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CUE WEIGHTING IN THE PERCEPTION OF PHONEMIC AND ALLOPHONIC LATERALS ALONG THE DARKNESS CONTINUUM: EVIDENCE FROM GREEK AND ALBANIAN

I Introduction

The acoustic signal cues the sounds of spoken language in many ways. Thus, voicing in stop consonants is signalled chiefly by a combination of Voice Onset Time and Fundamental Frequency at voicing onset (Llanos *et al.*, 2013, among others), whereas human listeners distinguish vowels by their duration as well as by the spectral values of their steady-state part (e.g., Ylinen *et al.*, 2009). The weighting of such multiple cues during sound perception has been repeatedly shown to depend on the language or dialect of the listener, and changes in weighting can lead to a reorganisation of a language's sound system (Podlipský, 2009).

In the domain of liquid sounds, much research has been devoted to the differences in cues and weighting of cues between listeners of languages with two liquids (such as American English) and listeners of languages with one liquid (such as Japanese) (for example, Flege *et al.*, 1996). However, there is still a want for studies of more intricate liquid systems; in particular, we lack studies of the inner perceptual structure of laterals along the perceptual darkness-clearness continuum. In light of this gap, the aims of the study presented here are (1) to elucidate the role of secondary acoustic cues in the perception of the lateral darkness-clearness continuum, and (2) to examine the question of whether listeners of a language, such as Greek, which puts the darkness-clearness continuum of laterals to an allophonic use differ in their weighting of cues from listeners for whom dark and clear laterals are contrasting phonemes, as in Albanian.

Laterals are known to vary in perceptual quality along a continuum ranging from dark to clear (Lehiste, 1964; Bladon and Al-Bamerni, 1976; Recasens, 2004). Since the Ancient grammarians, a dark lateral is described as perceptually similar to back and/or low vowels, whereas a clear lateral is said to resemble palatal or front vowels more closely (Belardi, 1984b).[1] In our

[1] The first scholars to describe lateral quality with the same technical terms as vowel quality are Velius Longus (2nd c. CE) and Consentius (5th c. CE) (Allen 1970, Belardi 1984a, 1984b).

days, the difference between the second and the first formant (F2-F1 difference) at the lateral's midpoint or during a portion of the lateral's steady part around the lateral’s midpoint is frequently used as a measure to indicate a lateral’s degree of darkness (Müller, 2011; Recasens, Fontdevila, and Pallarès, 1995; Recasens and Farnetani, 1990), with the F2-F1 difference being inversely related to degree of darkness. This means that, whereas a low F2 and a higher F1 are characteristic of laterals at the dark end of the continuum, a high F2 and a lower F1 are found in laterals at the clear end.

In addition to the F2-F1 difference, a further cue to the lateral darkness-clearness continuum may be found in the timing of the onset of formant transitions from the steady state of the vowel to the steady state of the lateral, which result from vowel-lateral coarticulation. Dark laterals are known to exert coarticulatory effects on their preceding vowels which can result in vowel backing or even breaking and diphthongisation (Müller, 2011; Andrade, 1999; Lehiste, 1964). It is, however, as yet unclear whether the duration of formant transitions from the vowel into the lateral also serves as a cue to the perception of a lateral's degree of darkness, and if so, how this cue would be weighted with respect to the first cue, the F2-F1 difference described above.

The present study investigates two languages representative of different uses of the lateral darkness-clearness continuum: Albanian and Greek. As stated above, Albanian has a phonemic contrast between dark and clear laterals. Greek has lateral allophony: In this language, the degree of darkness of the lateral varies diatopically and therefore serves mainly as a dialectal marker. More specifically, dark laterals in Greek are characteristic of the Northern dialect group as well as of the dialectal variants of Western Crete, whereas the most remaining dialect regions, as well as the standard (Athenian) variety of Modern Greek, have clear laterals (Trudgill, 2003; Κοντοσόπουλος, 2006a; Loukina, 2010). Λέγγερης (2013, 495) notes that the dark lateral of Albanian and the lateral of the Northern Greek urban dialect of Thessaloniki in the low vowel context bear a perceptual resemblance.

Loukina (2010) measured lateral formants for 21 speakers from Athens, Karditsa (Thessaly), and Nicosia (Cyprus). For Albanian, we have formant measurements from a single male speaker from Tirana by Bothorel (1969-1970) (F2 only), and two male speakers from Tirana by Jubani-Bengu (2012). The mean values from these studies are given in Table 1. This table also presents mean values of clear and dark laterals averaged over 23 European languages and dialects (two male speakers per language or dialect) (Recasens, 2012) for the purpose of contextualisation.

language	mean F1	mean F2	mean F2-F1	reference
Greek (Athens) /l/[2]	479 Hz	1540 Hz	1061 Hz	Loukina (2010)
Greek (Karditsa) /l/	435 Hz	1506 Hz	1071 Hz	Loukina (2010)
Greek (Nicosia) /l/[3]	418 Hz	1461 Hz	1043 Hz	Loukina (2010)
Albanian (Tirana) /l/	354 Hz	1586 Hz	1232 Hz	Bothorel (1969-1970); Jubani-Bengu (2012)
Albanian (Tirana) /ɫ/	355 Hz	934 Hz	579 Hz	Bothorel (1969-1970); Jubani-Bengu (2012)
cross-linguistic /l/[4]	347 Hz[5]	1469 Hz	1122 Hz	Recasens (2012)
cross-linguistic /ɫ/	399 Hz	1038 Hz	639 Hz	Recasens (2012)

Table 1 Average formant values (F1, F2, and F2-F1 difference) for different accents of Greek, Albanian, and average values for 23 European languages or dialects.

II Experiment

A Stimuli

A set of disyllabic non-word stimuli containing an intervocalic lateral was created. They followed the form /Vlə/ where V was one of the five vowels /a, e, i, o, u/, thus yielding the non-words /alə, elə, ilə, olə, ulə/. These vowels were close in quality to the cardinal vowels with the same transcriptions. Stress was always on the first syllable. Non-words rather than real words were chosen because they allow for cross-linguistic accessibility to the experiment.

The non-words were embedded in a German carrier sentence (“Maria hat [non-word] gesagt.” (“Mary said [non-word].”) to allow for more natural prosody than would have resulted from a list reading. They were read by a trained phonetician, a female native speaker of German (the author) and recorded at a sampling rate of 44.1 kHz. The recording took place in a sound-proof chamber using high-quality equipment at the Institute of Phonetics and Speech Processing in

[2] Averaged over the three words «πολλά», «καλά», and «πόλη».
[3] Averaged over the two words «πολλά» and «καλά».
[4] Recasens (2012) studied male speakers of British English RP, Newcastle and Leeds English, American English, Danish, Dutch, German, Norwegian, Swedish, French, Alguerese, Majorcan, Valencian, and Eastern Catalan, Italian, Occitan, Portuguese, Romanian, Spanish, Russian, Czech, Finnish, and Hungarian. Dark laterals in these languages, if they occur, are part of lateral allophony.
[5] Averaged over /a/-contexts and /i/-contexts.

Munich. The non-words were then excised from the carrier sentence and processed for stimuli creation in Praat (version 5.3.51, Boersma and Weenink, 2013). The acoustic material from the carrier sentence was not used any further.
Stimuli were resynthesised up to a frequency of 3500 Hz; the original for each vowel condition of the region above 3500 Hz was then pasted onto the resynthesised part in order to obtain more natural sounding stimuli where the speaker's non-linguistically relevant idiosyncratic resonance characteristics were preserved.
The lateral in each stimulus was manipulated using Linear Predictive Coding (LPC)-resynthesis along the following two parameters: formant values (F1, F2, F3), and temporal onset of formant transitions into the lateral. Recasens (2012) provides F1, F2, and F3 values for dark and clear laterals averaged from male speakers from 23 different languages and dialects. Based on these empirical values, the average F1, F2, and F3 values for dark and clear laterals, respectively, were chosen to provide the values for step 2 ("dark") and step 4 ("clear") stimuli on the formant-based darkness continuum. The formant values for F1 and F2 for the remaining steps (step 1 ("very dark"), step 3 ("medium"), and step 5 ("very clear")) were calculated from these values. Likewise, F3 values for step 2 ("dark") and step 4 ("clear") were averaged from the F3 values provided by Recasens (2012) for dark and clear laterals, respectively, and values for the other three steps were calculated. Since these formant values proceed from values averaged over male speakers, all values were multiplied by a factor of 1.2 (Traunmüller, 1988) to obtain appropriate values for a female voice. The resulting formant values for all five steps on the formant-based darkness continuum can be found in Table 2. Formant values for the vowels are based on the mean values of the speaker's naturally produced vowels in the non-word recordings, except for schwa the values of which are based on Stevens' (1998) values for a typical male speaker's schwa multiplied by the factor of 1.2, as described above. Formant values for the vowels are presented in Table 3.

formant	step 1 – very dark	step 2 – dark	step 3 – medium	step 4 – clear	step 5 – very clear
F1	450 Hz	398 Hz	347 Hz	296 Hz	250 Hz
F2	972 Hz	1083 Hz	1202 Hz	1326 Hz	1466 Hz
F3	2956 Hz	3026 Hz	3098 Hz	3172 Hz	3248 Hz
F2-F1	522 Hz	685 Hz	855 Hz	1030 Hz	1216 Hz

Table 2 F1, F2, F3, and F2-F1difference values for stimuli on the formant-

based darkness scale (Cue 1).

formant	/a/	/e/	/i/	/o/	/u/	/ə/
F1	783 Hz	417 Hz	273 Hz	404 Hz	298 Hz	600 Hz
F2	1391 Hz	2426 Hz	2302 Hz	887 Hz	841 Hz	1800 Hz
F3	2707 Hz	3069 Hz	3290 Hz	2919 Hz	2547 Hz	3000 Hz

Table 3 F1, F2, and F3 values for the five stressed vowels and the unstressed schwa in the stimuli.

Transitions were linearly interpolated between the vowel-specific values of F1 to F3 given in Table 3 and the lateral-darkness specific values given in Table 2. On- and offset times were kept constant for the lateral-to-schwa transitions; while the offset of the stressed-vowel-to-lateral transition remained at the same point in time, transition onset time varied. Results obtained by Recasens and Farnetani (1994) indicate that the vowel-to-lateral onset transition starts approximately after the first third of the vowel in the case of a dark lateral and after two-thirds of the vowel for a clear lateral. Based on these findings, the transition durations presented in Table 4 were used as values in the transition duration-based darkness continuum.

	step 1 – very dark	step 2 – dark	step 3 – medium	step 4 – clear	step 5 – very clear
transition duration	135 ms	110 ms	85 ms	60 ms	35 ms

Table 4 Duration values for stimuli on the transition duration-based darkness scale (Cue2). Step interval = 25 ms.

All parameters not involved in the acoustic cues under investigation were held constant across all stimuli (see Table 5). The duration for the lateral was based on cross-linguistic observations of the lateral's duration in spontaneous speech (see Müller, 2011, 138-139, tables 16 and 17 for an overview). The pitch contour was based on the speaker's mean f0 values across the five vowel conditions; it falls from the beginning to the end of the utterance. The intensity value for the lateral is based on the observation that the (clear) lateral in the speaker's non-manipulated recordings of the stimuli had an intensity ratio to the vowel of 0.9.

	stressed vowel	lateral	unstressed schwa
B1	50 Hz	100 Hz	50 Hz
B2	100 Hz	200 Hz	100 Hz
B3	150 Hz	300 Hz	150 Hz
duration	170 ms	60 ms	100 ms

pitch	246 Hz–230 Hz	230 Hz–213 Hz	213 Hz–188 Hz
intensity	75 dB	67 dB	71 dB

Table 5 Bandwidths, duration, pitch, and intensity values in the /Vlə/ stimuli.

The manipulation procedure described yielded a total of 125 different stimuli (5 vowel conditions × 5 steps on the F2-F1 difference dimension × 5 steps on the transition duration dimension) (see Figure 1).

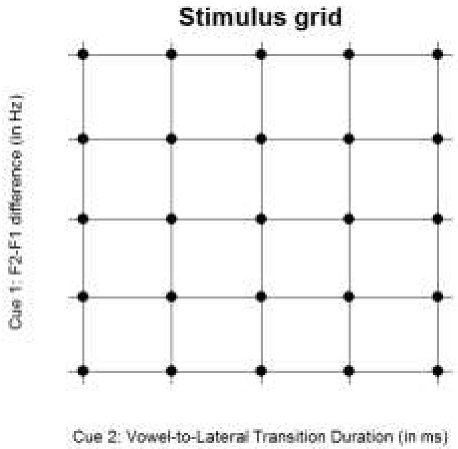


Figure 1 Stimulus grid. The lower left corner corresponds to the stimulus expected to be perceived as the darkest variant, while the upper right corner corresponds to the stimulus expected to be perceived as the clearest variant. Cue 1 values are shown on the y-axis (F2-F1) and Cue 2 values on the x-axis (V-to-L transition duration).

B Task

The stimuli were presented to subjects one by one in a web-based perception task using the Percy environment (Draxler, 2011). Upon listening to a stimulus, subjects had to rate the lateral's perceptual quality on a Visual Analog Scale (VAS) the endpoints of which were labelled "dark" and "clear", corresponding to a value of 100 and 0, respectively (left: "dark", right: "clear") for Greek listeners, and <ll> and <l> (left: "Vowel<lle>,"[6] right: "Vowel<le>") for Albanian listeners. After each trial, the pointer was automatically recentered at value = 50 on the Visual Analog Scale to avoid response bias. Participants could listen to each stimulus up to three times.[7] Note that the Visual Analog

[6] In the task directed at Albanian listeners, labels at the endpoints of the VAS differed according to vowel context; the endpoint stimuli were orthographically transcribed. Thus, for a stimulus /alə/, the end-points of the VAS would be labelled <alle> and <ale>, for a stimulus /elə/, <elle> and <ele>, and so on.

[7] Greek participants listened to the stimuli an average number of 1.4 times (standard deviation = 0.7 times), and Albanian participants an average number of 1.4 times (standard deviation = 0.6 times).

Scale allowed subjects to provide a gradual judgment rather than a categorical one. They proceeded at a self-paced rate through the experiment. The mean task completion time was just over 16 minutes, including a questionnaire on subject-specific variables. The demographic variables elicited before the task itself included gender, age, location of their primary school (city and country), mother tongue(s), language used most often in daily life, level of hearing ability, academic education, degree of education in phonetics, as well as several variables pertaining to the setting in which they took the experiment, especially the audio-device used to listen to the stimuli. After the task, subjects had the opportunity to indicate whether any stimuli corresponded to meaningful words in their language.

C Participants

Of the 103 Greek-speaking participants, 58 were excluded from the analysis for the following reasons: use of another language than Greek in daily life (n = 4), early bilingualism (n = 7), as well as prior phonetic training (n = 51). Of the remaining 41 participants, 40 had grown up in Greece, and 1 in Cyprus. There were 35 females and 6 males in this group. The mean age was 21 years (standard deviation = 4 years, range = 17–42 years). These listeners participated at a locale of their choice in Greece by using the web interface as described above. Several gift vouchers for an online-based department store were drawn in a raffle among the participants, regardless of whether their data was retained in the analysis.

77 Albanian listeners were recruited at a private university in Tirana. They were offered a small amount of money for their participation. 13 participants who grew up in a non-Albanian-speaking country were excluded from the dataset; out of the 64 participants who had grown up in Albania, a further 10 were removed because they reported using another language to a greater extent than Albanian in their daily life, and another 4 were excluded because they had received some training in phonetics in the course of their education. This means that a total of 50 participants were entered into the analysis of the Albanian listener group. The mean age of these participants was 24 years (standard deviation = 7 years, range = 18–52 years); 22 were female and 28 male.

All participants reported normal hearing abilities.

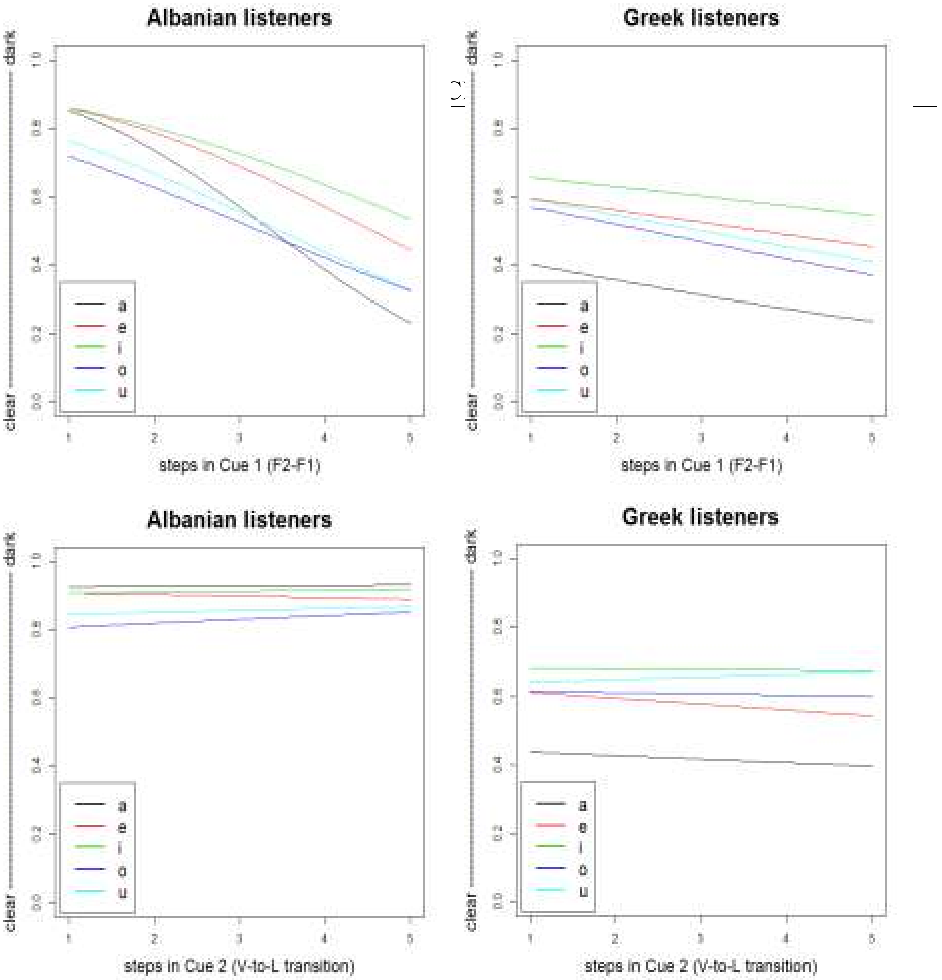
III ANALYSIS AND DISCUSSION

In order to compare allophonic and phonemic uses of the lateral darkness-clearness continuum, a Generalised Estimation Equation (GEE) model was fitted for each language group separately. Given the use of the Visual Analog Scale to record listeners' judgments, a quasi-binomial distribution was assumed. Fixed predictor variables were Cue 1 (F2-F1 difference) and Cue 2 (V-to-L transition duration), Vowel context (/a, e, i, o, u/), as well as two-way interactions between these variables. Listeners were treated as a random variable. The GEE model was chosen for its ability to control for the fact that multiple observations from the same subject are correlated. It fits a marginal model and does not need a full specification of the joint distribution; it models population averages. Furthermore, it has no likelihood function, but rather uses estimates of quasi-likelihood equations as parameter estimates.

Cue 1 (F2-F1 difference) had a highly significant effect on participants' VAS-ratings in both languages and in all vowel contexts. Albanian listeners made greater use of Cue 1 in the context of the vowel /a/ than in the other vowel contexts (/a/ vs. /e/: z= 4.71; /a/ vs. /i/: z= 5.49; /a/ vs. /o/: z= 5.38; /a/ vs. /u/: z= 4.12). The pattern of the vowel context's influence was more complicated in Greek: listeners' judgments in the /i/-context differed significantly from all other vowels contexts except the /e/-context (/i/ vs. /a/: z= -2.41; /i/ vs. /o/: z= -2.67; /i/ vs. /u/: z= -2.51). Their use of Cue 1 in the /e/-context, however, differed significantly from that in the /o/-context, but not the other vowel contexts (/e/ vs. /o/: z= -2.49); see Table 6 and Figure 2 (top panels) for details. The fact that listeners of Albanian and Greek alike show greatest percentages of change in the odds of judging a lateral as dark in the context of /a/ may be attributed to the formant values for Cue 1 being based originally on an /a/-vowel context.

	Cue 1 (formant values)		**Cue 2 (V-to-L transition duration)**	
	Albanian	Greek	Albanian	Greek
/a/	-52 % (z = **-9.79**)	-18 % (z = **-4.12**)	+2 % (z = 0.35)	-4 % (z = -0.95)
/e/	-40 % (z = **-6.32**)	-13 % (z = **-3.53**)	-5 % (z = -1.13)	-7 % (z =**- 2.04**)
/i/	-34 % (z = **-5.89**)	-11 % (z = **-2.53**)	+4 % (z = 0.58)	-1 % (z = -0.25)
/o/	-34 % (z = **-6.04**)	-18 % (z = **-4.06**)	+8 % (z = 1.77)	-2 % (z = -0.54)
/u/	-38 % (z = -**8.67**)	-17 % (z = **-3.86**)	+5 % (z = 1.01)	+3% (z = 1.10)

Table 6 Percentage of change in the odds to consider a lateral as dark for



every step increase in Cue 1, i. e. the distance between F2 and F1, or Cue 2, i. e. the duration of the formant transitions from the steady state of the vowel into the lateral, in all five vowel contexts. Z-scores associated with the estimates for the effect of Cue 1 and Cue 2 are given in parentheses; significant z-scores are in bold face.

Figure 2 Predicted response curves for Cue 1 (top) and Cue 2 (bottom) for Albanian-speaking listeners (left panels) and Greek-speaking listeners (right panel).

In contrast to Cue 1, the contribution of Cue 2 - the duration of the transition from the steady state of the preceding vowel into the lateral - to the perception of the darkness-clearness-continuum was overall smaller, reinforcing the hypothesis that this cue is secondary. The Albanian listeners did not seem to make use of Cue 2 in any vowel context: none of the sigmoid curves presented in Figure 2 (left bottom panel) is significantly different from the horizontal (zero percentage of change). In contrast to this, Greek listeners made significant use of Cue 2 in the /e/-vowel context; see Table 5 and Figure 2 (bottom panels) for details.

That the use of Cue 2 for Greek listeners is restricted to the /e/-context may be attributed to the fact that the magnitude of the formant transitions from the steady state of a front vowel such as /e/ into the lateral is greater than for transitions involving a back or low vowel, since the transitions are steeper in the former context, while they are shallower in the latter. This explanation, however, raises the question why the percentage of change for Cue 2 in the /i/-context differed from that of the /e/-context since both are front vowels. A reason for this difference may be sought in the fact that a lateral in an /i/-context is often palatalised in Greek, especially in the Northern variety, the language background for the majority of Greek participants, who were mostly students living in Thessaloniki; overall, the laterals in the /i/-context were perceived as darker than in the other vowel contexts, and the expectation of palatalisation was not fulfilled by the range of values presented for Cue 1. Greek listeners may thus have compensated for this circumstance by judging the laterals in the /i/-context as darker than in the remaining vowel contexts.

Given the results presented here, it is possible to establish the duration of the vowel-to-lateral formant transition as a possible secondary cue to the lateral darkness-clearness continuum besides the already well-studied variation in the formant values of the lateral's steady state (Cue 1 (F2-F1 difference) in the present experiment) (Stevens, 1998; Bladon, 1979; Chafcouloff, 1972), and this at least for languages such as Greek which have an allophonic use of the lateral darkness-clearness continuum. This is, to the author's best knowledge, the first time that the contribution of this secondary cue to the perception of the darkness-clearness-continuum in laterals has been examined.

IV CONCLUSIONS

The results demonstrate that not only listeners with a phonemic use of the darkness-clearness-continuum are able to distinguish degrees of darkness in laterals, but also, albeit to a minor degree, listeners of languages where the continuum is part of lateral allophony.

The results of the present study demonstrate that at least two acoustic cues serve to differentiate the darkness-clearness-continuum of laterals in perception. Of these two cues, it could be shown that one cue, the spectral information expressed as the difference between the second and the first formant of the lateral's steady state, was used as a primary cue for listeners of Albanian and Greek alike, while the other cue, the duration of the formant transitions from the preceding vowel into the lateral, was treated as a secondary cue. The differential use of these two cues was not, however, uniform across these two languages. Specifically, listeners of Greek, which do not use the lateral darkness-clearness-continuum contrastively, rely on the secondary cue to determine the degree of darkness-clearness of a given lateral, when the vocalic context is conducive to the perceptual saliency of that secondary cue. For Albanian listeners, on the other hand, who categorise the continuum into two phonemes, the secondary cue had no significant effect on their judgments. A cautious interpretation may suggest that the phonemicity of the lateral dark-clear distinction provides Albanian listeners with enough experience to efficiently identify any given lateral on the basis of the primary cue alone. More research into this area will help to clarify this question.

Finally, the existence of a secondary cue which contributes to the perceptual differentiation of the darkness-clearness-continuum in laterals raises the question whether further acoustic cues to this continuum exist. A possible third cue may be the lateral's duration. The relationship between a lateral's darkness degree and its duration was found to be uni-directional by Huffman (1997) and Van Hofwegen (2011), at least for American English. This means that laterals tend to be longer with increasing degree of darkness, but longer laterals are not necessarily darker. In the present experiment, lateral duration was held constant and thus ruled out as a cue potentially affecting listeners' judgments. A possible fourth cue may consist in the fundamental frequency of the lateral's steady state. While this parameter was also held constant in the present experiment, it is expected to vary according to the lateral's degree of darkness, in parallel with vowel intrinsic variation in fundamental frequency (Lehiste, 1970). Both additional cues should be the subject of future investigations into the perceptual make-up of the darkness-clearness-continuum of laterals.

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