Zellou, Georgia & Chitoran, Ioana. 2023. Lexical competition influences coarticulatory variation in French: comparing competition from nasal and oral vowel minimal pairs. *Glossa: a journal of general linguistics* 8(1). pp. 1–27. DOI: https://doi.org/10.16995/glossa.9801

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Lexical competition influences coarticulatory variation in French: comparing competition from nasal and oral vowel minimal pairs

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It is hypothesized that the phonological status of a phonetic feature across languages predicts patterns of coarticulatory variation. In French, vowel nasality encodes lexical contrast, e.g. *cède* /sɛd/ vs. *saint* /sɛ̃/. Vowel nasality also occurs as coarticulation from nasal consonants (e.g. *scènes* /sɛn/), though it is minimal in degree arguably due to pressure to maintain the contrast between phonologically oral and nasal vowels. Yet, the extent to which this constraint actively shapes coarticulatory patterns across words within French is underexplored. The present study investigates word-specific coarticulatory variation in French. One prediction is that nasal-coda words (CVNs) with a nasal vowel minimal pair competitor are produced with even less coarticulatory nasalization than CVN words that have no nasal vowel competitor, consistent with a coarticulatory constraint proposal. Yet, a competing hypothesis is that competition from CVC words creates greater confusability for CVNs and that enhanced coarticulatory cues provide robust perceptual cues about what is unique and distinctive about a CVN. Thus, an alternative prediction is that greater coarticulatory nasality will be produced on CVNs when there is a CVC minimal pair competitor. Results from 30 Metropolitan French speakers reveal that lexical competition from nasal vowel competitors predicts coarticulatory variation: CVNs with nasal vowel minimal pairs are produced with less anticipatory nasal coarticulation. Moreover, CVNs with highly frequency nasal vowel competitors are produced with even less anticipatory coarticulatory nasality. These findings have implications for the relationship between phonology and coarticulatory patterning, as well as cognitive mechanisms for lexically-conditioned phonetic variation.

1. Introduction

Each language uses a set of phonologically contrastive sounds as the building blocks for words. Yet, there is enormous variation in how phonemes are pronounced across languages, as well as across words within a language. Coarticulation refers to the articulatory and acoustic variability that arises from the fact that speech gestures are continuous and overlapping. Even if the phonological representations of adjacent segments are distinct, they influence each other to become more phonetically similar in natural speech. More specifically, coarticulation is a type of context-dependent phonetic variation that results from temporal overlap of gestural features from adjacent segments. For instance, in a vowel-nasal sequence, the velum lowering gesture associated with the nasal consonant starts during the preceding vowel. Coarticulatory variation is a natural property of produced speech, and in fact necessary for fluent production. In all languages, vowels are nasalized to some extent when they are produced before a nasal consonant, indicating that coarticulation is a universal feature of natural language production.

However, even though coarticulation is due to articulatory overlap, its patterning cannot be strictly reduced to resulting from automatic motor processes. For instance, there is much prior work demonstrating that patterns of coarticulation are language-specific (Keating & Cohn 1988; Manuel 1990; Beddor et al. 2002; Scarborough et al. 2015; Stoakes et al. 2020), suggesting that speakers learn aspects of coarticulatory detail in their grammatical systems. Coarticulation also varies systematically within a language, e.g., across words and communicative contexts (Solé 1992; Iskarous & Kavitskaya 2010; Zellou et al. 2016; Cho et al. 2017; Zellou 2017). Moreover, listeners show sensitivity to patterns of coarticulation in making linguistic decisions (Beddor et al. 2013), and speakers vary in their coarticulatory patterns in ways that appear to be sensitive to listeners' needs (Scarborough 2013; Scarborough & Zellou 2013; Zellou & Scarborough 2015). Thus, work investigating coarticulatory variation shows that speech production mechanisms are exquisitely sensitive to a speaker's dynamically changing goals during speech communication.

The case of variability in vowel nasality within and across languages provides a particularly critical set of phenomena to understand how lexical contrast shapes phonetic variation in ways that can inform models of speech production. In American English, for instance, nasal consonant-adjacent vowels are coarticulated, produced at least partly with a lowered velum, causing them to be nasalized as well. Thus, in a word like *ban*, the vowel is nasalized to yield [bæ̃n]. In French, vowel nasality is contrastive, for example, *beau* [bo] and *bon* [bõ] differ phonologically with respect to nasality on the vowel. Yet, oral vowels are produced with coarticulatory nasalization when they occur in the context of a nasal consonant in French (e.g., *bonne* [bɔ̃n]). Since nasal coarticulation might lead to confusability for listeners between non-contrastive and contrastive vowel nasality, the constrained degree of coarticulatory nasalization in French has been argued to be motivated to avoid confusability with phonologically nasal vowels (Chafcouloff & Marchal 1999: 75). However, this anticipatory nasal coarticulation has been observed to be of minimal extent (e.g., Cohn 1990; Spears 2006; Delvaux et al. 2008). Moreover, phonologically nasal vowels in French have been shown to have distinct tongue positions (Delvaux 2009; Carignan 2014). Therefore, there might be pressure to make the contrast between words with oral and nasal codas more distinct by enhancing the degree of coarticulatory nasalization.

The aim of the current study is to investigate non-contrastive patterns of anticipatory coarticulatory vowel nasalization in French. Carryover nasal coarticulation is also observed in French (e.g., *mais* 'but' /mɛ/ [mɛ̃]), and it has been observed to be comparable in degree to contrastive nasality (Cohn 1990). However, the present study focuses on the production of anticipatory coarticulation since it is most relevant for understanding how speakers modulate cues to upcoming segments that provide predictive information to listeners. The broader goal is to provide insight into the role of coarticulation in speech communication and the effect of lexical contrast in shaping patterns of phonetic variation.

1.1. Theoretical accounts of coarticulatory variation

A major theoretical stance is that phonetic variation can be related to perceptual motivations, i.e., that speakers structure the speech signal to be maximally intelligible for listeners, especially to be robust under all types of adverse communicative contexts. What does this mean for synchronic, within-language patterns of coarticulation? There are two different approaches to this question – *coarticulatory constraint* and *coarticulatory enhancement* accounts – which we explore in this section.

Some researchers hold that coarticulation can jeopardize phonological contrast in languages where the same phonetic value is realized as both a coarticulatory and a contrastive property. *Coarticulatory constraint* proposals, such as those by Manuel (1990; 1999; inter alia), hypothesize that coarticulation is constrained to maintain perceptual contrast as determined by the phoneme inventory of a language. For example, Manuel and Krakow (1984) found that the fewer phonemic vowels a language has, the more extensive the realization vowel-to-vowel coarticulation is, compared to a language with more phonemic vowels. In other words, the degree of vowel-to-vowel coarticulation is shown to be constrained when there are more phonemic vowel distinctions. In other words, the finite acoustic space for the range of possible vowel permutations requires vowel systems with more phonemic vowels to delimit contextual effects in order to maintain contrast between the vowels.

In French, words can differ phonologically with respect to nasality on the vowel (e.g., *beau* /bo/ vs. *bon* /bõ/). But non-contrastive coarticulatory nasality occurs in the context of nasal consonants, as well. In these cases, the vowels are underlyingly oral, but are produced with some amount of phonetic nasalization due to gestural overlap from the velum lowering associated with the coda (e.g., *bonne* /bon/ [bõn]: Cohn 1990; Delvaux et al. 2008). So oral vowels are nasalized when they occur adjacent to nasal consonants. This means that vowel nasality is both contrastive and non-contrastive in French. Hence, a listener who encounters a nasalized vowel in French would have to discern whether the nasality is the result of a contrastively (i.e., phonologically) nasal vowel or a phonetically nasalized oral vowel preceding a nasal consonant coda (note that nasal vowels are not allowed before nasal codas in French, *ṼN). Thus, in French, the very fact that vowel nasality is contrastive in the language might limit the realization of anticipatory coarticulation, or might lead to perceptual difficulty or confusion to the extent that it does occur. Comprehensive existing production studies of vowel nasality in French indeed indicate that contrastive nasality tends to be greater than anticipatory nasal coarticulation (Montagu & Amelot 2005; Delvaux et al. 2008). (In French, carryover nasal coarticulation is much greater in degree than anticipatory coarticulation, which is comparable to phonemic vowel nasality (Cohn 1990; Delvaux et al. 2008), but since we are interested in how coarticulatory variation may be relevant for providing predictive cues to listeners, the current study focuses on nasal coarticulation in words with VN sequences.) These differences in the patterns of nasalization across contrastive and anticipatory coarticulatory nasality might represent perceptually-motivated constraints on speakers.

Work by Cho and colleagues (e.g., Cho, Kim, & Kim 2017; Jang, Kim, & Cho 2018; Li, Kim, & Cho 2020) have investigated how coarticulatory vowel nasalization varies within a language as a function of prosodic prominence, such as contrastive focus marking. They find that vowels in CVN words that are produced in prosodically strong positions (either being phrase-initial or under contrastive focus) are produced with less coarticulatory nasalization than those in weaker positions. For instance, Cho et al. (2017) elicited contrastive focus through mini-dialogues such as the following: A: *Were you supposed to write BOB?* B: *No, I was supposed to write BOMB, wasn't I?*. Despite cross-linguistic differences in the implementation of contrastive focus, similar patterns of reduced nasal coarticulation under focus were found across English, Mandarin Chinese, and Korean. Cho and colleagues interpret this as a type of phonologically-conditioned coarticulatory constraint strategy: in strong positions, speakers reduce coarticulation, both to make cues to coda nasality more synchronous with its source and, potentially, in order to enhance phonetic cues for the [orality] feature of the vowel. While these languages do not have contrastive vowel nasalization, such patterns are consistent with the hypothesis that speakers will reduce coarticulation in order to make their phonological properties distinctive and apparent.

There is also evidence that coarticulatory constraint in French, specifically, leads to word-specific variation in contextual nasalization patterns. This evidence comes from vowel-specific variation in coarticulation. Dow (2020) reports that in French, nasal coarticulation in CVN words is greater in extent for high vowels, compared to non-high vowels. Dow argues that since French does not have phonologically nasal high vowels, the constraint on reducing coarticulation to avoid lexical confusion is not active for high vowels in pre-nasal contexts. Thus, the high vowel vs. non-high vowel asymmetry in patterns of coarticulation in pre-nasal contexts is argued to be due to the presence of phonological nasalization for non-high vowels.

Yet, the extent to which such a constraint actively shapes coarticulatory patterns in French is underexplored. Does lexical contrast actively constrain nasal coarticulatory variation across words in French? One prediction from a coarticulatory constraint hypothesis is that lexical competition from a nasal vowel (CṼ) word would lead to a reduction of nasal coarticulation in its nasal-coda (CVN) minimal pair, compared to CVN words without a nasal vowel minimal pair competitor.

Yet, another hypothesis about the role of coarticulation in speech communication is that it provides phonetic cues to what is unique about the identity of a particular lexical item (Scarborough 2013; Scarborough & Zellou 2013; Zellou & Scarborough 2015; Zellou & Scarborough 2019). *Coarticulatory enhancement* accounts view coarticulation as useful information for listeners, since it provides redundant and predictive (for anticipatory coarticulation) cues and can be used by listeners to make perceptually relevant predictions because it is systematic (Beddor 2009; Scarborough 2013). For instance, by increasing the degree of nasalization on an English word such as *bone*, speakers can make the lexical item more distinct, and thus easier to discriminate, from words without nasal segments such as *bode* (Beddor et al. 2013; Zellou & Dahan 2019).

Note that the predictions of a coarticulatory enhancement account seem to be not supported by the results observed in the work of Cho and colleagues outlined above. Why are CVN words in focus position produced with decreased coarticulation if the speaker is responding to a listener misunderstanding? A coarticulatory enhancement account might predict increased coarticulation in those contexts. However, the cross-linguistic observation of decreased coarticulation in focused positions is consistent with articulatory strengthening of segmental gestures when words are produced in prosodically strong phrasal positions (Fougeron & Keating 1997). The strengthening of segments leads their gestures to be more concentrated on their targets and results in a reduction of temporal overlap of speech sounds (Cho et al. 2017). While prosodic strengthening of words under focus will lead to gestural restructuring due to articulatory factors, a coarticulatory enhancement account might predict that speakers produce increased coarticulatory cues when prosodic factors are controlled for. As we explore in the next section, one way to investigate predictions made by a coarticulatory enhancement account is to compare across words, produced in the same prosodic context, that differ in their perceptual difficulty.

1.2. Lexically-conditioned phonetic variation

In exploring the source of lexically-conditioned phonetic variation, this paper also adds to the growing body of work investigating the cognitive processes driving word-specific speech production. Lexically-conditioned phonetic variation is when some acoustic property of words can be systematically related to the composition, architecture, or activation of the lexicon. A fact about the lexicon is that phonological competition is not equally distributed: some words have many minimal pair competitors and others have very few. One proposal is that speakers produce phonetic cues on words to make them more distinct from their lexical competitors. For example, speakers produce words that come from lexical neighborhoods containing more phonologically similar competitors with greater vowel dispersion than words with fewer lexical competitors (Wright 1997; 2004; Munson & Solomon 2004).

Some researchers (e.g., Wright 2004) have interpreted this pattern as perceptually-motivated: vowels in the words from more dense lexical neighborhoods are hyperarticulated to make them more distinctive and, thus, more intelligible. Furthermore, Wedel and colleagues (2018) examined spontaneous speech productions of English words and found that the existence of a minimal pair or not, not neighborhood density, predicts phonetic variation. For instance, they observed that the type of phonological contrast posed by a lexical competitor affected the phonetic variation: e.g., words with an initial voiceless stop are produced with longer VOT when an initial voiced stop minimal pair exists and initial voiced stop words are produced with shorter VOT when an initial voiceless stop minimal pair exists. Critically, though, they found that minimal pair-conditioned phonetic variation serves to maximize *phonetic distance* between lexical competitors. Specifically, words with lax vowels are produced with more vowel centralization when it has a tense vowel minimal pair competitor (e.g., 'ship' vs. 'sheep'). They argued that minimal pair competition promotes maximization of phonetic distance between lexical items.

Coarticulation has also been observed to be conditioned by lexical competition. Scarborough (2013; Scarborough & Zellou 2013) found that CVN words from more dense phonological neighborhoods are produced with greater coarticulation than words with fewer lexical competitors in English. Similar to the lexically-conditioned VOT and vowel space variation, this has also been argued to be perceptually-oriented: since words with many lexical competitors are more likely to be confusable in lexical access, enhancing their coarticulatory properties serves to make them more acoustically distinct from their phonological competitors. In other words, it shows that enhancement of coarticulatory vowel nasality in English is guided by communicative pressures to increase the cues for the final nasal sound to help listeners identify that the word is e.g., *bone* not *bode*.

Moreover, support for coarticulatory enhancement interpretation of production patterns in English comes from perceptual studies. In investigating the perceptual consequences of coarticulatory variation in English, Scarborough and Zellou (2013) reported that words containing enhanced nasal coarticulation are better perceived by listeners who completed a lexical decision task. These patterns have been interpreted as evidence that coarticulatory patterns are controlled and can be used to enhance the phonetic features of a vowel *in a particular consonantal context* in providing the listener with robust cues to the wholistic lexical form (Scarborough & Zellou 2013). Further evidence that American English listeners are able to leverage enhanced coarticulatory patterns to better comprehend words with nasal codas comes from Beddor, McGowan, Boland, Coetzee, & Brasher (2013) who tracked listeners' eye movements over images depicting CVC-CVNC minimal pair items as the speech signal unfolded. They found that listeners look more quickly to the CVNC item when hearing vowels containing earlier onset of coarticulatory vowel nasalization, than when the vowels contain later-occurring nasality.

What might a perceptually-motivated account predict about how lexical competition influences coarticulatory variation in French? For French, there is indeed lexical competition from CṼ minimal pairs on some CVN words, and some CVN words do not have a CṼ minimal pair. One prediction is that CVN words with a nasal vowel minimal pair competitor are produced with even less coarticulatory nasalization than CVN words without a nasal vowel minimal pair competitor. However, there is also lexical competition from minimal pair words contrasting with oral codas (CVCs) on CVN items in French. What role does that play in actively shaping coarticulatory variation? A perceptually-motivated coarticulatory enhancement prediction might be that increasing nasal coarticulation in CVN items makes them more distinctive from their CVC competitors. Relevant to this prediction is the observation that, in French, the tongue positions for phonologically nasal vowels are distinct from those in their oral counterparts (Delvaux et al. 2002; Demolin et al. 2003; Carignan 2013; Carignan 2017). More specifically, it is reported that the nasal vowel counterparts of oral /ɛ, ɔ, ɑ/ are realized with both F2, and sometimes F1, differences, so they are more accurately transcribed as [æ̃, õ, ɔ̃], respectively (Delvaux 2009; Carignan 2014; Dow 2020). Thus, it could be argued that due to differences in vowel qualities across nasal and oral vowels there is minimal risk for confusability of CVN as containing a /Ṽ/. Given the fact that vowels in CṼ and CVN words are already phonetically distinct, the contrast between CVC and CVN in French is a greater source of confusion since the vowels in those words are the most acoustically similar. Particularly because anticipatory nasal coarticulation is minimal, such confusability could be reconciled via systematic *increase* in the degree of nasal coarticulation present on CVNs that have a CVC minimal pair competitor. Thus, a perceptually-motivated coarticulatory enhancement prediction is that the presence of a CVC minimal pair competitor leads French speakers to produce a greater degree of nasal coarticulation in CVN words.

However, there is an alternative account of lexically-driven phonetic variation. Some have posited speaker-internal cognitive mechanisms of lexical activation as another factor shaping phonetic variation. In particular, when a word is activated, competitor words that share phonological features are activated as well. During speech production, it is proposed that when there is minimal pair competition, the competing feature is cognitively boosted in the process of increasing the activation of the target word and inhibiting the activation of the competitor word. Baese-Berk and Goldrick (2009) investigated how this mechanisms influences phonetic variation by comparing speakers' VOT durations when producing voiceless stop-initial English words that had a voicing minimal pair (e.g., *cod*, cf. *god*), compared to words without one (e.g., *cop*, **gop*). They found that words with a voicing lexical competitor are produced with longer VOTs, even when the competitor is not present in a condition that might lead to perceptual confusability.

What might a lexical activation account predict for lexically-conditioned coarticulatory variation in French? Since at the phonological level vowels in CVN words are underlyingly oral, having a nasal vowel minimal pair competitor would activate the featural contrast between oral and nasal vowels. Therefore, a coarticulatory constraint pattern of results would be consistent with a lexical activation account. However, we might make a further prediction based on the lexical frequency of the minimal pair competitor. Since a lexical activation account predicts that the process of inhibiting an active competitor leads to an enhancement of the contrasting feature, we might predict that highly frequent lexical competitors result in an even larger degree of phonetic enhancement.

1.3. Current study

The current study investigates these competing predictions about the role of lexical contrast in shaping patterns of produced nasal coarticulation in (Northern Metropolitan) French. We investigate the extent to which lexical competition influences patterns of produced nasal coarticulation in French words with nasal codas.

A coarticulatory constraint hypothesis for lexical competitor-driven variation in French is that coarticulatory nasality in CVN words is inhibited to reduce confusion from a CṼ minimal pair competitor. To test this, we compare acoustic vowel nasalization patterns for CVN words that have a nasal vowel minimal pair competitor (e.g., *crame* /kʁam/, cf. *cran* /kʁɑ̃/), relative to CVN words without a nasal vowel minimal pair competitor (e.g., *drame* /dʁam/, */dʁɑ̃/). If lexical contrast constrains production of coarticulatory patterns, we predict that French speakers will produce less nasal coarticulation on vowels in CVN words with a nasal vowel minimal pair competitor.

A coarticulatory enhancement hypothesis is that coarticulation is enhanced on CVN words with a CVC minimal pair competitor to make them more acoustically distinctive. Thus, we also compare CVN words that do have a CVC minimal pair competitor and CVN words that do not (e.g., *crame* /kʁam/, cf. *crabe* /kʁab/ vs. *flamme* /flam/, */flab/). If competition with non-nasal coarticulated CVC words matters, then French speakers will produce increased nasal coarticulation on vowels in CVN words with an oral CVC vowel minimal pair competitor.

We also explore the possibility of more fine-grained lexical competition effects. Specifically, we ask whether the *relative lexical frequency* of the nasal vowel minimal competitor, or the CVC minimal pair competitor, predicts produced nasal-coarticulatory patterns in French. If lexically-conditioned coarticulatory variation can be directly related to the presence and *strength* of lexical competition, this would suggest that lexical contrast-motivated mechanisms are online, active synchronic influences on speech production.

The findings are relevant for understanding cross-linguistic phonetic patterns: while coarticulatory patterns are language-specific, gestural overlap appears to be a ubiquitous property of natural speech. Careful description of within- and across-language speech patterns can reveal what aspects of coarticulation are universal vs. which are learned. The results of this study are also relevant for models of speech production that involve a role of the lexicon into mechanisms of articulation and phonetic variation. In the case of coarticulatory variation in French, there are lexical pressures *both* to decrease coarticulation (to avoid confusion between CVN words and nasal-vowel minimal pairs) and to increase coarticulation (to avoid confusion between CVN words and lexical competitors that contrast in coda orality). Exploring how lexically-specific coarticulation is patterned in French can contribute to understanding what is language-specific and what is universal about phonetic variation.

2. Methods

2.1. Target words

Critical target items consisted of 32 French C(C)VN words, taken from Lexique (New et al. 2004). In French, only the vowels /a, ɛ, ɔ/ have nasal vowel counterparts (/ɑ̃, ɛ̃, ɔ̃/ respectively), whereas the high, mid, and central vowels /i, y, u, e, ø, o, ə/ do not. Historically, French also has a front rounded nasal vowel /œ̃/, but this has merged with /ɛ̃/ in many varieties, including Northern Metropolitan French (Tranel 1987; Hansen 2001). Therefore, target words only included /a, ɛ, ɔ/. Sixteen target words were selected for which there is not a nasal vowel minimal pair in French (known hereafter as 'No CṼ MP'). Then, for each No CṼ MP item, a corresponding target word was selected, being a matching vowel counterpart, and as close as possible in phonological structure and lexical frequency, that did have a nasal vowel minimal pair ('With CṼ MP'). From this set of target words, we identified whether the target word has a CVC minimal competitor, defined as having an oral obstruent with the same place of articulation as the CVN target word. Within each of the No CṼ MP and With CṼ MP groups, roughly half of the items had a CVC minimal pair competitor in the language ('With CVC MP') and half did not have a CVC minimal pair competitor ('No CVC MP'). In total, 18 of the target words had a CVC lexical competitor and 14 of the words did not have an oral coda minimal pair competitor. Vowel quality was roughly balanced within each of the 4 minimal pair categories (1–3 words with /ɔ/, 2–3 words with /ɛ/, 3–5 words with /a/).

Table 1 contains the target words selected for this study, their CṼ MP and/or CVC MP category, and their lexical frequency taken from Lexique (New et al. 2004). The lexical frequencies were taken from the film subtitle frequencies provided in Lexique ('9_freqfilms2'). We selected the surface frequencies (not lemma frequencies) so that even morphologically related words (e.g., *pion* vs. *pionne*) would have unique frequency values. Lexical frequencies for CVN target words were taken as the orthographic matches for the words shown to participants (i.e., frequency was taken for *plaine*, not the more frequent *pleine* since the study presented the former word to participants as the production target). Where there were two competing frequencies for an identical orthographic form (e.g. *flâne*, the verb > *flâner* vs. *flâne*, the noun), we took the highest frequency value. Meanwhile, for the CVC and CṼ minimal pair competitors, frequency values of the most frequent lexical item for a given phonological form was selected (e.g., for /sɔ̃/, frequency counts range from 7.83 for *sons* 'sound-PLURAL' to 1740.43 for the possessive adjective 'his/her'; the latter value was selected as the CṼ competitor frequency value for the target CVN, *somme*).

Target CVN word	Nasal vowel MP Category	CVC vowel MP Category	Nasal MP	CVC MP
scènes /sɛn/ (11.3)	nasal.mp	CVC.mp	seins /sɛ̃/ (28.0)	cède /sɛd/ (6.0)
trogne /tʁɔɲ/ (0.1)	nasal.mp	CVC.mp	tronc /tʁɔ̃/ (4.8)	troc /tʁɔk/ (1.1)
clame /klam/ (0.7)	nasal.mp	CVC.mp	clan /klɑ̃/ (7.6)	clap /klap/ (1.4)
zen /zɛn/ (2.6)	nasal.mp	CVC.mp	zain /zɛ̃/ (0.000001)	zed /zɛd/ (5.4)
plaine /plɛn/ (3.5)	nasal.mp	CVC.mp	plein /plɛ̃/ (104.6)	plaide /plɛd/ (2.8)
crame /kʁam/ (1.2)	nasal.mp	CVC.mp	cran /kʁɑ̃/ (13.6)	crabe /kʁab/ (4.9)
flâne /flan/ (0.2)	nasal.mp	CVC.mp	flanc /flɑ̃/ (4.0)	flatte /flat/ (2.6)
pionne /pjɔn/ (0.01)	nasal.mp	CVC.mp	pion /pjɔ̃/ (3.0)	pioche /pjɔʃ/ (4.2)
fane /fan/ (0.4)	nasal.mp	CVC.mp	fend /fɑ̃/ (1.2)	fade /fad/ (1.4)
prenne /pʁɛn/ (21.02)	nasal.mp	CVC.mp	prin /pʁɛ̃/ (0.1)	prête /pʁɛt/ (66.3)
gène /ʒɛn/ (4.2)	nasal.mp	CVC.mp	geins /ʒɛ̃/ (0.2)	jette /ʒɛt/ (0.2)
flamme /flam/ (12.6)	nasal.mp	no.CVC.mp	flanc /flɑ̃/ (4.0)	
blâme /blam/ (2.9)	nasal.mp	no.CVC.mp	blanc /blɑ̃/ (53.9)	
somme /sɔm/ (28.3)	nasal.mp	no.CVC.mp	son /sɔ̃/ (1740.4)	
brame /bʁam/ (0.01)	nasal.mp	no.CVC.mp	bran /bʁɑ̃/ (0.2)	
glane /glan/ (0.3)	nasal.mp	no.CVC.mp	gland /glɑ̃/ (2.1)	
drame /dʁam/ (13.5)	no.nasal.mp	CVC.mp		drape /dʁap/ (0.1)
chêne /ʃɛn/ (4.3)	no.nasal.mp	CVC.mp		chaise /ʃɛz/ (32.7)
douane /dwan/ (4.3)	no.nasal.mp	CVC.mp		doivent /dwav/ (85.4)
tram /tʁam/ (5.5)	no.nasal.mp	CVC.mp		trappe /tʁap/ (4.86)
couenne /kwan/ (0.4)	no.nasal.mp	CVC.mp		coite /kwat/ (0.000001)
crosne /kʁɔn/ (0.000001)	no.nasal.mp	CVC.mp		crotte /kʁɔt/ (3.5)

(Contd.)

Target CVN word	Nasal vowel MP Category	CVC vowel MP Category	Nasal MP	CVC MP
glène /glɛn/ (0.000001)	no.nasal.mp	CVC.mp		glaise /glɛz/ (1.7)
oignes /waɲ/ (0.000001)	no.nasal.mp	no.CVC.mp		
grogne /gʁɔɲ/ (1.6)	no.nasal.mp	no.CVC.mp		
assommes /asɔm/ (0.4)	no.nasal.mp	no.CVC.mp		
blême /blɛm/ (1.2)	no.nasal.mp	no.CVC.mp		
poigne /pwaɲ/ (2.0)	no.nasal.mp	no.CVC.mp		
hyène /jɛn/ (1.6)	no.nasal.mp	no.CVC.mp		
scanne /skan/ (0.6)	no.nasal.mp	no.CVC.mp		
yen /jɛn/ (1.9)	no.nasal.mp	no.CVC.mp		
joigne /ʒwaɲ/ (0.7)	no.nasal.mp	no.CVC.mp		

Table 1: List of C(C)VN target words used in the current study. IPA transcriptions provided in slashes. Lexical frequencies provided in parentheses. Words were categorized as either having a CṼ minimal pair or not and as either having a CVC minimal pair or not. Minimal pair CṼ and CVC competitors with their lexical frequencies are also provided (in cases where frequency was 0, a very small number was included so that the values could be logged).

In addition, the production list also included 16 words containing a phonologically nasal vowel (‘CṼ’ words) and 16 words containing an oral vowel and an oral coda (‘CVC’ words), selected from the list of minimal pair competitors.

2.2. Participants and procedure

30 native Northern French speakers (mean age = 21.2 years old; range 19–31; 20 female, 0 non-binary or other, 10 male) completed the word list production study. Participants were students at Université Paris Cité, recruited via flyers and emails. All participants completed informed consent in accordance with the Université Paris Cité Comité d’Éthique de la Recherche (CER).

Participants were seated in a sound-proof booth facing a computer monitor. The experiment was presented to participants using a Qualtrics survey on the computer screen. Participants were told that they would be producing sentences which would be instructions on how to organize a set of words onto different lists. On each trial, participants read aloud instructions on where to place a given target word on one of five lists (e.g., *Écrivez le mot scènes sur la première liste*. “Write the word ‘*scènes*’ on the first list.”). The 32 target words (and 32 CṼ and CVC words) were presented randomly one time in the block.

Participants wore over-ear stereo headphones (AKG K-55) and their productions were recorded using an Audio-technica ATM33a microphone and USB audio mixer (Sound Devices, USB Pre 2) and digitized at a 44 kHz sampling rate.

2.3. Acoustic measurements

Words and phonemes were segmented using the Montreal Forced Aligner (McAuliffe et al. 2017). Following automatic force-alignment, all of the phoneme boundaries in the target words were hand verified, and corrected where necessary by phonetically-trained researchers.

Degree of nasalization was measured spectrally as A1-P0 (Chen 1997). This is a spectral measure of vowel nasalization reflecting the difference between the amplitude of the low frequency nasal peak, P0 (found around 250 Hz) whose amplitude increases with increased nasality, and the amplitude of the first formant peak, A1, whose amplitude decreases with increased nasality. These spectral characteristics are illustrated in **Figure 1**, which compares oral, nasal-coarticulated, and phonologically nasal vowels from one participant in this study. As seen, since A1 decreases and P0 increases as nasality increases, a smaller A1-P0 value indicates greater acoustic nasality. Since all of the target words used in the present study contained non-high vowels, A1-P0 is an appropriate measure (as opposed to A1-P1, which is appropriate acoustic nasalization in high vowels). A1-P0 measurements were made at ten equidistant timepoints automatically via a Praat script and hand-verified.

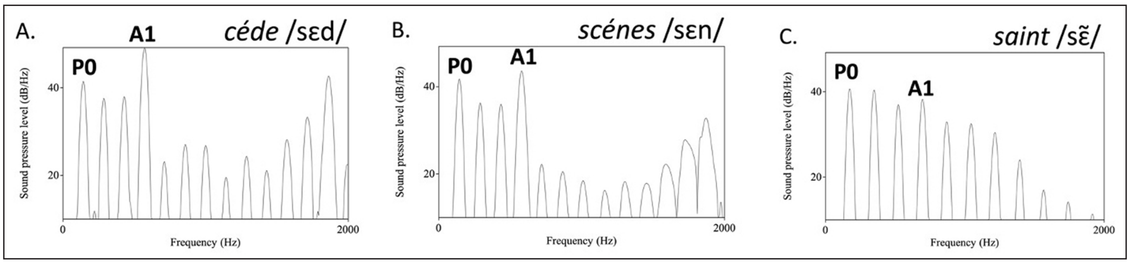

Figure 1: Acoustic properties of acoustic vowel nasalization (A1-P0). Spectra from **(A.)** an Oral vowel (from the word *céde* /sɛd/), **(B.)** a Nasal-Coarticulated vowel (*scénes* /sɛn/), and **(C.)** a Phonologically-Nasal vowel (*saint* /sɛ̃/) taken at vowel midpoint from one of the speakers in this study.

3. Results

3.1. Comparison across word types

Figure 2 shows mean acoustic nasality measures (A1-P0) taken at 10 equidistant timepoints over vowels from the 30 speakers' productions of CVC, CṼ, and CVN French words. A linear mixed effects model was run on these data using the *lme4* (Bates et al. 2014) and *p*-values were calculated using the *lmerTest* package (Kuznetsova, Brockhoff, & Christensen 2017) in R (version 4.1.2, R Core Team 2021). The model included fixed effects of timepoint (continuous variable, centered and scaled) and word type (CVC, CVN, CṼ), as well as the interaction between timepoint and word type. Word type was treatment coded, with CVC as the reference level, so that the model output shows the pairwise comparison between acoustic nasality in oral vowels and the other two levels. The dependent variable (A1-P0) was also centered and scaled prior to model fitting. The model included by-speaker and by-word random intercepts and by-speaker random slopes for each fixed effect as well as their interaction (lmer syntax: A1-P0~timepoint*word type + (1 + timepoint*word type | speaker) + (1 | word)).

The model output is provided in **Table 2**. The model revealed a main effect of word type, wherein vowels in both CVN and CṼ words contained overall greater vowel nasalization (lower A1-P0 value) than vowels in CVC words. There were also significant interactions between word type and timepoint, again with negative coefficients indicating that over time vowels in CVN and CṼ words become even more nasalized (even lower A1-P0 value) than vowels in CVC words. Thus, consistent with prior work reporting nasality in French using articulatory measures (e.g., Montagu & Amelot 2005; Delvaux et al. 2008), our speakers produce patterns of categorical nasalization on phonologically nasal vowels and a minimal amount of nasalization on vowels before nasal codas (with greatest nasalization at the vowel endpoint, nearest the nasal coda).

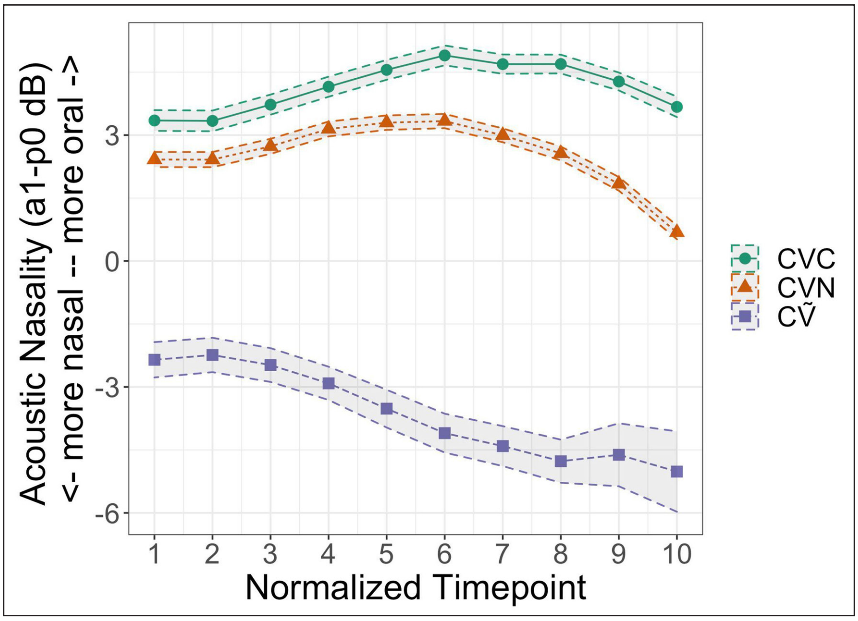

Figure 2: Mean acoustic nasality (A1-P0 dB) over 10 equidistant timepoints of vowels from CVC, CVN, and CṼ word productions by 30 French speakers. Ribbons depict standard errors.

3.2. Effect of lexical competition on CVNs

In order to test our specific hypotheses about the influence of lexical competition on degree of coarticulatory variation, a linear mixed effects model was run just on the acoustic nasality

	Coef.	*SE*	*df*	*t value*	*p value*	
Intercept	0.31	0.11	39.32	2.92	0.006	*
Timepoint (std)	0.06	0.02	29.19	2.64	<0.05	*
Word Type-CVN (v. CVC)	–0.26	0.06	75.97	–4.10	<0.001	***
Word Type-CṼ (v. CVC)	–1.41	0.12	58.94	–11.75	<0.001	***
Time * Word Type-CVN	–0.11	0.02	28.75	–5.55	<0.001	***
Time * Word Type-CṼ	–0.28	0.05	29.15	–5.68	<0.001	***
Random effects	***Variance***					
Speaker (Intercept)	0.28					
Timepoint (std)	0.01					
Word Type-CVN	0.04					
Word Type-CṼ	0.27					
Time * Word Type-CVN	0.01					
Time * Word Type-CṼ	0.06					
Word (Intercept)	0.03					
Num. observations (n = 15,435), speakers (n = 30), words (n = 64)						

Table 2: Model output: Acoustic nasality (A1-P0) in vowels from CVC, CVN, and CṼ words.

data from vowels in CVN words. There were three fixed effects of the model. First, timepoint (continuous variable, centered and scaled) was included. Second, CṼ MP category was included and sum-coded (With CṼ MP = 1, No CṼ MP = –1) such that the output of the model provides the comparison of the variable to the grand mean. Our hypothesis is that if pressure from CṼ minimal pair influences coarticulatory patterns, CVN words that have a CṼ minimal pair will be produced with less acoustic nasality, thus a higher A1-P0 value. We also hypothesized that pressure from a CVC lexical competitor might also influence coarticulatory patterns, but in the opposite direction: less acoustic nasality (higher A1-P0 value) for CVN words that do not have a CVC minimal pair competitor. Therefore, the third fixed effect we included was CVC MP category; in this case, we sum-coded the predictor so that the output level would also lead to a higher A1-P0 value (No CVC MP = 1, With CVC MP = –1).

The interaction between CṼ MP category and CVC MP Category was also included testing whether there is an additive effect of these two types of lexical pressures. Since we coded these predictors in a way that allows us to interpret a higher A1-P0 value as meaningful, we predict that a significant interaction between these two factors would result in an even more positive A1-P0 value in our model output. All two- and three-way interactions between timepoint, CṼ MP category, and CVC MP category were also included testing whether these effects are realized as differences in acoustic nasality that change over vowel duration. The model also included random intercepts for speaker and word. By-speaker random slopes for the interaction between CṼ MP category and timepoint, as well as the interaction between CVC MP category and timepoint were also included (inclusion of the three-way interaction as a random slope led to non-convergence). (lmer syntax: A1-P0~timepoint*CṼ MP category*CVC MP category + (1 + timepoint*CṼ MP category + timepoint*CVC MP category | speaker) + (1 | word)).

The model output is provided in **Table 3**. The model revealed a significant interaction between CṼ MP category and timepoint. The coefficient is positive indicating that over time A1-P0 values get even higher in CVN words with a minimal pair competitor (i.e., contain less acoustic vowel nasalization). This interaction is visualized in **Figure 3**, showing the mean A1-P0 values over normalized vowel duration for vowels in CVN words that have a CṼ minimal pair competitor and in CVN words that do not. As seen, in the portion of the vowel closest to the nasal coda, there is less coarticulatory vowel nasalization in CVN words that have a CṼ minimal pair competitor than CVN words that do not.

	Coef.	*SE*	*df*	*t value*	*p value*	
Intercept	0.06	0.11	33.74	0.53	0.66	
Timepoint (std)	–0.05	0.02	29.44	–2.46	< 0.05	*
With CṼ mp	0.02	0.03	44.50	0.68	0.66	
No CVC mp	0.02	0.04	43.87	0.59	0.73	
Time * With CṼ mp	0.03	0.01	28.82	2.70	< 0.05	*
Time * No CVC mp	–0.0002	0.01	28.65	–0.02	0.11	
With CṼ mp * No CVC mp	0.02	0.03	27.99	0.80	0.64	
Time * With CṼ * No CVC	0.03	0.01	8847.89	3.98	< 0.001	***
Random effects	***Variance***					
Speaker (Intercept)	0.31					
Timepoint (std)	0.01					
Has CṼ mp	0.01					
No CVC mp	0.01					
Time * Has CṼ mp	0.01					
Time * No CVC mp	0.002					
Word (Intercept)	0.03					
Num. observations (n = 9,025), speakers (n = 30), words (n = 32)						

Table 3: Model output: Acoustic nasality (A1-P0) in vowels from CVN words.

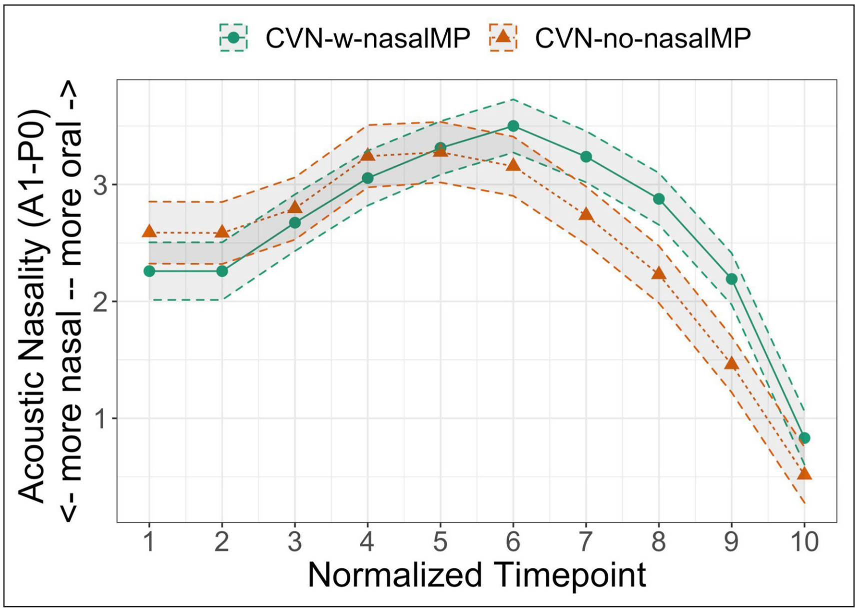

Figure 3: Mean acoustic nasality (A1-P0 dB) over 10 equidistant timepoints of vowels from CVN words that have a CṼ minimal pair competitor and CVN words that do not have a CṼ minimal pair competitor. Ribbons depict standard errors.

The model also computed a significant interaction between CṼ MP category, CVC MP category, and timepoint. The coefficient is also positive indicating that words with a CṼ minimal pair competitor and *without* a CVC minimal pair competitor are produced with less nasal (higher A1-P0 value) over time. This interaction is visualized in **Figure 4**: above and beyond that CVN words with a CṼ minimal pair competitor are produced with less coarticulatory nasalization, there is even larger difference between words with and without a CṼ minimal pair for words that do not have a CVC minimal pair competitor.

No other main effects or interactions were significant.

3.3. Lexical frequency effects

The analysis on acoustic vowel nasality in CVN words revealed an effect of having a CṼ minimal pair or not, both overall and in ways mediated by the existence of a CVC lexical competitor, on produced patterns of coarticulatory nasalization. This supports our primary hypotheses that lexical competition influences coarticulatory variation in French.

In addition to the categorical effect of having a minimal pair competitor with a specific phonological structure, we also hypothesized that the relative usage frequency of such a competitor influences production pattern. We tested this hypothesis with two separate linear mixed effects regression models run on the A1-P0 values. The first model was run on acoustic nasality values from the subset of CVN words that have a CṼ minimal pair competitor (n = 16,

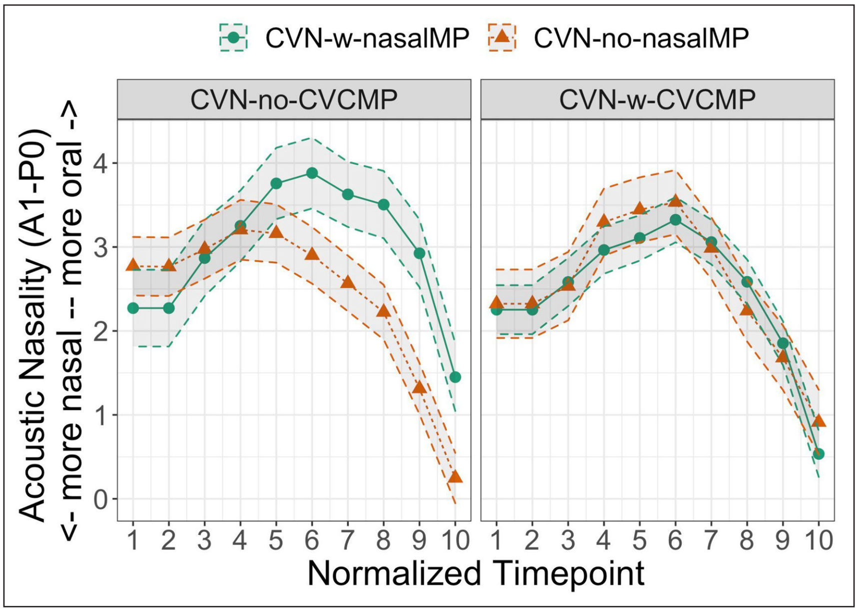

Figure 4: Mean acoustic nasality (A1-P0 dB) over vowel duration by CṼ MP category (linetype) and CVC MP category (panels). Ribbons depict standard errors.

see **Table 1**). The second model was run on acoustic measurements taken from CVN words that have a CVC minimal pair competitor (n = 18, see **Table 1**). Both models had identical fixed and random effects structures. The first fixed effect of the models was the lexical frequency value of the minimal pair competitor (logged, centered, and scaled). Additionally, since prior work has found that lexical frequency of a CVN word influences patterns of coarticulatory variation in American English (Zellou & Tamminga 2014), we also included a fixed effect of the lexical frequency value of the target CVN item (logged, centered, and scaled). The models included by-speaker and by-word random intercepts and by-speaker random slopes for item lexical frequency and minimal pair lexical frequency.

The output for the CVN words with nasal vowel (CṼ) minimal pairs is provided in **Table 4**, the one for CVN words with CVC minimal pairs is provided in **Table 5**. For the CṼ minimal pair model, there was a main effect of CṼ minimal pair lexical frequency, which is visualized in **Figure 5**: CVN words with more frequent CṼ lexical competitors are produced with less coarticulatory nasalization (higher A1-P0 value). No other main effects or interactions were significant. Meanwhile, there were no significant effects in the CVC minimal pair model.

4. General discussion

The goal of the present study was to investigate lexically-conditioned variation in anticipatory nasal coarticulation in Northern Metropolitan French. We find that variation in coarticulatory patterns produced on vowels in words with nasal-coda sequences (CVN) words is predicted by

	Coef.	*SE*	*df*	*t value*	*p value*	
Intercept	0.07	0.11	36.22	0.63	0.53	
Item Lexical Frequency	–0.03	0.04	17.42	–0.60	0.56	
Lex Frequency of CṼ mp	0.11	0.04	20.35	2.50	< 0.05	*
Random effects	***Variance***					
Speaker (Intercept)	0.29					
Item Lexical Frequency	0.01					
Lex Freq of CṼ mp	0.01					
Word (Intercept)	0.02					
Num. observations (n = 4,671), speakers (n = 30), words (n = 16)						

Table 4: Model output: Acoustic nasality (A1-P0) in vowels from CVN words with nasal vowel (CṼ) minimal pairs.

	Coef.	*SE*	*df*	*t value*	*p value*
Intercept	0.03	0.10	36.44	0.31	0.76
Item Lexical Frequency	–0.04	0.04	20.20	–0.90	0.38
Lex Frequency of CVC mp	–0.06	0.04	20.92	–1.43	0.17
Random effects	***Variance***				
Speaker (Intercept)	0.31				
Item Lexical Frequency	0.01				
Lex Freq of CVC mp	0.01				
Word (Intercept)	0.03				
Num. observations (n = 4,950), speakers (n = 30), words (n = 18)					

Table 5: Model output: Acoustic nasality (A1-P0) in vowels from CVN words with oral vowel (CVC) minimal pairs.

the existence of a phonologically nasal vowel (CṼ) minimal pair in the language. Specifically, CVN words that have a CṼ lexical competitor are produced with less coarticulatory nasalization than CVN words that do not have a CṼ minimal pair.

This observation is consistent with a longstanding theoretical proposal about how phonetic features are controlled by speakers as a function of the phonological system of their language. Specifically, it has been argued that the degree of anticipatory nasal coarticulation in French is constrained in order to avoid confusability with contrastive vowel nasalization (Chafcouloff & Marchal 1999; Manuel 1999). Indeed, consistent with prior empirical studies that have used a range of articulatory and acoustic measurements of vowel nasality (Cohn 1990; Rochet &

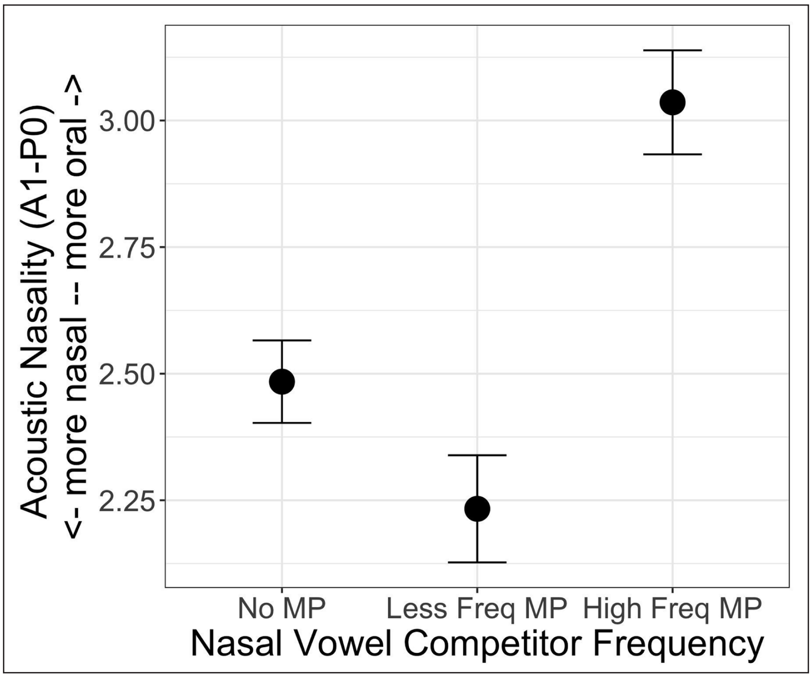

Figure 5: Effect of CṼ minimal pair lexical frequency on produced coarticulatory nasalization in target CVN words.

Rochet 1991; Spears 2006; Delvaux et al. 2008; Montagu & Amelot 2005), we see that overall coarticulatory vowel nasalization appears to be minimal, relative to that observed in e.g. American English, which has been shown to be extensive in both temporal and spectral extent (Solé 1992; Zellou 2022), and greatest in the portion of the vowel closest to the nasal coda. We observe that the degree of nasalization in CVN words is closer in distance (as measured acoustically) to that in CVC words than in phonologically nasal vowels. Our results also show that competition with an existing nasal vowel minimal pair appears to be a factor leading to even further reduction of anticipatory coarticulation in French. Thus, the theoretical proposal about how phonology shapes phonetic patterning in French can be extended to say that the presence of a minimal pair competitor contrasting in the feature [nasal] leads to the reduced coarticulatory realization of that property.

Yet, it has also been argued that speakers' use of coarticulatory variation can serve to enhance what makes a CVN word distinctive from a CVC word (where the codas contrast in nasality). For instance, CVN words with many lexical competitors are produced with greater coarticulatory nasalization in English (Scarborough 2013; Scarborough & Zellou 2013; Zellou & Scarborough 2019); this has been argued to be perceptually motivated as well since increased coarticulation is a way to provide more temporally distributed cues to a listener as to the identity of the upcoming coda (Beddor 2009). And, CVN words containing increased coarticulation are indeed more intelligible to listeners (Beddor et al. 2013; Scarborough & Zellou 2013). In French, CVN words are also in competition with CVC words, just as they are in competition with CṼ words. Thus, we also investigated whether the presence of a CVC minimal pair competitor (contrasting only in coda nasality) influences the realization of coarticulation. However, our results are more nuanced with respect to the influence of CVC lexical competition on coarticulatory variation in French. We find no main effect of CVC competition, rather it appears to modulate the effect of nasal vowel competition: the effect of a CṼ minimal pair in making the CVN vowel more oral is reduced when there is also a CVC lexical competitor (providing opposing pressure to make the vowel less oral), and when there is no CVC competition the effect of a CṼ competitor on reducing coarticulation is the greatest.

We also examined the role of lexical frequency of the competitor item on produced anticipatory coarticulation in CVN words. We observe that words with high frequency nasal vowel competitors are produced with less coarticulation (than both words with lower-frequent nasal vowel competitors and words with no nasal vowel competitor). Meanwhile, there is no effect of CVC competitor frequency on produced coarticulation. Thus, our findings provide robust evidence that nasal vowel competition, both in terms of the presence of a nasal vowel minimal pair in the lexicon and the CṼ competitor being highly frequent (and, thus, presumably exerting a more active competition effect), is a strong force influencing anticipatory nasal coarticulatory variation in French.

The interpretation that nasal vowel competition is a dominant predictor of anticipatory coarticulatory nasalization patterns is interesting, furthermore, given the fact that nasal vowels in French are often produced with distinct oral articulations than nasal-coarticulated vowels: Vowel qualities for Ṽ are distinct from their oral counterparts (Carignan 2013; Carignan 2017). Thus, phonologically nasal and nasal-coarticulated vowels (along with oral vowels) are actually quite phonetically distinct due to their different vowel qualities. In fact, from the perspective of perceptual confusability, CVC competitors arguably pose a greater threat on distinctiveness to CVN words than nasal vowel words if we consider both phonological and acoustic-phonetic similarity.

So, if perceptual confusability is not driving the observed anticipatory coarticulatory variation in French, what is the mechanism at play? One possibility is that the abstract phonological feature [+nasal] is shaping patterns of anticipatory coarticulatory variation in French. This is distinct from an account where the *acoustic-phonetic* properties of competitors influence coarticulatory variation because, as mentioned above, vowels in CVN and CṼ words are more acoustically distinct than vowels in CVN and CVC words. Thus, even though vowels in CVN and CṼ are not acoustically similar, these words share an abstract phonological nasal feature and that leads speakers to reduce anticipatory coarticulation. Moreover, this can be interpreted as providing support for the view that speaker-internal mechanisms can drive word-specific coarticulatory variation in French. Some have explained lexical competition effects as stemming from the nature of cognitive processes involved in lexical activation during speech production: a word's minimal pair will lead to an enhancement of the contrastive feature due to both an inhibition of the competitor and a boosting of the target word (e.g., Baese-Berk & Goldrick 2009). Such a mechanism can explain both the enhancement of the orality of a vowel in CVN contexts when there is a nasal vowel minimal pair competitor *and* the role of the competitor's usage frequency in modulating the effect.

This interpretation can lead to a revision of the hypothesis that constrained coarticulation in a nasal vowel-contrastive language serves a functional-intelligibility goal (e.g., Manuel 1999). From this perspective, the observation that French speakers produce CVN words that have a nasal vowel lexical competitor with even less coarticulatory nasalization can be viewed as speakers actively reducing anticipatory nasal coarticulation in order to avoid confusability between non-contrastive and contrastive vowel nasalization lexical items. Speakers' reduction of nasal coarticulation might be viewed as an effort to make the vowel more oral, and thus more distinctive from a nasal vowel, in order to make these words more intelligible. However, from a paradigmatic perspective, we find that competition from CVC words, which are actually more acoustically similar to and thus more likely to be confusable with vowels in CVN words, does not lead speakers to vary their coarticulatory patterns to the same extent. Thus, this suggests that some of the mechanisms underlying how phonology shapes phonetic variation are not strictly intelligibility-oriented.

The findings in this study are also relevant for understanding what is universal and what is language-specific about the mechanisms shaping coarticulatory variation. Coarticulation is a universal aspect of speech production. Yet, there is cross-language variation in coarticulatory patterns. In parallel, lexically-conditioned phonetic variation appears to be a cross-linguistic universal – words vary in their acoustic-phonetic patterning in every language that it has been examined. However, precisely *how* lexical competition influences speech production is realized differently across languages and across communicative contexts. With respect to anticipatory nasal coarticulation, CVN words with more phonological neighbors are produced with greater coarticulation in English (Scarborough & Zellou 2013). Yet, in French, we find that competition from nasal vowel words leads to reduced anticipatory nasal coarticulation. Thus, within-language coarticulatory variation is conditioned in different ways across languages. Note, however, that both languages do display lexically-conditioned coarticulatory variation. Hence, French and English are similar in that we find contrast-motivated within-language coarticulatory variation. Exploring whether lexically-conditioned coarticulatory variation is similarly patterned in other nasal vowel-contrastive languages, such as Lakota, Polish, or Hindi, is a ripe direction for future work to provide further insight into whether and how phonological nasality influences within-language coarticulation patterns.

4.1. Limitations and future directions

There were several limitations of the present study that open avenues for future research. For one, beyond lexical competition, several linguistic and socio-communicative factors are well-known to condition coarticulatory variation across languages. For instance, Scarborough and Zellou (2013) found that American English speakers produced less coarticulatory nasalization when talking to an imagined hard-of-hearing person, relative to when they produced the words to a real listener in an authentic communicative task. Perhaps, since the words in the present study were not produced with an authentic need to be intelligible, there was less actual perceptual pressure on speech production. A direction for future work is to compare these patterns when speakers are talking in more authentic contexts. Such a future direction can explore whether authentically listener-directed speech displays the same or different patterns of coarticulatory variation in French as those observed in the present study.

Another line of work that is relatively understudied is the perceptual consequences of coarticulatory variation on the intelligibility of CVN words for French listeners. While prior work has shown that enhanced nasal coarticulation leads to faster and more accurate word identification in American English (Scarborough & Zellou 2013; Beddor et al. 2013), this is underexplored for French. A question for future work is to what extent coarticulatory variation influences discrimination of the three-way CVC-CVN-CṼ lexical contrast in Parisian French.

Another ripe avenue for future work is to compare across different regional varieties of French. For instance, in Canadian French the nasal vowels are diphthongized in certain contexts (Walker 1984). Thus, nasal vowels are even more distinct in vowel quality from oral vowels than in Metropolitan French. Thus, perhaps, lexical competition from nasal vowels might be even more reduced than in European French, where sound changes have led to more distinct oral and nasal vowels. Meanwhile, in Canadian French, sound changes have led other oral and nasal vowel counterparts to be more similar. For instance, oral /a/ and nasal /ɑ̃/ have both fronted and are realized as [æ] and [æ̃], respectively (Walker 1984). Thus, we might predict even greater lexical competition effects in Canadian French where vowels have become more acoustically similar. Exploring the influence of lexical competition on coarticulatory patterns in other varieties of French is an open direction for future research.

Another relevant phenomenon at the phonetic-phonology interface in French is coarticulatory variation in carryover (NV) contexts, which was not explored in the current study. carryover coarticulation is extensive in degree in post-nasal contexts, and in fact, has been reported to be comparable in degree to contrastive nasality (Delvaux et al. 2008; Cohn 1990). Thus, the vowels in NV and NṼ words (e.g., *mais* 'but' /mɛ/ vs. *main* 'hand' /mɛ̃/) are more acoustically similar in terms of vowel nasalization than those in CVN and CṼ words. However, prior work examining phonological neighborhood effects on vowel nasalization patterns on coarticulated vowels in French found that, while there was no lexical difficulty effect on vowels in anticipatory coarticulatory contexts (VN), there was increased degree of coarticulation in carryover contexts (NṼ) in words with a larger number of phonological competitors (Scarborough 2004). One question is whether the increased coarticulation in NV words is motivated to make the vowels more distinct from CV lexical competitors, specifically. This is an open question and a ripe direction for future work examining phonological effects on coarticulatory variation in French.

5. Conclusion

The current study investigated the influence of two types of lexical competitors – words containing phonologically nasal vowels (CṼ) and oral vowels (CVC) – on variation in produced anticipatory nasal coarticulation in French. We found that French words with nasal codas are produced with less coarticulatory vowel nasalization when there is a nasal vowel minimal pair competitor; moreover, coarticulation is reduced even more when the nasal vowel competitor is highly frequent. While the influence of CVC lexical competition mediates the effect – the influence of a nasal vowel minimal pair is largest when there is no CVC competitor, the results indicate that contrast-enhancement is robustly influenced by a constraint to avoid confusability with the feature [+nasal]. This is despite the fact that CVN words in French are actually produced with minimal anticipatory coarticulation and also vowel quality differences between oral-nasal vowel counterparts are quite distinct. Thus, lexically-conditioned coarticulatory variation in French is driven by abstract phonological mechanisms, rather than an effort to make vowels in CVN words more distinct from their most acoustically similar competitors (vowels in CVC words).

Ethics and consent

Research was performed in accordance with the Université Paris Cité Comité d'Éthique de la Recherche (CER) (IRB number 00012021-108).

Acknowledgements

We thank Editor Köhnlein and two reviewers for their very helpful comments and suggestions. This work was supported by a Fulbright Research Award to GZ during the 2021–2022 academic year and Labex EFL (ANR-10-LABX-0083-LabEx EFL) to Université Paris Cité. The authors thank Ziqi Zhou for his help with data processing.

Competing interests

The authors have no competing interests to declare.

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