PERCEPTUAL CONFUSION AMONG LATERALS AND RHOTICS IN MODERN GREEK

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ABSTRACT

Misperception or perceptual confusion has been proposed as one of the leading causes of sound change. The present study investigates its rôle in the cross-linguistically common sound changes of rhoticisation (lateral to rhotic) and lambdacisation (rhotic to lateral). To this end, allophonic variants of the phonemes /l/ and /r/ in non-words were presented to native Greek listeners in an identification task. Results suggest that duration, but not spectral quality, influences the confusion of /l/ with /r/: Shorter laterals are more readily heard as rhotics than longer laterals. Among the variants of /r/, the approximant rhotic was most often confused with /l/, whereas the trill was most resistant to misperception. This study underlines the importance of taking into account sub-phonemic variation in the investigation of sound changes involving the liquids /l/ and /r/.

Keywords: speech perception, rhotics, laterals, sound change, Greek

1. INTRODUCTION

Sound changes by which laterals become rhotics and rhotics become laterals have occurred in the historical development of a large number of languages, such as Modern Greek ([52]), Danish ([40]), Old Bearnés (Occitan) ([93]), Alguerese Catalan ([88]), Albanian ([57]), or Atikamek Cree ([59]). Table 1 shows examples from these and other languages.

Articulation-centred approaches to sound change have explained the rhoticisation of laterals, especially to the alveolar tap rhotic, as the result of articulatory weakening whereby the tongue tip fails to achieve a firm central closure ([80, 28, 84, 86, 85, 63]); conversely, lambdacisation of a rhotic alveolar tap is seen as an instance of strenghtening or stiffening of the tongue tip gesture ([85, 63]).

In the listener-oriented approach to sound change, on the other hand, misperception is proposed as the main mechanism behind rhoticisation and lambdacisation ([55, 56]): When two sounds belonging to contrasting categories bear nevertheless acoustic similarity, listeners may happen to be confused and fail to recover the category intended by the speaker. If such errors go unnoticed, the perceptual confusion might set the seed for long-term sound change. While it is unclear whether such articulatory changes are a consequence of, or a prerequisite for, sound change via perceptual hypocorrection or confusion ([55, 56]), these approaches do not account for the acoustic characteristics of those lateral and rhotic variants or allophones that enable perceptual confusion in the first place.

Which acoustic characteristics are thus likely to play a role in perceptual confusion between rhotics and laterals and subsequent sound change? A prominent cue to the distinction between a lateral and, for instance, the alveolar tap is the duration of the intensity reduction in the spectrum with respect to the intensity level of the surrounding vowels, caused by a movement of the tongue tip toward the alveolar ridge. In a perception experiment investigating the perceptual confusion of laterals and rhotics in Greek, Müller ([49]) found that if laterals were shortened to an extent that their duration was only slightly longer than that of the tongue tip constriction duration of an alveolar rhotic tap, they could be misheard as a rhotic (lateral rhoticisation). Likewise, Romero and Martín ([77]) obtained similar findings in a task involving a choice between an alveolar tap and an alveolar fricative: listeners perceived more taps the shorter the alveolar fricative was (sibilant rhoticisation). Conversely, in Müller's ([49]) study, an alveolar rhotic with lengthened tongue tip constriction duration (termed in the present investigation "approximant rhotic") had a tendency to be perceived as a lateral.

Such experimental findings coincide with observations from dialectal variation: In the Italian varieties of Lucca and Elba, as well as in the dialects of Southern Lazio and Campania including Naples, rhoticisation of a lateral occurs only in the last syllable of proparoxyton words, i.e. in a weak prosodic position where segmental shortening is expected ([45, 75, 74]).

The duration of intensity reduction in the spectrum, however, may not be the only cue to perceptual

Table 1: Confusion of laterals and rhotics cross-linguistically.

word form	etymon or variant form	English gloss	language	source
Holeby	*Horeby* (attested 1398)	place name	Danish	[40]
murmurôn	*murmulôn*	to murmur	Old High German	[58]
ręver	Middle Low German *rēvel*	narrow strip of land	Low German (Hamburg-Harburg variety)	[54]
ammel	New High German *Eimer*	bucket	Low German (Hamburg-Harburg variety)	[54]
peregrīnus	*pelegrīnus*	pilgrim	Late Latin	[80]
crauste	*claustrum*	cloister	Old Bearnés (Occitan)	[93]
countrâli	Latin *contrārium*	contrary	Occitan (Nontron, Dordogne variety)	[93]
coutrâle	Latin *contrārium*	contrary	French (Prouvy, Nord variety)	[93]
ˈɔɾi	Latin *oleum*	oil	Alguerese Catalan	[88]
ˈmɔlt	Latin *mortuum*	dead (masc.)	Alguerese Catalan	[88]
purpu	Latin *polypum*	octopus	Sicilian	[93]
montigru	Latin *monticulum*	hill	Sardinian (Logudorese variety)	[93]
dërgoj	Latin *dēlēgō*	to send	Albanian	[57]
kulshedër	Latin *chersydrum*	dragon with many heads	Albanian	[57]
kiːr	kiːlawa	thou	Atikamek Cree	[59]
lopa	*ropa*	two	Hidatsa (Siouan)	[30]
longwe	*rongwe*	he is a man	Mohawk (Iroquoian)	[30]

confusion among rhotics and laterals. A further potential cue for the rhoticisation of laterals is their degree of darkness. The darkness-clearness-continuum is commonly correlated with the distance between the second and the first formant in the lateral: A large distance between these two formants will cause listeners to perceive a clear lateral, whereas a small distance will be heard as dark ([50]: 21–23 for a literature overview).

In fact, dialectological observations from Romance varieties suggest that darker varieties of laterals are more prone to develop into an alveolar tap during sound change ([2, 45, 50] for Occitan, [92, 20] for Sardinian, [22, 34, 45] for Portuguese, [81] for Italian). For instance, Provençal-Alpin and Auvernhat varieties of Occitan, in which laterals rhoticised, are spoken next to varieties with dark laterals in all syllable positions, and a similar observation is made by Schürr ([81]) for Italian varieties. Moreover, when the laterals rhoticised in the Auvernhat varieties of Occitan between the 16th and 18th centuries, only the lateral stemming from the Latin singleton was affected, despite the fact that shortening of the Latin geminate lateral to a singleton had been completed by the 10th century. Apparently, however, the shortened former geminate lateral continued to maintain its clear quality, and the dialect seems to have continued the former quantity (singleton vs. geminate) contrast as a quality (dark vs. clear) contrast ([48, 87, 15, 50]). If this reconstruction is correct, only the dark lateral underwent rhoticisation, while the clear lateral was maintained as such. In Italian dialects, rhoticisation in preconsonantal position is often restricted to cases where a labial or a velar consonant follows, whereas /l/-vocalisation took place before alveolars ([34]), thus suggesting a dark quality of the lateral in preconsonantal position in these dialects. In the case of Portuguese, Brazilian Portuguese is well-known for having pervasive /l/-vocalisation in preconsonantal position, but the Caipira dialect of Brazilian Portuguese has rhoticisation instead ([22]). Similarly to these Romance dialects, a women's variety of Southern Kurdish shows rhoticisation only of the dark lateral, but not of the phonemically distinct clear lateral ([43]), and in Albanian, where dark and clear laterals also contrast phonemically, cases of sporadic rhoticisation of the dark lateral can be found in dialectal variation ([57]). Finally, the outcome of the lambdacisation of the preconsonantal rhotic (before alveolar voiced stops only, however) in the Sardinian varieties of the villages of Villanova Tulo and nearby Nurri is a dark lateral ([92, 20]).

Examples of clear laterals developing into a rhotic,

specifically into a rhotic tap, nevertheless exist and constitute potential counterexamples to the idea that dark laterals undergo rhoticisation more readily. The Catalan variety spoken in L'Alguer (Sardinia) has clear laterals ([69]) and also historical rhoticisation of laterals ([88]); in this case, however, it cannot be ruled out that the clear laterals of contemporary Alguerese are a recent development due to increased contact with Standard Italian, which has clear laterals. Further examples of rhoticisation of clear laterals are attested in loanwords of Standard Italian origin in French and in Italian dialects ([34, 45, 75]) as well as in loanwords of Standard French origin in Occitan dialects ([79, 78, 86, 15, 85]).

When discussing acoustic cues to the lateral-rhotic distinction, it is necessary to bear in mind that the sound class described as rhotics contains a large variety of sounds, and that it is impossible to speak of *the* rhotic. The present study focuses on the alveolar tap as the most representative rhotic sound in the languages used here to exemplify liquid confusion. This is why less consideration is given to a cue that has been shown to contribute to the lateral-rhotic distinction in English, namely, the third formant. In many English accents, the height of F3 distinguishes between a retroflex approximant rhotic, and a lateral, often a generally dark lateral (see, e.g., [60]). Given the tongue tip retroflexion present in the English approximant rhotic, it is unclear whether the lowering of F3 in the rhotic as opposed to the lateral is truly indicative of rhoticity in a more general sense – i.e., whether this cue is transferable to other rhotic types such as taps and trills – or whether this is simply the cue for retroflexivity, which is well-known to involve a lowering of F3 caused by the curling-back movement of the tongue tip and the concomitant widening of the sublingual cavity ([83, 82, 31]).

Since the majority of laterals are alveolar or dental-alveolar, with darker laterals having a more advanced place of articulation ([32, 84, 13, 14, 42, 27, 85, 71, 72, 16, 37, 73, 94, 70, 67, 68, 63, 50]), this study is concerned with a subset of rhotic sounds that are also alveolar or dental-alveolar. Therefore, neither the English-type retroflex approximant nor the uvular fricative of German or French will be taken into consideration here.

In Greek, laterals and rhotics are clearly contrasting phonemes, as shown already by Ancient Greek minimal pairs such as *κολωνός* ('hill', noun) vs. *κορωνός* ('curved, crooked', adjective) ([39]). Nevertheless, Meyer ([44]), Bechtel ([8]), as well as the Greek-English lexicon of Liddell, Scott, and Jones ([39]) offer a number of examples for lateral-rhotic confusion from Ancient Greek. Some of these examples are shown in Table 2. The pronunciation of /r/ as a lateral even acquired fame as Alcibiades (ca. 450–404 BCE) and Demosthenes (382–322 BCE), the Athenian statesmen, were said to be unable to distinguish /r/ and /l/ in their speech, pronouncing them both as /l/, and this speech defect, as it was referred to, was even seen as a sign of sophisticatedness and elegance ([61, 62, 18, 65]).

In most Modern Greek dialects, historical rhoticisation, particularly of preconsonantal laterals, can be found ([52]; examples are given in Table 3). The standard Modern Greek language, however, is strongly influenced by the written form of Ancient Greek, and hardly contains any of these dialectal rhoticised forms. In the speech of most speakers, and certainly of all speakers in urban areas, the original forms with a lateral are thus present alongside the more dialectal rhoticised ones and may be used interchangeably ([52]).

The lateral in standard Modern Greek is clear, but several dialects (the Northern dialect group including the urban accent of the country's second-largest city, Thessaloniki, and areas of Western Crete) have a dark lateral before low and back vowels ([35]). Lacking phonetic descriptions of the Greek language from historical times, it is difficult to evaluate the degree of darkness of the lateral in the different varieties when the rhoticisation processes first set in.

The prevalent variant of the Modern Greek rhotic is an alveolar tap in all syllable positions, although in emphatic speech, it may be produced as a trill, again in all syllable positions. Moreover, the tap not always shows a complete closure, which makes it an approximant-like sound (importantly, without the retroflex lingual gesture found in the approximant rhotic of American English) ([3, 4, 53, 5, 6]).

Finally, different syllable positions contribute in different measures to liquid confusion. Dialectological observation suggests that the preconsonantal position is especially conducive to liquid confusion, not only in Greek dialects ([52]), but also in many dialects of Italian ([34, 45, 23, 75]) or in dialects of Spanish, especially in the southern part of the Iberian peninsula, and in several Caribbean dialects ([33, 64, 1, 63]). A high incidence of liquid confusion is also found in word-final and intervocalic position in many of these dialects, and in addition in languages such as Ladin ([34, 45]), many dialects of Occitan ([17, 48, 79, 2, 78, 45, 21, 10, 86, 11, 19, 42, 15, 85, 50]), or in Basque ([46, 89]). In the complex syllable onset, there are far fewer instances of liquid confusion. For Greek dialects, lateral rhoticisation has been reported for Tsakonian and the dialects of Southern Italy ([76, 35]). Cases of rhoticisation or lambdacisa-

Table 2: Confusion of laterals and rhotics in Ancient Greek. Examples.

word form with lateral	variant form with rhotic	English gloss	source
ἄλγος (noun)	ἀργαλέος (adjective)	pain (noun); painful (adjective)	[8, 39]
γλωσσαλγία (noun 1)	γλωτταργία (noun 2)	endless talking (noun 1); idleness of the tongue (noun 2)	[8, 39]
κεφαλαλγία	κεφαλαργία	headache	[8, 39]
ἀναγαργαλίζω (varia lectio)	ἀναγαργαρίζω	to gargle	[8, 39]
καρχαλέος	καρχαρέος	rough	[8, 39]
μορμύλος/μόρμυλος	μορμύρος/μόρμυρος	Pagellus mormyrus (a sea-fish)	[8, 39]
ναύκληρος, ναύκλαρος (noun 1)	ναύκραρος (noun 2)	shipowner and merchant (noun 1); in early Athens, the chief official of a division of the citizens (noun 2)	[8, 39]
κλίβανος	κρίβανος (Attic)	covered earthen vessel	[8, 39]
from Persian *shalvâr* or *shulvâr*	σαράβαρα	loose trousers worn by Scythians	[8, 39]
ἦλθον	ἔρχομαι	I came; I come	[44, 39]
εἷλον	αἱρέω	I took up with my hand; I take up with my hand	[44, 39]
κλῶμαξ	κρῶμαξ	heap of stones	[44, 39]
μέλλαξ (noun 1)	μεῖραξ (noun 2)	young man (noun 1); young girl (noun 2)	[44, 39]

Table 3: Confusion of laterals and rhotics in Modern Greek. All examples are from [52].

word form with lateral	variant form with rhotic	English gloss
αδελφός	αδερφός	brother
ήλθα	ἠρθα	I came
φθαλμός	φταρμός, εφταρμός	evil eye
ψάλτης	ψάρτης	cantor
βάλθηκε	βάρθηκε, βάρτηκε	it was put
ελπίδα	ορπίδα	hope
αλμυρός	αρμυρός	salty
from Italian *alburo*	άρμπουρο	mast
γλήγορα	γρήγορα	quickly
πελιστέρι	περιστέρι	dove
παλεθύρι	παραθύρι	window
κλιθάρι	κριθάρι	barley
αλέτρι	Ancient Greek ἄροτρον	plough
πλώρη	Ancient Greek πρῷρα	prow

tion in word-initial position seem to constitute the final stage in this sound change: for instance, in Romanian, all Latin singleton laterals rhoticised between the 4th and the 7th centuries, in all syllable positions, including the beginning of the word ([45, 29]).

2. EXPERIMENT

Which factors contribute to the confusion of laterals and rhotic sounds and, by extension, to sound change? A number of hypotheses arise from the dialectological and historical observations detailed in the introduction, section 1 above:

(1) Darker laterals ought to undergo perceptual

rhoticisation more often than clearer laterals, as their resonance characteristics are similar due to similar tongue body positions (cf. [63] for Spanish). (2) Shorter laterals should be confused with a rhotic more often than longer laterals, since shorter laterals, especially in the intervocalic position, resemble more closely an alveolar tap, which is the main rhotic variant in many of the languages and dialects discussed in the introduction. (3) Rhotic variants that resemble a lateral more closely should be affected by perceptual lambdacisation more often. Thus an approximant rhotic, especially when it is alveolar rather than retroflex, has a longer tongue tip movement than a tap ([7]); a trill with its repeated interruptions of the acoustic carrier, on the other hand, is very dissimilar to a lateral and therefore is not supposed to undergo lambdacisation readily. (4) Laterals and rhotics in preconsonantal, word-final, and intervocalic position ought to be more easily confused with each other than when they are in a complex onset cluster. In word-initial position, the smallest amount of confusion should occur.

In order to put these four hypotheses to a test, a perception experiment was designed. The present section describes in detail the construction of the speech material, the participants, as well as the presentation of the stimuli.

2.1. Stimuli

Laterals and rhotics were embedded in disyllabic meaningless words. As shown schematically in Table 4, the construction of these stimuli took into account all syllable positions in which both laterals and rhotics may occur in Greek. The inclusion of syllable position as a factor in the experiment was motivated by the differential freuqency of occurrence of rhoticisation and lambdacisation reported in historical and dialectological studies (see section 1 and hypothesis (4) above).

All stimuli, except for those in the word-final condition, were stressed on the first syllable. Stress placement on the last syllable in the word-final condition was motivated by purely euphonic considerations (note that the word-final condition contains the only consonant-final stimuli). Earlier studies on Greek [49, 51] found stress placement not to be a contributing factor to lateral rhoticisation and rhotic lambdacisation.

The stimuli were recorded by two male native speakers of Greek in a sound-attenuated booth at the Institute of Phonetics and Speech Processing of LMU Munich using high-quality equipment. The first speaker produced almost exclusively trills for the rhotic in all syllable positions and generally exhibited hyper-articulated speech, likely due to the laboratory setting. Therefore, a second speaker was recorded for the same set of stimuli. Only the stimuli containing rhotic trills were selected from the first speaker; all the remaining stimuli were taken from the second speaker. Both speakers were naïve as to the purpose of the study and had never had any phonetic training.

Since the two speakers differed significantly in speaking rate (paired t-test: $t[7]=7.12$, $p<0.001$), all stimuli were manipulated in duration so that, depending on the number of segments in the stimulus, word duration was in the approximate range of 240 ms – 260 ms. The rationale for this word length was that a full lateral is known to be about 60 ms long in Greek spontaneous speech (e.g., [41]). It was found that the lateral in the recorded tokens took up approximately 24% of the word duration and that this ratio did not differ significantly among the two speakers (paired t-test: $t[7]=-0.68$, $p>0.5$). Therefore, 60 ms was defined as 24% of the normalised word duration (ca. 250 ms).

Three variables, two for the stimuli containing laterals and one for the stimuli containing rhotics were created, as follows:

2.1.1. Lateral variable 1: duration

This variable was created in order to test hypothesis (2), namely that shorter laterals undergo perceptual rhoticisation more readily than longer laterals do. Two duration values for the steady state of the laterals were chosen: 60 ms, which corresponds to the average duration of the lateral in Greek spontaneous speech ([41]), and 30 ms, which comes closer to the average tap duration found in the speech-rate normalised stimuli (20 ms). Duration manipulation was done in Praat ([12]) by use of the PSOLA method ([47]). Transition durations were held constant in the two conditions: 30 ms from the steady state of the vowel /a/ into the lateral, and 25 ms from the lateral into the vowel.

2.1.2. Lateral variable 2: darkness degree

Laterals are known to vary in perceptual quality along a darkness-clearness continuum, with a low F2 (and a somewhat higher F1) at the dark end and a high F2 (and a somewhat lower F1) at the clear end. Hypothesis (1) supposes that degree of darkness is a factor in lateral rhoticisation, insofar as confusion with the rhotics should increase as degree of darkness in the lateral increases. A five-step darkness continuum was created by varying values for F1, F2, and F3 in the stimuli containing laterals. Specifically, the dis-

Table 4: Stimulus template. L = liquid (lateral or rhotic).

onset cluster	coda cluster	intervocalic	word-initial	word-final
/pLaka/	/kaLpa/	/kaLa/	/Laka/	/kataL/
	/kaLta/			
/kLaka/	/kaLka/			

tance between the first and the second formant was increased by 0.96 Bark for every step in the continuum. Table 5 shows the values in Bark for F1, F2, and F3, as well as F2–F1, at every step in the darkness continuum of the lateral. These values were based on a large cross-linguistic study on lateral formant values conducted by [69].

2.1.3. Rhotic variable: type

Hypothesis (3) states that perceptual lambdacisation of rhotics is dependent on rhotic type. Therefore, four different types of rhotic were presented to the listeners: two-closure trills, taps, taps without the svarabhakti vocoid[I] (i.e., constriction period only), and approximant rhotics.

- *Two-closure trills*: Stimuli containing trilled rhotics were taken from speaker 1, as described above. They were all set to two closure periods by deleting any additional closure period present in the signal.
- *Taps*: Stimuli containing taps were taken from speaker 2. Closure periods of the taps were set to a 20 ms duration; the svarabhakti vocoid was not modified.
- *Taps without svarabhakti vocoid*: An additional rhotic type – a tap without svarabhakti vocoid – was created by excising the vocoid from the signal. In Greek, a svarabhakti vocoid was found to be absent in 18% - 30% of coda clusters and in 0% - 22% of onset clusters in a study by Baltazani ([3, 4]). This rhotic type was included in the experiment in order to gain an understanding of the role of the svarabhakti vocoid in tap perception. As the tap never presents acoustic svarabhakti vocoids in intervocalic position, no additional rhotic type was created for this syllable position. The intervocalic tap without svarabhakti was included with the rhotic type "tap" on the grounds of its regular occurrence. This choice, of course, may be debated.
- *Approximant rhotics*: The fourth rhotic type, approximant rhotics, could not be directly recorded as the speakers avoided the casual speech style associated with these sounds in the laboratory setting. Approximant rhotics were therefore created as follows: The signal of the stimulus /ˈɾaka/, uttered by speaker 2 with a word-initial tap, contained an approximant-like stretch between the closure period for the tap and the full vowel /a/. This acoustic stretch was excised, adjusted to a 45-m-duration and inserted in lieu of the tap + svarabhakti vocoid sequence in the stimuli uttered by speaker 2.

To summarise, two distinct phonetic variables (duration and spectral quality/formant values) were varied independently in the laterals, while one variable only was chosen for the rhotics. The rationale for this choice is the fact that especially trills and taps shape the acoustic signal in ways that are very different from laterals and approximant rhotics: trills and taps are characterised by the alternation of vowel-like stretches (svarabhakti vocoids) and short closure or constriction periods with inherently short durations due to their manner of articulation as either a short ballistic movement or as an aerodynamically induced trilling of the tongue tip ([7]), while laterals and approximant rhotics have a more homogeneous intensity level and allow for quality modifications via formant structure. The individual duration values chosen for the stimuli, detailed above, are in agreement with relative duration values for laterals and different rhotic types in spontaneous speech (cf. [50], 136–140).

The combination of all variables (Syllable position, Lateral duration, lateral Darkness degree, and Rhotic type) yielded 111 different stimuli in total.

2.2. Participants and presentation

292 native listeners of Greek participated in the experiment (59 participants at the University of Cyprus, 233 participants at Aristotle University, Thessaloniki, Greece; mean age: 20.9 years (sd: 3.6 years)). They were paid for their participation.

The stimuli were presented to listeners over headphones in a random-order multiple forced-choice

Table 5: Degree of darkness in the lateral (values in Bark)

	very dark	dark	medium	clear	very clear
$F1$	5.77	5.46	5.15	4.84	4.53
$F2$	8.32	8.97	9.62	10.27	10.92
$F3$	14.16	14.3	14.44	14.58	14.72
$F2 - F1$	2.55	3.51	4.47	5.43	6.39

test. This design was chosen in order to gain a finer-grained picture of perceptual confusion involving laterals and rhotics. Benders and Escudero [9] presented evidence that listeners show a significantly larger boundary shift when presented with a restricted choice of possible answers than when they are given a larger set of answers to choose from. In their study, they showed that the location of Peruvian Spanish listeners' perceptual boundary between the Spanish vowels /i/ and /e/ on a F1 continuum differed significantly as an effect of the number of response categories (/i, e/ vs. /i, e, a, o, u/). Higher values of F1 were still categorised as /i/ in the two-answer group than in the five-answer group. It thus seems that listeners take into account all the available choices when perceiving a given stimulus.

In the present study, depending on the syllable position of the lateral or rhotic, the number of available choices ranged between five and eight. Fewer choices were presented, for example, in the coda cluster condition, because Greek phonotactics allow for a smaller set of sounds in this position than in other syllable positions.

The additional choices for the perception of the liquid sound in the stimulus included a voiced dental fricative/approximant /ð/, a voiced velar fricative/approximant /ɣ/, a voiced alveolar fricative /z/, a pre-nasalised voiced velar stop /^{ŋ}g/, a pre-nasalised voiced bilabial stop /^{m}b/, a pre-nasalised voiced alveolar stop /^{n}d/, an alveolar nasal stop /n/, a voiceless alveolar stop /t/, as well as, for each trial, the possibility of complete elision of the sound, /∅/.

3. RESULTS

Results for stimuli containing laterals and stimuli containing rhotics were analysed separately. The response variable was divided into three levels: "rho", "lambda", and "other". The last level, "other", grouped all the choices offered to the participants except "rho" and "lambda"; these remaining choices contained too few datapoints to warrant separate levels in the analysis. The data were analysed using multinomial logistic regression models (R ([66]); packages *nnet* ([90]) and *car* ([24]).

3.1. Stimuli containing laterals

The three predictor variables DARKNESS DEGREE, LATERAL DURATION, and SYLLABLE POSITION, and their interactions (three two-way interactions as well as one three-way interaction) were entered into the model. Overall accuracy of the model was good at 96% correct predictions. Contrary to hypothesis (1) stated at the beginning of section 2, DARKNESS DEGREE in the lateral did not contribute significantly to predicting participants' answers (χ^2[8]=3.97, p=0.86). LATERAL DURATION, on the other hand, did show the expected effect (χ^2[2]=14.43, p<0.001) (cf. hypothesis (2)), with long laterals being less likely to be perceived as /r/ or as another sound than short laterals, and thus confirmed the results of [49]. The strongest predictor, however, was the SYLLABLE POSITION in which the lateral was presented (χ^2[14]=855.04, p<0.001) (cf. hypothesis (4)).

Among the interactions tested, the interaction between the syllable position and the duration of the lateral was nearly significant at $\alpha \leq 0.001$ (χ^2[14]=34.70, p=0.002; see Figure 1), whereas the other three interactions did not reach significance (SYLLABLE POSITION × DARKNESS DEGREE: χ^2[56]=40.54, p=0.94; DARKNESS DEGREE × LATERAL DURATION: χ^2[8]=4.34, p=0.83; SYLLABLE POSITION × DARKNESS DEGREE × LATERAL DURATION: χ^2[56]=36.15, p=0.98). The predicted probability of choosing /r/ over /l/ in intervocalic position was 0.05 for short laterals and 0.02 for long laterals, even though the predicted probability of choosing one of the other responses presented over /l/ in intervocalic position was 0.11 for both long and short laterals (cf. Figure 1). Of the other sounds perceived for short laterals in intervocalic position, participants chose the interdental voiced fricative /ð/ in most cases (62%) (no consonant/perceptual elision:16% of cases; velar voiced fricative /ɣ/: 15%; alveolar voiced fricative /z/: 3%; alveolar nasal /n/: 3%; prenasalised voiced alveolar stop /^{n}d/: 1% of cases). A similar picture

was obtained for the long lateral in intervocalic position: participants chose again the interdental voiced fricative /ð/ was chosen in 67% of cases (velar voiced fricative /ɣ/: 15%; perceptual elision: 11%; alveolar voiced fricative /z/: 7%; alveolar nasal /n/: 1%).

3.2. Stimuli containing rhotics

The two predictor variables SYLLABLE POSITION (the same as for the laterals) and RHOTIC TYPE as well as their interaction were entered into the model. Here, the overall accuracy of the model at 83% correct predictions was lower than in the model for the laterals. Both predictor variables had a highly significant effect on the model's predictions (SYLLABLE POSITION: $\chi^2[14]=863.1$, $p<0.001$; RHOTIC TYPE: $\chi^2[6]=6054.1$, $p<0.001$), as did their interaction (SYLLABLE POSITION × RHOTIC TYPE: $\chi^2[42]=569.2$, $p<0.001$). As shown in Figure 2, the tap without svarabhakti vocoid was often perceived as neither /r/ nor /l/. A close inspection of the actual response data reveals that this rhotic variant was not perceived at all (perceptual elision) in most syllable positions; only in the sequence /pra/ was the tap without svarabhakti vocoid perceived as /ð/, and, less frequently, as /n/ (in 77% and 24% of cases, respectively), while in word-initial position, it was perceived as /ɣ/ or /ð/ (in 38% of cases each).

4. DISCUSSION

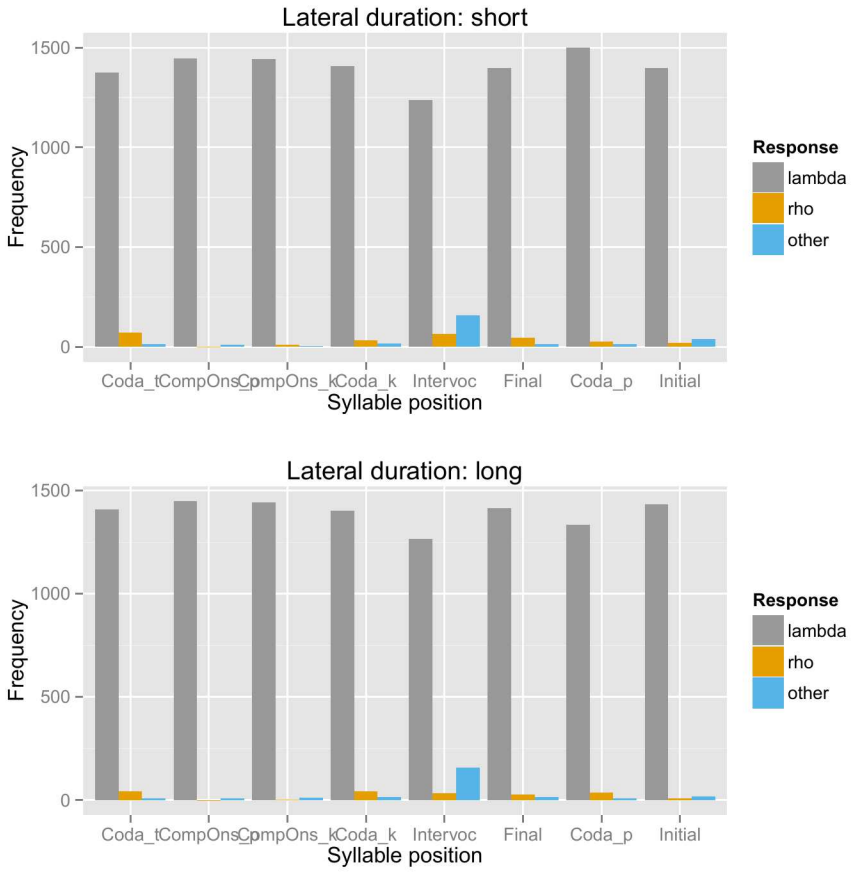
4.1. Misperception of laterals

The multinomial logistic regression model of participants' responses to stimuli containing laterals that varied in two acoustic dimensions (degree of darkness and duration) had a prediction accuracy of 96%. This value suggests that the factors studied in this investigation provide a good account of the phonetic conditions which give rise to misperception of laterals.

While the degree of darkness in the laterals did not contribute to correctly predicting whether a lateral stimulus was perceived as such or as another sound, the duration of the lateral (long vs. short) and the syllable position in which it appeared had a significant effect on model predictions. Figure 1 shows that one syllable position in particular increases the risk of misperceiving laterals as either a rhotic tap or as an intervocalic voiced fricative, and, much less though, as a range of other sounds. For some of these other sounds, the numerical distribution of participants' responses in the data indicates that degree of darkness, while of no effect for perceptual lateral rhoticisation, could play a role in misperception. This is the case for perceptual elision, with 41 elision responses to very dark laterals, gradually decreasing to 26 responses for very clear laterals, across all syllable positions (15 responses for very dark laterals in intervocalic position, gradually decreasing to 7 responses for very clear laterals in that position), and a similar effect might obtain in the perception of a lateral as the interdental voiced fricative /ð/, with 41 /ð/-responses to very dark laterals, gradually increasing to 56 /ð/-responses to very clear laterals across all syllable positions (33 /ð/-responses to very dark laterals, gradually increasing to 47 /ð/-responses to very clear laterals in intervocalic position). Given the low number of cases of perceptual elision or perception of /ð/, compared to perception of /r/, and particularly of correct identification as /l/, a statistical analysis was not meaningful; this is why only a numerical description is given here. To summarise, these data indicate that darker laterals may escape perception more easily than clearer laterals, and that clearer laterals would more readily be heard as /ð/ than darker laterals. Future research will show whether the prediction derived from these findings, namely that /ð/-perception of a lateral increases as its degree of darkness decreases is supported by cross-linguistic empirical observations in the domains of historical sound change and synchronic dialectal or socio-phonetic differentiation. A potential counterexample to this prediction is, for example, the Albanian word form "gjillë" [ˈɟiłə], a dialectal variant of the word "gjidhë" [ˈɟiðə] 'all' (adj.) (itself a variant of standard "gjithë" [ˈɟiθə]) (Albanian contrasts clear /l/ and dark /ł/ phonemically and orthographically) ([57]).

Figure 1 shows that predicted probabilities for perceptual rhoticisation of the lateral were highest in intervocalic position (although the risk of rhoticisation was still low at 5% for the short lateral, and 2% for the long lateral, see section 3.1). Since the Greek rhotic is canonically a tap in all syllable positions ([3, 4, 53, 5], it is assumed that listeners, when pressing the answer button showing a transcribed «ρ» for a lateral, confused the lateral with a (perhaps reduced) tap rather than another, less common variant of the Greek rhotic such as the trill or the approximantized variatnt of the tap. Of course, this assumption will need to be subject to further testing. Such an interpretation is appealing, however, insofar that a tap in intervocalic position lacks distinct svarabhakti vocoids in the acoustic signal, since these would be overlaid by the surrounding vowels. The most prominent acoustic cue to the tap would then be the characteristic reduction in intensity during tongue tip closure or tongue tip constriction. Further support for

Figure 1: Absolute frequency of responses to lateral stimuli depending on LATERAL DURATION (upper panel: short, lower panel: long) and SYLLABLE POSITION.



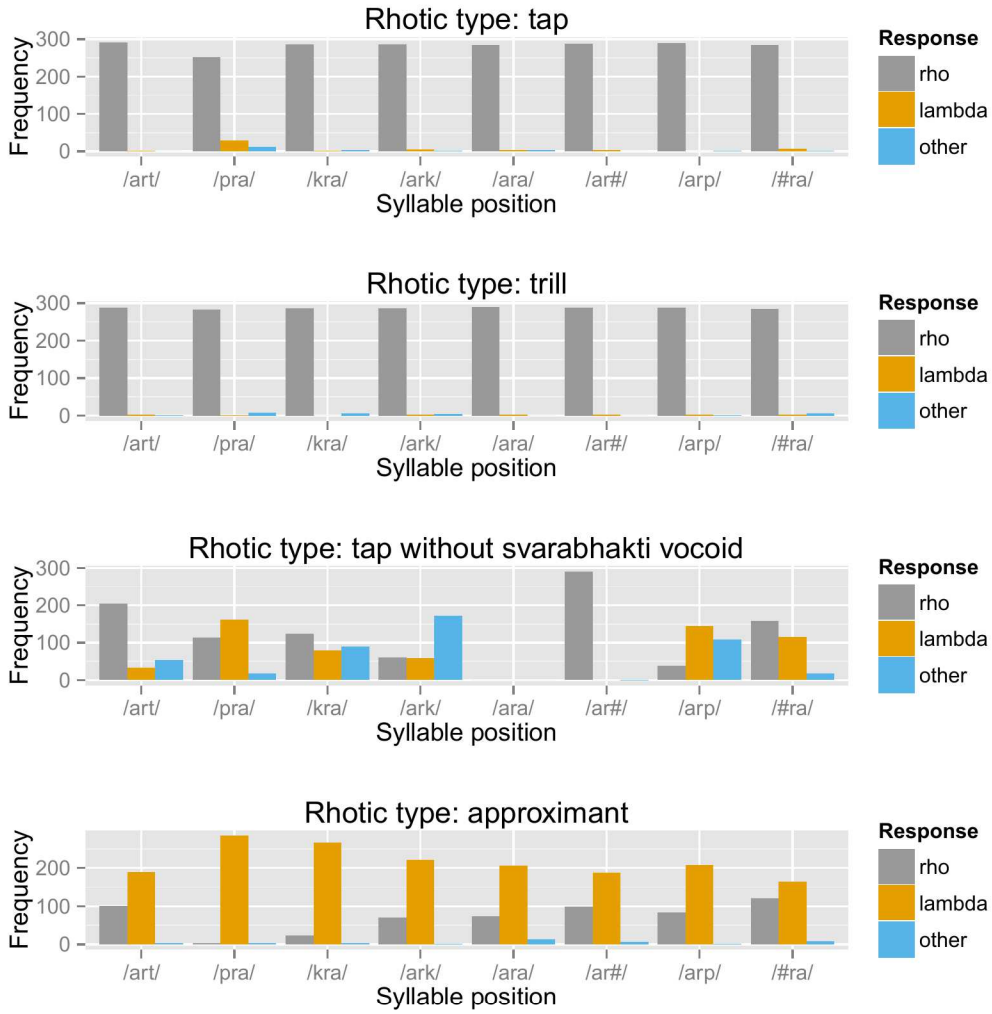
this interpretation comes from the fact that the predicted probabilities of lateral rhoticisation in intervocalic position were higher for shorter than for longer laterals, given that a short reduction in intensity resembles the reduction seen in intervocalic taps.

4.2. Misperception of rhotics

The rhotics presented in the experiment were categorised into rhotic types, and results showed that some types behaved very different from others. In particular, trills and taps yielded high levels of correct identification as rhotics (cf. Figure 2). The tap in the sequence /pra/, nevertheless, had a higher predicted probability of being identified as a lateral (10%) than in other syllable positions (ranging from <0.01% in /arp/ to 2% in /ark/ or in /ra/). A reason for this might be that, although it was aimed for a stimulus set consisting entirely of non-words, it could not be avoided that a few stimulus forms represented meaningful words. Specifically, the form /plaka/ is a meaningful Greek word ('board, tombstone, dial, blackboard, tile, plaque, plate, fun') and thus could have attracted /l/-responses (cf. [25]). This interpretation is backed up by the fact that the highest predicted probabilities for /l/-responses for the rhotic types tap without svarabhakti vocoid and approximant (56% and 97%, respectively) are also found in the sequence /pra/. Similarly, the two other meaningful stimulus forms, /karta/ ('card') and /katar/ ('Qatar'), also attracted relatively high predicted probabilities for (correct) /r/-responses relative to predicted probabilities for other syllable positions within the same rhotic type, cf. Figure 2.

The approximant rhotic type was predicted by the model to elicit more /l/-responses than /r/-responses, and this for all syllable positions. The lowest predicted probability for perceptual lambdacisation was in word-initial position /#ra/ (56%), which is also the syllable position from which the original approx-

Figure 2: Absolute frequency of responses to rhotic stimuli depending on RHOTIC TYPE and SYLLABLE POSITION.



imant rhotic was taken (see section 2.1.3). Three explanations may be advanced for these high rates of perceptual rhotic lambdacisation, i.e. misperception of /r/ for /l/: First, although approximant rhotics and perhaps more frequently, very reduced taps, exist in Greek casual speech, these do not have the same consistent approximant pronunciation as do, for example, English rhotic approximants. The clear speech nature of the stimuli may have biased listeners against the correct perception of a variant strongly associated with casual speech.

Second, laterals preceding low or back vowels are very similar to the English rhotic approximant in some Greek dialects, especially in Western Crete ([35, 36]). However, only four out of 292 participants were originary from Western Crete, i.e. indicated having attended primary school in Chania district. They perceived the rhotic approximant in 94% of cases as /l/ across syllable positions, against perceptual lambdacisation in 74% of cases across syllable positions for all 292 participants. This seems to show that the alveolar non-lateral approximant is part of their phonemic representation of the lateral, against, perhaps, listeners with a different dialectal background. Note that the canonical rhotic in the Western Crete dialect is a tap, as elsewhere in Greek ([35, 36]).

Third, the approximant rhotic lacks the characteristic contrast of intensity reduction during tongue tip constriction or closure as well as a svarabhakti vocoid which make up taps and trills; instead it presents formant structure, as does the lateral. Moreover, the

approximant rhotic is generally longer than the tap, and this fact was taken into account in creating the stimuli. Its duration renders it thus similar to the lateral. The main difference to the lateral lies in the approximant rhotic's lacking lateral side channels.

The category tap without svarabhakti vocoid was included in the study in order to test the role of svarabhakti vocoids in perception. The characteristic shape of the tap as a sequence of a svarabhakti vocoid and an intensity reduction period due to tongue tip constriction or closure or vice versa and the concomitantly high predicted probabilities of correct /r/-responses to rhotic taps in the present study are thus compared to the scenario where the tap lacks this svarabhakti vocoid. The interest of this comparison arises from the observation made by Baltazani ([3, 4]) that 18% to 30% of taps in /rC/-clusters may lack their svarabhakti vocoid, while it is absent with taps in 0% to 22% of /Cr/-clusters. How is a tap perceived that lacks the svarabhakti vocoid? The model presented here predicts that it is not perceived at all in most cases. Exceptions are the word-initial position and the onset cluster /pra/. Elision of rhotics (the exact variant of which is not always easy to determine from the literature) occurred in the historical development of many languages, e.g., in Albanian ([57]), Latin, Ancient Greek, and Sanskrit ([44, 80, 38, 39]), Prakrit ([91]), Faliscan ([80]), Occitan, Italian, Spanish, French [93]), and Franco-Provençal [93, 26]). The reason why the svarabhakti vocoid would become reduced to the point of disappearing altogether cannot be answered by the data presented in this investigation. It may be suggested, nevertheless, that prosodic factors of various kinds (word stress, sentence stress, etc.) may be held accountable for such variation.

A caveat needs to be voiced here, however: the model's accuracy amounted only 83% correct predictions as compared to the empirical data, which leads to suspect that the factor of rhotic type investigated here might be too coarse to account for listeners' responses and that a finer-grained approach is called for a more thorough understanding of the mechanism behind perceptual lambdacisation of rhotics.

5. CONCLUSIONS

This study has shown that acoustic factors exist which can account for the mutual confusion of laterals and rhotics through misperception. While lateral degree of darkness could not be shown to play a rôle in lateral rhoticisation –the misperception of /l/ for /r/–, the analysis confirmed previous studies showing that rhoticisation (to a tap) mainly hinges on the sound's duration. Rhotic lambdacisation –the misperception of /r/ for /l/– was studied for different types of rhotics, and high rates of lambdacisation were found for the approximant rhotic variant, whereas taps and trills were almost invariably perceived as rhotics. When the svarabhakti vocoid was missing in the tap, however, leaving only the closure or constriction period, many participants were not able to perceive the sound at all.

The findings from this study underline the importance of taking into account the precise phonetic variant or allophone of a sound category when investigating sound change, whether the investigation is done by extrapolating from current findings to older stages of a language, which have been transmitted to us only in written form, or by designing new experimental approaches to sound change problems. An understanding of the underlying mechanisms of sound change will only prove successful if all aspects of speech, from fine phonetic detail to phonemic categories, are taken into consideration.

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[1] A svarabhakti vocoid is the short vocalic element that can appear preceding or following the constriction of the tap, or between the individual closures of the trill.