The adaptation of French liquids in Haitian: a test of the perceptual hypothesis

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Abstract:
Haitian, a French-lexifier creole with a Gbe substrate, shows an asymmetry in the way it has adapted French liquids: the French lateral was maintained in postvocalic coda position in Haitian, but the French rhotic was systematically deleted in this position. This paper presents the results of a perception study showing that the lateral is generally more perceptible than the rhotic in coda position in Modern French. The hypothesis that perception played a role in the phonological asymmetry in Haitian is compatible with these results. The paper sketches an analysis of how the perceptual asymmetry between French coda laterals and rhotics resulted in the emergence of a new phonological grammar, distinct from both the grammar of the substrate and superstrate languages. This analysis is in line with previous works on the role of perception in second language acquisition, loanword adaptation, creolization, and sound change more generally.

Keywords: Haitian, French, creole, liquids, syllable, perception

1. Introduction

Haitian, a French-lexifier creole, shows an asymmetry in the way it has adapted French liquids [l] and [ʁ]: the French lateral was maintained in postvocalic coda position in Haitian, but the French rhotic was systematically deleted in this context. This paper explores the hypothesis that perception played a role in this asymmetry, with the rhotic being less perceptible than the lateral in coda position (Russell Webb 2010). The results reported in the paper are based on an experiment studying the perception of Modern French liquids by French native listeners.

Throughout this paper, the term *liquid* will be used to refer to the class including the *lateral* phoneme and the *rhotic* phoneme. This terminology does not imply that the phonemes have

the same phonetic realization in Haitian and in French. Indeed, the rhotics in Modern French and Haitian are described as having different points of articulation, uvular and velar, respectively (Delattre 1959).

Section 1.1 describes the distribution of liquids in Haitian, Modern French, and Gbe. Gbe languages, a group of languages spoken in West Africa, are genetically related to the languages spoken by the slaves brought by the French in Haiti in the 17th and 18th centuries (Valdman 2015:183). These languages constitute the substrate of Haitian Creole and are therefore likely to have played an important role in shaping the phonological patterns in Haitian. Section 1.2 presents two hypotheses that have been proposed to explain why the distribution of liquids is asymmetric in Haitian but not in Modern French and Gbe languages. Section 1.3 describes the specific hypothesis that was tested in the experiment.

1.1. The distribution of liquids in Haitian, Modern French, and Gbe

Both Modern French and Haitian have a rhotic phoneme, transcribed as the voiced uvular fricative [ʁ] in French and as the voiced velar fricative [ɣ] in Haitian. The two rhotics are historically related but their distribution differs across the two languages (Tinelli 1981; Nikiema & Bhatt 2003; Brousseau & Nikiema 2006; Russell Webb 2010; Valdman 2015). In French, [ʁ] occurs both in onset and coda positions. In Haitian, [ɣ] only occurs in onset position before unrounded vowels. In onset position before rounded vowels, French [ʁ] corresponds to Haitian [w]. In coda position, French [ʁ] corresponds to zero in Haitian. The distribution of the rhotics in French and Haitian is illustrated in Table 1.

		French	Haitian	
Onset	#ʁV$_{[-round]}$	rêver [**ʁ**eve]	reve [**ɣ**eve]	‘to dream’
	ʁV$_{[-round]}$	serrer [se**ʁ**e]	sere [se**ɣ**e]	‘to clench’
	CʁV$_{[-round]}$	prix [p**ʁ**i]	pri [p**ɣ**i]	‘price’
	#ʁV$_{[+round]}$	rose [**ʁ**ɔz]	wòz [**w**ɔz]	‘pink’
	VʁV$_{[+round]}$	zéro [ze**ʁ**o]	zewo [ze**w**o]	‘zero’
	CʁV$_{[+round]}$	troquer [t**ʁ**oke]	twoke [t**w**oke]	‘exchange’
Coda	VʁC	merci [mɛ**ʁ**si]	mesi [mɛsi]	‘thank you’
	Vʁ#	la mer [lamɛ**ʁ**]	lamè [lamɛ]	‘sea’
	VCʁ#	livre [liv**ʁ**]	liv [liv]	‘book’

Table 1.

The rhotic in Modern French and in Haitian. Haitian data from Valdman (1996).

Deletion of the coda rhotic is categorical in Haitian. Although there is no phonetic study testing this hypothesis directly, two facts make it very likely: (i) the forms without coda rhotics in Haitian are not reported to carry any phonetic trace of a rhotic[1] and (ii) words are spelled identically whether a coda rhotic is present or not in the French corresponding word. For instance, French *coup* [ku] 'blow' (noun) and *cours* [kuʁ] 'class' (noun) correspond to a single form *kou* [ku] in Haitian (Valdman 1996:470).

By contrast with the rhotic, other consonants generally have the same distribution in Modern French as spoken in France and in Haitian. One systematic exception is word-final Obstruent-Liquid (OL) clusters, where both the rhotic and the lateral are systematically deleted in Haitian, e.g. French *table* [tabl] ~ Haitian *tab* [tab] and French *livre* [livʁ] ~ Haitian *liv* [liv] (Valdman 2015:172). In other contexts, nonrhotic consonants generally have the same distribution in the two languages. In particular, nonrhotic consonants are allowed in postvocalic coda position both in French and Haitian, as illustrated in Table 2.

		French	Haitian	
Word-finally	VS#	tête [tɛ**t**]	tèt [tɛ**t**]	'head'
	VN#	pomme [pɔ**m**]	p**ò**m [pɔ**m**]	'apple'
	VF#	richesse [ʁiʃɛ**s**]	richès [ɣiʃɛ**s**]	'wealth'
	VG#	portail [pɔʁta**j**]	p**ò**tay [pɔta**j**]	'gate'
	Vl#	sel [sɛ**l**]	sèl [sɛ**l**]	'salt'
Word-medially	VSC	action [a**k**sjɔ̃]	aksyon [a**k**sjɔ̃]	'action'
	VNC	samedi [sa**m**di]	samdi [sa**m**di]	'Saturday'
	VFC	costume [kɔ**s**tym]	kostim [kɔ**s**tim]	'suit' (n)
	VlC	Allemand [a**l**mɑ̃]	alman [a**l**mɑ̃]	'German'

Table 2.

Postvocalic coda consonants in French and Haitian (S=stops, N=nasal stops, F=fricatives, G=glides). Haitian data from Valdman (1996).

[1]Some words show [ɣ]/∅ morphological alternations (e.g. *mèg* [mɛg] 'thin' ~ *mègri* [mɛgɣi] 'thinned' or *sik* [sik] 'sugar' ~ *sikre* [sikɣe] 'sweet'). Some authors argue that coda [ɣ] has to be present underlyingly in these words (e.g. /mɛgɣ/; see Nikiema & Bhatt 2003). However, the fact that these alternations exist does not imply that the rhotic is phonetically present in the surface forms.

This paper focuses on the treatment of the French postvocalic coda rhotic in Haitian. Why is [ɣ] not allowed in postvocalic coda position but other consonants are? In particular, why do the two liquids [ɣ] and [l] pattern differently? The distribution of the Haitian rhotic is more constrained than the distribution of [l] (Steele & Brousseau 2006:343-345). On purely phonological grounds, this is surprising: neither Modern French nor Modern Gbe languages show an asymmetry in the distribution of the two liquids. Liquids [l] and [ʁ] have the same distribution in Modern French: both are allowed in onset and coda positions (Tranel 1987). Modern Gbe languages also have a uvular fricative, transcribed as [ʁ] (Capo 1991:55), and a lateral, transcribed as [l] (Capo 1991:49). The two sounds have the same distribution in Gbe languages: they are both illicit in coda position, following from a general ban on coda consonants in these languages. Why do the liquids pattern differently in Haitian but not in the modern languages historically related to it?

1.2. The phonological hypothesis and the phonetic hypothesis

Two hypotheses have been put forward to explain the divergence between the distributions of [l] and [ɣ] in Haitian. According to one hypothesis, the source of the asymmetry lies in the French phonological input: in the variety of French to which the first Haitian speakers were exposed during the second half of the 17th century and throughout the 18th century (Valdman 2015:170), coda rhotics were consistently deleted. The outcome in Haitian is therefore what is expected from completely **faithful adaptation**. This hypothesis implies that the input to creole formation was quite different from Modern French. For instance, it implies that the phrase *la mer* 'the sea', pronounced as [lamɛʁ] in Modern French and adapted as [lamɛ] in Haitian, was pronounced as [lamɛ] in 17th-18th century French. This hypothesis, proposed by Valdman (2015:65-66) and summarized in (1), will be referred to as the **phonological hypothesis**. This hypothesis is phonological because the input to creole formation is hypothesized to be **phonologically** asymmetric (coda laterals present vs. coda rhotics absent).

(1) Phonological hypothesis
The French upon which Haitian Creole is based consistently deleted coda rhotics in exactly the same environments as present-day Haitian. Therefore, the outcome in Haitian is what is expected from completely **faithful adaptation**.

According to another hypothesis, the asymmetry has a phonetic/perceptual source: French coda rhotics had weaker perceptual cues than coda laterals and were therefore harder to perceive and adapt for the first Haitian speakers. As a result, coda laterals were maintained in Haitian but not coda rhotics. The outcome is what is expected from **perceptually-filtered adaptation**: coda rhotics were filtered out because they were under a perceptual threshold θ whereas coda laterals were adapted because they were above θ. This hypothesis, proposed by Russell Webb (2010) and summarized in (2), will be referred to as the **phonetic hypothesis**. This hypothesis is phonetic because the input to creole formation is hypothesized to be **phonetically** asymmetric (coda rhotics are less perceptible than coda laterals).

(2) Phonetic hypothesis
Coda rhotics were less audible than coda laterals in the French upon which Haitian Creole is based. Therefore, the outcome in Haitian is what is expected from **perceptually-filtered adaptation**.

In the phonetic hypothesis, the fact that both liquids were retained in onset position in Haitian is explained as the result of them being either familiar enough to speakers with a Gbe background (both [ʁ] and [l] occur in onset position in Gbe) or perceptually salient enough in the French input. Consonants are particularly salient in onset position (Wright 2004).

Contrary to the phonological hypothesis, the phonetic hypothesis does not require that coda rhotics were categorically deleted in 17th-18th century French. It just requires that coda [ʁ] was less audible than coda [l] in the input. Note that the two hypotheses are not completely incompatible: coda rhotics may have been subject to categorical deletion in some contexts in the French input and weaker than coda liquids when phonetically present.

In accordance with the phonological hypothesis, coda rhotics are reported to have been subject to deletion in French varieties spoken in France around the time of Haitian formation (Fouché 1952; Zink 1986). However, deletion was probably never as systematic in French as in Haitian (Russell Webb 2010:267). According to Fouché (1952:863-864), rhotic deletion was quite widespread in word-medial coda positions in the speech of the working class and the bourgeoisie in France.[2] However, for word-final positions, Fouché (1952:668) only

[2] Of course, hypotheses about the realizations of sounds in the 17th and 18th centuries must be taken with some caution.

reports categorical rhotic deletion after [i] and [e] in polysyllabic words. For instance, the rhotic was systematically deleted in *-er* infinitives without leaving any trace, e.g. *chanter* [ʃɑ̃te] 'to sing', but it was maintained in monosyllables like *mer* [mɛʁ] 'sea'.

In Modern French as spoken in France, the postvocalic coda rhotic is subject to reduction but not to categorical deletion. For instance, Gendrot (2014) distinguishes three phonetic variants of the rhotic phoneme: uvular fricative, uvular approximant, and elided. However, he finds that even variants which he labels as elided are still identified as rhotics by listeners. This suggests that the coda rhotic is never deleted categorically in Standard French, at least postvocalically: it is still signaled by formant transitions at the offset of the vowel, manifested by an increase in the first formant and a decrease in the second formant (Delattre 1959; Gendrot 2014). Therefore, the patterns of rhotic reduction in Modern French and in Haitian are of a different nature: the reduction in French involves gradient reduction whereas the reduction in Haitian involves complete deletion.

Some French varieties outside of France show a differential treatment of postvocalic coda rhotics and laterals. Of particular interest are French varieties spoken in the Americas, as they are geographically closer to Haitian and may therefore be linguistically closer to the French variety spoken by French colons in Haiti (Valdman 2015:171).

Varieties of French spoken in the Americas show patterns of consonant reduction that are also found in Haitian. For instance, Modern Québec French speakers tend to delete liquids in word-final OL clusters (Côté 2004). However, the way postvocalic coda rhotics are treated differs in Québec French and in Haitian. Coda rhotics are optionally vocalized in Québec French (e.g. *porte* [pɔʁt]/[pɔət] 'door'), whereas postvocalic coda laterals are generally not (Côté 2004:168-171). However, this is different from the Haitian pattern, where coda rhotics are completely deleted and not vocalized.[3] In the varieties of French spoken in Louisiana, coda rhotics may be deleted, but deletion is never as systematic as in Haitian and deletion of the coda lateral is also reported (Klingler & Lyche 2012).

[3]In French, mid vowels are lowered before coda [ʁ] as a result of the *loi de position*, which requires mid vowels to be low before coda consonants. Mid vowels remained low in Haitian after the elision of coda rhotics. This could be taken as a vocalic trace of the rhotic. However, synchronically, the low mid vowels coming from *loi de position* contexts and contrastive low mid vowels are not distinguishable, at least in the orthography (e.g. *respè* [ɣɛspɛ] from *respect* [ʁɛspɛ] vs. *rivyè* [ɣivjɛ] from *rivière* [ʁivjɛʁ]). Also, this phenomenon is limited to mid vowels.

Another reason why the asymmetry is unlikely to be due a phonological asymmetry in the input is the fact that the pattern of rhotic deletion vs. lateral maintenance in postvocalic coda positions is also observed in more recent cases of language contact with French. The most relevant case is the case of French loanwords in Fon, a Modern Gbe language. Although both liquids are licit in coda position in Modern French, only coda laterals are maintained in French loanwords in Fon: word-final [ʁ] is deleted in the loanword [dilɛtɛ] from French *directeur* [diʁɛktœʁ] 'director' but word-final [l] is maintained in the loanword [kɔlu] from French *col* [kɔl] 'collar' (Gbéto 2000:34, 54). This pattern of adaptation is not identical to the Haitian pattern, as coda [l] is adapted as [lu] in Fon, with vowel epenthesis. However, the asymmetry in the treatment of the coda liquids (maintenance of [l] vs. deletion of [ʁ]) is identical in the two languages.

Deletion of the coda rhotic is attested in several varieties of French spoken in Africa, e.g. in Ivory Coast (Boutin & Turcsan 2009) and in the Central African Republic (Bordal 2012). It is also attested in other geographical areas where the French presence is more recent: in Vietnamese, word-final [l] is adapted as [n] in French loanwords but word-final [ʁ] is systematically deleted (Kang, Phạm, & Storme 2016). The French presence in Vietnam dates back to the 19th century.

To summarize, the complete deletion of coda rhotics in Haitian is unlikely to correspond to a faithful adaptation of the French input because categorical deletion is only observed in a limited set of contexts in the history of the French language. Also, deletion of the coda rhotic is observed in other cases of language contact with French and there is no reason to think coda [ʁ] was systematically deleted in the input, in particular in cases where the contact with French is more recent.

Russell Webb's (2010) analysis of coda rhotics in Haitian as resulting from perceptually-filtered adaptation is part of a more general project examining the influence of perception in creole formation (see also Russell Webb 2008). Russell Webb draws on results from the study of second language acquisition and loanword adaptation to elucidate the perceptual mechanisms involved in the formation of sound patterns in creole languages. The parallel is based on the assumption that adult listeners who speak substrate languages play a primary role in shaping the phonologies of creole languages, as adult listeners do in loanword

adaptation (see Russell Webb 2010:265-267 for discussion). The idea that the listener plays a central role in language change has also been advocated by Ohala (1981) in the analysis of historical sound change.

Studies in second language acquisition and loanword adaptation have shown that the perception of nonnative speech sounds and sound patterns is shaped by listeners' experience of their native sound systems. For instance, Flege (1989) found that Chinese learners use the burst cues specific to their native /t/ ~ /d/ contrast when they perceive /t/ and /d/ in English. In Chinese, /t/ and /d/ occur only in word-initial positions. When they perceive English /t/ and /d/ in word-final positions, Chinese listeners rely on the same burst cues as in word-initial positions in Chinese: their performance is hardly affected when closure voicing is removed, but decreases significantly when the burst is removed.

Examining French and English loanwords in Japanese, Peperkamp, Vendelin, & Nakamura (2008) provide evidence that the perception of nonnative sounds plays a role in loanword adaptation. English word-final [n] is adapted as [n] in Japanese whereas French word-final [n] is adapted as [nɯ], with an epenthetic vowel. The two nasal phonemes are adapted differently because they have different phonetic realizations in English and French and correspond to different percepts for Japanese listeners. The authors show that French but not English word-final [n] has a strong vocalic release and that Japanese listeners perceive this release as their native vowel [ɯ].

There is also evidence that languages' phonotactic properties influence the way listeners perceive sequences of sounds. This is relevant to the present study as the phonotactics of French and Gbe differ: coda consonants are allowed in the former but not in the latter. In a series of experiments comparing Japanese and French listeners, Dupoux et alii (1999) found that the phonotactic properties of Japanese (where consonant clusters are very limited) induced Japanese listeners to perceive 'illusory' vowels inside consonant clusters in VCCV sequences. French listeners, who are familiar with consonant clusters, did not report the presence of a vowel between the consonants.

If the mechanisms involved in creole phonological restructuring are similar to the mechanisms at play in second language acquisition and loanword adaptation (see Russell Webb 2010 and Valdman 2015 for discussion), the perception of French liquids by the first

Haitian speakers should have been shaped both by the phonetic realization of the French liquids and by the phonology of Gbe languages. If the perceptual cues signaling the rhotic were less salient than the perceptual cues signaling the lateral in coda position in French, as hypothesized by Russell Webb (2010), then the coda rhotic was probably particularly hard to detect. The phonotactic ban on coda consonants in Gbe languages is likely to have added to the difficulty, by making Gbe listeners unlikely to posit underlying coda consonants in general.

Similar asymmetries between coda l-sounds and coda r-sounds have been found in other cases of language contact. Coda [l] is systematically adapted in English loanwords by Korean speakers (e.g. *pildeu* 'field') but coda [r] is systematically deleted (e.g. *hadeu* 'hard') (Heo & Lee 2004). This suggests that there might be acoustic differences that make rhotics particularly hard to perceive in coda positions as compared to laterals.

In French, the perceptual weakness of the rhotic could be related to its uvular fricative articulation. The Modern French uvular rhotic is realized as a voiceless fricative [ʁ̥] or a voiced approximant [ʁ]. Gendrot (2014) hypothesizes that the interaction of voicing and manner follows from the articulatory difficulty to maintain voicing and frication at the same time (Ohala 1983:201-202), particularly for a consonant articulated in the back of the mouth (Ohala 1983:194-201). This difficulty results in a dichotomy in the realization of the rhotic: if it is voiceless, it can be realized as a fricative; if it is voiced, the frication is harder to produce and the rhotic is realized as a voiced approximant. When the rhotic is realized as a voiced approximant [ʁ] in postvocalic coda position, the sequence [Vʁ] is expected to be hard to distinguish from [V], due to the similarity between vowels and approximants. When the rhotic is realized as a voiceless fricative [ʁ̥], the sequence [Vʁ̥] is expected to be harder to distinguish from [V] in a noisy environment.

Why would the perception of [l] be less affected in coda position? The French lateral is realized as a dental lateral approximant. The realization of the lateral is affected by the vocalic context: the F2 locus of [l] tracks the F2 of the adjacent vowel and the vowel has a greater coarticulatory influence on coda [l] than on onset [l] (Chafcouloff 1985). This means that [l] could also be hard to distinguish from the preceding vowel in coda position specifically.

However, [l] has internal cues that are likely to be more robust to noise than the internal cues of [ʁ]. In coda position, [l] is fully voiced (Chafcouloff 1985) whereas [ʁ] may be devoiced (Gendrot 2014). Periodic speech sounds are known to be more resistant to noise (Alwan, Jiang, & Chen 2011; Winn, Chatterjee, & Idsardi 2013). Therefore, the difference in voicing could be one of the bases for a perceptual asymmetry between the two liquids.

Finally, vowels are shortened before word-final [l] but not before word-final [ʁ] in French (Storme 2017). This means that word-final [l] is potentially cued by vowel duration in Vl# sequences whereas word-final [ʁ] is not. This difference holds for word-final contexts only: word-medially, both coda liquids trigger shortening of a preceding oral vowel. Therefore, the lateral is not expected to have an additional durational cue in word-medial positions.

1.3. Goal

The hypothesis that the French rhotic is less perceptible than the lateral in coda position has not been tested empirically. The only experiment investigating the perceptibility of French [ʁ] is Gendrot (2014), but it does not provide a comparison with coda [l]. The goal of this paper is to fill this gap by presenting the results of a study comparing the perceptibility of [l] and [ʁ] in Modern French in coda contexts.

The perceptibility of a consonant in a given context is taken to be the perceptual distance between this consonant and its absence in this context. d(x-∅, A) represents the perceptual distance between a sound x and its absence in a context A. The general hypothesis is summarized in (3).

(3) Hypothesis
In coda positions, the perceptual distance between [l] and ∅ is larger than the perceptual distance between [ʁ] and ∅: d(l-∅, coda) > d(ʁ-∅, coda).

Only a small set of coda contexts will be considered in this study: word-final positions after [i] and [a] ([i_#], [a_#]) and word-medial positions after [i] and [a] and before [t] ([i_t], [a_t]). [i] and [a] were chosen because they differ along several dimensions which were shown to be crucial for word-final [ʁ] identification in French: F2 and duration (Gendrot

2014). If the perceptibility of [ʁ] varies across vocalic contexts, this variation is likely to be manifested with [i] and [a].

Most relevant for Haitian is the perceptibility of [l] and [ʁ] in word-final positions. In word-final positions, coda-[ʁ] deletion in French is reported by Fouché (1952) to apply systematically only after [e] in the relevant period.[4] For other vocalic contexts, both coda [ʁ] and [l] are expected to have been present in the French input. In word-medial positions, the coda rhotic was particularly prone to deletion in the French input (Fouché 1952:863-864). As a consequence, it cannot be totally excluded that the difference in the treatment of word-medial liquids in Haitian follows from a phonological asymmetry in the input.

The details of the perception experiment are presented in section 2 and their results in section 3. Section 4 discusses some limitations of the study, proposes an interpretation of specific effects of the segmental context on the perceptibility of [l] and [ʁ], and presents a formalized analysis of the treatment of French liquids in Haitian as perceptually-filtered phonological adaptation. Section 5 concludes.

2. Method

A perception experiment was run to test the hypothesis that coda [l] is more perceptible than coda [ʁ]. The stimuli are presented in section 2.1. The task that participants performed is described in section 2.2. The theoretical and statistical models used to infer the perceptual distances from the data collected in the experiment are briefly described in section 2.3.

2.1. Stimuli

Nonce words varying by the presence/absence of [ʁ] or [l] were constructed. There was a total of 18 nonce words of the form [am{i,a}{ ʁ,l,∅}{o#, to#, #}], where ∅ is the empty segment and # marks the end of the word. Two properties of the nonce words were manipulated: the vowel that precedes [ʁ] or [l] ([i]/[a]) and the postconsonantal context. Note

[4] [i] is also reported to favor deletion of the rhotic. However, rhotics were reintroduced after [i] in *-ir* infinitives in French (Fouché 1952). It is therefore unclear whether rhotics were absent or not in the input in this context.

that [ʁ] was systematically deleted and [l] maintained in the coda contexts considered in the experiment in Haitian, as shown in Table 3.

	French	Haitian	
iʁ# ~ i#	rire [ʁiʁ]	ri [ɣi]	'to laugh'
aʁ# ~ a#	retard [ʁətaʁ]	reta [ɣeta]	'delay'
aʁt ~ at	partir [paʁtiʁ]	pati [pati]	'to leave'
iʁt ~ it	virtuel [viʁtyɛl]	vityèl [vitjɛl]	'virtual'
il# ~ il#	inutile [inytil]	initil [initil]	'useless'
al# ~ al#	cathédrale [katedʁal]	katedral [katedɣal]	'cathedral'
ilt ~ ilt	filtre [filtʁ]	filt [filt]	'filter'
alt ~ alt	altitude [altityd]	altitid [altitid]	'height'

Table 3.

Treatment of French coda laterals and rhotics in Haitian in the segmental contexts considered in the experiment.

Two native French speakers (a male and a female) were recorded reading the nonce words in the carrier sentence *Le mot X commence par un 'a'* 'The word X starts with an "a"'. Two lists of sentences were created, one with the nonce words varying by the presence or absence of [ʁ] and the other one with the nonce words varying by the presence or absence of [l]. Because there were six segmental contexts, each list contained twelve sentences (six for the condition where the consonant is present and six for the condition where the consonant is absent). Each list was read three times by both speakers, each time in pseudorandom order. This yielded a total of 144 items. Recordings for the stimuli were done using a Shure SM58 microphone sampling at 44 kHz in a sound-attenuated booth.

With the aid of a Praat script (Boersma & Weenink 2014) written by Gabriel Beckers, the root mean square amplitude of the sound files was equalized and scaled to a max peak value of 1. This was done to control for variations in intensity in the stimuli. With the aid of a Praat script written by Daniel McCloy, the sound files were mixed with white noise, using a signal-to-noise ratio of -3 dB (noise louder than signal). Two native French speakers checked that the stimuli were still audible. A substantial amount of noise was used in order to maximize the chance to see an effect and to make the task harder for French listeners who are familiar with liquids in coda position.

2.2. Task

The experiment was based on a forced-choice word identification task run online. It contained two parts: one where participants had to identify whether they heard words with or without [ʁ] and the other one where they had to identify words differing by the presence or absence of [l].

In each part, 72 stimuli were presented in random order. Participants were instructed to listen to the stimuli via headphones at a comfortable intensity level. They were asked to identify the word they heard, for instance *amirto* or *amito*, by checking the corresponding box. Four stimuli served as practice items. The experiment was conducted in a single session and no feedback was given. There was no limit on the response time but participants were asked to respond as quickly as possible.

2.3. Participants

Twenty native French speakers participated on a voluntary basis. French speakers were chosen rather than speakers of a Gbe language for practical reasons. See section 4.1 for discussion.

2.4. Analysis

Confusion matrices were built from the data collected in the experiment. A confusion matrix shows the number of times the relevant ([ʁ] or [∅] in the r-experiment and [l] or [∅] in the l-experiment) were identified correctly or incorrectly. The confusion matrices were analyzed using Equal-variance Gaussian Signal Detection Theory (SDT; Macmillan & Creelman 2005), a model that is widely used in studies of perception. SDT makes it possible to interpret confusion matrices in terms of perceptual distance and bias. The perceptual distance between [ʁ] and ∅ and the perceptual distance between [l] and ∅ are measures of how distinct [ʁ] and [l] are from ∅, respectively. Bias is a measure of the preference that listeners have for a specific answer, independent of the stimulus (e.g. a preference for answering [l] or ∅ in the l-experiment). The reader is referred to Macmillan & Creelman (2005) for more details on SDT and the assumptions of this model.

A probit regression model with binomial error was fit to corrected versions of the confusion matrices using the *glm* function in R (R Core Team 2016), with Preliquid vowel={[i],[a]}, Postliquid context={[o], [t], #}, Liquid={[ʁ], [l]}, and all their interactions as predictors. Probit regressions and binomial errors are used to model datasets where the dependent variable is binary (presence or absence of the liquid).

For each context and pair [ʁ]/∅ and [l]/∅, the model gives an estimate of the perceptual distance between the liquid and zero and an estimate of participants' bias to answer that the liquids is present or absent. The bias parameters are not directly relevant for the hypothesis tested in this paper and therefore will not be reported.

Corrected confusion matrices were used instead of the original ones. This is a common practice with SDT models fit within a frequentist statistical approach (see Lee & Wagenmakers 2013 for a Bayesian approach). The motivation is purely technical. When discrimination is extremely accurate, it is difficult to estimate the parameters of the model: if a sound is always correctly identified (as was sometimes the case in the present study), the distance parameter corresponding to the relevant pair of sounds will be very large (in principle, it corresponds to an infinite perceptual distance) and the standard deviation for this parameter will be very large too. Very large standard deviations are problematic because it is hard to conclude whether the estimate for the relevant perceptual distance is significant or not. For instance, in the present study, discrimination was at ceiling in the [i_o] condition for [ʁ] (see Table 5), yielding a very large standard deviation for the perceptual distance between [ʁ] and ∅ in this context. As a consequence, the perceptual distance between [ʁ] and ∅ in this context did not come out as significant in the model based on the original confusion matrices. This is clearly incorrect though: the perceptual distance between [ʁ] and ∅ should be large in this context since listeners do not make any identification errors.

Corrected matrices are a way to avoid this problem. Adding a small amount to each cell count makes it possible to avoid the problems due to perfect discriminability. Following Brown & White's (2005) recommendations, 0.3 was added to each cell count in the original confusion matrices shown in Table 5.

3. Results

The original confusion matrices (without correction) are shown in Table 4. The rows correspond to the stimuli that were played to the listeners and the columns to the listeners' response. For instance, the table in the top left corner in Table 4 describes the patterns of identification of [ʁ] and ∅ in the [a_o] context. Among the 120 presentations of [amao], 118 were correctly identified as [amao] and two were incorrectly identified as [amaʁo]. Among the 120 presentations of [amaʁo], three were incorrectly identified as [amao] and 117 were correctly identified as [amaʁo].

	∅	ʁ
∅	118	2
ʁ	3	117

aʁo/ao

	∅	ʁ
∅	118	2
ʁ	0	120

iʁo/io

	∅	l
∅	120	0
l	0	120

alo/ao

	∅	l
∅	76	44
l	7	113

ilo/io

	∅	ʁ
∅	112	8
ʁ	5	115

aʁto/ato

	∅	ʁ
∅	99	21
ʁ	21	99

iʁto/ito

	∅	l
∅	102	18
l	0	120

alto/ato

	∅	l
∅	66	54
l	1	119

ilto/ito

	∅	ʁ
∅	101	19
ʁ	31	89

aʁ#/a#

	∅	ʁ
∅	115	5
ʁ	36	84

iʁ#/i#

	∅	l
∅	118	2
l	0	120

al#/a#

	∅	l
∅	112	8
l	2	118

il#/i#

Table 4.

Confusion matrices by liquid and by context (data pooled across subjects).

Figure 1 shows the perceptibility of [l] and [ʁ] across the six segmental contexts in the experiment. The perceptibility of a consonant corresponds to the perceptual distance between this consonant and ∅, as estimated from the confusion matrices in Table 4 using the SDT model and the correction described in section 2.4. The four coda contexts are on the left side of the figure. The two onset contexts are on the right side.

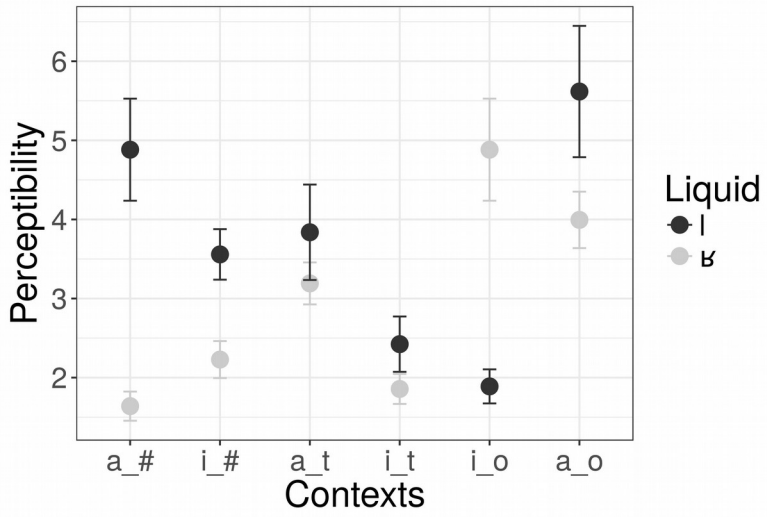

Figure 1.

Perceptibility of [l] and [ʁ] (in units of standard deviation).

In onset position ([a_o] and [i_o] contexts), liquids have a high perceptibility, if one puts aside the case of the lateral between [i] and [o]. In this context, listeners frequently incorrectly identified the nonce word *amio* as *amilo* (see Table 4). This is not incompatible with the perceptual hypothesis though: Gbe speakers were familiar with [l] occurring in this position in their native language and this could be the reason why French [l] was maintained in this position despite its low perceptibility.

The contexts that are most relevant for the perceptual hypothesis are the coda contexts ([a_#], [a_t], [i_#], [i_t]), as liquids did not occur in these positions in Gbe. The word-final context [a_#] is particularly relevant, as the rhotic does not seem to have been particularly subject to deletion in the French input in this position.

In the coda contexts, [l] was found to be more perceptible than [ʁ] on average: the perceptual distance between nonce words with and without coda [l] is 1.41 (±.26) units of standard deviation larger than the perceptual distance between nonce words with and without coda [ʁ] ($p < .001$). The perceptual advantage of coda [l] over coda [ʁ] was also found to depend on the segmental context, as can be clearly seen in Figure 1. The numbers in Table 5 indicate the difference between the perceptibility of [l] in the context indicated in the row and the perceptibility of [ʁ] in the context indicated in the column. Positive values correspond to a greater perceptibility of [l]. For instance, the top left cell indicates that [l] is more perceptible than [ʁ] in word-final position after [a] and the difference is equal to 3.24 units of standard deviation. The reader can check that this number corresponds to the difference between the perceptibility of [l] and [ʁ] in the [a_#] context in Figure 1. Significant estimates ($p < .05$) are bolded. P-values were corrected for multiple comparisons using the Bonferroni correction.

	d(ʁ-∅, a_#)	d(ʁ-∅, i_#)	d(ʁ-∅, a_t)	d(ʁ-∅, i_t)

d(l-∅, a_#)	**3.24 (.67)**	**2.65 (.69)**	1.69 (.70)	**3.03 (.67)**
d(l-∅, i_#)	**1.92 (.37)**	**1.33 (.40)**	.37 (.42)	**1.70 (.37)**
d(l-∅, a_t)	**2.20 (.63)**	**1.61 (.65)**	.65 (.66)	**1.98 (.63)**
d(l-∅, i_t)	0.78 (.40)	.19 (.42)	-.77 (.44)	.57 (.40)

Table 5.

Differences in perceptibility between [l] and [ʁ] in the four coda contexts (model estimates and standard deviations).

Several points can be made based on the results in Table 5. First, coda [ʁ] was never found to be significantly more perceptible than coda [l]. Second, coda [l] was always found to be more perceptible than coda [ʁ] in word-final position, in accordance with the perceptual hypothesis. Finally, the results are not as expected for two contexts. [l] was not found to be more perceptible in the [i_t] context than [ʁ] in coda position in general (see the last row in Table 5). [ʁ] was not found to be less perceptible in the [a_t] context than [l] in coda position in general (see the third column in Table 5). These results are problematic for a strong version of the phonetic hypothesis. See section 4.3 for a discussion of the implication of these results for the treatment of liquids in word-medial contexts.

4. Discussion

The results are compatible with the perceptual hypothesis. Coda [l] was found to be more perceptible than coda [ʁ] on average. In particular, coda [l] was found to be more perceptible than coda [ʁ] in word-final position. This is the context where the phonological hypothesis failed to predict rhotic deletion. In word-medial positions, [l] was not always found to be more perceptible than [ʁ]. This suggests that, for word-medial positions, an alternative to the phonetic hypothesis should probably be entertained.

Section 4.1 addresses some potential limitations of the present study related to the realization of the Modern French rhotic and the linguistic background of the listeners. Section 4.2 proposes an interpretation of the perceptual results in coda position based on previous research on [ʁ] and [l] in French and on an acoustic study of some of the stimuli used in the experiment. Section 4.3. discusses the implications of the perceptual results in word-medial coda contexts. Section 4.4 sketches an analysis of how the asymmetric perception of French

word-final liquids by Gbe listeners might have led to the emergence of a new phonological grammar, the Haitian grammar.

4.1. Potential limitations of this study

Two potential limitations of the present study must be addressed. First, the rhotic is realized as a uvular fricative or approximant in Modern French but this was not necessarily the case in 17th-18th century France.

The rhotic in 17th-18th century France is specifically reported to have been prototypically produced as a uvular trill [ʀ][5] rather than as a uvular fricative or approximant, as in Modern French (Zink 1986:29, 158). How problematic is it? The results of the experiment can still be relevant even if the prototypical rhotics in 17th-18th century French and in Modern French are not perfectly identical, as long as their perceptual properties are affected similarly by the syllabic context.

There is evidence in modern languages that uvular trills can have fricative-like variants in coda position. In the Dutch dialect of Maastricht, the uvular trill [ʀ] is realized as a partially devoiced uvular fricative [ʁ̥] in coda position (Gussenhoven & Aarts 1999:156), similar to the Modern French uvular fricative. This can be attributed to the difficulty to maintain voicing in coda obstruents, and in particular in obstruents articulated in the back of the mouth (Ohala 1983). If the same physiological facts held in French when Haitian emerged, the uvular trill might have had a coda allophone similar to the Modern French coda rhotic [ʁ̥]. Finally, the fact that coda rhotics are generally elided and coda laterals maintained in French loanwords in Fon suggests that the conditions that led to the Haitian pattern remained, despite the later change from the trill to the fricative in French.

Another potential limitation of the present study has to do with the language background of the listeners. Listeners who participated in the experiment were native French speakers. By contrast, the listeners involved in the emergence of Haitian had a Gbe linguistic background.

[5] It is important to stress that this is the protypical realization rather than the only realization of the rhotic. In French varieties spoken today across the world, the realization of the rhotic is quite variable. For instance, Klingler and Lyche (2012) report that, in Louisiana, the rhotic may be realized as an apical tap or a uvular fricative depending on the geographical location. This variability is likely to hold of the 17th-18th century French rhotic as well.

As reviewed in section 1.2, there is evidence that a speaker's first-language frames his/her ability to perceive in another language. Therefore, the results of the present study do not necessarily extend to Gbe listeners.

There are reasons not to be too pessimistic though. Liquids do not have an asymmetric phonological behavior in Modern French: both are allowed in coda position. If a perceptual asymmetry between the liquids is found, it cannot be attributed to the phonology. There is a frequency asymmetry in favor of coda [ʁ] in Modern French, with coda [ʁ] being more frequent than coda [l] in New et al.'s (2007) corpus of French subtitles (see Table 6).[6] This frequency asymmetry should favor [ʁ] over [l] in perception if anything. If coda [ʁ] is found to be harder to perceive than coda [l], as hypothesized, this cannot be attributed to a frequency effect. All in all, the linguistic background of French listeners (phonology and frequency) is not expected to favor coda [l] over coda [ʁ] in perception.

		Number	Frequency
l	onset	31,426	95,596
	coda	9,224	55,624
ʁ	onset	66,323	88,800
	coda	30,075	107,444

Table 6.

Number of occurrences of onset/coda [l]/[ʁ] in the French lexicon and frequency of words containing at least one onset/coda [l]/[ʁ] (per million of words).

Finally, as long as perception is not entirely determined by the grammar but also by external factors such as the strength of cues in the acoustic signal, a significant perceptual asymmetry between coda [l] and coda [ʁ] should be detectable even in French listeners.

4.2. Acoustic analyses

The perceptibility of [l] and [ʁ] was found to depend on specific aspects of the segmental context. This section proposes to intepret these effects based on previous research on the acoustic cues of [l] and [ʁ] and on an acoustic study of the stimuli.

[6]This asymmetry is probably partly due to high frequency suffixes like *–eur* (e.g. *chanteur* 'singer') and *–ir* (e.g. *finir* 'to end').

The perceptibility of coda [ʁ] was found to be better in the [a_t] context than in the other coda contexts, in particular in the minimally different [i_t] context. Can the difference between the [a_t] and [i_t] contexts be accounted for? Formant transitions are important cues for [ʁ] identification in [aʁ] sequences (Gendrot 2014). In particular, the presence of [ʁ] in *par la* [paʁla] 'by the' vs. *pas le/les/la* [pala] 'not the' is signaled by a lowering of [a]'s F2. Table 7 shows the mean F2 value of [i] and [a] in the nonce words *amito*, *amirto*, *amato*, and *amarto* that were presented to the participants in the experiment. Vowel F2 was measured at the vowel midpoint. One data point from the male speaker was discarded because it did not show a clear second formant to measure.

	[i]	[a]
_t	2112	1728
_ʁt	2054	1376

Table 7.

Mean vowel F2 (in Hz) in word-medial position before [t] and [ʁt] (data pooled across the two speakers).

As Table 7 shows, the lowering effect of [ʁ] is stronger on the F2 realization of [a] than on the F2 realization of [i]. This could explain the difference found in the perceptual data: the greater perceptibility of [ʁ] after [a] than after [i] could follow from a greater F2 distance between [ʁ] and ∅ after [a] than after [i].

Why is the effect of [ʁ] stronger on [a] than on [i] in this position? The higher resistance of [i] to coarticulation could follow from a desire to maintain [i] distinct enough from [y], which has a similar F1 value as [i] but a lower F2 value. There is no such risk with [a]: backing [a] will not compromise any contrast as dramatically since no other vowel is as low as [a]. This hypothesis predicts that one should not generally see an improvement in the perceptibility of word-medial coda [ʁ] with vowels other than [a]. This remains to be tested experimentally.

Why was coda [ʁ] found to be more perceptible word-medially than word-finally after [a]? Gendrot (2014) found that the duration of the V-to-C interval in [aʁC] vs. [aC] sequences is relevant for the perception of [ʁ]: this interval is shorter when the rhotic is present. In the carrier sentence used in the experiment, the target word was at the end of a syntactic phrase. Listeners might have had difficulties deciding whether the longer duration of the V-to-C

interval in the r-less condition word-finally was to be attributed to the absence of a rhotic or to the presence of a prosodic boundary. In the word-medial condition, there is no such ambiguity: if the V-to-C interval is quite long, it cannot be attributed to a prosodic boundary and has to be attributed to the absence of a rhotic.

The [i] context does not show a similar asymmetry between word-final and word-medial codas. However, this is not necessarily problematic for the interpretation that was previously given for the [a] context. Gendrot's (2014) study was specifically about the perceptibility of the rhotic after [a]. Because [a] and [i] have very different durations ([a] is longer than [i]), the findings about the durational cues available in the [a] context do not necessarily apply to the [i] context. Further research investigating the effect of vowel quality on the perceptibility of coda [ʁ] is required to address these questions more thoroughly.

The perceptibility of coda [l] was found to be the worst in the [i_t] context. Chafcouloff (1985) found that the F2 locus of [l] is quite high after [i]. The fact that [l] is flanked with two sounds with high F2 targets, [i] and [t], might explain why it is particularly hard to perceive in this context: [l] is expected to be assimilated to its context and therefore less perceptible.

4.3. Implications of the results in word-medial contexts

The hypothesis that coda [l] is systematically more perceptible than coda [ʁ] in word-medial contexts was not supported. This means that alternatives to the phonetic hypothesis should probably be entertained to explain the phonological asymmetry in Haitian in this context.

As already mentioned in the introduction, Fouché (1952) reports that word-medial coda rhotics were prone to deletion in 17th century and 18th century French. It is therefore possible that the asymmetry between the liquids in Haitian in word-medial contexts is due to a phonological asymmetry in the input.

4.4. The role of perception in grammar change

This section sketches an analysis of how the imperfect perception of French liquids by Gbe listeners led to the emergence of a new phonological grammar for liquids, distinct from both the Gbe and French grammars. Only word-final positions are considered, as these are the

contexts where the phonetic hypothesis is best supported. For concreteness, Optimality Theory (OT; Prince & Smolensky 1993) is used as a grammatical framework. However, the grammatical framework is not crucial. OT is used because it provides (i) a simple account of the difference between the three relevant languages with just three constraints and (ii) a simple analysis of the sound change in Haitian as a change in the relative ranking of two constraints. The present analysis is comparable to Russell Webb (2010), although simplified for expository purposes.

The phonological grammars modeling the distribution of Gbe, French, and Haitian are shown in (4). *CodaR and *CodaL are markedness constraints penalizing candidates with coda rhotics and coda laterals, respectively. Max(C) is a faithfulness constraint that penalizes deletion of underlying consonants. The symbol >> indicates that the constraint on the left side of >> takes precedence over the constraint on the right side of >>. For instance, the ranking in (4a) says that it is more important to ban rhotics and laterals from coda positions than to delete underlying consonants in surface forms.

(4) Constraint rankings

a. Gbe: *CodaR, *CodaL >> Max(C) (coda liquids are banned)
b. French: Max(C) >> *CodaR, *CodaL (coda liquids are allowed)
c. Haitian: *CodaR >> Max(C) >> *CodaL (only coda laterals are allowed)

The ranking in (4a) ensures that any liquid present in the input in coda position will not surface in the output (e.g. *sel* /sɛl/ → [sɛ], *la mer* /lamɛʁ/ → [lamɛ]): the two markedness constraints banning coda liquids outrank the faithfulness constraint requiring that input liquids are present in the output. This ranking models the distribution of [ʁ] and [l] in Gbe.

The ranking in (4b) ensures that any liquid present in the input will surface in the output whether in onset or coda position (e.g. *sel* /sɛl/ → [sɛl], *la mer* /lamɛʁ/ → [lamɛʁ]). This ranking models the distribution of [ʁ] and [l] in French.

The ranking in (4c) ensures that any lateral present in the input will surface in the output whether in onset or coda position and that any coda rhotic will be banned in the output (e.g. *sel* /sɛl/ → [sɛl], *la mer* /lamɛɣ/ → [lamɛ]). This ranking models the distribution of [ɣ] and [l] in Haitian.

When exposed to a French word with a coda liquid, Gbe speakers check their phonological grammar in (4a) and notice that it does not generate the output. Assuming that they are learning French, they then update their grammar accordingly in order to generate the output. For concreteness, let us assume that learning happens according to the Gradual Learning Algorithm (GLA; Boersma & Hayes 2001). The GLA is a learning algorithm for OT that specifies how OT constraints should be reranked in case the output form heard by the learner for a given input form differs from the output form predicted by his/her current grammar.

On a given evaluation of a French word with a coda lateral, a Gbe speaker following the GLA will demote the markedness constraint that favors the losing candidate without coda lateral (e.g. /sɛl/ → [sɛ]) and promote by the same amount the faithfulness constraint that favors the winner with a coda lateral (e.g. /sɛl/ → [sɛl]). After enough French words with coda liquids have been processed by the learner, enough promotions of Max(C) and demotions of *CodaL will have been performed so that Max(C) eventually outranks *CodaL.

On a given evaluation of an input word corresponding to a French word with a coda rhotic, the situation is different. Assuming the perceptibility of the rhotic in this position is too low for a Gbe speaker unfamiliar with coda consonants to perceive it, the rhotic is not represented in the input. Because the output without coda rhotic is already derived by the Gbe grammar, no update is performed and Max(C) remains ranked under *CodaR.

Liquids in onset positions are already allowed by the Gbe grammar. Therefore no further constraint reranking is required. The grammar where only Max(C) and *CodaL have been flipped corresponds to the Haitian grammar in (4c).

One potential problem for this account is the behavior of word-final rhotics before vowel-initial words when the two words form a phrase. In this context, the rhotic is expected to be more perceptible than a word-final rhotic before a pause or a consonant (see Fougeron 2007 for an acoustic comparison of word-final [ʁ] in prevocalic position and word-initial onset [ʁ] in French). It is plausible that the rhotic was lost in this context not for perceptual reasons but because Haitian speakers generalized the form from prepausal and preconsonantal contexts across word-final contexts. The interaction of perceptual factors and generalization has been documented in the literature on loanword adaptation (e.g. Kang 2010).

5. Conclusion

The Haitian case is an interesting test case in creole sound restructuring because the distribution of liquids in Haitian differs from the distribution of the corresponding sounds in the substrate language (Gbe) and the superstrate language (French) and therefore a purely phonological account is problematic. This paper provided a test of the hypothesis according to which the asymmetric adaptation of French liquids in Haitian is perceptually motivated, with the coda rhotic being less perceptible than the coda lateral in French. The results of a perception experiment studying the confusability of the liquids with zero in different contexts are compatible with this hypothesis, in particular for word-final positions.

More generally, the results of this study support the hypothesis that perception plays a role in shaping creoles' sound patterns (Russell Webb 2010) and that listeners play a crucial role in sound change (Ohala 1981).

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