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1 Introduction

When a speaker produces a vowel, there is an open resonating chamber of air that flows from the source at the larynx, to the opening at the lips; optionally, a speaker can lower the velum, thereby directing the airway both through the oral cavity and the lips as well as through the nasal cavity through the nostrils. A *nasal* vowel is characterized by complete lowering of the velum throughout the entire duration of the vowel. Lowering the velum to open the velopharyngeal port during the production of a vowel creates a nasal and oral acoustic coupling. An oral vowel can also become *nasalized* when the velum lowering gesture occurs before (or after) a nasal consonant. This happens when the velum lowering gesture does not precisely coincide with making the oral closure, resulting in a duration of acoustic coupling at the end (or beginning) of the oral vowel. Additionally, the phonemic status of nasalized and nasal vowels in the world's languages is variable; for example, English does not make a phonemic contrast between oral and nasal vowels: oral vowels are allophonically nasalized in the environment of a following nasal consonant. Other languages, such as French, contrast nasal vowels phonemically with oral vowels. Where English displays allophonic nasalization of oral vowels, French suppresses nasal coarticulation when the oral vowel contrasts phonemically with a corresponding nasal vowel.

In this paper, I examine how native English speakers, who do not make a categorical distinction between oral and nasal or nasalized vowels, produce French nasal and nasalized vowels at different stages of L2 French learning. As French is a language that displays very low coarticulation effects when a categorical contrast is made between nasal vowels and oral vowels, I hypothesize (a) L2 speakers will produce a high amount of coarticulation in V_oN contexts, and (b) nasal vowels will not be produced with complete nasalization, relative to stage of L2 acquisition. This inherently hypothesizes acquisition of a nasal vowel is a gradient process from oral to nasalized to nasal, with nasalization becoming a greater percentage of the vowel until full nasalization is achieved. Vowels in six contexts are considered, where V_n is a nasal vowel and V_o is an oral vowel: English (1) V_oC, (2) V_oN; French (3) V_oC, (4) V_oN, (5) V_nC, (6) $V_n\#$.

One issue raised in the analysis is the general difficulty of isolating and identifying the phonetic features of nasal and nasalized vowels, due to the complex interactions of the oral formants, nasal formants, and anti-formants produced in the acoustically coupled oral-nasal cavity. Although prior approaches examining nasal coarticulation phonetically are widely inconsistent, F1/F2 shifts and waveform complexity features are identified as potential acoustic cues for L2 French learners to produce nasal vowels.

Results from this experiment show that L2 French learners at all stages of acquisition are capable of producing full nasal vowels in the $V_n\#$ context, indicating the categorical feature of nasality is easily acquired. Making allophonic changes is shown to be a more gradual process, with more advanced speakers suppressing nasal coarticulation in contexts where an oral vowel is contrastive with a nasal vowel. Beginner speakers produce coarticulation in these contexts at a rate consistent with English coarticulation. For vowels with no phonemically contrastive nasal counterpart, all speakers produced high amounts of coarticulation.

2 Background and Previous Literature

2.1 Vocalic systems of English and French

[1]This study was conducted under IRB 2014-0184. Versions of this paper were presented at WECOL/AZLS 2013 and PLC 38. Here I thank all of my participants, conference correspondents, Shuo Zhang for his Praat scripts, and anonymous reviewers.

The General American English oral vowel inventory is composed of 11 vowels[2], [i, ɪ, e, ɛ, æ, ɑ, ɔ, o, u, ʊ, ʌ, (ə)]. The vowels contrast in terms of their acoustic and articulatory properties, [±back, ±low, ±high, ±round, ±ATR]. English vowels become nasalized when they precede a nasal consonant, which is due to the fact that the velum moves slowly in comparison to the active oral articulators. In anticipation to make the nasal consonant, the velum opens earlier than the oral closure, causing the vowel become nasalized. This nasalization only occurs in the VN context in English; nasalization is never used as a contrastive feature of English vowels where a vowel is not followed by a nasal. In other terms, we can say that in English, vowels are underspecified for the [±Nasal] feature.

French vowels contrast along the same [±back, ±low, ±high, ±round, ±ATR] features as English, but unlike English, French vowels are specified for the [±Nasal] feature. There are 11 contrastive oral vowels in French, as well as 3–4 contrastive nasal vowels[3], [i, y, e, ø, ɛ, œ, a, ɑ, ɔ, o, u, ɛ̃, ɔ̃, ɑ̃]. Oral vowels in French also nasalize in VN context, but studies have shown there is significantly less coarticulation when the vowel in this context is contrastive with a nasal counterpart, namely [ɔ, ɛ, ɑ] (Spears 2006, Cohn 1990).

2.2 Previous literature

The configuration of the vocal tract when making nasal or nasalized vowels is considerably complicated, because both the nasal cavity and the oral cavity are resonating at the same time, producing both oral and nasal vowel formants. Due to the complex interactions between the formants and anti-formants created from this configuration, the amount of literature on isolating visible acoustic features in spectrograms has been relatively limited. Measuring and predicting the interaction and combination of these oral and nasal formants has been a notable problem in the phonetic literature, even with the advancement of acoustic analysis technology. The wide variety of techniques—including airflow traces (Cohn 1993), electromyography (Bell-Berti 1976, 1993), MRI (Demolin, Metens, & Soquet 2000, Delvaux et al. 2002), Velotrace (Horiguchi & Bell-Berti 1987), spectral analysis, and many others (see Krakow & Huffman 1993)— used in earlier studies increases the difficulties in comparing results.

Early literature focuses on identifying a single phonetic attribute for the perception of vowel nasalization. In Delattre (1954, 1965)'s investigations, he found that the main characteristics of nasalization exist in the low-frequency region of F_o1[4]. Delattre showed that increasing the F_o1 bandwidth and lowering its amplitude lead to a higher degree of perceptible vowel nasalization. Delattre also pointed out that nasal sounds commonly had two fixed amplitude peaks at about 250 and 2000 Hz, and a variable peak at around 900 Hz. The F_o1 results of Delattre's (1954) study were confirmed by House & Stevens (1956), observing the lowered F1 amplitude and a 250 Hz peak during nasal coupling. They also observed a secondary cue of an anti-formant between 700 and 1800 Hz.

Maeda (1993)'s examination of nasalized vowel spectra suggests one general property is a flattening of the spectrum in the F1-F2 region. Maeda observes that this spectral "spreading" in the low-frequency region (about 200–2000 Hz) is up to 10 Bark (1.3 kHz). He also points out that the distance between F1 and F2 correlates to and can predict the degree of nasalization perceived. In sum, damping is to be expected when the velum lowers, due to the addition of anti-formants and the increased oral-nasal tract volume, and therefore increased resonating wall surface area of the oral-nasal tract.

The general cues in these studies are meant to be common identifiers of vowel nasalization across all articulations. Recent research has observed more significant differences of phonetic cues to nasalization which depend on the place of articulation of the vowel. Delvaux et al. (2002) include both MRI imaging and acoustic analysis in their study on the acoustic and articulatory prop-

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[2]Some dialects of American English make a distinction between [æ, a, ɑ]. Schwa [ə] is the symbol used for an unstressed vowel with neutral tongue position.

[3]Belgian French speakers use [œ̃] contrastively. In this study, I focus on the three widely-used nasal vowels [ɑ̃, ɛ̃, ɔ̃]. Delvaux (2002) suggests [œ̃] and [æ̃] may be going through a merger, as they are very close phonetically.

[4]F_o indicates an oral formant; F_n indicates a nasal formant.

erties of French nasal vowels. Delvaux et al. examine both nasal and nasalized vowels in three environments: [p]_#, orals and nasals in the phonological environment following voiceless /p/; NVN vs. NV, comparing nasalized oral vowels and nasal vowels in a nasal environment; and VVV, comparing all oral, nasalized, and nasal vowels in any position. Concerning energy bands, they found a general lower energy in nasal and nasalized vowels across the entire frequency domain than oral vowels, echoing Maeda (1993)'s results. Interestingly, /ɛ̃/ was found to have more energy than /ɛ/ around F2. The largest difference in amplitude between the nasal/nasalized vowels and the oral vowels was found in the F3 region. They suggest that an anti-formant may cause F3 to shift to a higher frequency or be split into two less-intense peaks.

Notably, Delvaux et al. (2002) outline the differences in vowel nasalization according to vowel place. For the [ɑ~ɑ̃] pair, the differences they found between the nasal vowel and nasalized vowel is that F2 is lower for the nasal vowel, but not for the nasalized one (compared to the oral vowel). [ɑ̃] was also found to be more damped and with a lower F2 than [ɑ]. When comparing [ɛ~ɛ̃], F1 is higher and F2 is much lower for [ɛ̃] than [ɛ], and is also more acoustically dampened than the oral counterpart. Nasalized vowels have a lower F2 than the oral vowels, but not as much as the nasal vowels. For female speakers, F2 is cancelled out and one large band remains instead of F1 and F2 in the nasalized vowel [ɔ], whereas [ɔ̃] has a pole around F2.

Overall, the differences found in nasalized vowels, when compared to their oral counterparts, are reinforced for the nasal vowels. Feng (1996) suggests nasalization properties such as those discussed in Delvaux et al. (2002) actually can be considered as dynamic trend from an oral configuration to a more [ŋ]-like configuration, although this target is never actually reached in a nasal vowel.

Regarding the differences found between the English nasal coarticulation in nasalized vowels compared to French coarticulation, Spears (2006) observes that French vowels with no nasal counterpart have a high degree of nasalization, similar to English, whereas nasal coarticulation in oral vowels which are phonemically contrastive by the feature [+Nasal] tend to suppress coarticulatory effects to preserve the phonemic distinction. This suppression is well-attested for French (Clumeck 1967, Cohn 1990, Rochet & Rochet 1991), although due to the difficult nature of measuring nasality, not all vowels in the French inventory have been studied.

Flemming (2004)'s Dispersion Theory (DT) of contrast and perceptual distinctiveness formalizes a phonological theory based on contrasts in vowel inventories. According to DT, a speaker uses a constraint-based framework and the goals of (i) maximizing contrast distinctiveness, (ii) minimizing articulatory effort, and (iii) maximizing the number of contrasts to build a vowel inventory. Flemming (2004) predicts Spears (2006)'s results that French suppresses nasalization to avoid confusion with the categorical nasal vowels, while English does not due to a lack of contrasts.

The selection of previous literature on adult gradual acquisition of French nasal vowels is very limited. Meers (2009) studied the acquisition of French front rounded and nasal vowels by native English speakers in a perception experiment. She concluded that L2 French learners acquire nasal vowels faster than front round vowels, although this was based solely on perception data. The present study focuses on the ability of L2 French speakers to produce nasal and nasalized vowels at different stages of acquisition.

In sum, these previous studies have focused either on nasal properties of individual vowels, or sought to find a common feature of nasalization which is perceptible and replicable in simulation. Also, a Dispersion Theory of contrasts predicts French and English nasalization patterns.

3 Methodology

3.1 Recordings

The participants in this study were nine students (six females and three males) currently attending Georgetown University. Their ages ranged from 20–29. The French experience of the participants ranges from beginner to advanced, with three of the nine (two females and one male) at each level. The 'Beginner' participants, coded B1–3, had limited experience learning French. Two of the three speakers only had high school (4 years) French; one had 1.5 semesters in college. The ‘Intermediate’ participants, coded I1–3, had slight variations in experience: one with 4 years college but no experience since graduating (2 years), two with high school (4 years) and 1 year college with limited time abroad. The ‘Advanced’ participants, coded A1–3, all have 8 years experience in French each, including years in middle school, high school, and college. Two of the three advanced speakers have experience speaking French abroad. When asked, all participants rated themselves (beginner, intermediate, or advanced) consistently with the groups they were placed in by the experimenter according to their years of experience. All three participants are acquaintances with the experimenter, who is a female graduate student of Linguistics with equivalent advanced experience.

Recordings were conducted in 15-minute sessions in the sound-attenuated Data Acquisition Lab at Georgetown University. Sessions consisted of the participant reading two randomized word lists, the first in English and the second in French. The English word list was made up of 25 English randomized words that contained either an oral or nasalized (VN) vowel, in addition to randomly placed distracter words. Members of the word list situate vowels of interest in B_D monosyllabic context to limit coarticulatory effects, or B_N when nasalized effects were of interest. IPA transcriptions of French tokens are standard transcriptions from a French dictionary, verified by the experimenter. The participants produced each English word in the carrier phrase “Say ___ happily” [seɪ ___ hæpɪli]. I chose the glottal fricative to minimize coarticulatory effects after both consonant- and nasal-final words. The French word list contained 69 French words[5] with oral, nasal, and nasalized vowels. To maintain consistency, French words were chosen to closely resemble or contain the B_D and B_N context used in the English word list, with 1 or 2 syllable words, although this was not possible with all French vowels due to lexical limitations. French words were produced in the carrier phrase “Dites ___ deux fois” [dit ___ dø fwa] (meaning “Say ___ two times”). Individual tokens were discarded if the intensity was overall too low to access an accurate formant measurement, or if the vowel was produced at the incorrect place of articulation.

3.2 Digital methodology

Digital analysis was conducted using Praat acoustic analysis software, in which I converted all audio files from .mp3 to .wav. All words were then separated from their carrier phrases, derandomized, and sorted by vowel type; participants’ recordings were kept in separate files. In Praat, spectrogram and formant settings were set to the standards, with a view range of 0–5000 Hz, maximum formant at 5500 Hz, and LPC set to 5 formants. Oral vowel formant measurements for English and French were made in the center of the steady-state duration of the vowel. These measurements were extracted with the use of a Praat script, which returns the F1, F2, and F3 formants in Hertz at the position indicated on the textgrid. Vowel measurements were double checked by hand after extraction. Vowel formant plots were made using online normalization software: NORM Vowel Normalization and Plotting Suite (Thomas & Kendall 2004). All plots were normalized using the Lobanov method. Lobanov normalization factors out physiologically-caused differences to better analyze linguistic variables (Lobanov 2005).

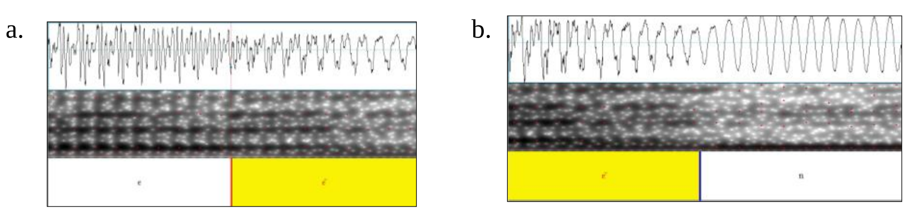


Figure 1: Participant 13 Oral Vowel / Nasalized Vowel / Nasal Consonant.

Nasalization was determined by examining both amplitude levels, formant transitions, and the shape and complexity of the waveform. Figure 1 from the participant I3 shows noticeable differ-

[5]Three French words ‘peuvent’ [pœv] *can* and ‘dais’ [dɛ] *canopy* were discarded before phonetic analysis due to incorrect pronunciation by at least three of the nine participants.

ences between the waveforms of (a) an oral vowel and nasalized vowel, and (b) a nasalized vowel and a nasal consonant. From Figure 1 above, it is evident that the amount of complexity in the waveform gradually lessens from /ɛ/ > /ɛ̃/ > /n/. These differences, along with amplitude differences and formant changes (discussed in section 4.3), guided the segmentation process in this study, and are discussed in Section 5 as a possible cue for production.

4 Analysis

4.1 English nasalization: V_oN context

The nasalization of English oral vowels occurs in pre-nasal consonant position. Because English does not make a phonemic contrast between nasal and oral vowels, English speakers tend to have a greater amount of nasalization than speakers of languages where a contrast is made. Figure 2 shows the advanced speaker A2 producing the words [bɑdi] 'body' and [bɑ̃ni] 'bonny'.

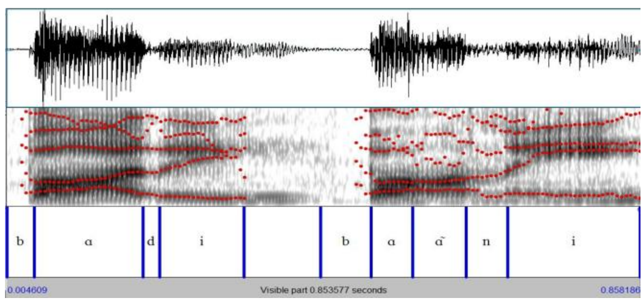
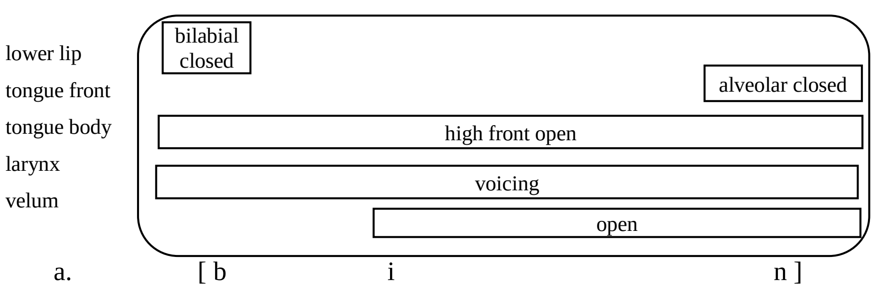


Figure 2: [bɑdi] 'body' and [bɑ̃ni] 'bonny' from speaker A2.

The nasalization in this example is evident from the disappearance of F3 in the second word, compared to the __[d] context.

As mentioned in Section 2.1.1, nasal coarticulation can be explained in terms of gesture coordination and overlap. The coordination of these articulatory gestures is at the basis of Browman and Goldstein's (1986, 1992) theory of Articulatory Phonology (hereafter AP). In AP, gestural units are abstract characterizations of articulatory events made up of sets of articulators which create constrictions at constriction locations. Utterances are organized constellations of gestures, which can be diagramed in gestural scores. Modeling nasalization with gestural scores is ideal due to the complex coordination of the velum and oral articulators needed to create oral, nasalized, and nasal vowels. A gestural score for the English word *bean* [bin] is given below, along with a segmented waveform and spectrogram, in Figure 3(a-b). The result of the early opening of the velum causes the last approximately 75% of the vowel [i] to be nasalized.



a.

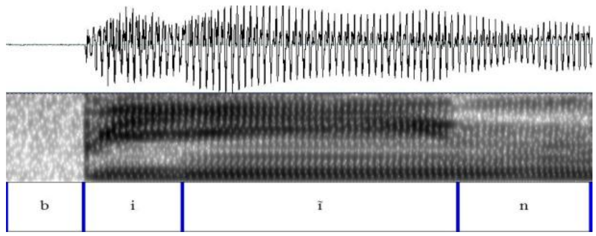
b.


Figure 3: (a) a gestural score of A1's production of *bean* [bin]and (b) waveform and spectrogram of English *bean* [bin] by Female speaker A1.

Using the methodology described above, the percentage of nasalization was measured for all English oral vowels in the V_oN context, except for [ʊ], which does not occur in the V_oN context in English. Table 2 provides a list of tokens and their average coarticulation as a percentage of coarticulation duration over the entire vowel duration (from release burst to alveolar closure). Each percentage is an average of 9 tokens, one from each speaker. All vowels have nasal coarticulation that spans for more than half of the vowel duration. Longest coarticulation across all speakers came from low front vowels [æ] and [e]. This suggests that while the tongue front lowers to produce the vowel, the back of the mouth can more easily achieve a [ŋ]-like configuration, the cue to nasalization suggested by Feng (1996).

IPA Vowel	**Token**	**Average Percentage**
æ	BAN	79 %
e	BANE	75 %
ɔ	DAWN	75 %
i	BEAN	65 %
ɛ	BEN	64 %
u	BOON	60 %
ɑ	BONNY	60 %
ɪ	BIN	58 %
o	BONE	55 %
ʌ	BUN	47 %
	Total average:	63.8 %

Table 2: Coarticulation Percentages.

In addition to spectrograms, waveforms, and gestural scores, nasal airflow studies measure velum movement, albeit indirectly. Airflow traces measure airflow from the mouth and the nose separately, thereby indicating when the velum is open or closed. Cohn (1993) measured nasalization patterns in English, French, and Sudanese using airflow traces. Figure 7 gives the nasal airflow traces of the English (a) V_oC context *deed* /did/ and (b) V_oN context *dean* /din/ in the carrier phrase "say ___ twice" :

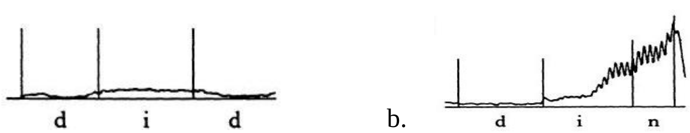
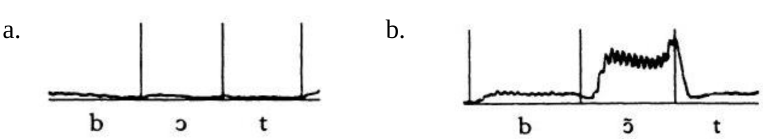
a.


Figure 4: English airflow traces of (a) *deed* [did] and (b) *dean* [dean].

In (4a), the velum is closed the entire time, and the nasal airflow trace is flat; that is, no air is flowing through the nose. In (4b), nasal airflow begins before the nasal consonant due to the velum opening early, and the vowel is consequently nasalized for the last half of its duration, consistent with the durations measured in the present study.

4.4 French nasalized and nasal vowels

Nasal airflow traces show the differences between English and French patterns of nasalization. Cohn (1993) gives nasal airflow traces of native French speakers (Figure 5a-d) of four of the contexts examined in this study (a) V_oC, (b) V_nC, (c) V_nN, and (d) V_nN (= V_n#N). Comparisons to the French airflow data are made throughout this section.



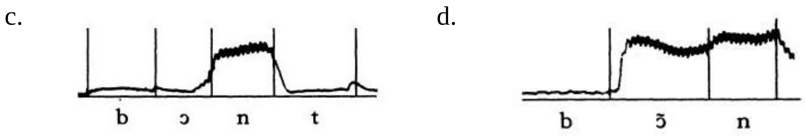


Figure 5: (Cohn 1993) Native speaker French nasal airflow traces of (a) *botte* /bɔt/ 'boot'; (b) *bonté* /bɔ̃t(e)/ 'goodness'; (c) *bonne tête* /bɔnt(ɛt)/ 'good head'; (d) *bon nez* /bɔ̃#n(e)/ 'good nose' in the phrase "*dites* __ *deux fois*" 'say __ twice'.

4.4.1 French contrastive and non-contrastive V_oN

As discussed in Section 2.2, the contrastive nature of French oral and nasal vowels directly effects the duration of coarticulation in the V_oN context. It is attested that French vowels with a phonemically contrastive counterpart [ɑ~ɑ̃, ɛ~ɛ̃, ɔ~ɔ̃] suppress coarticulation to promote the listener-based goal of avoiding confusion (Flemming 2004). I hypothesized that relative to stage of acquisition, L2 French learners have a high amount of coarticulation for both contrastive and non-contrastive French oral vowels preceding a nasal consonant. Beginners had the highest percentage of nasal coarticulation, at 67%. This is almost identical to the average English rate of coarticulation of 66% for the equivalent vowels [ɑ, ɛ, ɔ]. Intermediate speakers had a dramatically lower rate of coarticulation, at 40%. At this stage, the learner is starting to acquire the French allophone pattern. Advanced speakers have the lowest percentage of coarticulation, at 28.5%. The advanced L2 learners have the closest production to native French, shown in the airflow trace (5c).

French vowels without nasal counterparts do not need to suppress coarticulation, and are therefore hypothesized to retain high amounts of coarticulation throughout the stages of acquisition. For the purposes of this study, only [i, e, y] were examined. Results show no great difference between the three levels: beginner 67%; intermediate 72%; advanced 62%. Learners at all stages are therefore retaining more coarticulation for non-contrastive oral vowels.

4.4.2 Nasal vowels: V_n#

For a nasal vowel, as in (5b and 5d), nasalization begins much closer to the start of the vowel. The goal for the L2 French learners is to produce a nasal vowel with the velum opening gesture aligned as close to the oral opening gesture as possible. At all stages of acquisition, speakers produced full nasal vowels when they occurred at the ends of words, suggesting the velum may start in the open position even during the initial consonant in a monosyllabic word.

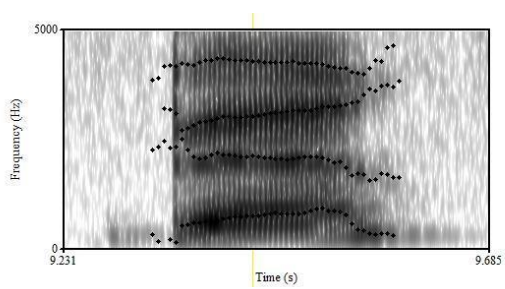


Figure 6: 'bain' [bɛ̃] *bath* by participant A1.

4.4.3 Pre-consonantal nasal vowels: V_nC

Perhaps the most difficult coordination to master in the acquisition of French nasal vowels is the CV_nC sequence, which requires both early onset of nasality as well as alignment of the cessation of nasality with the consonant closure. An example of native French airflow trace of this context is given in (5c). The gestural score below shows the coordination required to achieve a native French target pronunciation of 'bander' [bɑ̃de] *to bandage*.

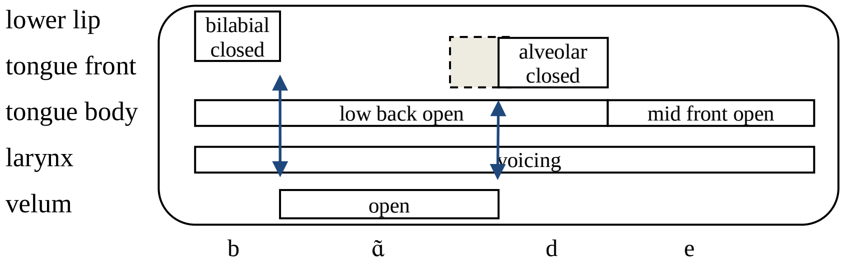


Figure 7: Gestural score of French ‘bander’ [bãde] *to bandage*.

For the French learners, the alignment of closing the velum and making the oral closure proved to be the most difficult. For all the speakers, the alveolar closure anticipated the velum closure, resulting in the articulation of a nasal consonant; this anticipation is represented by the shaded grey box in the gestural score above.

The participants in this study showed variation in the degree of divergence of the coordination of the velum gestures in this context. The average duration of the resulting ‘nasal consonant’ (the portion of the gestural score indicated by the shaded box) was 105 ms for the beginner group, 92 ms for the intermediate group, and 75 ms for the advanced group; this result indicates a gradual acquisition in the coordination of the velum closure and oral closure.

The second coordination is that of the bilabial closure release and the opening of the velum. A greater percentage of nasalization indicates closer coordination of these two gestures. The beginner and intermediate groups both averaged 70% nasalization, while the advanced speakers averaged 79% nasalization of the nasal vowel. It is important to note here that native French speakers do not have 100% nasalization of this nasal vowel, as indicated by the airflow trace in (5c). Interestingly, when no consonant preceded the nasal vowel (#V_nC), nasalization occurred throughout the entire vowel for all speakers, while the coordination of the velum closure was consistent with the level of acquisition. One example is ‘honte’ [ɔ̃t] *shame* from participant A2:

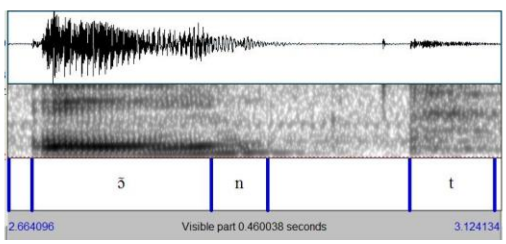


Figure 8: Waveform and spectrogram of A2: ‘honte’ [ɔ̃t] *shame*.

In sum, the results in this section indicate beginners have low coordination abilities to align gestures in V_nC contexts and make French allophonic contrasts in V_oN contexts, resulting in English-levels of coarticulation despite a contrastive nasal vowel. Acquisition of this coordination is gradual, as opposed gross categorical acquisition nasal vowels in the V_n# context, which are acquired at a very early stage.

4.5 Acoustic cues of nasalization

4.5.1 [ɑ~ɑ̃]

For the nasal vowels, all speakers show a lowering of F1 and F2, although F2 lowers more than F1. These two formants also are notably closer together in the nasal vowel. For all speakers, F2 rises in the nasalized condition, which is markedly different from the increasingly lowered F2 of the nasal vowel. F1 lowers in the nasalized context, but not as far as the nasal vowel.

4.5.2 [ɛ~ɛ̃]

In this set of vowels, the nasalized and oral vowels are approximately equivalent in terms of F1/F2 height for the intermediate and advanced speakers. The beginners show a higher F2 and a drop in F1 in the nasalized vowel. This may be due to the extensive coarticulation made by the beginners in the nasalized context. For all speakers, the nasal vowels have a higher F1 than both the nasalized and oral vowels.

4.5.3 [ɔ~ɔ̃]

The nasal [ɔ̃] has a lower F2 in the beginner and intermediate speakers. F1 shows variation; it is lower (than the oral F2) in the beginner, equal in the intermediate, and higher in the advanced speakers. This may show a progressive movement of [ɔ̃] to a higher position in the vowel space through the stages of L2 French acquisition. All speakers show F1 and F2 becoming closer in the nasal vowel context.

5 Discussion and Theoretical Implications

The data collected in this study are representative of how L2 French learners acquire the categorical difference between nasalization and nasal vowels. The spectrograms of nasal vowels show that L2 French speakers at every stage of acquisition are capable of making accurate word-final nasal vowels, which does not confirm the original hypothesis, wherein speakers at earlier stages of acquisition will not make complete nasal vowels. However, this does not confirm that the acquisition of nasal vowels is not a gradient process; nasal vowel acquisition may take place at an earlier stage than examined in this study.

Importantly, the results of this study show the gradual acquisition of non-coarticulated oral vowels in French in a context where English displays high rates of nasalization. More advanced speakers are better able to suppress nasalization in order to preserve the contrast between oral vowels and their nasal counterparts. This reflects Cohn (1990)'s findings that native French speakers have much less nasal coarticulation for these vowels than English speakers, who do not make a phonemic contrast between nasal and nasalized vowels. The acquisition of this coarticulation suppression is more gradual than acquiring the nasal/oral vowel phonemic contrast, which the beginning speakers could successfully produce word-finally in the present recordings.

A gestural approach to the acquisition of nasal vowels and suppression of coarticulation gives support to an articulatory-based approach to phonology (AP). Learners are in fact acquiring alignment of velum gestures to oral gestures. For the V_oN context, the data shows how the velum opening gradually becomes more aligned with the oral closure of the nasal consonant. A more difficult context for the learners, CV_nC requires velum movement alignment with two oral closures; from the data is also appears to be a gradual process, with advanced speakers making the closest alignment.

The acoustic results of this study shed light on possible cues for nasal perception and production. Overall, the first two formants, F1 and F2, come closer together in nasal vowels than in either nasalized vowel or oral vowel counterparts. This supports Maeda (1993)'s results, in that the degree of distance between F1 and F2 corresponded to the degree of nasalization perceived by listeners. Lowering F1 and F2 is a sign of backing and raising the vowel, which may help L2 French learners in producing a greater degree of nasalization. For all speakers, the nasal F2 was either lower or equivalent to the F2 in the oral vowel, whereas F1 varied across places of articulation and levels of acquisition. This F2 behavior in the nasal vowels is consistent with Delvaux et al. (2002)'s study, suggesting F2 lowering may be the most significant factor in producing nasal vowels. Conversely, F2 tends to rise in the production of nasalized vowels across speakers and across contexts, which is not consistent with Delvaux et al. (2002)'s results that predict a lower F2 in nasalized contexts.

The methodology used here can also contribute to the efforts of future phoneticians working on nasalization. Amplitude changes, formant movement, and the complexity of the waveform are all indicators of differences between oral vowels, nasal vowels, and nasal consonants. Section 3.2 points to differences in the waveform as a cue for segmentation- a technique which is not used in any previous literature.

The results of this study show promising avenues for future research in L2 phonemic category acquisition. Several additional nasal cues have been identified in the literature, but not explored here, including amplitude differences, bandwidth changes, and effects on higher formants, especially F3. As scope limited this paper to examining formant and waveform changes, these cues are left to future research.

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