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

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June 11, 2016

Abstract

Haitian Creole shows an asymmetry in the way it adapted French liquids: the French lateral has a correspondent in Haitian in post-vocalic coda position, but the French rhotic was elided in this position. This paper provides the first empirical test of the hypothesis according to which this asymmetry is perceptually grounded, with the French coda rhotic being less perceptible and therefore harder to learn than the French coda lateral. The results are broadly compatible with the perceptual hypothesis: (i) the coda lateral was to found to be more perceptible on average than the coda rhotic for French hearers in four different segmental contexts and (ii) the coda lateral was found to be never less perceptible than the coda rhotic in any of those contexts. The results also suggest that the deletion vs. maintenance of a sound in a given context cannot be explained only in terms of whether this sound is above or under a certain perceptual threshold in this context, but that either a notion of average perceptibility or phonological regularization across contexts is necessary in addition.

1 Introduction

Both French and Haitian, a French-lexifier creole, have a rhotic phoneme, transcribed as the voiced uvular fricative [ʁ] in French and as the voiced velar fricative [ɣ] in Haitian. Even though the two rhotics are historically related, their distribution differs across the two languages. French onset rhotics were adapted as [ɣ] or [w] before unrounded and rounded segments respectively in Haitian, but coda rhotics were systematically elided (Tinelli, 1981; Nikiema and Bhatt, 2003; Brousseau and Nikiema, 2006; Russell Webb, 2010; Valdman, 2015), without leaving a trace. As a result, words that were distinct in French became homophonous in Haitian. For instance, French *coup* [ku] "blow" (noun) and *cours* [kuʁ] "class" (noun) were both adapted as Haitian *kou* [ku] (Valdman, 1996, p. 470).[1] The patterns of adaptation of the French rhotic in Haitian in onset and coda positions are illustrated in Table 1: French onset [ʁ]s have a correspondent in Haitian (boldfaced), whereas French coda [ʁ]s don't.

		French	Haitian	
Onset	#ʁV_{-round}	rêver [**ʁ**eve]	reve [**ɣ**eve]	"to dream"
	VʁV_{-round}	serrer [se**ʁ**e]	sere [se**ɣ**e]	"to clench"
	#ʁV_{+round}	rose [**ʁ**ɔz]	wòz [**w**ɔz]	"pink"
	VʁV_{+round}	zéro [ze**ʁ**o]	zewo [ze**w**o]	"zero"
Coda	VʁC	merci [mɛ**ʁ**si]	mesi [mɛsi]	"thank you"
	Vʁ#	la mer [lamɛ**ʁ**]	lamè [lamɛ]	"sea"

Table 1: Distribution of the rhotic in French and Haitian. Haitian data from Valdman (1996). The French rhotic is systematically transcribed as [ʁ], even though it might have variable realizations.

By contrast, other French consonants generally have a correspondent in Haitian in post-vocalic coda position, as illustrated in Table 2.

	French	Haitian	
VS#	tête [tɛ**t**]	tèt [tɛ**t**]	"head"
VN#	pomme [pɔ**m**]	pòm [pɔ**m**]	"apple"
VF#	richesse [ʁiʃɛ**s**]	richès [ɣiʃɛ**s**]	"wealth"
VG#	portail [pɔʁta**j**]	pòtay [pɔta**j**]	"gate"
Vl#	sel [sɛ**l**]	sèl [sɛ**l**]	"salt"
VSC	saxophone [sa**k**sofɔn]	saksofòn [sa**k**sofɔn]	"saxophon"
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**mã]	alman [a**l**mã]	"German"

Table 2: Post-vocalic coda consonants in French and Haitian (S=stops, N=nasal stops, F=fricatives, G=glides). Haitian data from Valdman (1996).

Why did coda [ʁ] elide but not other coda consonants? The fact that the distribution of the Haitian rhotic ended up much more constrained than that of [l] in particular (Steele and Brousseau, 2006, pp. 343-345) is mysterious from the

[1] Some words show ʁ/∅ morphological alternations, e.g. *mèg* [mɛg] "thin" and *mègri* [mɛg**ʁ**i] "thinned" or *sik* [sik] "sugar" and *sikre* [sik**ʁ**e] "sweet." Some authors argue that ʁ has to be present underlyingly in coda in Haitian, e.g. /mɛgʁ/ (Nikiema and Bhatt, 2003). But the form without [ʁ] does not carry any phonetic reflex of [ʁ].

perspective of Haitian's substrate and superstrate languages, Gbe languages and French: the two sounds have the same distribution in French (both are licit in post-vocalic coda position) and in Gbe languages (both are illicit in post-vocalic coda position).

In French, [l] and [ʁ] belong to the same distributional class, the liquids (e.g. Tranel (1987)). Elision of the rhotic in coda position appears sporadically throughout the history of French, but never to the same extent as in Haitian (Zink, 1986; Russell Webb, 2010; Gendrot, 2014). In some varieties of French (e.g. in Québec French), the rhotic is subject to deletion in word-final clusters, e.g. Québec French *piasse* "dollar" [pjas] < *piastre* "piastre" [pjastʁ] and *livre* "book" [livʁ]/[liv]. But this deletion also affects the lateral, e.g. Québec French *tabarnac* (swear word) [tabaʁnak] < *tabernacle* "tabernacle" [tabɛʁnakl] and *règle* [ʁɛgl]/[ʁɛg] (Côté, 2004). In Haitian, both the lateral and the rhotic were deleted in this environment, e.g. *syèk* [sjɛk] "century" < *siècle* [sjɛkl] and *liv* "book" [liv] < *livre* "book" [livʁ]. In Québec French, post-vocalic coda rhotics may be vocalized, e.g. *porte* [pɔʁt]/[pɔət], whereas post-vocalic coda laterals are generally not (Côté, 2004, pp. 168-171). But this is different from the Haitian pattern: in Haitian, post-vocalic coda [ʁ] is deleted and not vocalized.[2] The distribution of Haitian [l] and [ɣ] in post-vocalic coda position is not a direct reflection of French: to our knowledge, there is no variety of French where the deletion of the coda rhotic is as systematic and the distributions of [l] and [ʁ] as divergent as in Haitian.

Modern Gbe languages have a uvular fricative, transcribed as [ʁ] (Capo, 1991, p. 55), and a lateral, transcribed as [l] (Capo, 1991, p. 49). Both are illicit in coda position, as consonants are in general in these languages. The distribution of the rhotic and the liquid in Haitian therefore does not reflect Gbe either. Finally, the pattern of rhotic deletion vs. lateral maintenance in post-vocalic coda position is also observed in French loanwords in some Gbe languages, for instance in Fon, e.g [dīlɛ̄tɛ̂] < *directeur* [diʁɛktœ**ʁ**] (Gbéto, 2000, p. 34) vs. [kɔ́**l**ù] < *col* [kɔ**l**] (Gbéto, 2000, p. 54). This suggests that (i) the pattern observed in Haitian is not just an accident and (ii) it may have its source not just in French or in Gbe, but in the contact of the two languages.

One general approach to language change in language contact situations, including in creolization, assumes that linguistic patterns from a source language are adapted or not depending on how hard they are to learn (e.g. Thomason and

[2]In French, mid vowels are lowered before coda [ʁ]'s as a result of the *loi de position*, which requires all 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 reflex 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. in *respè* [ɣɛsp**ɛ**] from *respect* [ʁɛsp**ɛ**] vs. *rivyè* [ɣivj**ɛ**] from *rivière* [ʁivj**ɛ**ʁ]. Also, this phenomenon is limited to mid vowels.

Kaufman (1988, pp. 49-50)). In the specific case of the adaptation of French liquids in Haitian, Russell Webb (2010) hypothesized that the difficulty is perceptual in nature, in line with Ohala's (1981) theory of "the listener as a source of sound change." The asymmetry between French and Haitian follows from a perceptual asymmetry between the post-vocalic coda liquids in French, with the rhotic being less perceptible than the lateral and therefore harder to learn. The fact that both onset [l] and onset [ʁ] were retained can be explained either as the result of them being familiar enough to Gbe speakers ([ʁ] and [l] occur in onset position in Gbe) or perceptually salient enough in the input. Onset positions are expected to be generally the most perceptible positions for consonants, based on the availability of release transitions.

We propose a specific implementation of this hypothesis, the "perceptual filter" model. This model has two steps, shown in (1): the input of the superstrate language (e.g. French) is filtered through a perceptual filter influenced by the linguistic experience of a speaker of the substrate language (e.g. Gbe), as detailed in (1a), and the perceptually filtered input form serves as an input to phonological learning, as detailed in (1b). The grammar resulting from the learning of the superstrate language by speakers of the substrate language might differ both from the superstrate grammar and substrate grammar. This is because the input from the superstrate grammar has been perceptually filtered and therefore can differ from the original input.

(1) The perceptual filter model
The surface representations (SR) in a Creole language are derived from the superstrate SRs in two steps:

a. Perceptual filter
Superstrate SRs are perceptually filtered by hearers accustomed to the sound patterns in their native language (=the substrate):
   i. Familiar sounds in familiar positions or perceptible enough have a correspondent.
   ii. Familiar sounds in unfamiliar positions have a correspondent **only if they are perceptible enough**, i.e. if their perceptibility is above a perceptual threshold θ.

b. Phonological learning
The substrate grammar is updated so that the candidate identical to the perceptually filtered input is selected as the output of the grammar.

This model is able to derive the distribution of Haitian liquids, assuming that coda [l] was more perceptible than coda [ʁ] for the first Haitian speakers. We show how it does so in the next two paragraphs.

Perceptual filter. Because onset liquids exist both in French and in Gbe, onset liquids are not filtered out by the perceptual filter: hence, *rêver* [**ʁ**eve] "to dream" $\xrightarrow{Perc}$ /**ɣ**eve/, *léger* [**l**eʒe] "light" $\xrightarrow{Perc}$ /**l**eʒe/.[3] However, because coda liquids do not exist in Gbe, only French coda liquids that are perceptible enough have a correspondent in the perceptually filtered input. Assuming that coda rhotics' perceptibility is smaller than θ and coda laterals' perceptibility is larger than θ, coda laterals have a correspondent in the perceptually filtered input, but not coda rhotics: *sel* [sɛ**l**] "salt" $\xrightarrow{Perc}$ /sɛ**l**/ and *la mer* [lamɛ**ʁ**] "the sea" $\xrightarrow{Perc}$ /lamɛ/.

Phonological learning. For concreteness, assume that phonological grammars are OT grammars (Prince and Smolensky, 1993). *CODAR and *CODAL penalize candidates with a coda rhotic and a coda lateral respectively. MAX(LIQUID) penalizes candidates where a liquid (rhotic or lateral) present in the input has no correspondent in the output. The ranking in (2a) ensures that any liquid present in the input in coda position will not surface in the output (e.g. *sel* /sɛl/ $\xrightarrow{Phon}$ [sɛ], *la mer* /lamɛʁ/ $\xrightarrow{Phon}$ [lamɛ]). This ranking models the distribution of [ʁ] and [l] in Gbe. This is the ranking from which learning starts. The ranking in (2b) ensures that any liquid present in the input will surface in the output whether in onset or coda position (e.g. *sel* /sɛl/ $\xrightarrow{Phon}$ [sɛl], *la mer* /lamɛʁ/ $\xrightarrow{Phon}$ [lamɛʁ]). This ranking models the distribution of [ʁ] and [l] in French.

(2) a. Gbe: *CODAR, *CODAL ≫ MAX(LIQUID) ≫ *ONSETLIQUID
    b. French: MAX(LIQUID) ≫ *CODAR, *CODAL, *ONSETLIQUID

Assume that phonological learning happens by re-ranking constraints and is error-driven, i.e. the learner alters its current ranking hypothesis only when the input data conflicts with it (e.g. Boersma and Hayes (2001)). For its output to match the filtered input (with coda laterals and without coda rhotics), a Gbe speaker will need to update his grammar so that MAX(LIQUID) and *CODAL are flipped in the ranking in (2a). MAX(LIQUID) and *CODAR need not be flipped as coda rhotics are not perceived: the Gbe subranking *CODAR ≫ *ONSETLIQUID is consistent with the input data and therefore is not altered. Flipping MAX(LIQUID) and *CODAL in the Gbe grammar in (2a) yields the Haitian grammar, shown in (3). This grammar only allows coda laterals to surface.

(3) Haitian: *CODAR ≫ MAX(LIQUID) ≫ *CODAL, *ONSETLIQUID

The model can explain the distribution of the liquids in Haitian, and more generally in any loanwords borrowed from French by Gbe speakers. However, the success of this model depends on an assumption that has not yet been tested yet,

[3] We assume that the mapping from ʁ to ɣ is a perceptual rather than a phonological mapping but this is not crucial to the analysis.

i.e. that coda [l] is more perceptible than coda [ʁ]. The only experiment investigating the perceptibility of French [ʁ] we know of is Gendrot (2014), but it is limited to word-final position and it does not provide a comparison with coda [l]. The goal of this paper is to fill this gap.

Following Russell Webb (2010, p. 267), we assume that the Modern French rhotic and lateral are similar enough to their correspondents at the time of creole genesis, in the 17th-18th century. Although the rhotic in 17th century France was probably realized as a uvular trill rather than as a uvular fricative (Zink, 1986, pp. 29, 158), we think that investigating the perceptibility of the Modern French rhotic is still relevant. First, it is not necessary that the sounds were realized exactly as their Modern correspondents for the results of the experiment to be relevant, as long as their perceptual properties were affected similarly by the syllabic context. Second, the fact that coda rhotics are generally elided and coda laterals maintained in French loanwords in Fon, as discussed above, suggests that the conditions that led to the Haitian pattern remained, despite the later change from the trill to the fricative in French.

In order to measure the perceptibility of a consonant in a given context, we measure the perceptual distance between this consonant and its absence in this context. We note d'(x-$\emptyset$, A) the perceptual distance between a sound x and its absence in a context A. The hypothesis that was tested is summarized in (4).

(4) Hypothesis
In coda positions, the perceptual distance between [l] and $\emptyset$ is larger than the perceptual distance between [ʁ] and $\emptyset$: d'(l-$\emptyset$, coda) $>$ d'(ʁ-$\emptyset$, coda).

Because the elision of coda rhotics applied across the board in Haitian, the hypothesis should hold true across all segmental contexts, except probably in word-final position before a vowel. In this position, [ʁ] should be roughly as perceptible as in onset position (see Fougeron (2007) for an acoustic comparison of [ʁ] in this position and word-initial onset [ʁ]). Also, in languages with coda fricative elision, fricatives sometimes give rise to sandhis in this context (Sole, 2010), e.g. in the French liaison: see *les parents* [**le**paʁɑ̃] "the parents" vs *les enfants* [**lez**ɑ̃fɑ̃] "the children." It is plausible that the rhotic was lost in this context not for perceptual reasons but because Haitian speakers generalized the form from pre-pausal and pre-consonantal contexts. Because there are fewer words starting with a vowel than a consonant in French, word-final coda rhotics in pre-vocalic position are likely to have been infrequent enough in the input received by early Haitian learners to motivate the extension of the pattern that emerged in the pre-vocalic and pre-pausal contexts.

In the experiment, only a small set of segmental contexts were considered for practical reasons. The details of the experiment are presented in section 2 and their results in section 3. Section 4 concludes with a discussion.

2 Method

A perception experiment was run to test the hypothesis that coda [l] is more perceptible than coda [ʁ]. The stimuli that the participants listened to are presented in section 2.1. The task that they performed is described in section 2.2. The theoretical and statistical model used to infer the perceptual distances from the data collected in the experiment is detailed 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] and the post-consonantal context. Note that [ʁ] was systematically deleted and [l] maintained in the coda contexts considered in the experiment in Haitian, e.g. *pati* [pati] "to leave" < *partir* [paʁtiʁ], *reta* [ɣeta] "delay" < *retard* [ʁətaʁ], *vityèl* [vitjɛl] "virtual" < *virtuel* [viʁtyɛl], *ri* [ɣi] "to laugh" < *rire* [ʁiʁ], *altitid* [altitid] "height" < *altitude* [altityd], *katedral* [katedɣal] < *cathédrale* [katedʁal], *filt* [filt] "filter" < *filtre* [filtʁ], *initil* [initil] "useless" < *inutile* [inytil].

The preceding vowel was either [i] or [a]. [i] and [a] were chosen because they differ along several dimensions that were shown to be crucial for word-final coda [ʁ] identification in French: F2 and duration (Gendrot, 2014). If the perceptibility of [ʁ] varies across vocalic contexts, this is likely to be manifested with [i] and [a].

Two native French speakers (a male and a female) were recorded reading the nonce words in the carrier sentence "Le mot ... commence par un a." Because the word *commence* starts with a [k] and the consonants [ʁ] and [l] in the word-medial coda condition were followed by [t], the word-final and word-medial conditions are not perfect minimal pairs: they differ both by word position (word-final vs word-medial) and the following segmental context ([t] vs [k]). However, we did not expect [k] in the following word to have a strong coarticulatory effect on [l] or [ʁ] (see the Discussion).

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]. Each list contained twelve sentences, six with the consonant and six without. Each list was read three times by both speakers, each time in pseudo-random 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 at MIT.

With the aid of a Praat script (Boersma and Weenink, 2014) written by Gabriel

Beckers,[4] 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,[5] the sound files were mixed with a noise with a signal-to-noise ratio of -3 dB (noise louder than signal) with the final intensity matched to the stimulus intensity. Two native French speakers checked that the stimuli were still audible. An substantial amount of noise was used in order to maximize the chance to see an effect.

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 French native speakers participated on a voluntary basis. French speakers were chosen rather than speakers of a Gbe language for practical reasons. The "perceptual filter" hypothesis states that what is relevant is the perceptibility of coda liquids for Gbe speakers rather than for French speakers. However, 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, it is expected that, if there is any perceptual asymmetry between coda [l] and coda [ʁ], it should be detectable for French speakers. The addition of noise allowed us to make the task harder for the French speakers.

2.4 Analysis

Confusion matrices were built from the data collected in the experiment. A confusion matrix shows the number of times each of the stimuli (signal or noise) was identified correctly or incorrectly. The confusion matrices were analyzed using

[4] http://wwwbio.leidenuniv.nl/ eew/G6/staff/beckers/beckers.html

[5] https://github.com/drammock/praat-semiauto/blob/master/MixSpeechNoise.praat

Signal Detection Theory, SDT (Macmillan and Creelman, 2005). SDT makes it possible to interpret confusion matrices as psychologically meaningful measures of discriminability and bias. Discriminability is a measure of how distinct the signal and the noise are. Bias is a measure of how the decision-making criterion differs from the optimal decision criterion. SDT distinguishes two components in the identification task: first, the stimulus (signal or noise) is mapped by the hearer onto a value on a single internal perceptual variable (information acquisition); second, a response is selected (signal or noise) by comparing this value to a criterion (decision). Information acquisition is assumed to be influenced by external/internal noise: different presentations of a single stimulus yield a distribution of perceptual values for this stimulus. In the most common equal-variance form of SDT, both the noise and signal distributions are assumed to have the same variance ($sd = 1$). Decision is made by establishing a criterion along the perceptual dimension.

Figure 1 illustrates the components of the SDT model used in the analysis. The distributions of the perceptual values for the two stimuli Signal and Noise are represented on the left and right respectively. The means of the signal distributions are separated by d, the perceptual distance between the two stimuli. The criterion is represented by the vertical bar with equation $x = c$. c is the location of the criterion relative to the midpoint between the signal distributions (centered on 0). Positive c corresponds to a bias against responding "Signal." All stimuli with perceptual values smaller than the criterion are treated as Noise; all stimuli with perceptual values larger than the criterion are treated as Signal. The proportion of signal stimuli correctly identified as signal stimuli (the area in light grey in Figure 1) is defined as the Hit rate, θ_h. The proportion of noise stimuli incorrectly identified as signal stimuli (the area in dark grey in Figure 1) is defined as the False alarm rate, θ_f.

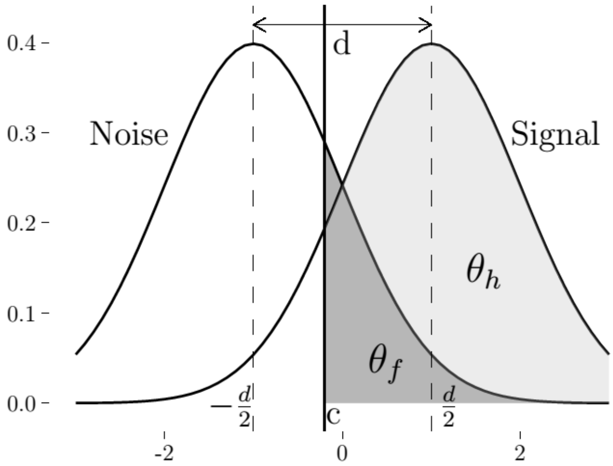

Figure 1: Equal-variance Gaussian Signal Detection Theory framework.

θ_h and θ_f are related to d and c via the cumulative distribution function of the standard normal distribution, Φ:

$$\begin{cases} \theta_h = \Phi(-c + d/2) \\ \theta_f = \Phi(-c - d/2) \end{cases}$$

By applying the inverse of Φ, i.e. the probit function $z()$, to both sides of the equations above, we obtain the linear equations:

$$\begin{cases} z(\theta_h) = -c + d/2 \\ z(\theta_f) = -c - d/2 \end{cases}$$

These equations can be rewritten as a single equation:

$$z(P(response = Signal|stimulus)) = -c + d * S$$

with S standing for a variable with a value of 0.5 when the stimulus is Signal and -0.5 when the stimulus is Noise:

$$\begin{cases} S = 0.5 & \text{if } stimulus = Signal \\ S = -0.5 & \text{if } stimulus = Noise \end{cases}$$

The probit of the response probability is a linear function of the stimulus variable S, where the coefficient of S equals d and the intercept equals $-c$.

In the experiment, the nonce words with ʁ or l were treated as the Signal and the words without ʁ or l as the Noise. 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 pre-C={i,a}, post-C={o, t, #}, and C={ʁ, l} and all their interactions as predictors. Corrected confusion matrices were used instead of the original ones because it was difficult to estimate model parameters when discrimination was extremely accurate. For instance, discrimination was at ceiling in the [i_o] condition for [ʁ], yielding very large standard deviations for the estimated perceptual distances. Following Brown and White (2005)'s recommendations, we added 0.3 to each cell count in the original confusion matrices.

3 Results

The non-corrected confusion matrices are shown in Figure 2.

	0	ʁ
0	118	2
ʁ	3	117

(a) aʁo/ao

	0	ʁ
0	118	2
ʁ	0	120

(b) iʁo/io

	0	l
0	120	0
l	0	120

(c) alo/ao

	0	l
0	76	44
l	7	113

(d) ilo/io

	0	ʁ
0	112	8
ʁ	5	115

(e) aʁto/ato

	0	ʁ
0	99	21
ʁ	21	99

(f) iʁto/ito

	0	l
0	102	18
l	0	120

(g) alto/ato

	0	l
0	66	54
l	1	119

(h) ilto/ito

	0	ʁ
0	101	19
ʁ	31	89

(i) aʁ#/a#

	0	ʁ
0	115	5
ʁ	36	84

(j) iʁ#/i#

	0	l
0	118	2
l	0	120

(k) al#/a#

	0	l
0	112	8
l	2	118

(l) il#/i#

Figure 2: Confusion matrices. Data pooled across subjects.

Figure 3 shows the distance parameters d for each consonant in each context. Figure 4 shows the bias parameters c for each consonant in each context. Both were estimated by the SDT model fit via probit regression.

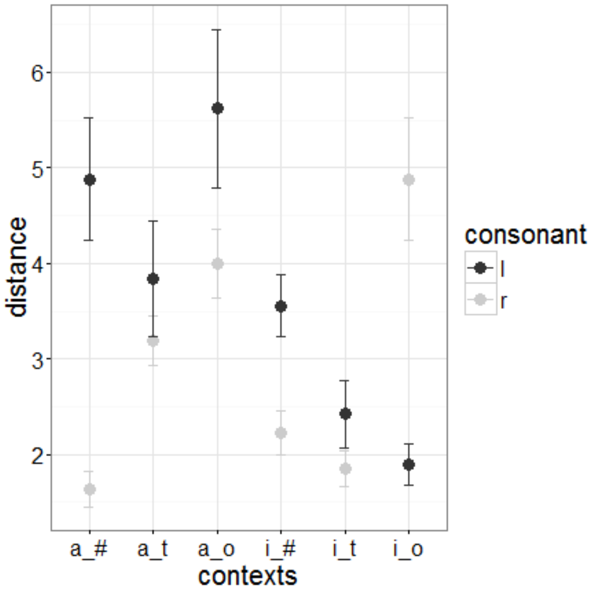

Figure 3: Estimated perceptual distances between nonce words with and without [ʁ] or [l] (in units of standard deviation).

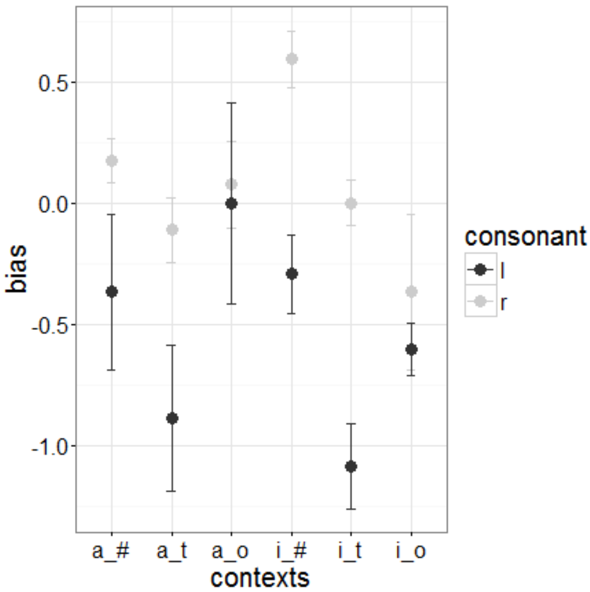

Figure 4: Estimated biases (in units of standard deviation). A positive value corresponds to a bias in favor of the nonce word without [ʁ] or [l]. A negative value corresponds to a bias in favor of the nonce word with [ʁ] or [l].

On average, coda [l] was found to be more perceptible than coda [ʁ], with the average perceptual distance between nonce words with and without coda [l] being 1.41 ($\pm.26281$) units of standard deviation larger than the perceptual distance between nonce words with and without coda [ʁ] ($p < .001$). However, the difference in perceptibility between coda [l] and coda [ʁ] also depends on the segmental context. Coda [l] was found to be more perceptible than coda [ʁ] only in eight of the sixteen relevant comparisons, as shown in Table 3. In the other contexts, the perceptibility of coda [l] was not found to be significantly different from that of coda [ʁ]. Note however that coda [ʁ] was never found to be significantly more perceptible than coda [l].

	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 3: Differences in perceptibility between [l] and [ʁ] in the four coda contexts (model estimates and standard deviations). Positive values correspond to a greater perceptibility of [l]. Significant estimates ($p < .05$) are bolded. P-values were corrected for multiple comparisons using the Bonferroni correction.

4 Discussion

The results are broadly compatible with the perceptual hypothesis, as (i) coda [l] was found to be more perceptible than coda [ʁ] on average and (ii) coda [ʁ] was not found to be more perceptible than coda [l] in any context. However, they do not support the specific version of the perceptual hypothesis put forth in the introduction. This is because the results also suggest that the segmental context matters in determining the perceptibility of [ʁ] vs [l] in coda position. In particular, the perceptibility of coda [ʁ] was found to be improved in medial coda after [a] as compared to other coda contexts, even though coda [ʁ] was lost in this context, e.g. *pati* [pati] "to leave" $<$ *partir* [paʁtiʁ]. Also, the perceptibility of coda [l] was found to be worsened in medial coda after [i] as compared to other contexts, even though coda [l] was maintained in this context, e.g. *filt* [filt] "filter" $<$ *filtre* [filtʁ]. In 4.1, an interpretation of these results is proposed based on previous research on the perceptibility of [ʁ] in French and on a preliminary acoustic study of the recordings used in the experiment. In 4.2, we discuss two ways of fixing the "perceptual filter" hypothesis: resorting to average perceptibility across contexts or to phonological regularization. In 4.3, a frequency-based hypothesis is considered and shown to fail to derive the Haitian pattern.

4.1 Explaining the results

The perceptibility of coda [ʁ] was found to be improved in medial coda after [a] as compared to other coda contexts: the a_t context is the only coda context in which the perceptual distance between [ʁ] and its absence is larger than 3 units of standard deviation (see Figure 3). This improvement might explain the absence of a difference between coda [l] in general and coda [ʁ] in this particular context (see column 3 in Table 3). Since vowel duration and formant transitions from the preceding vowel are important cues for word-final coda [ʁ] identification (Gendrot, 2014), it is not very surprising that the perceptibility of [ʁ] might be affected differently after [i] than after [a]: [i] is higher, fronter, and shorter than [a] (Calliope, 1989; Gendrot and Adda-Decker, 2005; Rochet and Rochet, 1991). We must account however for why [ʁ]-perceptibility is better after [a] than after [i] in word-medial coda, but not in word-final coda though.

We start with the comparison between word-medial coda [ʁ]s after [i] and after [a]. Gendrot (2014) showed that the presence of [ʁ] in the sequences *par le/les/la* [paʁlV] vs *pas le/les/la* [palV] is signaled by a lowering of [a]'s F2. We assume that [ʁ] identification relies on the same cues in word-medial as in word-final codas and after [i] as after [a]. We hypothesize that [ʁ] is less perceptible after [i] than after [a] in word-medial coda because it does not lower [i]'s F2 as much as [a]'s F2. The higher resistance of [i] to coarticulation could follow from a desire to maintain [i] distinct enough from other neighbouring vowels like [y] and [e]. There is no such risk with [a], as backing [a] will not compromise any contrast as dramatically: no other vowel is as low (has as high F1) as [a]. In the appendix, we show measurements suggesting that the hypothesis according to which [i] is less coarticulated with [ʁ] than [a] is correct.

We move on to the comparison between word-medial and word-final coda positions. The reason why [ʁ] was found to be less perceptible in word-final than in word-medial coda after [a] might have to do with the nature of the following consonant: [t] in word-medial coda vs [k] in word-final coda (in the word *commence* [komɑ̃s] "start"). Uvular [ʁ] is expected to be more similar to [k], a velar, than to [t], a dental, and this might have affected its perceptibility in the word-final vs word-medial coda position. If this hypothesis is correct, it is expected that the perceptibility of word-final [ʁ] should be slightly improved when followed by a non-velar consonant.

The perceptibility of coda [l] was found to be worsened in medial coda after [i] as compared to other coda contexts: the i_t context is the only coda context where the perceptual distance between [l] and its absence is smaller than 3 units of standard deviation (see Figure 3). This worsening might explain the absence of difference between coda [ʁ] in general and coda [l] in this particular context (see the last row in Table 3). 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.

4.2 Weakening the "perceptual filter" hypothesis

In general, coda [l] was found to be more perceptible than coda [ʁ]: the distance between words with and without coda [l] is larger than 3 units of standard deviation in 3 out of 4 cases and the distance between words with and without coda [ʁ] is smaller than 3 units of standard deviation in 3 out of 4 cases (see Figure 3). Based on these preliminary results, a possible alternative in the "perceptual filter" paradigm might be entertained, where the average perceptibility of a sound across contexts (here, the coda contexts) plays a role rather than its perceptibility in each context (here, the different coda contexts corresponding to different segmental environments). A sound (here [ʁ]) can be filtered out in all contexts (here all coda contexts) if it is only perceptible enough in a minority of them (here in the a_t context). A sound (here [l]) can have a correspondent in all contexts (here coda contexts) in the perceptually filtered input if it is perceptible enough in enough of these contexts (here in the i_#, a_, and a_t contexts). The idea is that a hearer hearing a sound that is on average more perceptible than another sound becomes more accustomed to the cues signaling this sound and is therefore better equipped to detect them in contexts where they are less salient. More segmental contexts should be considered to test whether this hypothesis is on the right track.

Discrepancies between the perception data in experiments, which tend to be variable, and the patterns of adaptation, which tend to be more regular, have also been observed in loanword phonology (Peperkamp and Vendelin, 2008; Kang, 2010). Kang (2010) argues that this is because loanwords start as phonetic adaptations of the input language and are regularized over time. A similar explanation could be given to the Haitian data. The first layer of the Haitian vocabulary could have reflected the way French sounds were perceived by Gbe speakers, i.e. with a few coda [ʁ]s and more coda [l]s being faithfully reflected in Haitian surface forms. The preference for a simpler grammar could have later led to a regularization, resulting in the deletion of all coda [ʁ]s and the maintenance of all post-vocalic coda [l]s.

4.3 Problems for a frequency-based approach

Sound frequency has also been argued to play a role in explaining patterns of deletion in language change, with sounds occurring more frequently being more likely to be transmitted across generations (see for example Cohen Priva's (2008) “phone informativity”). We apply our own version of this line of analysis to Haitian, hypothesizing that the frequency of sound patterns in the input to the learner explains the asymmetry between the adaptation of coda [ʁ] and [l]. We show that, even though this analysis is able to predict an asymmetry between the adaptation of coda [ʁ] and coda [l], it wrongly predicts that coda [ʁ] should have been retained rather than coda [l]. We assume throughout that the substrate and superstrate phonologies were the same at the time of Creole genesis as now, at least with respect to the distribution of liquids, and that the frequencies of sound patterns in contemporary French reflect the frequencies of sound patterns in the variety of French that served as input to the first Haitian speakers.

Assume that a Gbe speaker is exposed to words produced by French speakers (e.g. *sel* [sɛl], *la mer* [lamɛʁ]) and modifies its initial grammar gradually so that it produces the same output words as the grammars of French speakers. If learning happens but is incomplete, the resulting grammar will differ both from the substrate and superstrate grammars. For its output to match the French output, a Gbe speaker will need to update his grammar so that the ranking of MAX(LIQUID) and *CODAR and the ranking of MAX(LIQUID) and *CODAL are flipped. The Haitian grammar, shown in (5a), corresponds to the Gbe grammar where only the ranking of MAX(LIQUID) and *CODAL has been flipped and can therefore be conceived as the product of partial learning of French. This grammar maps [sɛl] to [sɛl] and [lamɛʁ] to [lamɛ]. Another potential result of partial learning is the grammar of Haitian′, shown in (5b), where only the ranking of MAX(LIQUID) and *CODAR has been flipped.

(5) a. Haitian: *CODAR ≫ MAX(LIQUID) ≫ *CODAL, *ONSETLIQUID
b. Haitian′: *CODAL ≫ MAX(LIQUID) ≫ *CODAR, *ONSETLIQUID

Since words with coda [ʁ]s are more frequent than words with coda [l]s in French (see Table 4), a learner of French will get more evidence for flipping the ranking of MAX(LIQUID) and *CODAR than the ranking of MAX(LIQUID) and *CODAL. Partial learning should result in Haitian′ rather than Haitian. A model building on phonological learning and frequency asymmetries alone is unable to capture the Haitian pattern.

		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 4: Number of occurences 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). Data from Lexique 3.80 (New et al., 2007).

5 Conclusion

In this study, we examined the asymmetric adaptation of French liquids in Haitian Creole (deletion of coda [ʁ] vs maintenance of coda [l]) focusing on the "perceptual filter" hypothesis, according to which the asymmetry follows from the greater perceptibility of coda [l] for speakers unhabitued to coda consonants in general. The results do not support the simplest version of this hypothesis, where sounds present in unfamiliar contexts in the input are deleted in contexts where their perceptibility is below a certain threshold and retained in contexts where their perceptibility is above this threshold. This is because coda [l] was not found to be more perceptible than coda [ʁ] in all coda contexts. However, they are compatible with weaker versions of the perceptual hypothesis, where average perceptibility or phonological regularization are also given a role. We also showed that the asymmetry cannot be explained in terms of frequency alone as words with coda [l] occur less frequently than words with coda [ʁ] in French. More generally, the results of this study are in line with models attributing a role both to the target and source phonologies and to perceptual factors in explaining patterns arising from language contact, e.g. creolization, loanword phonology, and second language learning.

6 Appendix

Table 5 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 testing the perceptibility of [ʁ].

	[i]	[a]
t	2112	1728
ʁt	2054	1376

Table 5: Mean vowel F2 (in Hz) in word-medial position before [t] and [ʁt] (data pooled across the two speakers). 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.

Table 6 shows the mean duration of the sequence spanning from the beginning of the medial vowel ([i] or [a]) to the beginning of [t] in the nonce words *amito*, *amirto*, *amato*, and *amarto* that were presented to the participants in the experiment testing the perceptibility of [ʁ].

	[i]	[a]
Vt	231	232
Vʁt	265	284

Table 6: Mean duration (in ms) of the sequence spanning from the beginning of the vowel to the beginning of [t] in word-medial position (data pooled across the two speakers).

The F2 difference between the vowel allophones before [t] and before [ʁt] is larger for [a] than for [i]. The duration difference between the sequences with [ʁ] and without [ʁ] is larger when the vowel is [a] than [i]. This might explain why [ʁ] was less perceptible after [i] than after [a] in this condition (see Discussion).

Acknowledgements

Thank you to Edward Flemming, Adam Albright, Michel DeGraff, Junko Îto, Juliet Stanton, Donca Steriade, the members of the Phonology Circle at MIT, the members of the *Groupe de Recherche sur les Grammaires Créoles* in Paris, participants in Console 2016 in York, and participants in OCP 2016 in Budapest for helpful comments on this project. All errors are my own.

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