An Optimality Approach to Chain Shifts: Nasal Vowel Lowering in French*

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This paper provides an optimality-theoretic account on lowering of nasal vowels in French from a (functional and) phonetic viewpoint. I will first claim that nasal vowel lowering in French was initiated by nasalization of a high vowel, in which the first formant (F1) of /i/ (or/y/) was elevated by prominent nasal acoustic energy. Second, I will argue that the subsequent lowering of tense vowels /e, y, o/ to [ɑ̃, œ̃, ɔ̃] is a consequence of dispersion of contrast between adjacent vowels, for which we evaluate a sequence of relevant adjacent vowels, rather than individual vowels in isolation. Third, I will discuss a case of neutralization in /en, an/→/ɑ̃/ change, a challenging case to the dispersion pattern of contrast. I will argue that the final output of the nasal vowel pattern is a consequence of constraint interactions. We will also observe that there is a strong tendency that we maintain the closest formant values of the inputs in the outputs as possible. This result is also obtained by the pattern evaluation of the adjacent vowels. Fourth, I will discuss possible theoretical problems in a rule-based approach, in comparison with the consequences in our current analysis. Finally, I will add a theoretical implication of the result in relation to the functional goals of Dispersion Theory (Lindblom 1986, Flemming 1996).

1. Oral and (lax) Nasal Vowels in French

In French, there are twelve oral vowels and four nasal vowels as shown below (Argod-Dutard 1996 : 46, Clark & Yallop 1995 : 28, 32).[1]

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[1] It seems to be a matter of controversy whether we recognize two distinct *ɑ*'s, ie., the front [a] and the back [ɑ]. In Casagrande (1984), for example, only one [a] is assumed, while many phonetic and phonological surveys such as Argod-Dutard (1996) and Clark & Yallop (1995) recognize two distinct [a] and [ɑ]. Many dictionaries such

(1) a. Oral vowels[2]

Front			Back
i	y		u
e	ø		o
(ɛ)	œ	(ə)	ɔ
a			ɑ

b. Nasal vowels: ɛ̃, œ̃, ɔ̃, ɑ̃

In this figure, we can state that French does not allow a tense nasal vowel, observing that all the four nasal vowels appear to be lax, even though they differ in height: [ɑ̃] is the only low vowel, while the other three [ɛ̃, œ̃, ɔ̃] are mid. Thus, we can assume that, although it is low, [ɑ̃] (rather than [ã]) can occur due to its laxness. This assumption may look unnatural but we can find phonological evidence from the general tense/lax alternation in French. In the alternation of *sot/sotte* 'silly,' for example, we get a lax vowel only in a closed syllable (i.e., VC) generating [so] and [sɔt]. Assuming that the nasal vowels are derived from underlying VN sequences (Schane 1971, Casagrande 1984), we can account for the vowel laxing in the following way.

(2) /bon/ → bɔn → bɔ̃n → [bɔ̃]

In other words, we first get closed syllable laxing before nasalization since only the lax vowels are subject to nasalization. Then lax vowels undergo nasalization and postvocalic nasal deletion occurs because French does not allow a sequence of a nasal vowel and a nasal consonant within a syllable.

In order to account for the scalar changes of vowel height in nasalization, we represent the height distinctions in terms of the first formant (F1) frequencies. In general, the height of a vowel is inversely related to F1 since the F1 values of the high vowels /i, y, u/ are around 300 Hz, while the low

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as *Robert & Collins' Dictionaire Français-Anglais, English-French Dictionary* (1978) also recognize both low vowels.

[2] The underlined parts of the following figure show the vowels.

si 'if'	su 'known'			pou 'lice'
ses 'his'	ceux 'these'			peau 'skin'
sept 'seven'	seul 'only'	autrefois 'formerly'		port 'port'
la 'the'				las 'tired'

Also, the four nasal vowels can be illustrated in *un bon vin blanc* [œ̃ bɔ̃ vɛ̃ blɑ̃] 'a good white wine.'

vowel [a] (or [ɑ]) may have 800 Hz as its F1 value. Therefore, the F1 values of mid vowels are located in between these values.[3] As these values are scalar, however, they will be decomposed into binary features in a way similar to the traditional treatment of vowel height, in which two binary features are used to define four degrees of height. As shown in the following table, the first formant frequency (F1) dimension can be decomposed onto four features distinguishing five levels of F1 (i.e., [i, ɪ, e, ɛ, a]) (Flemming 1995, 1996).[4]

(3)

Unround vowels		i	e	ɛ	a	ɑ
F1	lowest	+	–	–	–	–
	low	+	–	–	–	–
	high	–	–	+	+	+
	highest	–	–	–	+	+
F2	high	+	+	+	+	–

Round vowels		y	ø	œ	u	o	ɔ
F1	lowest	+	–	–	+	–	–
	low	+	–	–	+	–	–
	high	–	–	+	–	–	+
	highest	–	–	–	–	–	–
F2	high	+	+	+	–	–	–

We represent the distinction between vowels in terms of the F1 values. Thus, the degree of distinction between [i] and [ɛ] is 3, but 2 for the distinction between [e] and [ɑ].

2. Lowering of High Vowels: Enhancement by Nasal

As described in (1), there is no high nasal vowel. That is, any sequence of a high vowel and a nasal consonant is subject to vowel lowering.

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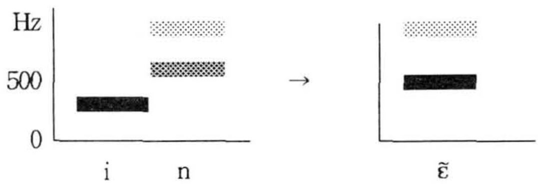
[3] According to Peterson and Barney (1954 : 183), for example, the F1 value ranges of the English mid vowels are 530-610 Hz for [ɛ] and 570-590 Hz for [ɔ]. (The F1 value of a male is lower than that of a female.) Compare these F1 values with those of non-mid vowels: 270-310 Hz for the high vowel [i] and 730-850 Hz for the low vowel [ɑ]. Also, refer to Schwartz et al. (1997) for details.

[4] We may not need [+lowest F1] here since French has only four degrees of vowel height and there is tense/lax distinction in mid vowels. So this representation is presented for general use.

Observing this, I will claim that the whole system of vowel lowering begins with lowering of high nasal vowels and there is good phonetic explanation for this claim. In general, only vowels have the most distinctive resonance in spectrum but nasals also have very strong resonance due to the elongation of the vocal tract by the opening of the nasal cavity. This acoustic energy of nasals is called anti-resonance and the frequency ranges of the (major) anti-resonances vary with place of articulation.[5] However, a second anti-resonance in the area of 600 Hz for a male tract seems to be constant regardless of place of articulation (Stevens 1998). In the following figure, the second anti-resonance is represented as the darker shaded bar, while the F1 of the vowel as the solid bar.

(4) Elevation of F1



As we can see in (4), the F1 value of /i/ is elevated by the presence of the second anti-resonance of the nasal. Thus, the sequence of /in/ undergoes vowel-consonant coalescence resulting in [ɛ̃], which is a case of phonetic enhancement in which nasalization enhances vowel lowering. This is a very natural phonetic process and we can also find similar cases in other languages. In various dialects of English, for example, the /i/ and /e/ distinction often disappears due to the presence of an immediately following nasal consonant. Thus, both /pin/ and /pen/ are often pronounced the same, i.e., [pɛ̃n], in Southern dialect of American English.[6] Also, the underlined

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[5] The labial nasal [m] is characterized by an anti-resonance which is lower (in the 500-1500 Hz range) than that for [n] (around 2,000-3,000 Hz) or for [ŋ] (above 3,000 Hz) (Borden et al. 1994 : 121).

[6] Ken Stevens (p.c.). Notice, however, that the degree of nasality in English nasalized vowels is much lower than that of French nasal vowels. According to an experiment using Nasometer, we get 50% nasality for English, where as 80% for French.) Thus, the (English) nasalized vowel may be represented as [ɛ̆] to be differentiated from the corresponding (French) nasal vowel [ɛ̃].

high vowel in *Where have you been*? is often pronounced as a mid vowel in other English dialects.

Lowering enhancement is motivated by the constraint banning a high nasal vowel. In order to provide an optimality-theoretic account for French vowel lowering, we can formulate the following phonetic enhancement constraint. ([+low F1] indicates a high vowel.)

(5) *[+low F1, +nasal] → No nasal high vowel is allowed.

This constraint requiring lowering of a high nasal vowel conflicts with one of the following faithfulness constraints, Max-IO, because the input nasal segment may not appear due to the inviolable constraint (5). In other words, the vowel-nasal coalescence conflicts with the principle maintaining all input segments.

(6) Faithfulness constraints: Max, Dep, Ident(F)

Moreover, we need constraint (7) accounting for the fact that an oral vowel is merged with a nasal consonant within a syllable. Being purely phonetic, this constraint is claimed to be language universal.

(7) *VN → No oral vowel is allowed before a nasal consonant.

(7) requires mandatory (i.e., phonemic) nasalization in French (and in other languages (allophonically)). Thus, any vowel followed by a nasal within a syllable is expected to become a nasal vowel. For example, an oral vowel in a word like /vin/ should become a nasal one [ɛ̃].

Notice, however, that nasality in French vowels is contrastive (Schane 1971) and French does not allow a nasal consonant after a nasal (not a nasalized) vowel within a syllable. For this, we need another (and language-specific) constraint (8). Notice here that we need to differentiate (contrastive) nasal vowels and (phonetically) nasalized vowels.

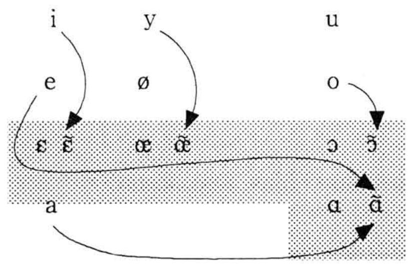
(8) *ṼN] → No nasal consonant is allowed after a nasal vowel.

This constraint requires that a nasal vowel and a nasal sequence not be allowed within a syllable. Due to these two constraints (7) and (8), a VN] sequence in an input shows up as Ṽ, rather than *ṼN or VN.[7]

3. Dispersion in Lowering

Considering high vowel lowering, we examine the general pattern of lowering for other vowels, focusing on the directions and the targets of lowering.

(9)



Here, we first notice that lowering of nasal vowels allows only lax outputs (except the schwa). In other words, there is no tense nasal vowel. Therefore, we can posit the following constraint requiring that we do not allow tense nasal vowels.

(10) *Tense Ṽ → No tense nasal vowel is allowed.

With this constraint along with the other ones discussed in the previous section, we now attempt to account for the nasalization and lowering of vowels. First, we begin with the account on high vowel lowering in the following way.[8]

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[7] Or as the phonetically motivated ṼN (i.e., a sequence of a nasalized vowel and a nasal consonant), depending on the lexical item.

[8] There is good evidence for positing /in/ as the input for [ɛ̃]. For example, the nasal vowel [ɛ̃] in *vin* alternates with an oral vowel in those morphologically related words such as *vinasse* [vinas] 'cheap low quality wine,' *vineux* [vinø] 'vinous,' *vinicole* [vinikɔl] 'wine-producing,' and *vinification* [vinifikɑsjɔ̃] 'wine production,' etc. We can also find similar examples very easily: e.g., *fin* (masc.) [fɛ̃]/*fine* [fin] (fem.) 'slender, thin.'

(11)

Input /vin/	*VN]σ	*ṼN	*[+N, +lowF1]	*Tense Ṽ	Max-IO	Ident(nas)
a. vin	*!					
b. vĩn		*!	*	*		*
c. vẽn		*!		*		*
d. vɛ̃n		*!				*
e. vĩ			*!	*	*	*
f. vẽ				*!		*
g.☞ vɛ̃					*	*

In this table, we first eliminate (11a) in that it retains an oral vowel before a nasal. Second, those three candidates (11b, c, d) are dropped by allowing a nasal consonant after a nasal vowel. They also fatally violate *Tense Ṽ. Thus, we have three candidates (11e, f, g) left for further evaluation. Then, we discard (11e) [vĩ] not reflecting lowering enhancement since the high nasal vowel has [+low F1]. (Both (11b) and (11g) commit fatal violation of this constraint.) Finally, the last candidate [vɛ̃] is selected as the optimal output since the competing candidate [vẽ] (fatally) violates *Tense Ṽ.[9]

With the same mechanism, we can account for the selection of the round [œ̃] or [ɔ̃]. Thus, observing that lowering does not affect the backness (or roundness), we can say that lowering elevates the F1 value, while keeping the F2 value (for backness). However, there should be a limit for F1 elevation since nasalization of a high vowel produces a mid vowel, not a low one. In other words, a high vowel gets lowered to a mid vowel, but not further down to a low vowel. Moreover, just like a high vowel, a mid tense vowel becomes a mid lax vowel, rather than a low one, when it becomes a nasal. In other words, there is a tendency to keep the vowel height as close to that of the input vowel as possible. For this, I will posit the following faithfulness constraints prohibiting an output from changing F1 for height, as well as F2 for backness, value of the input.

(12) Ident(F1), Ident(F2)

These faithfulness constraints are in conflict with those other constraints

[9] Unless we recognized the three degrees of nasality (i.e., V, V̋, Ṽ), this kind of approach has to deal with opacity in those feminine nouns such as *la Seine* [sɛn] where we may not insert a schwa after the nasal. I am grateful to Greg Iverson for raising this possible opacity issue.

involved in vowel lowering. Therefore, employing these faithfulness constraints, we can illustrate the selection of a mid lax vowel [ɔ̃] from the oral tense counterpart /o/.[10] (We omit the low ranking constraints, Max-IO and Ident(Nas), for a simpler description.)

(13)

Input /bon/	*[+N, +lowF1]	*Tense Ṽ	Ident(F2)	Ident(F1)
a. bõ		*!		
b.☞ bɔ̃				*
c. bɑ̃				**
d. bœ̃			*	*

Here we can see the role of the featural faithfulness constraint, Ident(F1), by which a strong (but wrong) candidate *[bɑ̃] can be eliminated. This means that even if we allow lowering for nasalized vowels, they have to maintain the closest F1 value of the input as possible. On the other hand, the last candidate is no competition here due to the violation of Ident(F2). In a similar way, we can explain the high vowel to mid vowel change in the following tableau.

(14)

Input /vin/	*[+N, +lowF1]	*Tense Ṽ	Ident(F2)	Ident(F1)
a. vĩ	*!	*		
b. vẽ		*!		*
c.☞ vɛ̃				**
d. vã		*!		***
e. vɑ̃			*	***

The first candidate is the worst choice since it violates two inviolable constraints. (14b, d) are also eliminated due to the tense nasal vowels. Thus, we need to consider (14c) and (14e) for further evaluation. Then, Ident (F2) (along with Ident(F1)) takes a crucial role in the selection of the optimal output (14c).

4. Dispersion of Contrast

So far, especially in (13), we have observed the role of Ident(F2). However,

[10] We may consider another wrong alternative *[bɛ̃] but it violates an additional (and inviolable) constraint Ident(round).

we still face a case where Ident(F2) does not play any significant role. This case is related to the problem of explaining why lowering of the mid vowel /e/ does not produce the low vowel [ɑ̃], rather than the lax mid vowel [ɛ̃] which is much closer to [e]. For example, we need to explain why we get [vɑ̃] for the input /vent/ 'wind,' not [vɛ̃] or [vã]. We can, of course, eliminate [vã] since only lax vowels are subject to nasalization. But it is a different matter to explain why we do not get [vɛ̃]. For this problem, we need to consider the whole paradigm of vowel shift, rather than each individual vowel. Note that the place of [ɛ̃] has been already occupied by the lowering of /in/. If we allow [ɛ̃] as the output for /en/, there is no distinction between this nasalized vowel and the other [ɛ̃] from the different input /in/. For example, we will face an undesirable consequence where *vin* and *vent* should be pronounced the same.

In order to solve this problem, therefore, we need to posit a constraint requiring that the F1 distinction (or the minimun F1 distance between vowels) be maintained.

(15) Maintain F1 contrast
Maintain input F1 contrasts between adjacent vowels in the output.

This constraint shows the input-output correspondence of a vowel system, rather than an individual vowel, stating that any F1 contrast in the input should be maintained in the output.[11] Therefore, the one F1 contrast between /in/ and /en/ must be maintained in the output. (So, if there are N distinctive vowels in the input, the output is supposed to obey Maintain N-1 constraints.) In other words, any possible neutralization is to be avoided by this constraint. For example, as the nasalization and lowering of the high vowel /i/ occupies the slot for [ɛ̃], there is no chance for /e/ to show up as the same nasal vowel [ɛ̃]. So, we can maintain F1 contrast of the input in the output representation by moving the /en/ further down to [ɑ̃] in the auditory space. Consequently, we can illustrate the selection of the optimal output from *vin-vent*, as follows. (Here we ignore non-nasal consonants)

[11] It thus reflects the second principle in Flemming (1996), i.e., Maximize the distinctiveness of contrasts, as discussed later in this paper.

(16)

	/in-en/	*[+N, +lowF1]	*Tense Ṽ	Maintain 1 F1 contrast	Ident(F2)
a.	ĩ--ẽ	*!	**		
b.	ĩ--ɛ̃	*!	*		
c.	ẽ--ɛ̃		*!		
d.	ɛ̃--ɛ̃			*!	
e.☞	ɛ̃--ɑ̃				*

As we can see in this tableau, Maintain F1 contrast takes the crucial role in the selection of the optimal nasal vowel distribution, which has the most optimal dispersion pattern.

5. A Challenge to Dispersion

This explanation, however, is not a solution for the realization of the input /an/, in that the location of the lowest nasal vowel has been already taken by the mid vowel lowering. That is, there is no further space left for /an/ since there is no lower place in the vowel system. Let us take a look at the following tableau. (Here we use Maintain 2 F1 contrast since there are three different vowels for two F1 contrasts in the input.)

(17)

	/in-en-an/	*[+N, +lowF1]	*Tense Ṽ	Maintain 1 F1 contrasts	Ident(F2)
a.	ĩ--ẽ--ã	*!	***		
b.	ĩ--ɛ̃--ã	*!	**		
c.	ẽ--ɛ̃--ɑ̃		*!		
d.	ɛ̃--ã--ɑ̃		*!	*	*
e.💣	ɛ̃--ɛ̃--ɑ̃			*	
f.?	ɛ̃--ɑ̃--ɑ̃			*	*
g.	ɛ̃--ɛ̃--ɛ̃			**	

We get the wrong output (17e) since it has only one violation, while the correct one has two. Thus we need a further device to make [ɛ̃--ɑ̃--ɑ̃] win over [ɛ̃--ɛ̃--ɑ̃].

In order to solve this problem, we need to take a closer look at the feature matrix, where we can see that all the front vowels take two steps for lowering. For example, there are two degrees of formant (i.e., F1) distinction between /i/ and [ɛ̃] or between /e/ and [ɑ̃]. In other words, nonlow front vowels are supposed to go down at least two steps in the formant scale. We may thus posit the following constraint.

(18) MinDistF1=2
Maintain at least 2 distinctions of F1 between input and output.

This constraint indicates that there should be a minimum distance of F1 between the input oral vowel and its corresponding nasalized output. In other words, the height of a vowel should be changed in nasalization, but not too much (in order to comply with MinDistF1=2). Note that, by Maintain F1 contrast, the optimal output vowel is supposed to maintain the closest F1 value of its input, but the contrast should not be too big due to MinDistF1=2. Therefore, if the minimum distance between the input and the output is 1, it is less favorable than the distance with the 2 minimum distance. Moreover, if the MinDistF1 is more than 2, it is also less favorable than the one with MinDistF1=2.

(19) MinDistF1=1 << MinDistF1=2 >> MinDistF1=3,... >> MinDistF1=n

This single constraint, MinDistF1=2, is like a razor with two edges cutting out both too much and too less contrast, indicating a strong restriction, <u>neither too far, nor too close</u>.

Now we note that, unlike Maintain *N* F1 contrast, this constraint represents an input-output faithfulness relation. Therefore, we assign a violation mark if there is less than two degrees of distinction between an input vowel and its corresponding nasalized output. For example, we assign two violation marks for (20d) since there is only one F1 difference in the /i/-[ɛ̃] pair and another less than 2 F1 difference in the /a/-[ɑ̃] pair. However, there is only one violation in (20f) in which [ɑ̃] does not have enough F1 distinction from the input /a/.

(20)

/in-en-an/	*[+N, +lowF1]	*Tense Ṽ	MinDistF1=2	Maintain 2 F1 contrast	Ident(F2)
a. ĩ--ẽ--ã	*!	***	***		
b. ĩ--ɛ̃--ã	*!	**	***		
c. ẽ--ɛ̃--ɑ̃		*!	***		
d. ɛ̃--ã--ɑ̃		*!	**	*	
e. ɛ̃--ɛ̃--ɑ̃			**!	*	
f.☞ ɛ̃--ɑ̃--ɑ̃			*	*	*
g. ɛ̃--ɛ̃--ɛ̃			**!	**	

In (20), we first eliminate (20a, b, c d) for violating (both or one of) the two top constraints. Thus, we have (20e, f, g) for further evaluation and MinDist(F1) takes the crucial role in the selection of the optimal output pattern. As for (20e), the F1 distance between the input vowel /e/ and its correspondent [ɛ̃] is 1 and the F1 distance in the /a/-[ɑ̃] pair is zero, while the F1 distance in the /i/ and [ɛ̃] is 3. Therefore, there are two violations in this candidate. Similarly, in (20g), there is not enough F1 distance in the /e/-[ɛ̃] and /a/-[ɛ̃] pairs since the F1 distance is just 1 in each case. The only pair complying with the constraint is /i/-[ɛ̃] in which the F1 distance is 3. In (20f), however, there is only one violation of MinDistF1=2 since there is only one pair /a/-[ɑ̃] violating it for its zero F1 distance, while the F1 distance in the other pairs maintain two or three. As a result, in spite of the additional violation of Ident (F2), (20f) is selected as the optimal output pattern due to the least violation of MinDistF1=2.

6. Problems with a Rule-based Approach

In earlier approaches to nasal vowel lowering, various rules and their strict ordering relations are required. For example, in Casagrande (1984 : 121), there are at least three rules required to derive a correct derivation for vowel lowering, i.e., Nasalization, Nasal Deletion, and Nasal vowel Lowering. Moreover, these rules are to be strictly ordered due to their feeding relationship. Furthermore, these rules are also ordered to precede another rule, Final Schwa Deletion, to derive a correct surface form for a vowel final word. Let us take a look at the following derivation for *fin* (masculine)/*fine* (feminine) 'slender, thin.'

(21) a.	*fine* (fem.)	*fin* (mas.)	
	/fin-a/	/fin/	Underlying Representation
	ə	---	Posttonic Vowel Reduction
	fin	---	Final Schwa Deletion
	*fɛ̃	fɛ̃	Nasalization, Nasal Deletion, Nasal Vowel Lowering
b.	/fin-a/	/fin/	Underlying Representation
	ə	---	Posttonic Vowel Reduction
	----	fɛ̃	Nasalization, Nasal Deletion, Nasal Vowel Lowering
	fin	---	Final Schwa Deletion

Besides the complexity of the description, there are several theoretical problems in this approach. First, there is no explanation on the trigger of the lowering. In other words, as there is no direct relation between the underlying oral vowel and the following nasal consonant, it is not possible to explain why only the nasal vowels get lowered. Therefore, it is not clear what part of the vowel system initiates the overall vowel lowering. In our current approach, however, we can explain this in terms of F1 elevation of a high vowel by acoustic nasal energy (i.e., high anti-resonance).

Second, there is no limit for lowering in this approach since all nasal vowels are expected to become [low] by Nasal Vowel Lowering. As mentioned earlier in this paper, [ɛ] as well as [ɑ] are considered to be low in Casagrande (1984). Following this assumption, regardless of their height, all the nasal vowels are to become [+low]. Then it is difficult to anticipate which of the two low vowels will show up during the lowering processes of the front vowels /i, e, a/ since there is no height difference between [ɛ̃] and [ã]. In our new approach, however, there is no possibility to have such a problem since the difference between these vowels is represented in terms of F1 features.

Third, it is difficult to explain why we get neutralization of /en, an/ → [ɑ̃] change. In other words, there is no reason for not getting another type of neutralization, i.e., /in, en/ → [ɛ̃], rather than the /en, an/ → [ɑ̃] neutralization. But this is no problem in our approach because we can account for this aspect with respect to the interaction of two constraints.

As we have observed so far, our current approach has numerous (theoretical and practical) advantages over a traditional approach like Casagrande's.

7. Further Implications

We have discussed how the overall pattern of lowering of French nasal vowels from a phonetic and phonological points of view. There are several claims proposed in this paper.

First of all, I have claimed that the overall lowering pattern is triggered by the high vowel nasalization and lowering, in which the nasal acoustic energy elevates the first formant of the preceding high vowel. So the high vowel nasalization process can be interpreted as a case of enhancement of lowering. In order to provide a phonetically real explanation, I have proposed to decompose the scalar F1 values into binary features in the manner of the traditional account of vowel height. Moreover, it has been mentioned that the vowel nasalization is a case of vowel-consonant coalescence since the nasal consonant cannot be maintained after a nasal vowel in French. (I have also proposed to differentiate a (purely phonetic) nasalized vowel and a nasal vowel.)

Second, as for the high vowel lowering, I have proposed several constraints by which we get only lax vowels in which, due to Ident(F2), the backness contrast in the input is strictly maintained in the output. Moreover, observing that there is a limit of lowering, I have proposed Ident(F1) in order to maintains the F1 contrast of the input as close as possible in the output. As a consequence, we get [vɛ̃], not [vɑ̃] (or [vã]) from the input /vin/ 'wine.'

Third, I have proposed an additional constraint, Minimun Distance for formant, accounting for the mid vowel lowering /en/ → [ɑ̃] in which we get the same low vowel just as the same one [ɑ̃] from /in/. Here, I proposed to employ the concept of Dispersion Theory since we need to take the whole (front) vowels into consideration in order to explain the correct nasal output vowels. In other words, we need to take the /in--en--an/ into consideration to make relate them to their corresponding [ɛ̃--ɑ̃--ɑ̃] pattern. In other words, by introducing the MinDist(F)=2 constraint, we can explain the whole pattern of the nasalization of the front vowels. Therefore, it is shown that constraints of this type imply that the well-formedness of a vowel system cannot be evaluated in isolation because it depends on the well-formedness of the contrasts between adjacent vowels.

In principle, these results are compatible with the functional goals of Dispersion Theory (Lindblom 1986, Flemming 1995). In Dispersion Theory, there are constraints on the well-formedness of phonological contrasts. Thus the selection of phonological contrasts is subject to the following three functional goals (Flemming 1995, 1996).

(22) a. Maximize the number of contrasts.
b. Maximize the distinctiveness of contrasts.
c. Minimize articulatory effort.

Among these three goals, high vowel lowering by nasal is a case of minimization of articulatory effort since it is much easier to make a mid nasal vowel, rather than a high nasal vowel. Second, mid vowel lowering reflects the goal of maximization of distinctiveness of contrasts. In other words, the selection of [ɛ̃] (for the input /i/) is a result of the goal to maintain the distinctiveness of two inputs /i/ and /e/ in the output. Therefore, the output of /i/ nasalization (i.e., [ɛ̃]) becomes distinct from that of the /e/ nasalization, [ɑ̃]. However, the current observation on nasal vowel lowering in French does not provide much evidence for the first goal, i.e., Maximize the number of contrasts. Notice that this goal may be interpreted as the listener's intention to maintain the maximum number of vowels. Nevertheless, we might consider the overall vowel nasalization to be relevant to this goal, observing that the nasal vowels are distinct from the input vowels in tenseness (due to *Tense Ṽ).

Furthermore, nasalization of the low vowel is a possible challenge to Dispersion Theory (especially the second goal for maximization of distinctiveness), in that we get the neutralized output [ɑ̃] for the input /an/, which is identical to the output for another input /en/. The optimal output [ɑ̃] is a consequence of the interaction of two constraints, MinDist(F1) and Maintain contrast. We observe here that dispersion of the nasal vowels depends on the values of the corresponding input vowels because there is a strong tendency that we maintain the closest formant values of the inputs in the outputs as possible. In other words, even if we need a certain degree of distance between vowels (i.e., MinDist(F1)=2), the distance should not be too far (i.e., Ident(F1) and Ident(F2)). This result is obtained by the pattern evaluation of the adjacent vowels since the well-formedness of the vowel system cannot be evaluated in isolation.[12]

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[12] Refer to Ahn (2000) for an extension of this approach to Middle Korean vowel shifts.

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