Darkness in [l] as a scalar phonetic property: implications for phonology and articulatory control

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Abstract
Dorsopalatal contact and F2 data for speakers of dialectal groups with dark [l] (Majorcan Catalan, Eastern Catalan) and clear [l] (German, Catalan from the València region) provide some support for the hypothesis that degree of velarization or pharyngealization in the alveolar lateral consonant does not proceed categorically but gradually across dialects. Indeed, F2 frequency data for [l] in the context of [i] reveal that darkness does not distinguish the two dialectal groups but varies gradually from dialects with a very dark realization of [l] (Mallorqui) to those with a very clear realization (Valencià) through dialects exhibiting intermediate degrees of darkness (Eastern Catalan, German). A similar scenario applies to the [a] context. This finding questions the complex, two-gestural status of dark [l] and the notion that dark [l] should always be more coarticulation resistant than clear [l].

Keywords: Velarization, pharyngealization, Catalan, German, acoustic analysis, electropalatography, coarticulation.

Introduction

Categorical vs. gradual nature of the darkness scale
The main goal of the present paper is to investigate whether [l] darkness, namely, the phonetic property according to which the alveolar lateral may sound darker (and thus, more [u]-like) or clearer (and thus, more [i]-like), should be considered a categorical or a multivalued feature. In this study, the 'darkness' scale encompasses
both dark and clear realizations of [l] so that strongly dark variants are specified for a darkness maximum and very clear variants for a darkness minimum.

The possibility that darkness should be considered a categorical feature is in agreement with phonetic descriptions grouping languages and dialects depending on whether they exhibit a clear or a dark variety of [l]. Indeed, realizations of [l] have been characterized as clear in Spanish, Italian, French and German, and as dark in Portuguese and Catalan (at least syllable finally), in some allophones of English and in Russian (whenever hard, non-palatalized). Dark [l] has been set in contrast with clear [l] based on well defined articulatory and acoustic properties, namely, the formation of a post-dorsal velar or pharyngeal constriction and active pre-dorsum lowering causing F2 to lower and F1 to raise. Based on this tongue body configuration, dark [l] is commonly labelled velarized or pharyngealized. Moreover, it has been suggested that this [l] variety should be assigned the status of a complex segment involving two independently controlled lingual gestures, i.e. tongue tip raising and tongue post-dorsum retraction (Browman and Goldstein, 1995). The production of clear [l], on the other hand, involves the activation of the tongue tip only.

Possible evidence in favour of the categorical dichotomy between dark [l] and clear [l] and thus, of the hypothesis that speakers exert active control on two vs. one lingual regions during the production of these two varieties of the alveolar lateral, derives from data on V-to-C coarticulation in the sequence [ili]. This is so since the lingual configuration for [i] is antagonistic to that for dark [l], i.e. the tongue dorsum is raised and fronted for [i] and lowered and backed for dark [l]. Accordingly, electropalatographic data for different languages in the literature show considerably more tongue dorsum contact for clear [l] than for dark [l] (see, e.g. EPG data for Italian, Eastern Catalan and American English in Recasens and Farnetani, 1990). Moreover, correlation values between dorsopalatal contact area and F2 frequency, which are positively related according to the acoustic theory of speech production (Fant, 1960), allow drawing a clearcut division between German clear [l] and Eastern Catalan dark [l] in the sequence [ili] (Recasens, Fontdevila and Pallarés, 1995).

An important research topic is to test the validity of the alternative hypothesis, i.e. that darkness in [l] could turn out to be a scalar, non-categorical phonetic property. For that purpose we will attempt to find out whether differences in darkness degree occur not only between sound systems with a clear or a dark variety of [l] but also between languages or dialects exhibiting the same [l] type. If this happens to be the case, the obvious conclusion would be that degree of velarization or pharyngealization in [l] does not proceed categorically but gradually across dialects. Darkness should then be considered an articulatory and acoustic continuum proceeding from strongly dark varieties of [l] to very clear ones through realizations exhibiting intermediate degrees of velarization or pharyngealization. This issue is relevant as to whether phonological features in phonological theory should be formulated in binary or in multivalued terms (Ladefoged, 1971).

Recent experimental data speak in support of the gradualness hypothesis. On the one hand, the fact that the mean F2 for [l] in the sequence [ili] is found at 1680 Hz in the case of male speakers of German and above 1800 Hz in the case of male speakers of French, Italian and Spanish suggests that [l] is less clear in the former language than in the latter (Recasens et al., 1995; Recasens, 1987; Chafcouloff, 1972, 1985; Bladon and Carbonaro, 1978). On the other hand, the
finding that dark [I] in the same string [ili] has a higher mean F2 across male speakers of Eastern Catalan (1350 Hz) than across male speakers of American English (about 1000 Hz) indicates that [I] could be darker in the latter dialect vs. the former (Recasens et al., 1995; Lehiste, 1964, p. 40). It should be noted in this respect that differences in degree of darkness in [I] could also be associated with factors outside the consonant. Thus, as discussed in Recasens et al. (1995), the finding that clear [I] is more resistant to effects in tongue dorsum raising and fronting exerted by [i] in German than in other languages with a clear variety of [I] could be related to the fact that German opposes tense to lax vowels and is a stress-timed language.

F2 frequency data in the literature also reveal the existence of dialect-specific differences in darkness degree for [I] in the context of [a]. Generally speaking, those differences are smaller than the ones found in the context of [i] in agreement with the fact that the production of both [I] and [a] involves some tongue pre-dorsum lowering even if the alveolar lateral is clear. The reason for this articulatory characteristic appears to be that the passage of airflow through the sides of the oral cavity is easier to fulfil if the pre-dorsum is slightly lowered than if it occupies a high position. Moreover, analogously to the scenario for [ili], differences in darkness degree apply both to dialects with a dark variety of [I] and to dialects exhibiting a clear variety of the consonant. Thus, on the one hand, [I] could be somewhat darker in American English than in Eastern Catalan, i.e. mean F2 is 1065 Hz in the latter dialect and about 1000 Hz in the former (Recasens et al., 1995, Lehiste, 1964, p. 16). On the other hand, mean F2 proceeds from a relatively low frequency of 1215 Hz in Castilian Spanish to a relatively high frequency of 1500 Hz in Italian through intermediate frequency values such as 1340 Hz in Southern French, 1360 Hz in German and 1400 Hz in Argentinian Spanish (see references above). Acoustic differences between dialects with a clear variety of [I] appear to have an articulatory correspondence; indeed, X-ray data suggest that clear [I] may be produced with a lower pre-dorsum position in Castilian Spanish than in French, German or Italian (Navarro Tomás, 1917, 1972, p. 114; Delattre, 1965, p. 89).

In summary, articulatory and acoustic data for [I] in the adjacency of [i] and [a] reveal that the degree of darkness may vary across dialects exhibiting a dark variety of [I], i.e. mean F2 for the consonant in both vowel contexts appears to be relatively lower in American English than in Eastern Catalan. On the other hand, dialects with clear [I] may be divided into three groups, i.e. those showing a high F2 next to [i] and [a] (Italian, French), those exhibiting a high F2 next to [i] and a low F2 next to [a] (Castilian Spanish), and those showing a low F2 next to [i] and a high F2 next to [a] (German). This classification could be refined taking into consideration F1 and F3 which, in the case of [I], are positively related to tongue pre-dorsum lowering and to front cavity size, respectively (Fant, 1960).

**Testing the gradualness hypothesis**

In order to test the gradualness hypothesis, dorsopalatal contact and F2 frequency data for two Catalan dialects exhibiting a clear and a dark variety of [I] (i.e. Valencià and Mallorquí) will be subject to investigation in the present paper. These articulatory and acoustic data will be analysed in conjunction with those for clear [I] in German and for dark [I] in Eastern Catalan reported in previous publications.

Judging from the auditory impression of [I], Mallorquí should be grouped with American English rather than with Eastern Catalan. Indeed, the [I] of Mallorquí
appears to be strongly dark and has often turned to [w] syllable-finally before another consonant (Recasens, 1996, p.306, 315). On the other hand, the [l] of Valencià sounds similar to that of Castilian Spanish and may be articulated with a slightly lowered tongue pre-dorsum (Navarro Tomás and Sanchis Guarnier, 1934, p.135).

In the light of these observations, an analysis of dorsopalatal contact and F2 data for [l] will allow testing whether differences in darkness degree between clear [l] in German and Valencià and dark [l] in Mallorqui and Eastern Catalan are categorical or gradual. In the latter event, the degree of darkness for [l] is expected to vary in the progression Mallorquí > Eastern Catalan > German > Valencià in the context of [i] and in the progression Mallorquí > Eastern Catalan > Valencià > German in the context of [a].

Differences in darkness degree should be reflected mostly by differences in F2 frequency, and by differences in F2 and dorsopalatal contact area combined. Dorsopalatal contact area alone is a reliable measure of the contrast between clear [l] and dark [l] in the context of [i]. Thus, percentages of electrode activation at the palatal zone in the sequence [ili] are lower for dark [l] in Eastern Catalan (0.21%) than for clear [l] in German, Spanish and Italian (0.37%, 0.48% and 0.40%–0.50%, respectively; Recasens et al., 1995; Fernández, 2000; Recasens and Farnetani, 1990; Farnetani, 1990). However, the fact that [a] requires a low tongue body does not allow tracking fine differences in dorsopalatal contact for [l] next to this vowel by means of electropalatography. This would explain why percentages of electrode activation at the palatal zone for [l] in the sequence [ala] are very low and not reliably linked to differences in darkness, i.e. they amount to 0.03% in Eastern Catalan, 0.05% in German, 0.19% in Spanish and about 0.1% in Italian (see references above).

Coarticulation and darkness degree

Coarticulation data in the literature indicate that, in comparison to clear [l], dark [l] is more resistant to vowel coarticulation at the tongue dorsum (Recasens and Farnetani, 1990; Recasens, Fontdevila and Pallarès, 1996). This difference is mostly related to the context of [i], i.e. dark [l] blocks V-to-C effects from [i] to a larger extent than clear [l].

A goal of the present paper is to test whether, if darkness is a scalar feature, coarticulatory sensitivity also proceeds gradually from strongly clear [l] (which would allow large articulatory and acoustic differences between [ili] and [ala]) to strongly dark [l] (which would be largely insensitive to those vowel-dependent differences). Consonant types implemented through intermediate degrees of velarization are expected to exhibit moderate degrees of vowel coarticulation.

A measure of coarticulatory resistance (i.e. MCD) will be computed applying the formula \( \text{MCD} = \frac{(F2_{ili} - F2_{ala})}{2} \) (see Bladon and Al-Bamerni, 1976). Since [i] contributes much more than [a] to differences in darkness for [l], our expectation is that coarticulatory resistance should decrease in the progression Mallorquí > Eastern Catalan > German > Valencià.

Some support for the scalar nature of the darkness property derives from the fact that there is no one-to-one relationship between darkness and coarticulatory resistance. Thus, data in the literature indicates that, in spite of being clear, German [l] exhibits a low rather than a high MCD value (159.2) which resembles the MCD
value for dark [l] in Eastern Catalan (142.1) (Recasens et al., 1995). This piece of evidence suggests that coarticulatory resistance also proceeds gradually through realizations of [l] differing in darkness degree rather than categorically according to [l] type.

**Method**

Electropalatographic (EPG) and acoustic data were collected for [l] next to [i] and [a] in the symmetrical sequences [ili] and [ala]. Seven repetitions of meaningful Catalan words containing these sequences were uttered in short meaningful sentences by five speakers of Mallorqui (AR, BM, MJ, ND, CA) and by five speakers of Valencia (VB, JM, MS, VG, AV). Data for other sequences (i.e. [ulu], word initial [li], [la], [lu], word final [il], [al], [ul]) were also recorded but will not be reported in this paper.

Linguopalatal contact configurations were gathered with the Reading EPG-3 system every 10 ms using artificial palates equipped with 62 electrodes (Hardcastle, Jones, Knight, Trudgeon and Calder, 1989). Acoustic data were digitized at 10 kHz, filtered at 4.8 kHz, and processed with the Kay Computerized Speech Lab analysis system using the same temporal resolution as the EPG data.

Closure onset and offset were determined by the presence of full activation at two or more electrodes placed at the central columns of the artificial palate. Whenever closure was not available (for speaker AR and occasionally for speaker CA), the onset and offset of [l] was determined from inspection of spectrographic displays and identified with the formant transition endpoints for the two adjacent vowels. Linguopalatal contact data for [l] were analysed at a single frame, i.e. at PMC (point of maximum constriction) or frame showing the highest number of on-electrodes over the entire palate surface. Whenever a linguopalatal contact maximum lasted for more than one frame, PMC was taken to occur at the medial frame or at the first of two consecutive frames depending on whether the number of frames exhibiting a maximum contact degree was 3, 5... or 2, 4..., respectively.

As shown by the EPG contact configurations in figure 1, electrodes are arranged in eight rows and in four columns on each half of the artificial palate. In each linguopalatal contact representation, the frontmost row 1 (just behind the upper teeth) is displayed at the top and the backmost row 8 (just in front of the soft palate) at the bottom. The palate surface has been subdivided into four articulatory zones for data interpretation, i.e. front alveolar (rows 1, 2), postalveolar (rows 3, 4), prepalatal (rows 5, 6), mediopalatal (7) and postpalatal (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).

Dorsopalatal contact size was computed using the Qp index (quotient of overall electrode activation at the palatal zone). The values of this index were obtained by averaging all contacted electrodes at rows 5, 6, 7 and 8 by the total amount of 32 electrodes. F2 was measured on spectrographic displays with the help of LPC spectral displays.

Correlation analyses between Qp and F2 were carried out on data for all repetitions of the sequence [ili] according to the five speakers of Mallorqui and Valencià referred to above, and on mean data across repetitions of [ili] from those speakers, four speakers of German and five speakers of Eastern Catalan (i.e. HT,
Figure 1. Mean linguopalatal contact patterns for /l/ across repetitions of the sequence [ili] in dialects with dark /l/ (Mallorquí, Eastern Catalan) and in those with clear /l/ (German, Valencian). Data are given for five speakers of Mallorquí, Eastern Catalan and Valencian, and for four speakers of German. Electrodes have been represented in black (80–100% activation), grey (40–80% activation) and white (less than 40% activation).
Results

Articulatory and acoustic values

Inspection of the linguopalatal contact configurations displayed in figure 1 reveals the presence of less dorsopalatal contact at the four back rows for speakers of the two dialects with dark [I] (Mallorqui, Eastern Catalan) than for those of the two dialects with clear [I] (German, Valencià). Indeed, mean Qp values across speakers for [ili] in table 1 are 0.18 and 0.21 for dark [I] and 0.37 and 0.44 for clear [I]. Qp values in the table and EPG configurations in the figure show that individual speakers of a given dialectal group could belong to another group, e.g. the (low) Qp value for the German speaker BP is more appropriate for dark [I] than for clear [I], the (low) Qp value for the Eastern Catalan speaker DR could belong to the Mallorqui group for the same reason, and the (high) Qp value for speaker AR could be assigned to Eastern Catalan rather than to Mallorqui.

Table 1. Qp and F2 values for [I] in the sequences [ili] and [ala] for all speakers of Mallorqui (5), Eastern Catalan (5), German (4) and Valencià (5). Mean and standard deviation values across speakers are also given

<table>
<thead>
<tr>
<th></th>
<th>[ili]</th>
<th></th>
<th>[ala]</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Qp</td>
<td>F2</td>
<td>Qp</td>
<td>F2</td>
</tr>
<tr>
<td><strong>Mallorqui</strong></td>
<td></td>
<td></td>
<td><strong>E.Catalan</strong></td>
<td></td>
</tr>
<tr>
<td>Speaker AR</td>
<td>0.362</td>
<td>1397</td>
<td>0.067</td>
<td>1177</td>
</tr>
<tr>
<td>Speaker BM</td>
<td>0.214</td>
<td>1351</td>
<td>0.036</td>
<td>1143</td>
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<tr>
<td>Speaker MJ</td>
<td>0.071</td>
<td>1023</td>
<td>0.000</td>
<td>1017</td>
</tr>
<tr>
<td>Speaker ND</td>
<td>0.156</td>
<td>1220</td>
<td>0.036</td>
<td>1026</td>
</tr>
<tr>
<td>Speaker CA</td>
<td>0.103</td>
<td>1151</td>
<td>0.018</td>
<td>1057</td>
</tr>
<tr>
<td>Mean</td>
<td><strong>0.181</strong></td>
<td><strong>1228.6</strong></td>
<td><strong>0.031</strong></td>
<td><strong>1084.0</strong></td>
</tr>
<tr>
<td>SD</td>
<td>0.115</td>
<td>151.5</td>
<td>0.025</td>
<td>72.0</td>
</tr>
<tr>
<td><strong>German</strong></td>
<td></td>
<td></td>
<td><strong>Valencià</strong></td>
<td></td>
</tr>
<tr>
<td>Speaker HT</td>
<td>0.469</td>
<td>1914</td>
<td>0.000</td>
<td>1615</td>
</tr>
<tr>
<td>Speaker PJ</td>
<td>0.513</td>
<td>1795</td>
<td>0.131</td>
<td>1246</td>
</tr>
<tr>
<td>Speaker BP</td>
<td>0.194</td>
<td>1448</td>
<td>0.044</td>
<td>1138</td>
</tr>
<tr>
<td>Speaker MV</td>
<td>0.300</td>
<td>1568</td>
<td>0.000</td>
<td>1453</td>
</tr>
<tr>
<td>Mean</td>
<td><strong>0.369</strong></td>
<td><strong>1681.1</strong></td>
<td><strong>0.044</strong></td>
<td><strong>1362.7</strong></td>
</tr>
<tr>
<td>SD</td>
<td>0.148</td>
<td>211.9</td>
<td>0.062</td>
<td>212.9</td>
</tr>
<tr>
<td><strong>Valencià</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speaker VB</td>
<td>0.542</td>
<td>2163</td>
<td>0.134</td>
<td>1120</td>
</tr>
<tr>
<td>Speaker JM</td>
<td>0.384</td>
<td>1566</td>
<td>0.040</td>
<td>1317</td>
</tr>
<tr>
<td>Speaker MS</td>
<td>0.299</td>
<td>1969</td>
<td>0.004</td>
<td>983</td>
</tr>
<tr>
<td>Speaker VG</td>
<td>0.460</td>
<td>2223</td>
<td>0.031</td>
<td>1354</td>
</tr>
<tr>
<td>Speaker AV</td>
<td>0.504</td>
<td>1989</td>
<td>0.080</td>
<td>1051</td>
</tr>
<tr>
<td>Mean</td>
<td><strong>0.438</strong></td>
<td><strong>1981.8</strong></td>
<td><strong>0.058</strong></td>
<td><strong>1165.1</strong></td>
</tr>
<tr>
<td>SD</td>
<td>0.097</td>
<td>257.1</td>
<td>0.050</td>
<td>163.6</td>
</tr>
</tbody>
</table>
Mean F2 values for [ili] in the table are clearly higher for the two linguistic systems with clear [l] (1681 Hz and 1982 Hz) than for those with dark [l] (1229 Hz and 1349 Hz). The two [l] types are clearly split by a dividing line occurring about 1450 Hz and there is practically no overlap between them.

Interestingly enough, there appears to be a gradual decrease in Qp and F2 in the progression Valencia > German > Eastern Catalan > Mallorqui, as predicted. Moreover, while ANOVAs yielded a highly significant dialect-dependent difference between the Qp and F2 data for Mallorqui and Valencia (F(1,68)=62.43, p<0.000; F(1,68)=147.86, p<0.000), that was so for F2 but not for Qp when the groups subject to statistical analysis were Eastern Catalan and German (see Recasens et al., 1995).

Dialect-dependent differences for [ala] (see table I) are smaller than those for [ili] for reasons pointed out in the Introduction section. There also appears to be a relationship between the Qp and F2 values and the degree of darkness for [l] such that dialects with dark [l] show a lower Qp and F2 than those with a clear variety of the consonant. The dividing line between those two dialectal groups appears to be 0.04 for Qp (range 0.03–0.06) and 1100 Hz for F2 (range 1065–1363 Hz). In agreement with our initial hypothesis, F2 values in this vowel context condition vary in the progression German > Valencia > Mallorqui, Eastern Catalan.

MCD for the four dialects under analysis yielded the lowest value for Mallorqui (MCD = 72.3) and the highest value for Valencia (MCD = 408.4). Dialects exhibiting intermediate degrees of velarization show intermediate MCD values, i.e. 142.1 for Eastern Catalan and 159.2 for German. Moreover, given that both values are relatively low, they are more appropriate for dark [l] than for clear [l] (see also Introduction section).

Articulatory-acoustic correlations

Articulatory-acoustic correlations between the Qp and F2 data for [l] in the adjacency of [i] in Mallorqui and Valencia yield an r value of 0.7202. Figure 2 (top left graph) plots F2 data as a function of Q data for all repetitions of [ili] according to all speakers. This graph indicates a separate distribution between the datapoints for dark [l] in Mallorqui and those for clear [l] in Valencia. Moreover, while the articulatory and acoustic dimensions are highly correlated, F2 contributes more than Qp to the differentiation of the two dialectal groups.

The top right graph of Figure 2 plots Qp and F2 values for [l] in Mallorqui, Eastern Catalan, German and Valencia (means across repetitions for the individual speakers). Correlation values in this case are slightly higher than those for Mallorqui and Valencia alone, i.e. r=7603. In the graph, the F2 data allow grouping the four dialectal units according to darkness degree in the expected progression Mallorqui > Eastern Catalan > German > Valencia. This F2 data distribution may be taken in support of the notion that substantial differences in darkness degree may be available for realizations of dark [l] as well as for realizations of clear [l]. Differently from the F2 data, the Qp data do not allow grouping the four dialectal units coherently.

Correlation values between Qp and F2 for [ala] are very low (below 0.1), both in Mallorqui and Valencia, and in Mallorqui, Eastern Catalan, German and Valencia. Indeed, the two bottom graphs in figure 2 show that an increase in Qp does not cause F2 to rise.
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Figure 2. F2 frequency values (ordinate axis) against Qp values (abscissa axis) for [l] in the sequences [ili] (top) and [ala] (bottom). Data on the left graphs correspond to Mallorquí and Valencià (for all speakers and repetitions) and those on the right graphs to Mallorquí, Eastern Catalan, German and Valencià (across repetitions for all speakers).

Discussion

Experimental evidence reported in the present paper is in support of the notion that darkness degree in [l] should be viewed as a continuum since dialects with dark [l] (American English, Eastern Catalan) and those with clear [l] (German, Spanish, French, Italian) may show different degrees of this phonetic property. If we take the F3 frequency in the [i] context as reference, dark [l] happens to be strongly dark in Mallorquí and American English and less dark in Eastern Catalan, and clear [l] is clearer in Valencià and Spanish than in German. As expected, F2 values for realizations of [l] in the context of [a] are similar in Mallorquí and American English, and lower in Valencià than in German, Spanish and French.

Another relevant finding is that dark [l] is more coarticulation resistant than clear [l] when extreme realizations of both [l] types in Mallorquí and Valencià are taken into account. However, in spite of exhibiting very different F2 values in the two vowel contexts, dark [l] in Eastern Catalan and clear [l] in German show comparable MCD values and thus, analogous intermediate degrees of vowel coarticulation. This is so since, in comparison to Valencià, F2 values for German are lower in the case of [ili] and higher in the case of [ala].

While rendering a binary feature approach inadequate, results reported in the present investigation also question the validity of the complex, two-gestural status of dark [l]. It should be noted that the presence vs. absence of active tongue dorsum
control in forming a secondary constriction at the velar zone or at the pharynx should yield very different Qp and F2 values for the alveolar lateral in the sequence [ili]. Data reported in this study are only partly in support of this expectation. Moreover, a good deal of overlap between both [I] types is also available for the Qp and F2 values for the alveolar lateral next to [a]. In view of these findings, we would like to suggest that the production of both dark [I] and clear [I] requires a single gesture while involving different degrees of pre-dorsum lowering and post-dorsum retraction. Front dorsum lowering may be associated with laterality both for clear [I] and for dark [I], and is clearly enhanced during the production of dark [I].

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