and 930 Hz for the low frequency condition and between 825 Hz and 1150 Hz for the high frequency condition.

Cluster	Speaker	Tongue contact: Condition	Tongue contact: Number of «on» electrodes	F2: Condition	F2: Frequency values in Hz
lb	BM	low	0	low	657
	MJ		0		666
	CA	low	1	high	882
	BM		0		824
	ND	high	8	low	755
	ND		8		762
	CA	high	8	high	898
	ND		7		827
ls	MJ	low	0	low	828
	MJ		0		875
	CA	low	0	high	1144
	CA		0		1070
	ND	high	8	low	862
	BM		7		861
	BM	high	6	high	1048
	ND		6		1019
ld	MJ	high	8	low	642
	MJ		8		678
	BM	high	8	high	1168
	BM		8		1121
lk	MJ	low	1	low	920
	MJ		2		928
	MJ	low	1	high	1082
	MJ		3		1037
	MJ	high	8	low	799
	CA		8		879
	BM	high	8	high	1052
	BM		7		1047

Table 1. Articulatory and acoustic characteristics for /l/ in the /lC/ tokens selected as perception stimuli. See text for details.

The perception stimuli were excised from the corresponding original sentences and had a /VlCV/ structure. The reason for including four segments was twofold: shorter stimuli made up of two or three phonetic segments would have rendered /l/ hardly noticeable, while listeners could have guessed the meaning of the excerpts presented for identification had they been more than four segments long (e.g., [olˈbɔ] cannot be identified with any meaningful word in Catalan but [molˈbɔ] means ‘very good’ in this language). We made sure that the stimuli presented for perceptual identification did not contain any traces of the phonetic segments preceding V1 and following V2 or any disrupting shirps.

In order not to bias listeners against the /w/ identification responses, we added one token of the four sequences /VwbV/, /VwdV/, /VwsV/ and /VwkV/ to the /l/ perception stimuli. The /w/ stimuli were built up by replacing /l/ from the clusters /lb, ld, ls, lk/ by /w/ excerpts excised from the meaningful sentences *té mal al peu* ‘his/her foot aches’ (/ɛw/), *beu-te la tassa* ‘drink what’s in the cup’ (/ɛwt/) and *deu ser el dotzè* ‘it must be the twelfth’ (/ɛws/).

All stimuli were normalized for intensity. For each selected token, we calculated the V2 energy maximum using a 10 ms window energy contour encompassing the entire /VlCV/ sequence. The ratio between the mean energy value averaged across vowels and tokens and the energy value for each stimulus was multiplied by the energy value for each stimulus. This procedure ensured that the intensity level was raised for those stimuli which were too silent and was lowered for those which were too loud, while leaving unmodified the inherent amplitude differences between consecutive portions of each stimulus. All tokens were lengthened 1.5 times in order to make sure that listeners could hear the alveolar lateral. The duration of /l/ across C2 conditions and speakers ranged between 52 ms and 75 ms for the original stimuli and between 78 ms and 112.5 ms for the lengthened stimuli.

The perception test consisted of 144 randomized stimuli, i.e., 112 /lC/ stimuli (28 original tokens x 4 times) and 32 /wC/ stimuli (4 original tokens x 8 times). 17 informants were asked to identify the stimuli as /l/ or /w/ by writting «L» or «U» on an answer sheet.

The number of /w/ identification responses was submitted to two-way ANOVAs with ‘condition’ (‘Lco-LF2’, ‘Lco-HF2’, ‘Hco-LF2’ and ‘Hco-HF2’) and ‘context’ (‘lb’, ‘ld’, ‘ls’, ‘lk’) as factors. The dependent variable ranged from 0 to 8 where 8 was the maximal number of /w/ identification responses for each cluster and testing condition. Pairwise Bonferroni post-hoc tests were run on the significant main effects. Significant interactions were explored by means of one-way ANOVAs performed on all levels of one factor while keeping each level of the other factor constant. The level of significance was $p < 0.05$.

3 Results

In order to find out whether formant values were associated with the degree of alveolar contact, F2, F1 and F2-F1 frequency values were correlated with the number of «on» electrodes at alveolar closure location for all tokens of /lb, ls, lk/ selected for perceptual analysis (data for /ld/ were excluded since, as indicated in the Method section, a complete closure is always present in this case). Correlation analyses yielded low *r* values about 0.2 or less, thus indicating that degree of alveolar contact proceeds independently of darkness degree.

Results for the perception tests are given next.

(a) The percentage of /w/ identification responses for the /wC/ sequences was lower than expected, i.e., about 60% across subjects and 70% for the best subjects (11). It may be that the glide was confused with /l/ to some extent due to the procedure which was used for the preparation of the /w/ stimuli (see Method section).

(b) As for the /lC/ stimuli responses, statistical results yielded a main effect of ‘condition’ ($F(3,224) = 7.916$, $p = 0.000$). According to the post-hoc tests, this main effect turned out to be associated with a significantly higher number of /w/ identification reponses for the Lco-LF2 condition than for the other three conditions. Mean identification scores across /lC/ clusters presented in Figure 2 reveal indeed the presence of higher /w/ identification percentages for the former condition (30%) than for the three latter ones (10-15%).

There also was a main effect of ‘context’ ($F(3,224) = 6.372$, $p = 0.000$) which was associated with a higher number of /w/ identification responses for the cluster /lb/ than for the cluster /ld/. According to Figure 2, the percentage of /w/ identification responses decreases with the cluster taken into consideration in the progression /lb/ (24%) > /ls, lk/ (13-16%) > /ld/ (about 3%). Identification percentages are thus highest for /lb/ and lowest for /ld/, those for /ls, lk/ falling in between.

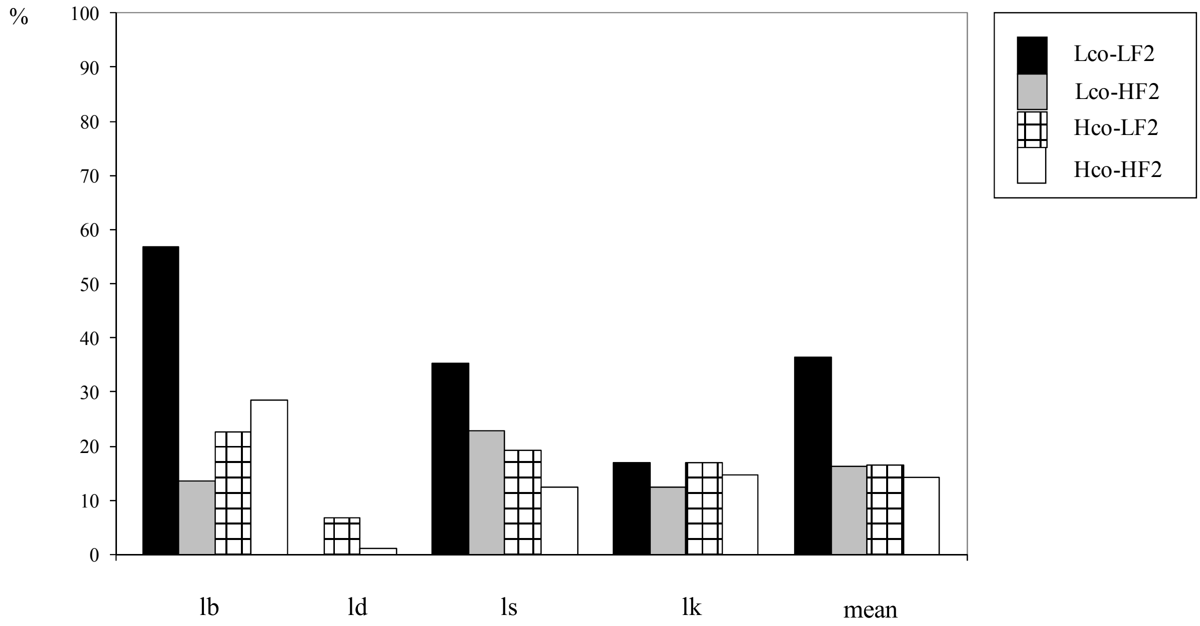

Figure 2. /w/ identification percentages for the /lC/ stimuli plotted as a function of cluster and EPG contact - F2 condition. Mean percentages across clusters are also given.

Statistical results also yielded a significant ‘condition’ x ‘context’ interaction ($F(7,224) = 2.367$, $p = 0.024$) which turned out to be associated with more /w/ identification responses for the Lco-LF2 condition than for the other three conditions in the case of the cluster /lb/ only. As shown in Figure 2, both for /lb/ and /ls/, the vocalization percentages are highest for the Lco-LF2 condition and not consistently different among the Lco-HF2, Hco-LF2 and Hco-HF2 conditions (i.e., for the three latter EPG contact - F2 frequency conditions, the number of /w/ identification responses decreases in the progression Hco-HF2, Hco-LF2 > Lco-HF2 for /lb/ and in the reverse progression for /ls/). The percentage of /w/ identification responses for the clusters /lk/ and /ld/ does not seem to be associated with any specific EPG contact-F2 combination.

Figure 3 (left) presents the /w/ identification percentages for subject groups reporting maximal, intermediate and minimal /w/ elicitations. A comparison among all three graphs indicates a similar behavior for all three subject groups, with the Lco-LF2 condition performing better than the other EPG contact-F2 conditions in the case of clusters /lb/ and /ls/, and with cluster /lb/ yielding the highest number of /w/ identification responses and cluster /ld/ the lowest.

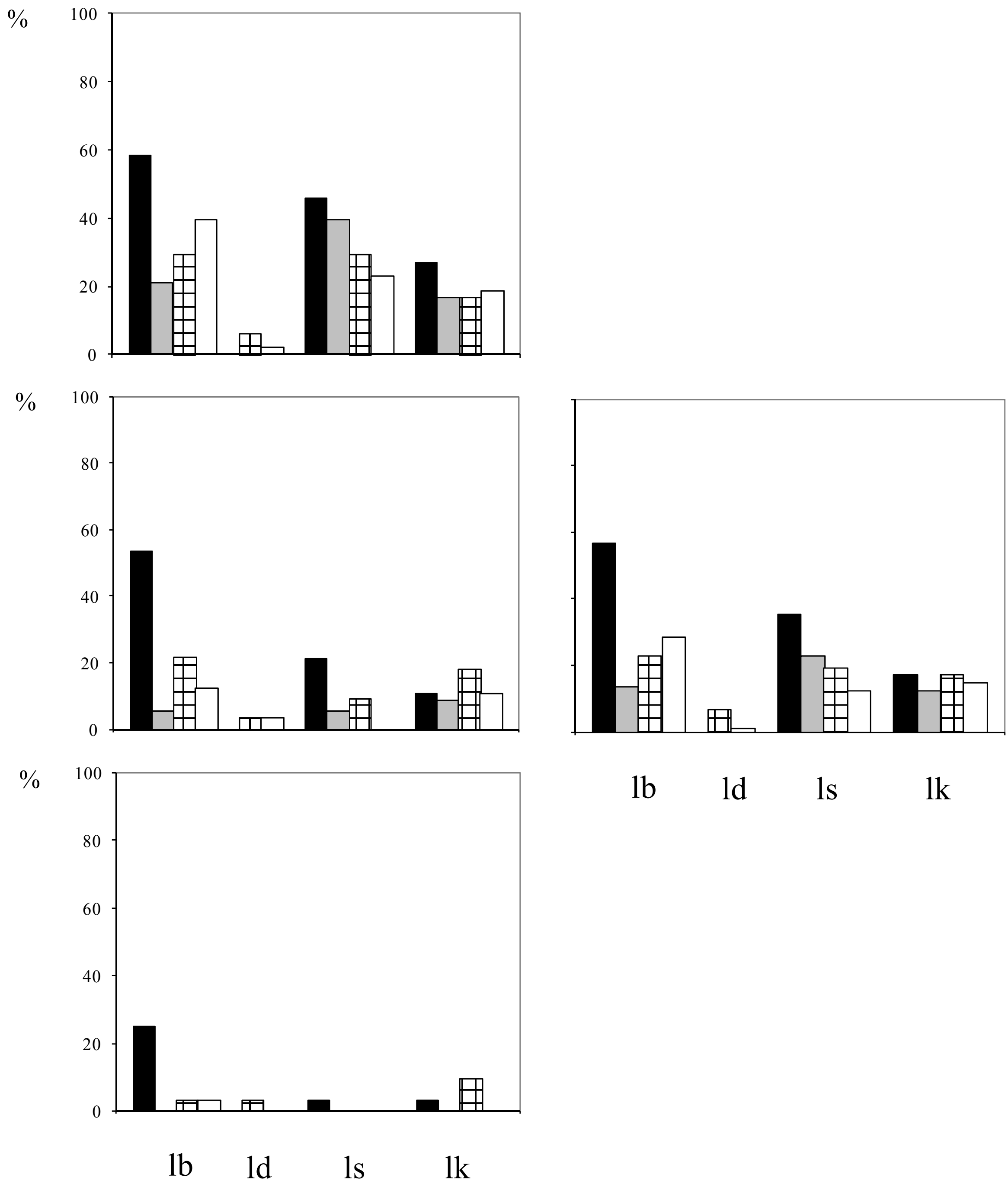

Figure 3. /w/ identification percentages for subject groups reporting a maximal (top left), an intermediate (middle left) and a minimal (bottom left) number of /w/ responses. Identification percentage ranges are 20-25%, 10-25% and 0-5%, respectively. Mean percentages across speakers are also shown for comparison (right). Different bar colours correspond to different EPG contact - F2 conditions (see Figure 2).

4 Summary and discussion

Identification responses for /lb/ and, less so, for /ls/ reveal that a low degree of tongue contact and a low F2 frequency are needed for dark /l/ to be heard as /w/, and thus appear not to be fully in support of either the articulation-based hypothesis or the acoustic equivalence hypothesis. These perceptual results are consistent with production data for dark /l/ in Majorcan

Catalan showing that alveolar contact loss occurs more frequently before labials than before velars and /s/, and that dorsopalatal contact and F2 frequency for the alveolar lateral are minimal before labials.

The fact that a lower F2 frequency for /lb/ than for /ls, ld, lk/ in the case of the other three EPG contact-F2 combinations did not result in a high number of /w/ identification responses also indicates that, while a low F2 appears to be needed for /l/ to be heard as /w/, the degree of tongue contact has to be also low for this to happen. Lower /w/ identification percentages for /ls, lk/ than for /lb/ appear to be also compatible with both the articulation-based and acoustic equivalence hypotheses since alveolar contact loss occurs less frequently before the two former consonants than before the latter and F2 for /l/ turns out to be higher before /s, k/ than before /b/.

Results for /ld/ appear to be more in support of the articulation-based hypothesis than of the acoustic equivalence hypothesis. Indeed, a minimal number of /w/ identification responses for this cluster is consistent with the presence of a complete closure (no instances of partial or complete undershoot were found to occur for /ld/) irrespective of whether F2 is lower or higher.

It may be that our perceptual results were partially affected by the experimental design. The reason why the number of /w/ identification responses was highest for the Lco-LF2 condition when the consonant following /l/ was /b/ may be due to the fact that the vowel preceding /lb/ was not a schwa but the darker back rounded vowel /o/. Other findings suggest, however, that the experimental design did not have any consequences on the identification results. Thus, the number of /w/ identification responses for the Lco-LF2 condition was also relatively high in the case of the cluster /ls/, where /l/ was preceded by schwa, and low in the case of the cluster /ld/, where /l/ was preceded by schwa and exhibited a very low F2 frequency, about 650 Hz. Moreover, lower F2 frequency values for /lb/ than for all other clusters in the case of the three other EPG contact – F2 frequency conditions did not result in a higher number of /w/ identification responses.

Perceptual identification results reported in this paper suggest that listeners pay attention to both articulatory and acoustic cues when decoding the acoustic signal, and indicate that articulatory and acoustic factors need to be subject to manipulation simultaneously in perception tests seeking to evaluate the causes of sound change. Future work on the subject will submit other phonetic cues which may cause dark /l/ to be identified as /w/ to perceptual evaluation (see Introduction) in better controlled contextual conditions.

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