

## Directional asymmetry in nasalization: a perceptual account\*

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**Jeong, Sunwoo. 2012. Directional asymmetry in nasalization: a perceptual account.** *Studies in Phonetics, Phonology and Morphology* 18.3. 437-469. In this paper, I conduct a typological study on contextual vowel nasalization to elucidate the directional asymmetry involved in the process. I show that carryover nasalization is the default and extensive form of phonetic coarticulation in many languages and that it often exceeds the degree of anticipatory nasalization as coarticulation. On the other hand, I also show that anticipatory nasalization occurs more frequently than carryover nasalization as a phonological assimilation process. Consequently, I conclude that the relevant directional asymmetry in contextual vowel nasalization does not involve one direction of nasalization having absolute ascendancy over the other, but rather involves each direction of nasalization having different kinds of ascendancies at different levels of grammar. This mismatch between phonetic and phonological tendencies in contextual vowel nasalization is claimed to arise due to an asymmetry in perception: anticipatory nasalization is more easily perceived than carryover nasalization, rendering the extensive degree of anticipatory coarticulation unstable in nature. Therefore, languages will either opt to suppress anticipatory coarticulation below a certain threshold or opt to phonologize it into a more stable assimilation pattern. This perceptual hypothesis is validated by the result of an AXB perception experiment which shows that anticipatory coarticulation is more easily perceived than carryover coarticulation. (Seoul National University)

Keywords: nasalization, coarticulation, assimilation, perceptual asymmetry

### 1. Introduction

Contextual vowel nasalization is a process whereby a vowel takes on the nasality of a neighboring nasal consonant. Many previous studies on this process point out an asymmetry in the direction of nasalization. Interestingly, these studies diverge with respect to the preferred direction of nasalization. In the relatively more common view (J. Ohala 1975, Ruhlen 1978, Kawasaki 1986 and others), a vowel preceding a nasal consonant is the typical target of nasalization, thus being more extensively and more commonly nasalized than a vowel following a nasal. Under this view, anticipatory nasalization ( $VN \rightarrow \tilde{V}N$ ) is the more prevalent and universal form of nasalization. On the other hand, a completely opposite view (Delvaux et al. 2008, among others) has also been suggested, in which a post-nasal vowel is more heavily and more frequently nasalized than a pre-nasal vowel. In this view, carryover nasalization ( $NV \rightarrow N\tilde{V}$ ) is

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the more dominant form of nasalization.

In this paper, I aim to resolve this conflict about the preferred direction of vowel nasalization. After reviewing the empirical data and analyses adopted in the previous studies to support either of the two contradicting views, I propose an alternative that can be consistent with the evidence of the two previous views. In my approach, the true directional asymmetry in contextual vowel nasalization does not involve one direction of nasalization having absolute ascendancy over the other, as the two existing views predict, but rather involves each direction of nasalization having different kinds of ascendancies at different levels of grammar. Specifically, vowel nasalization is mainly anticipatory in the phonological level but carryover in the phonetic level. This argument is based on my review of the relevant facts that shows that the degree of carryover nasalization is generally extensive as gradient, phonetic coarticulation but seldom categorical, whereas the degree of anticipatory nasalization is often categorical as phonological assimilation but non-extensive when it is manifested as phonetic coarticulation.

A potential objection to this argument is that it is not in agreement with the conventional assumption on the relationship between phonology and phonetics. It is generally assumed that phonetic and phonological patterns go hand in hand, and gradient, phonetic tendencies become precursors to more categorical, phonological changes. The nasalization pattern predicted by this paper shows an anomalous tendency by suggesting a discrepancy between phonetic coarticulation tendency (which is in favor of carryover nasalization) and categorical phonological pattern (which is in favor of anticipatory nasalization); phonetically robust phenomena of carryover nasalization do not culminate into phonological changes, whereas phonetically non-extensive phenomena of anticipatory nasalization often result in categorical phonologizations of the nasalization process.

To resolve this puzzle, this paper examines a possibility where the seemingly problematic phonetics-phonology discrepancy is due to an asymmetry in nasality perception. To be more specific, it is hypothesized that anticipatory nasalization is more easily perceived than carryover nasalization. This perceptual tilt eventually gives rise to frequent phonologizations of anticipatory nasalization processes. On the other hand, carryover nasalization is less liable to phonologization because it is dominantly left unperceived by the listeners. To verify this hypothesis, an AXB perception experiment was conducted. Results show, confirming the hypothesis, that vowels in anticipatory nasalization context were indeed perceived as more nasalized than vowels in carryover nasalization context, even when the vowels in the two contexts had identical degrees of nasality. The possible cause of the asymmetry in the auditory perception of nasality will be discussed later on in the paper.

The organization of the rest of the paper is as follows: In section 2, the argument supporting the primacy of anticipatory nasalization is examined.

In section 3, the opposing argument that supports the primacy of carryover nasalization is reviewed briefly. In section 4, my own argument, the predicted typology of this argument, and further implications underlying the argument are presented. In section 5, a perceptual hypothesis that can account for the phonetics-phonology discrepancy is proffered. Finally in section 6, the result of an AXB perception experiment that supports this perceptual hypothesis is reported.

## 2. The primacy of anticipatory nasalization

Although the issue of universals matters in all phonological theories, Optimality Theory (Prince and Smolensky 2004) is a theory that most directly incorporates the considerations about typological universals into its framework. In OT, the notion of universal is reflected in universal markedness constraints, and its actual manifestation is worked out by language specific rankings. Using this OT framework, standard textbook analysis (for instance, Kager's OT analysis, 1999) of the process of nasalization assumes only the following universal markedness constraints: context specific markedness constraint \*VN that triggers anticipatory nasalization, and context-free markedness constraint \* $\tilde{V}$  that bans nasal vowels.

Table 1. Constraints used in the standard analysis

Commonly adopted markedness constraints	Rarely (or never) adopted markedness constraints
*VN, * $\tilde{V}$	*NV, * $\tilde{V}N$

Table 2. Typology: expected patterns

Constraint Ranking	Contrast Patterns	Oral (vs) Nasal V	Attested Patterns
* $\tilde{V}$ >> ID(N), *VN	no contrast	always oral	ba, ban
ID(N) >> * $\tilde{V}$ , *VN	phonemic	always oral/nasal	ba, bā, ban, bān
*VN >> * $\tilde{V}$ >> ID(N)	allophonic	oral elsewhere nasal before nasal	ba, bān
*VN >> ID(N) >> * $\tilde{V}$	neutralization	oral/nasal nasal before nasal	ba, bā, bān

To be more specific, in standard OT analysis, the assumed universal constraint set does not contain any hypothetical markedness constraints such as \*NV or \* $\tilde{V}N$ , as summarized in the table above (Table 1). (cf \* $\tilde{V}N$  = No nasal vowel is allowed before a nasal. \*NV = No oral vowel is

allowed after a nasal.)

In sum, the postulated markedness constraints, along with the relevant faithfulness constraint IDENT(nasal), would interact in different ways through diverse constraint rankings and ultimately yield the factorial typology above (Table 2).

The nature of the set of constraints employed above tells us that this analysis and its ensuing typological prediction presuppose that anticipatory nasalization is common, whereas carryover nasalization is rare. This is an assumption which is supported directly or indirectly in many previous studies including Schourup (1972), Bhat (1975), J. Ohala (1975), Ruhlen (1978) and Kawasaki (1986). The major reason behind this wide spread support is that there are diverse types of evidence that seem to support the frequent occurrence of anticipatory nasalization and the relative lack of carryover nasalization.

Such supporting evidence can be divided into two main categories. The first concerns synchronic, categorical nasalization processes, and the second, diachronic development of nasal vowels. I will now briefly look at each type of evidence.

### 2.1 Synchronic evidence

Many studies on language typology suggest that anticipatory nasalization is more common than carryover nasalization. This is because non-contrastive but fully nasalized vowels predominantly take place before N (in VN sequences) than after N (in NV sequences) in many languages. For example, the following typological study by Kawasaki (1986) explicitly states that anticipatory nasalization is more common by citing 17 languages (Azerbaijani, Cayapa, Chipewyan, Delaware, English, Hupa, Kashmiri, Malay, Nahuat, Nez Perce, Panamanian Spanish, Tagalog, Tewa, Tolowa, Tunica, and Wolof) that are claimed to show prominent processes of anticipatory nasalization.

In general, a syllable-final nasal nasalizes a vowel more than a syllable-initial nasal (Kawasaki 1986: 83).<sup>1</sup>

A more comprehensive typological study is provided by Cohn (1993b). In this study, 117 languages were surveyed. Nasalization is said to be

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<sup>1</sup> Previous studies have noted that within the more general process of anticipatory nasalization, vowels that are adjacent to tautosyllabic nasals VN]σ are more extensively nasalized than vowels that are adjacent to heterosyllabic nasals V]σN (Krakow 1994). The significance of such syllabic effect in nasalization is duly noted. However, in this paper, the two subprocesses of anticipatory nasalization will generally be treated as a single category. This is because I have found no language data where the two subprocesses made a significant difference in the more general pattern of directional asymmetry in nasalization. Only in particular subsections of the paper where the distinction between VN]σ and V]σN is deemed relevant will this subcategorization be explicitly reminded.

anticipatory in 61 languages (52%), progressive (carryover) in 30 (26%), and bidirectional in 26 (22%). Therefore, this study also concludes that anticipatory nasalization is indeed a dominant form of nasalization. On the other hand, this study also suggests that progressive nasalization is 'more common than often assumed.' Hence, the result of the study might seem like introducing certain qualifications to the more definitive argument made in the previous study (Kawasaki 1986). However, most of the 30 cases of carryover nasalization in Cohn's study are related to the process of nasal spread or nasal harmony (Blust 1997).<sup>2</sup>

By reviewing previous works on nasal harmony (for instance, Walker 2003, Piggott 2003) I have concluded that the cases of nasal harmony are subject to a different mechanism compared to local cases of nasalization; thus, I have excluded them from the scope of this paper. Therefore, excluding the cases of nasal harmony, Cohn's work also seems to suggest that local cases of nasalization are almost always anticipatory and seldom carryover in nature.

To summarize, several typological studies based on a significant amount of synchronic language data seem to suggest that vowels are more extensively and more frequently nasalized in anticipatory context than in carryover context. In the next section, another type of evidence for the primacy of anticipatory nasalization, namely, the diachronic evidence, will be examined.

## 2.2 Diachronic evidence

The historical development of phonemic nasal vowels has long been a subject of interest to many scholars (Haden and Bell 1964, Chen 1973, Trigo 1983, Hajek 1993, Ohala 1993, Beddor 2007). The diachronic process underlying the emergence of phonemic nasal vowels might be used as yet another type of evidence, albeit indirect, implying that anticipatory nasalization is more robust and frequent than carryover nasalization. This is because most phonemic nasal vowels in various languages almost always result from the reinterpretation of VN sequences and seldom from NV sequences (e.g. Romance languages such as French and Portuguese, Indic languages such as Hindi, Bengali and Punjabi, as well as many other languages such as Old Church Slavic).

To be more specific, although opinions vary on the detailed processes and mechanisms behind contrastive nasal vowel development, many scholars seem to agree at least on the following outline of the typical diachronic process whereby phonemic nasal vowels emerge (Chen 1973,

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<sup>2</sup> Nasal harmony denotes the process of nasalization that is continued throughout several segments. This type of nasalization, sometimes described as 'suprasegmental nasalization', is known to have both rightward (progressive) and leftward (regressive) direction of nasalization. Hence, not all suprasegmental nasalizations are carryover in nature, but almost all *phonological cases of carryover nasalization* seem to be suprasegmental in nature, not local.

Chen and Wang 1975, Trigo 1988, Hajek 1997, Ohala 1993, Beddor 2009):

1. The V in the VN sequence is produced with (anticipatory) nasalization.
2. The consonantal quality of N is attenuated over the course of time.  
(According to Chen (1973), to velar nasals; according to Trigo (1988), first to velar nasals, and then to nasalized glides). (or)  
The coda N is mistakenly not perceived by the listeners. (Ohala 1993)
3. N is deleted (according to Ohala (1993), due to hypo-correction).
4. The nasalized V is left.  
(Without the N that conditioned the nasalization.)

Therefore, the diachronic data concerned with the emergence of phonemic nasal vowels suggest that the most canonical precursor for the relevant sound change is VN (heavily nasalized vowel + nasal sequence). This historical fact may in turn imply that vowels are nasalized more heavily and more often in pre-nasal position than in postnasal position.

At this point, it must be noted that such diachronic argument cannot be considered as conclusive evidence for the primacy of anticipatory nasalization. This is because the frequent emergence of phonemic nasal vowels from VN sequence can also be explained by just assuming the coda-onset asymmetry. It is well known that codas are more easily deleted than onsets. With this fact in mind, one might be able to argue that the vowels resulting from carryover nasalization did not develop into phonemic nasal vowels simply because the conditioning environment, the onset nasal, did not get deleted. Therefore, although the diachronic evidence proposed above proves that anticipatory nasalization occurred quite frequently, it cannot prove the lack of comparable cases of carryover nasalization. In other words, the diachronic evidence alone cannot guarantee the prevalence of anticipatory nasalization over carryover nasalization.

It has been noted above that the evidence is inconclusive regarding the issue of whether carryover nasalization had occurred as a robust process in prior historical states. Nevertheless, one can at least conclude that the hypothetical NṼ (nasal + heavily nasalized vowel sequence), regardless of its existence or non-existence, seldom became precursors to phonological sound change. Therefore, if the previous section 2.1 has shown that carryover nasalization plays only a marginal role as a synchronic phonological process, this section 2.2 shows that its role is also insignificant in producing diachronic phonological change.

### 2.3 Problematic patterns

So far, this paper has briefly gone over some supporting evidence for the primacy of anticipatory nasalization. Because this supporting evidence is

comprised of quite a large set of language data, the standard constraint-based analysis of nasal vowel typology that follows from this assumption on the primacy of anticipatory nasalization is able to cover a lot of the attested data patterns. But there is also a significant amount of data that it cannot explain.

If one recalls the standard OT analysis mentioned in the previous section, it will be remembered that the analysis posited \*VN as the only relevant constraint and did not posit any hypothetical constraints such as \* $\bar{V}N$  or \*NV. Therefore, in this analysis, no constraint ranking can capture the following attested patterns.

**Table 3. Unexpected patterns**

Constraint Ranking	Contrast Patterns	Oral (vs) Nasal V	Attested Patterns
none	neutralization	oral/nasal oral before n	ba, b̄a, ban
none	allophonic	oral elsewhere nasal after nasal	ba, n̄a

First of all, the analysis cannot predict a language that normally allows phonemic nasal vowels but disallows them specifically in the pre-nasal context. French is one such example. Second of all, the analysis cannot predict a language that shows a more extensive degree of carryover nasalization compared to anticipatory nasalization. Cairene Arabic and Greek are examples of such languages.

### 3. The primacy of carryover nasalization

The problematic cases mentioned in the previous section have often served to develop the opposite argument that carryover nasalization is in fact more universal than anticipatory nasalization is. In this section, this competing hypothesis will be examined. Before discussing a more general and comprehensive data set concerning the hypothesis, I will begin with the data of one specific language, French.

The nasalization process in French merits special attention, because French is an ideal counterexample to the classic view of vowel nasalization in that it shows both the active suppression of anticipatory nasalization and the robust occurrence of carryover nasalization.

#### 3.1 A case study: French

As already mentioned in the previous section, one striking peculiarity in French is that it minimizes anticipatory nasalization of the vowels before nasal stops. In other words, French neutralizes its oral-nasal vowel

distinction before tautosyllabic nasals not to nasal vowels, but to oral vowels. This is interesting because vowel nasality in general is not suppressed in French (because French has phonemic nasal vowels) but somehow, it is suppressed only before nasals; in other words, there seems to exist a certain force in French that specifically aims to suppress the process of anticipatory nasalization. As I have already shown, this tendency cannot be captured by any possible ranking of a set of OT constraints adopted for the conventional analysis of vowel nasalization.

Therefore, works in the previous literature have mostly focused on why anticipatory nasalization is minimized in French. Many analyses claim that French suppresses contextual vowel nasalization because vowel nasality is a contrastive feature in French (Flemming 2004, Spears 2006). In other words, in order to ensure maximum perceptual distance between phonemic nasal vowels and oral vowels, French oral vowels nasalize only to a minimum degree when they are adjacent to nasal stops.

Such explanation seems intuitively plausible, but additional data complicates the picture. It has been shown that French vowels undergo extensive carryover nasalization, unlike the case of anticipatory nasalization (Delvaux 2003, 2009, Cohn 1990). If contextual nasalization is minimized in order to ensure perceptual distinctiveness between nasal vowels and nasalized oral vowels, it is hard to explain why only anticipatory nasalization is subject to the restriction, and why carryover nasalization still happens extensively in French.<sup>3</sup> Therefore, the perceptual distinctiveness hypothesis by itself is not sufficient to explain the patterns present in the French data.

An explanation that fully accounts for this French data pattern will be suggested in section 7, based on the results of a perception experiment that has been undertaken for this paper. For now, it suffices to accept that the French data clearly show that 1) anticipatory nasalization can be actively suppressed, and that 2) carryover nasalization can be extensive, contrary to the argument made in section 2. To further support these generalizations that make contradictory claims to the classical assumption, more comprehensive data sets from other languages will now be inspected.

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<sup>3</sup> In addition, one must also take into account the fact that the oral-nasal vowel distinction is neutralized to oral vowels before tauto-syllabic nasals in French. In other words, there may not be that much context-specific need to minimize anticipatory nasalization, if the reason behind it is to distinguish  $\check{V}N]_{\sigma}$  and  $VN]_{\sigma}$ : such distinction does not hold in the first place, because only oral vowels can occur before the tautosyllabic N. Nonetheless, one may still be able to claim that anticipatory nasalization is minimized in French to ensure enough perceptual distance between  $\check{V}]_{\sigma}N$  and  $V]_{\sigma}N$  (vowels preceding *heterosyllabic* nasal consonants; in this case, the contrast still holds). Another line of approach which may be a bit more controversial is to claim that anticipatory nasalization has been minimized to ensure perceptual distance between  $VN$  and  $\check{V}$ , not between  $VN$  and  $\check{V}N$ .

### 3.2 Other phonetic data

French is perhaps the most extensively studied language where carryover nasalization has been proven to be significantly more extensive than anticipatory nasalization. But French data cannot simply be considered as an exception. Phonetic studies have shown that quite a few other languages also show significant degree of carryover nasalization. The following are the list of languages where the phonetically measured degree of carryover nasalization is shown to be quite extensive: Japanese (Ushijima and Hirose 1974), Swedish (Clumeck 1975), Dutch (Schouten and Pols 1979), Italian (Farnetani 1986), Akan (Huffman 1988), Ikalanga (Beddor and Onsuwan 2003) and French (Cohn 1988, Delvaux et al. 2008) (7 languages in total). Moreover, in all of these languages, the degree of nasality<sup>4</sup> in carryover nasalization exceeded that of anticipatory nasalization.

To gain a deeper understanding of the pattern, a closer inspection of one of the data from the languages listed above will be conducted. The study by Clumeck (1975) shows that in Swedish, anticipatory nasalization occurs only minimally. On the other hand, according to the graph presented in the paper, carryover nasalization in Swedish is shown to occur quite extensively. In the case of carryover nasalization, the time of velic closure after the vowel onset is around 150-200 ms for the vowels with total duration of 200-250 ms; in other words, more than two thirds of the vowel is nasalized. In contrast, only around one half to one third of the vowel is shown to be nasalized in the case of anticipatory nasalization.

At this point, it must be briefly noted that not all the studies cited above agree on the methodology concerning the measurement of nasalization. In fact, one of the difficulties in comparing the quantified nasalization data from various sources lies in the fact that the experimental methods often vary depending on the study. For example, the research on Japanese (Ushijima and Hirose 1974) cited above used a fiberoptic measurement whereby the timing and degree of the velum lowering was directly observed; on the other hand, studies on languages such as Greek (Diakoumakou 2004) and Ikalanga (Beddor and Onsuwan 2003) carried out acoustic analyses of the spectra to measure the degree of nasalization. In addition to these methods, aerodynamic (e.g. Medeiros 2011) studies and electromagnetic studies have also been carried out.

Because of this difference in experimental methodology, a direct comparison between the quantified data derived from various studies concerning nasalization must be undertaken with precaution. Nonetheless, what is known for sure at this point is the fact that all the studies cited above consistently report carryover nasalization to be significantly more extensive than anticipatory nasalization at least *within* the data of each

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<sup>4</sup> There are various ways to measure the degree of nasality. In this paper, I will stick to the conventional method where the nasalized portion of the vowel relative to the total duration of the vowel is calculated.

language.

To summarize, there seems to be a non-negligible amount of data that claim carryover nasalization to be quite extensive in many languages, and in all the languages cited above, not simply extensive but significantly more extensive than anticipatory nasalization. Based on the growing amount of phonetic data, some scholars have proceeded to conclude that carryover nasalization is the more universal form of nasalization compared to anticipatory nasalization.

(...) many studies that focused on the difference between carryover and anticipatory nasalization concluded on the preeminence of the first over the second (...) (Delvaux et al. 2008)

Although such an argument covers the new type of phonetic data that has been examined in this section quite well, this view is also problematic because as has already been seen in the previous section, many other types of language data show a more extensive degree of anticipatory nasalization than carryover nasalization.

Therefore, the two opposing arguments each examined in section 2 and section 3, both with significant supporting data, seem to be leading to an impasse and make one wonder whether there is really a directional asymmetry worth discussing in the first place. Are the patterns of nasalization just random and language specific after all? In the next section, I will argue that there *is* in fact a clear directional asymmetry that merits attention, but that this asymmetry is more complex in nature from the predicted asymmetries propounded by the two opposing viewpoints that have been examined so far.

#### 4. Asymmetries in different levels

In this section, based on a careful reanalysis of the supporting data of the two opposing arguments concerning directional asymmetry in nasalization and the discussion of other additional language data, I will propose the following argument: *Carryover nasalization is more extensive as phonetic coarticulation, but anticipatory nasalization is more common as phonological assimilation.*

To put it differently, following the conventional characterization of ‘coarticulation’<sup>5</sup> as a process that is phonetic in nature, and ‘assimilation’<sup>6</sup> as a process that is phonological in nature, the extensive degrees of carryover coarticulation generally fall in the mid range between the non-

<sup>5</sup> For example, according to Zellou (2012), coarticulation refers to the fact that ‘speech often displays features of multiple segments simultaneously, even if the phonological representations of these segments are distinct.’

<sup>6</sup> In phonological assimilation process, the assimilated segment acquires the relevant feature of the source segment in the level of phonological representation.

extensive degrees of anticipatory coarticulation and categorical degrees of anticipatory assimilation.

Several observations led me to this conclusion. First, observations about data involving anticipatory nasalization are as follows:

1. In languages that are purported not to have any salient phonological process of contextual nasalization, anticipatory nasalization is less extensive in degree of phonetic coarticulation than carryover nasalization. Languages such as Greek and Swedish prove this point.
2. In other languages where anticipatory nasalization *is* found to be extensive, it is not only just extensive, but usually categorical in nature, which means that the entire portion of the vowel is nasalized. Languages such as English (Solé 1992)<sup>7</sup> and Hindi (M. Ohala 1975), as well as other languages similar to Hindi where the vowel oral-nasal contrast is neutralized to full nasal vowels in anticipatory context, prove this point.
3. Also, anticipatory nasalization is typically related to other corollary phonological processes involving the loss of lexical contrast, such as neutralization of vowel quality or neutralization of vowel nasality.
  - (a) Neutralization of vowel quality: For example, it is claimed that in some dialects of English, the high-mid distinction of front vowels (e.g. [i] and [e] in [tin] vs. [ten]) is neutralized in the context *before* nasal stops (Johnson 2003).<sup>8</sup> However, no comparable process of vowel quality neutralization is claimed to happen in the context *after* nasals.
  - (b) Neutralization of vowel nasality: It is well known that languages with phonemic nasal vowels often neutralize their oral-nasal distinction of vowels into nasal vowels when they are adjacent to nasal stops<sup>9</sup> (Hyman 1975, Kawasaki 1986, Flemming 2001). This neutralization pattern in turn entails the contextual nasalization of an underlyingly oral vowel, and it occurs dominantly before nasal stops (anticipatory context) and not after them (carryover context). More about this in 6 below.

In Brazilian Portuguese, both (a) and (b) occur in anticipatory context (Quicoli 1990). Vowels /e/, /ɛ/ and /ẽ/ are neutralized to [ẽ] in VN

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<sup>7</sup> For English, there have been contradictory claims concerning the categorical nature of anticipatory nasalization. Cohn (1993a) claims that it is extensive but not categorical, whereas Solé (1992) claims that it is categorical. Based on other additional experimental data (e.g. Malécot 1960, Flege 1988, Chen et al. 2007), as well as my own pilot experiment, I conclude that anticipatory nasalization in English is categorical. In my pilot experiment, the effect of speech rate on carryover and anticipatory nasalization was examined. In the case of anticipatory nasalization, as speech rate got slower and the target vowel got longer, the duration of vowel nasalization also got longer accordingly, in order to categorically nasalize the vowel to its full length. On the other hand, in the case of carryover nasalization, the duration of nasalization remained relatively fixed, irrespective of speech rate and target vowel length.

<sup>8</sup> This process is related to the fact that vowel nasalization in general produces the tightening and centralization of the vowel space (Lindblom 1986, Wright 1986).

<sup>9</sup> An exception that has already been seen is French, where the contrast is neutralized to oral vowels.

sequence, and vowels /o/, /ʌ/ and /ɔ̃/ are neutralized to [ɔ̃].

4. Finally, anticipatory nasalization is often involved in the diachronic development of phonemic nasal vowels, as has already been seen in section 2.2.

All these observations led me to conclude that, to put it roughly, anticipatory nasalization is phonological in nature. In comparison, observations about data involving carryover nasalization are as follows:

5. Carryover nasalization is found to be extensive across the board in almost all types of language data. But this extensive degree of carryover nasalization usually remains gradient in nature (generally, around 70-90% of the vowel length is nasalized) in local cases of nasalization, and not categorical.
6. Additionally, carryover nasalization seldom triggers salient phonological processes such as neutralization, in stark contrast to the case of anticipatory nasalization.

It has already been shown that neutralization of vowel oral-nasal distinction occurs quite frequently in VN sequences. In contrast, vowel neutralization is rare in NV sequences although it does exist in languages such as Nupe (Hyman 1973, 1975). In fact, a certain implicational relationship seems to hold; if a vowel is neutralized after N, then it is neutralized before N.

For example, a survey of neutralization pattern by Kawasaki (1986) cites 14 languages (Beembe, Bengali, Brazilian Portuguese, Chinese, Goajiro, Hindi, Island Carib, Kashmiri, Mazatec, Mixtec, Punjabi, Takum Jukun, Tewa and Yuchithan) that neutralize the vowel oral-nasal distinction in anticipatory context. On the other hand, this study cites only 7 languages (Bengali, Ijo, Mazatec, Mixtec, Navaho, Nupe and Quiotepec Chinantec) that are purported to neutralize such contrast in carryover context.

Excluding the three languages (Bengali, Mazatec, Mixtec) that show neutralization in both VN and NV context, there are only 4 languages that show neutralization solely in NV context, compared to 11 languages that show neutralization solely in VN context. In addition, the 4 languages that are purported to show neutralization solely in carryover context are mostly languages with simple CV structure (the sequence of tautosyllabic VN is not allowed in the first place in such languages).

Therefore, comparing only the case of tautosyllabic anticipatory nasalization with carryover nasalization, the supposed implicational relationship between the two directions of nasalization fully holds: If  $\tilde{V}$  and V are neutralized after the tautosyllabic N, then it is definitely neutralized before the tautosyllabic N.

In sum, neutralization of vowel oral-nasal contrast is rare in carryover nasalization, whereas it is quite common in anticipatory nasalization. In addition, carryover nasalization does not trigger any neutralization in

vowel quality, whereas anticipatory nasalization does trigger such neutralization processes, as has already been seen.

7. Finally, carryover nasalization seldom triggers diachronic changes where phonemic nasal vowels are developed.

These observations in turn led me to conclude that, to put it roughly, carryover nasalization is phonetic in nature. Hence, the true asymmetry in contextual vowel nasalization does not involve one direction of nasalization having absolute primacy over the other. Instead, it stems from the asymmetry in the implementation mode: carryover nasalization dominantly manifests itself as phonetic coarticulation tendency, whereas anticipatory nasalization, if it is condoned, usually manifests itself as categorical phonological pattern.

#### 4.1 A recapitulation of the relevant data

In the table below, I present a comprehensive set of data that supports the argument developed in the previous section; namely, that carryover nasalization is usually extensive but not categorical, whereas anticipatory nasalization is either non-extensive or altogether categorical.

Not all the data that have been mentioned in the two previous sections (section 2 and 3) have been included in the table. This is due to the fact that some language data, especially those in section 2, lack definitive, phonetically quantifiable values and hence are unsuitable in providing my argument with the appropriate range of support.

The case of anticipatory nasalization has been further subdivided into two cases in the table below: the one concerned with tautosyllabic nasals and the one concerned with heterosyllabic nasals. Nevertheless, it can be observed that the two subcategories do not behave in a significantly different way when they are compared with the case of carryover nasalization.

The study by Diakoumakou (2004) has served as the main starting point of my data research; more than half of the data presented below originally figured in this work.

(It is reminded again that a direct comparison between the data must be made with certain qualification because, as already pointed out in the previous section, the studies that have been cited employed diverse experimental methods.)

Data source: English (Flege 1988, Solé 1992), Greek (Diakoumakou 2004), French (Cohn 1990), Spanish (Solé 1992), Italian (Farnetani 1986), Japanese (Ushijima and Hirose 1974), Hindi (M. Ohala 1975)<sup>10</sup>, Swedish

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<sup>10</sup> The numeric values shown in the table (a rough estimate) have been calculated by myself relying on the graphs shown in the paper; this has been done in order to render the table easier to understand.

(Clumeck 1975), Brazilian Portuguese (Medeiros 2011), Ikalanga (Beddor and Onsuwan 2003), Thai (Onsuwan 2003), Cairene Arabic (my pilot production experiment), Moroccan Arabic (Zellou 2012), Akan (Huffman 1988).

**Table 4. The ratio of the nasalized portion of the vowel**

type	language	carryover NV	anticipatory	
			VN] <sub>σ</sub>	V] <sub>σ</sub> N
type 1	English	82%	100%	-
	Hindi	70%	100%	-
	Bengali	(ext)	100%	-
	B. Portuguese	(ext)	-	100%
	Akan	85%	-	100%
type 2	Italian	(ext)	43%	-
	French	73%	33%	17%
	Greek	71%	55%	29%
	Spanish	-	43%	-
	Thai	-	40%	-
	Swedish	(ext)	(lim)	-
	C. Arabic	72%	38%	-
	M. Arabic	(ext)	45%	-
	Ikalanga	76%	-	33%
	Japanese	(ext)	(lim)	-

cf. (ext) = extensively but non-categorically nasalized, (lim) = limited nasalization (less than 50%), (-) = unattested sequence in the language or no data available.

To give an example, one of the data from the table that has not been directly covered in the previous sections, namely, that of Hindi, will be briefly inspected. The study by M. Ohala (1975) shows that Hindi undergoes extensive carryover nasalization. It can be seen from the nasograph data in the paper (M. Ohala 1975: 322) that the only difference between the underlyingly oral vowel [a] in [mas] and the underlyingly nasal vowel [ã] in [mäs] is the degree of velum lowering near the end of the vowel: [ã] shows relatively more extensive velum lowering near the end of the vowel, but otherwise, the position of the velum is similarly low throughout at least two thirds of the vowel section for both [a] and [ã]. Therefore, one can conclude that [a] in [mas] is quite heavily nasalized, although this nasalization is not categorical in nature.

Ohala's study also shows that anticipatory nasalization is even more extensive than the carryover one in Hindi. This is expected, because Hindi neutralizes the vowel oral-nasal distinction before nasal stops into nasal vowels; in such cases, the nasalization of the vowel must be categorical, because the vowel is manifested as the equivalent of full phonemic nasal

vowel. In the next section, it will be shown that Hindi is an example of type 1 language.

#### 4.2 Predicted typology

As one can see from the table above, the typology that follows from my proposal mainly predicts two types of languages. The major difference between the two types resides in whether a language has phonologized the process of anticipatory nasalization or not. If it hasn't, then it belongs to type 2 language, and in such cases, anticipatory nasalization is less extensive than carryover nasalization as phonetic coarticulation. If a language does have a phonological process of anticipatory nasalization, then it belongs to type 1 language, and in such cases, anticipatory nasalization is categorical.

**Table 5. Predicted typology**

	nasalized portion of the vowel (%)
<b>type1</b>	anticipatory <i>assimilation</i> > carryover coarticulation (phonologization of $\check{V}N$ )
<b>type2</b>	carryover coarticulation > anticipatory coarticulation (no phonologization of $\check{V}N$ )

Following this typology, an impossible language pattern under my proposal would be the coexistence of non-extensive carryover coarticulation with extensive anticipatory coarticulation. This is because, as one will see more clearly in the next section, I expect extensive degree of anticipatory coarticulation to be inherently unstable in nature. Therefore, extensive anticipatory coarticulation will either get quickly phonologized into a deeper, more categorical phonological assimilation pattern (triggering corollary changes such as neutralization if necessary), or it will be suppressed, and remain only as non-extensive coarticulation tendency.

The recapitulative table presented above Table 4 that forms the basis of my proposal is comprised of data of 15 languages. This may seem as too small a number to make any definitive, generalized statement about typology. The difficulty of retrieving relevant data for the typological argument suggested in this paper is due in part to the fact that the scope of this argument transcends the traditional domain of typology. Works on sound typology usually focus on definitive phonological patterns, whereas the typological pattern argued by this paper must take into account phonetic coarticulation patterns as well. There is considerable difficulty in finding larger scaled data sets where quantifiable values of both carryover and anticipatory nasalization have been recorded from phonetic, experimental studies.

Nevertheless, at least all the experimental data that were available seem

to coherently fit into one of the two types of languages suggested in the above typology, supporting the validity of the typological argument.

#### 4.3 Phonetic-phonology discrepancy

As suggested above, carryover nasalization is more extensive than anticipatory nasalization, when both directions of nasalization remain at the level of phonetic coarticulation. However, at the level of phonological assimilation, it is anticipatory nasalization which is more often observed as categorical nasalization patterns. This discrepancy between phonetic coarticulation tendencies and categorical phonological patterns has been noted to be an aberrant pattern. In the next section, I will develop a perceptual hypothesis that accounts for this discrepancy, by positing a perceptual bias to be at work in creating an asymmetrical pattern. Testing the existence of this hypothetical perceptual bias will provide empirical evidence as to why the unusual discrepancy between phonetics and phonology arises.

### 5. A perceptual hypothesis

I hypothesize that languages will more frequently phonologize vowel nasalization in anticipatory context than in carryover context because anticipatory nasalization is perceptually more salient than carryover nasalization. Therefore, even when the degree of nasalization in anticipatory coarticulation is smaller, it will be more likely to get phonologized into categorical assimilation process than carryover nasalization.

The possibility that a certain perceptual asymmetry may exist in two directions of nasalization has already been briefly noted in the work by Cohn (1990). Mentioning that the case of anticipatory nasalization has been the only subject of attention in English although carryover nasalization in English is also quite extensive, she claims as follows:

It would be beyond the scope of this study to pursue this question, but it may well be the case that anticipatory nasalization is perceptually more salient than carryover nasalization. (Cohn 1990: 147)

Including the above-mentioned work, the perceptual hypothesis delineated in this section has been constructed based on two main observations derived from previous works. The first observation is the fact that carryover nasalization, compared to anticipatory nasalization, is more likely to be left unnoticed by the scholars and the language speakers alike. Often, even skilled phoneticians and phonologists become aware of the existence of carryover nasalization in a certain language only after

obtaining actual experimental data of that language.

For example, in Medeiros (2011), the author examined the process of anticipatory nasalization in Brazilian Portuguese (henceforth BP) and compared its phonetic realization with the realization of BP phonemic nasal vowels. Although the degree of carryover nasalization in BP is not the main subject of the paper and is therefore left unmentioned by the author, the sample nasograph in the paper clearly shows that carryover nasalization is quite extensive in BP; almost as extensive as anticipatory nasalization. Nonetheless, people normally assume Brazilian Portuguese to have only the process of anticipatory nasalization and not that of carryover nasalization, an assumption that is also reflected in the neutralization pattern of the language (section 4).

The second observation is that the intensity of the source of nasalization, that is, the adjacent nasal consonant, is related to the perceived nasality of the nasalized vowel, as mentioned in Kawasaki (1986). In this study, the author reported the result of a perception test concerning the process of contextual nasalization. NVN stimuli where the two flanking nasals were attenuated in intensity<sup>11</sup> (in varying steps) were used. Although the degree of nasalization of the middle vowel remained the same throughout all stimuli, listeners perceived the vowel to be more nasalized when the two flanking Ns were attenuated in intensity. In sum, the amplitude of the two adjacent nasals was correlated inversely with the perceived nasality of the vowel.

In Kawasaki (1986), cases of carryover and anticipatory nasalization were not separately examined. The vowels of the stimuli were always nasalized from both directions and the intensities of the two nasal consonants were always attenuated in pairs to a same degree. However, I thought that the findings of this study could be extended to construct a hypothesis that argues for the asymmetry in perception between carryover and anticipatory nasalization. My reasonings are as follows:

In Kawasaki (1986), only the *intensity* of the flanking nasals was expected to affect the perceived nasality of the vowel. I derived insights from the general idea behind this study, but substituted the notion of *intensity* with a more general notion, *saliency* in my hypothesis. The term *saliency* was posited in order to encompass a broader range of factors that may render a sound perceptually salient. I thus hypothesized that not only the intensity of the source nasal consonant but also more complex measures of saliency, such as how many acoustic cues the source consonant has, or how positionally prominent the source consonant is, will also affect the perceived nasality of the nasalized vowel.

Pursuing this line of thought, I came up with the following hypothesis: It is well known that codas are positionally less salient and contain less acoustic cues than onsets (Steriade 2008). Therefore, the vowel following

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<sup>11</sup> This was achieved by manipulating the amplitude in appropriate scales.

the inherently more prominent onset nasal will be perceived as less nasal, and the vowel preceding the less prominent coda nasal will be perceived as more nasal (The perceived nasality of the nasalized vowel and the saliency of the source nasal consonant will be inversely related.) Since carryover nasalization mostly concerns onset nasals and anticipatory nasalization coda nasals, vowels in anticipatory context will be perceived as more nasalized than vowels in carryover context.<sup>12</sup>

At this point, the notion of coarticulation parsing becomes relevant. In the next section, I will adopt the definition of parsing and further refine my hypothesis.

### 5.1 Parsing and coarticulation

Although speech sounds are temporally realized as a continuous sequence without clear boundaries in between, it is processed by speakers and listeners as discrete segments. The overlapping effect between adjacent segments is referred to as coarticulation, and it is generally hypothesized that the acoustic consequence of coarticulation is parsed out and reallocated to the source of coarticulation; in other words, the overlapping sequences of sounds are rendered discrete again in speech perception.

The existence of this tendency for ‘coarticulation parsing’ was demonstrated by Fowler (2000). In this study, the effect of parsing in the perception of anticipatory nasalization in English was examined. (Only the case of heterosyllabic anticipatory nasalization was inspected in the study, and no comparison was made between carryover and anticipatory nasalization. This is perhaps because no asymmetry was hypothesized between the two processes of nasalization.) The study reported the results of several types of perception tests that had been undertaken, including an AXB test.

The results indicated that the listeners parse out the coarticulated nasality of VN sequences in their perception: the V with the same degree of nasality was perceived as less nasal when it was situated before the nasal consonant N than when it was situated before the oral consonant C.

Nonetheless, based on the results of other experiments in the paper, the author qualified her claim by stating that this ‘parsing’ of coarticulated nasality was ‘incomplete’ in nature. This statement signifies that the V in

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<sup>12</sup> This hypothesis gives an adequate answer to why anticipatory nasalization involving *tautosyllabic* nasal consonants may be more easily perceived than carryover nasalization. But what about cases of anticipatory nasalization involving *heterosyllabic* nasals? In fact, one may not even need to introduce abstract phonological terms such as onsets or codas to account for the relative saliencies of the nasal consonants in NV and VN sequences. N in NV may be presumed to be more salient than N in VN simply because it comes first in order. In terms of temporal realization of sounds, people generally seem to pay more attention to the preceding segments rather than the following segments; this general tendency may also work to create difference in saliency between the two sources of coarticulation. This alternative hypothesis is not pursued further in the paper but is left to be examined in future studies.

VN was not perceived as completely oral by the subjects of the experiments.

Therefore, based on the findings of this study and adopting the notion of ‘parsing’, I shall revise and refine my initial hypothesis as follows: The nasality of a vowel following a nasal consonant is more strongly parsed out (parsing is nearly complete). On the other hand, the nasality of the vowel preceding a nasal consonant is less strongly parsed out (parsing is incomplete). I hypothesize that this is because the acoustic or perceptual saliency of the adjacent nasal consonant determines the strength of parsing. The stronger the flanking nasal consonant, the stronger the parsing effect; consequently, the more oral the vowel will sound.

In the next section, I give out the outline and results of a perception test which showed that my hypothesis is indeed valid; carryover nasalization was perceived as less nasal, and anticipatory nasalization, more nasal.

## 6. An AXB perception test

The main structure of the AXB test was as follows: vowels with 4 distinct degrees of nasality  $\{a_0, a_1, a_2, a_3\}$  were synthesized and used as A and B and the vowel part of X.  $a_0$  was an oral vowel,  $a_1$  moderately nasalized vowel,  $a_2$  extensively nasalized vowel, and  $a_3$  fully nasalized vowel. A and B were single vowels that differed in their degree of nasality and X was a monosyllabic or a disyllabic word containing either anticipatory environment (am) or carryover environment (ma).

The subjects were asked to choose between A and B the vowel that sounded more similar to the vowel contained in the middle word X. For example, the subject would hear the sequence  $[a_1 \text{ } ba_2m \text{ } a_2]$  (an anticipatory case), and choose between the two buttons ‘The first one’ (A,  $a_1$  in this case) and ‘The last one’ (B,  $a_2$  in this case) from the computer screen the one that sounded more like the vowel contained in the middle word (X,  $ba_2m$  in this case).

Praat (Boersma 2001) was used to run the test, along with a relevant Praat script devised for AXB tests. In addition to the answers, response times were also collected; they do not figure in the analysis section below because they did not turn out to be significantly meaningful.

### 6.1 Hypothesis

I hypothesized that depending on whether X contains [am] or [ma], the percentage of selecting the less nasalized vowel would differ. For example, for the stimulus type  $[a_1 (m)a_2(m) a_2]$ , I expected that the subjects would choose  $a_1$  (the less nasalized vowel) to a smaller extent when the stimulus is  $[a_1 ..a_2m a_2]$  (X has anticipatory context) and to a greater extent when the stimulus type is  $[a_1 ma_2.. a_2]$  (X has carryover context). This is because the parsing effect was hypothesized to be stronger in carryover context. Hence,

I expected that vowels in carryover context would be more likely to be perceived as oral.

## 6.2 Subjects

The participants for the experiment were 21 native speakers of Korean from the community at Seoul National University, aged between 20-30. I chose to employ Korean subjects because in Korean, no salient process of carryover or anticipatory nasalization is reported; both anticipatory and carryover nasalization can be safely assumed to occur only minimally in the language. Although it is impossible to completely eliminate the effect of language specific learning, it may be expected that Korean speakers would be relatively less affected by knowledge of coarticulation or assimilation processes of nasalization.

## 6.3 Synthesis of the stimuli

Vowels were synthesized using Hlsyn (Kenneth N. Stevens, Corine A. Bickley, David R. Williams, Copyright 1990-2001, Sensimetrics Corporation, version 2.2), a Klatt-type quasi-articulatory formant synthesizer. To create four distinctive levels of nasality, I adjusted the length of velo-pharyngeal port opening (one of the higher-level articulatory parameters) in Hlsyn. This made Hlsyn automatically introduce additional pole-zero pairs to the system and adjust related lower-level Klatt (formant-based) parameters.

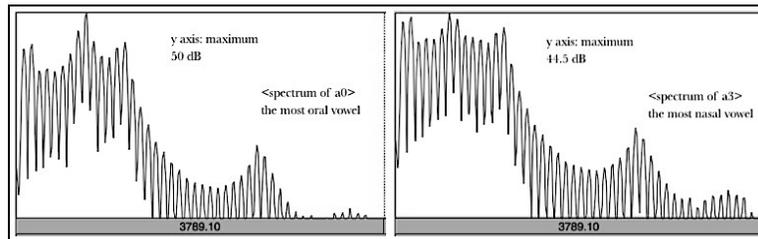


Figure 1. Spectra of oral vowel a0 (left) and full nasal vowel a3 (right)

The acoustic correlate of vowel nasality is complex in nature and varies depending on the quality of the vowel. Nevertheless, there is one relatively stable cue to vowel nasality, which is the widening of the lower formant bandwidth in the spectrogram (Maeda 1993, Stevens 2000), as well as a general weakening of the amplitude. In the spectrum, this is manifested as the levelling and flattening of spectral peaks in the lower frequency region. Such acoustic characteristics occur in nasalized vowels because additional pole-zero pairs are introduced when the oral tract is coupled with the nasal

tract. These pole-zero pairs are superimposed on existing spectral peaks, and generally work to lump the sporadically high peaks into a more levelled plateau in the lower frequency region.

To confirm that the synthesized vowels used in the test accurately portrayed 4 distinct strata of nasality, I inspected the spectra and spectrograms of the synthesized vowels. These spectra and spectrograms confirmed that the bandwidths of the lower formants were appropriately widened (flattened), as can be seen above. Also, I conducted an informal pre-test where a Hindi speaker was asked to sort the 4 synthesized vowels in ascending degree of nasality. The subject correctly sorted the vowels in the right order in her first try: {a<sub>0</sub>, a<sub>1</sub>, a<sub>2</sub>, a<sub>3</sub>}.

#### 6.4 Stimuli

In order to control all potential variables that may affect the outcome, it would have been ideal to posit X as either [am] or [ma]. Instead, [bam] was used as X for anticipatory type stimuli, and [ama] was used as X for carryover type stimuli.

First of all, an additional [a] was inserted in carryover type stimuli to prevent the language specific knowledge of Korean from interfering with the outcome.

In Korean, there exists a process called denasalization<sup>13</sup>, where the first nasal consonant of the word is partially denasalized, as in the example [m<sup>b</sup>ul] ‘water’. For Korean speakers, [ma] without denasalization would have sounded unnatural. Because in the word medial position, the denasalization process does not occur (The word [imo] ‘aunt’ without any denasalization is a quite natural sequence in Korean), the first [a] was added to prevent [m] from becoming the first sound in the sequence, and subjects were told to compare only the vowel from the second syllable of X with A and B.

To prevent the preceding [a] from affecting the perception of nasality of the following [a] of [ama] in any way<sup>14</sup> the first [a] was very short and only

<sup>13</sup> It has been claimed that not only the process of nasalization, but also that of ‘denasalization’ (Chen and Clumeck 1975, Hyman 1975), a process that is in its nature both parallel and antithetic to contextual vowel nasalization, may be as common as the process of nasalization, and hence, to a certain extent, universal; in other words, according to this view, when faced with a sequence of vowel and nasal consonant such as VN or NV, languages may either resort to vowel nasalization, or they may resort to the competing productive process of partial denasalization of the nasal consonant. However, whether denasalization is really as common as nasalization, and whether the two processes are related and how, and what other constraints lead a language to favor one over the other, are not the kind of problems that forms the main topic of this paper and thus have not been included in the discussion.

<sup>14</sup> This seems like a highly unlikely possibility anyway, since the nasal consonant intervenes between the two vowels. To my knowledge, no previous studies mention any significant case where a neighboring vowel across a consonantal segment affects the perceived nasality of the vowel from the next syllable. Nonetheless, extra precaution was taken to eliminate any possible effect of the first [a], and a very short a<sub>2</sub> (extensively nasalized vowel), not a<sub>0</sub> (oral

transient in nature, and the subjects were told to focus only on the second syllable and disregard the first [a] of X.

Second, [b] was inserted in anticipatory type stimuli because onsetless syllables are marked and hence not the most default type of sequence where anticipatory nasalization can be found. Also, the lack of onset might affect the subjects to be biased towards the answer that is more in accordance with my hypothesis.

The full set of vowels  $\{a_0, a_1, a_2, a_3\}$  including oral vowel  $a_0$  and full nasal vowel  $a_3$  were used for A and B. As for the vowels of X, only  $a_1$  (moderately nasalized vowel) and  $a_2$  (extensively nasalized vowel) was used. In each AXB,  $A \neq B$ , and the orderings were switched between AXB and BXA in a single stimulus type to prevent the order of options from affecting the responses. Pauses of 1 second were inserted between A and X and X and B. Within the constraints of these general guidelines, all the possible AXB combinations ( $4 \times 2 \times 3 = 24$  for each carryover/anticipatory case) were created for the test.

**Table 6. Sets of AXB stimuli adopted in the experiment**

carr/ant order	carryover		anticipatory	
	AXB	(BXA)	AXB	(BXA)
X contains $a_1$	$a_1$ - $ma_1$ - $a_2$	( $a_2$ - $ma_1$ - $a_1$ )	$a_1$ - $a_1m$ - $a_2$	( $a_2$ - $a_1m$ - $a_1$ )
	$a_1$ - $ma_1$ - $a_3$	( $a_3$ - $ma_1$ - $a_1$ )	$a_1$ - $a_1m$ - $a_3$	( $a_3$ - $a_1m$ - $a_1$ )
	$a_0$ - $ma_1$ - $a_2$	( $a_2$ - $ma_1$ - $a_0$ )	$a_0$ - $a_1m$ - $a_2$	( $a_2$ - $a_1m$ - $a_0$ )
	$a_0$ - $ma_1$ - $a_3$	( $a_3$ - $ma_1$ - $a_0$ )	$a_0$ - $a_1m$ - $a_3$	( $a_3$ - $a_1m$ - $a_0$ )
	$a_0$ - $ma_1$ - $a_1$	( $a_1$ - $ma_1$ - $a_0$ )	$a_0$ - $a_1m$ - $a_1$	( $a_1$ - $a_1m$ - $a_0$ )
	$a_2$ - $ma_1$ - $a_3$	( $a_3$ - $ma_1$ - $a_2$ )	$a_2$ - $a_1m$ - $a_3$	( $a_3$ - $a_1m$ - $a_2$ )
X contains $a_2$	$a_1$ - $ma_2$ - $a_2$	( $a_2$ - $ma_2$ - $a_1$ )	$a_1$ - $a_2m$ - $a_2$	( $a_2$ - $a_2m$ - $a_1$ )
	$a_1$ - $ma_2$ - $a_3$	( $a_3$ - $ma_2$ - $a_1$ )	$a_1$ - $a_2m$ - $a_3$	( $a_3$ - $a_2m$ - $a_1$ )
	$a_0$ - $ma_2$ - $a_2$	( $a_2$ - $ma_2$ - $a_0$ )	$a_0$ - $a_2m$ - $a_2$	( $a_2$ - $a_2m$ - $a_0$ )
	$a_0$ - $ma_2$ - $a_3$	( $a_3$ - $ma_2$ - $a_0$ )	$a_0$ - $a_2m$ - $a_3$	( $a_3$ - $a_2m$ - $a_0$ )
	$a_0$ - $ma_2$ - $a_1$	( $a_1$ - $ma_2$ - $a_0$ )	$a_0$ - $a_2m$ - $a_1$	( $a_1$ - $a_2m$ - $a_0$ )
	$a_2$ - $ma_2$ - $a_3$	( $a_3$ - $ma_2$ - $a_2$ )	$a_2$ - $a_2m$ - $a_3$	( $a_3$ - $a_2m$ - $a_2$ )

The complete list of AXB stimuli that have been used in the experiment is presented in the table above. The first segments of X ([b] or [a]) have been omitted in the table for the ease of comparison. AXB and BXA will not be distinguished in the analysis section and will be considered as a single stimulus type from now on.

## 6.5 Results

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vowel) was adopted as the first [a] in all stimuli to prevent the oralness of the first vowel from affecting the subjects to be biased towards the answer that is more in accordance with the current hypothesis.

Each stimulus type shown in the table above was repeated 4 times for each subject. 4 tokens were too small a number to inspect any effect of speaker variability. Therefore, the results from each speaker were integrated according to stimulus type. The total number of responses for each stimulus type was 84 (21 subjects x 4 repetitions of the stimulus (2 times as AXB and 2 times as BXA)).

In the following table, I present the results of the test. For each stimulus type, the count in the parentheses represents the number of responses selecting the less nasalized vowel. For example, the number 41 in the top left box denotes the number of  $a_0$  selections (as opposed to  $a_1$ ) in  $a_0$ - $a_1$ - $a_1$  type stimulus. The percentage of responses selecting the less nasalized vowel was also calculated for each stimulus type.

**Table 7. Number of responses where the less nasalized vowel was selected**

	$a_0$ - $a_1$ - $a_1$	$a_0$ - $a_1$ - $a_2$	$a_1$ - $a_1$ - $a_2$
carryover	48.81% (41/84)	<b>72.62% (61/84)</b>	<b>80.95% (68/84)</b>
anticipatory	36.9% (31/84)	<b>48.81% (41/84)</b>	<b>52.38% (44/84)</b>
	$a_1$ - $a_1$ - $a_3$	$a_0$ - $a_1$ - $a_3$	$a_2$ - $a_1$ - $a_3$
carryover	90.48% (76/84)	96.43% (81/84)	84.52% (71/84)
anticipatory	82.14% (69/84)	91.67% (77/84)	82.14% (69/84)
	$a_0$ - $a_2$ - $a_2$	$a_0$ - $a_2$ - $a_1$	$a_1$ - $a_2$ - $a_2$
carryover	41.67% (35/84)	46.43% (39/84)	<b>71.43% (60/84)</b>
anticipatory	34.52% (29/84)	36.9% (31/84)	<b>45.24% (38/84)</b>
	$a_2$ - $a_2$ - $a_3$	$a_1$ - $a_2$ - $a_3$	$a_0$ - $a_2$ - $a_3$
carryover	72.62% (61/84)	91.67% (77/84)	89.29% (75/84)
anticipatory	70.24% (59/84)	90.48% (76/84)	90.48% (76/84)

As can be seen from the table, a higher number of responses with less nasalized vowel were obtained for carryover context compared to the corresponding anticipatory context in almost all types of stimuli (11 out of 12). Therefore, already at a first glance, the general tendency seems to point to the fact that vowels in carryover context are heard as less nasalized than vowels in anticipatory context. However, the amount of difference between the two cases seems to vary according to stimulus type.

Therefore, to test whether the difference in response between the carryover case and the anticipatory case was statistically significant not just for some individual stimuli types but more globally as a general tendency, a logistic regression was conducted. In this regression model, carryover (vs) anticipatory factor was the main independent variable and the number of responses with the less nasalized vowel was the dependent variable.

After several model testing, the identities of A, B, X and step size were also included in the regression model as independent variables. The notion

of step size was used to indicate the distance between A and X as well as the distance between X and B. For example, stimulus type  $a_1\text{-}m\text{-}a_2\text{-}a_2$  would have 1-0 as step size ( $X\text{-}A=1$ ,  $X\text{-}B=0$ ) and stimulus type  $a_0\text{-}a_2\text{-}a_3$  would have 2-1 as step size. A regression model with step size as an independent variable showed a significantly improved model fit compared to the model without step size ( $\chi^2(5)=16.198$ ,  $p < 0.01$ ). Also, the interaction between A and B was posited in the final model. This is because the model with  $A\sim B$  interaction also showed a significantly improved model fit compared to the model without one ( $\chi^2(1)=9.1993$ ,  $p < 0.01$ ).

The ultimate result of the logistic regression showed that carryover (vs) anticipatory distinction was a highly significant factor ( $p < 0.001$ ), as well as the identity of A, B, X and 0-2 step size (for all of these variables,  $p < 0.001$ ). Other step sizes were not shown to be statistically significant.

### 6.6 Results depending on stimuli types

As can be seen in the table from the previous section, the difference in response between carryover and anticipatory nasalization case was most striking in three types of stimuli (marked in bold-faced letters in the table):  $a_0\text{-}a_1\text{-}a_2$ ,  $a_1\text{-}a_1\text{-}a_2$  and  $a_1\text{-}a_2\text{-}a_2$ . It would be interesting to see whether these stimuli types (especially the stimulus type  $a_1\text{-}m\text{-}a_2\text{-}a_2$ )<sup>15</sup> behave in a significantly different way from other stimuli types.

Therefore, a chi-square test between the responses of carryover and anticipatory cases of the stimulus type  $a_1\text{-}m\text{-}a_2\text{-}a_2$  was conducted. Recall that in the carryover case  $a_1\text{-}m\text{-}a_2\text{-}a_2$ , the less nasalized vowel  $a_1$  was chosen 72% of the time, whereas in the anticipatory case  $a_1\text{-}a_2\text{-}m\text{-}a_2$ ,  $a_1$  was chosen only 48% of the time. The test yielded a low p-value ( $\chi^2(1) = 10.8$ ,  $p < 0.01$ ), demonstrating that the anticipatory/carryover distinction played a significant factor in determining how often the less nasalized tokens were selected as responses.

As a comparison, a chi-square test between the responses of carryover and anticipatory cases of the stimulus type  $a_0\text{-}a_1\text{-}a_3$  was also conducted. This stimulus type was chosen because in this stimulus type, both carryover and anticipatory cases showed a high tendency of choosing the less nasalized vowel (In the carryover case,  $a_0$  was chosen 96% of the time and in the anticipatory case, it was chosen 91% of the time).

The test yielded a p-value ( $\chi^2(1) = 0.957$ ,  $p > 0.01$ ) that was statistically not significant, showing that the null hypothesis (the difference in selecting the less nasalized vowel as a response is not significant between carryover and anticipatory case) cannot be rejected for this stimulus type.

In sum, the results of the two chi-square tests seem to show that

<sup>15</sup>  $a_0\text{-}a_1\text{-}a_1$  and  $a_1\text{-}a_2\text{-}a_2$  may be the two most important types of stimuli because in these stimuli, the vowel in  $X = B$  (the more nasalized vowel); therefore, responses that chose A (the less nasalized vowel) over B support the existence of the parsing effect in a more straightforward way.

carryover/anticipatory distinction is indeed a significant factor (in determining how often the less nasalized tokens are selected) for some types of stimuli, but not very much so for other types of stimuli.

Nonetheless, the local tendency for the latter types of stimuli seems to have been diluted in the regression model, indicating that the carryover vs. anticipatory distinction remains a significant factor even when the global analysis takes into account the latter types of stimuli. Below, I present a comparison of the mosaic plots (Figure 2) from the two different chi-square tests (darker shades indicate the percentages of choosing the less nasalized vowel).

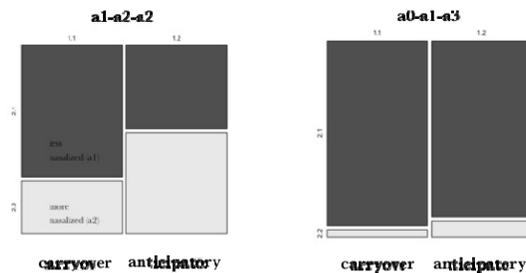


Figure 2. Mosaic plots; left: a<sub>1</sub>-a<sub>2</sub>-a<sub>2</sub> right: a<sub>0</sub>-a<sub>1</sub>-a<sub>3</sub>

By examining the table of results in the previous section (Table 7), the following generalizations concerning the difference in responses between stimuli types can be elicited: First of all, it seems that when the stimulus had a<sub>3</sub> as the more nasalized vowel (B), the less nasalized vowel (A) was highly preferred in both carryover and anticipatory cases (more than 80% of the time). In other words, for stimuli where B= a<sub>3</sub>, the percentage of choosing the less nasalized vowel converged to a very high percentage in both carryover and anticipatory nasalization cases.

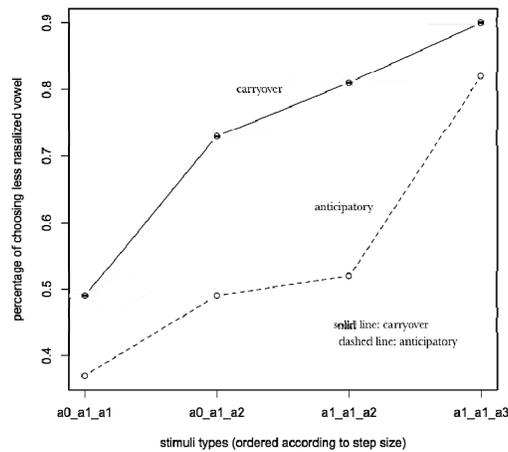
This might signify that the most nasal vowel a<sub>3</sub> was perceived as being very different in quality from a<sub>1</sub> and a<sub>2</sub> vowels in both carryover and anticipatory context and induced the subjects to choose the only other remaining alternative as their answer.<sup>16</sup> In fact, the effect of a<sub>3</sub> had already been captured by the regression model; the identities of B, especially when B=3, had significantly low p-values in the regression model, as well as 0-2 step size (0-2 step size indicates the a<sub>1</sub>-a<sub>1</sub>-a<sub>3</sub> type stimulus).

Second, when the stimulus had a<sub>0</sub> (oral vowel) as the less nasalized vowel (A), the difference in response between carryover and anticipatory case was not very salient. Although the less nasalized vowel (A= a<sub>0</sub>) was

<sup>16</sup> The a<sub>3</sub> effect might have arisen due to the unbounded nature of the synthesis; the quality of the most nasal vowel a<sub>3</sub> verged on hypernasality and was quite different from the qualities of the rest of the synthesized vowels.

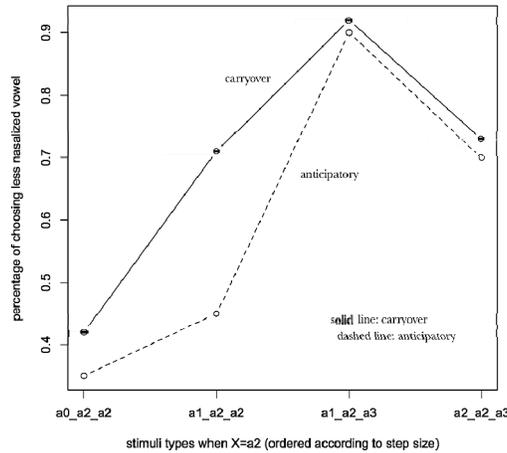
indeed chosen more often in carryover cases than in anticipatory cases, the difference between the two cases was not as great as the difference shown in certain other types of stimuli such as  $a_1$ - $a_2$ - $a_2$ . This might signify that although the parsing effect was stronger in carryover cases, the vowels were not always perceived as completely oral.

Finally, when neither A nor B was  $a_0$  or  $a_3$ , carryover cases had significantly more number of responses that selected the less nasalized vowel, compared to anticipatory cases.



**Figure 3. Difference in responses according to stimuli types (X contains  $a_1$ )**

To visualize more clearly the varying degree of difference between anticipatory and carryover nasalization cases according to stimuli types, two graphs were created (figure 3 and figure 4). The stimuli types in the x-axis were ordered according to step size. (As the x-value progresses in the rightward direction, the distance between A and X gets smaller *or* the distance between X and B gets larger.) The y-axis denotes the percentage of choosing the less nasalized vowel as a response. In the above graph (figure 3), the vowel in X is  $a_1$ . In the following graph (figure 4), the vowel in X is  $a_2$ . The two interpolating lines (solid lines for carryover cases and dashed lines for anticipatory cases) in the two graphs were added for the ease of understanding, but they may not be strictly appropriate since one cannot be sure whether the distance between the stimuli types in the x-axis is linear.



**Figure 4. Difference in responses according to stimuli types (X contains  $a_2$ )**

In the first graph, one can see that the y-values of the anticipatory and carryover cases generally converge at both extreme ends of the x-axis, but that they are quite different in the mid range. Similarly in the second graph, the mid-lower range when the stimulus type is  $a_1$ - $a_2$ - $a_2$  shows a great difference in y-value between anticipatory and carryover cases, whereas the values converge at both extreme ends of the x-axis, especially in the right end. The two graphs also seem to show, to a certain point, the quantal nature of perception (Stevens 2000, Johnson 2003). This is because the lines of both carryover and anticipatory cases from the two graphs are roughly quasi-sigmoid in shape (One must, however, exclude the value of  $a_2$ - $a_2$ - $a_3$  in the second graph in order for this observation to be valid). The major difference between the anticipatory and carryover cases seems to lie in where the low y-value threshold that occurs right before the sudden jump to a high y-value exists.

## 7. Conclusion derived from the test

To recapitulate the result of the perception experiment, vowels in carryover nasalization context were generally perceived as less nasalized than vowels in anticipatory nasalization context. Also, the result shown in the stimulus type  $a_1$ - $a_2$ - $a_2$  proved to a certain point the existence of coarticulation parsing effect in the perception of carryover nasalization. However, no direct proof of this parsing effect was found in the case of anticipatory

nasalization, at least within the results of this experiment.<sup>17</sup> Therefore, my initial hypothesis that carryover nasalization will be perceived as less nasal than anticipatory nasalization because the coarticulation parsing effect is stronger in carryover cases, has been confirmed.

Based on the results of this perception experiment, I propose that the extensive degree of anticipatory coarticulation is unstable perceptually, because it is quite salient. Consequently, languages are likely to exploit this saliency and phonologize the anticipatory coarticulation into a more categorical assimilation pattern. On the other hand, precisely because of this saliency, other languages may choose to work the other way around and keep the coarticulatory effect of anticipatory nasalization harnessed to a non-extensive level. Whatever option is chosen, extensive anticipatory nasalization as a case of gradient coarticulation will not often be attested in actual language patterns because of its unstable nature.

### 8. Perception and neutralization

The AXB perception test delineated above has been conducted mainly to provide a reason behind the phonetics-phonology discrepancy in contextual nasalization pattern. Additionally, the results of the test can clarify the issue of asymmetry in the neutralization pattern as well.

It has been noted in the previous section that the vowel oral-nasal contrast is often preserved after a nasal consonant, i.e. in carryover context. (No neutralization occurs in such context.) What is interesting to note is that such contrast is shown to be preserved even when the underlyingly oral vowel shows quite an extensive degree of nasalization in the surface form. In other words, the contrast between /na/ and /nã/ is quite easily preserved, even when the /na/ is phonetically heavily nasalized as [nã]. On the other hand, in stark contrast to such cases of carryover nasalization, the vowel oral-nasal contrast is almost always neutralized before a nasal, i.e. in anticipatory context.

For example, recall the case of French and Hindi in section 3. In both languages, the nasalization of the underlyingly oral vowels in carryover context is shown to be quite extensive. Surprisingly, the contrast between phonemic nasal vowel and extensively nasalized oral vowel is maintained in carryover context, and no neutralization occurs. On the other hand, the contrast is neutralized in anticipatory context in both languages. (In French, it is neutralized to oral vowels and in Hindi, to nasal vowels.) An additional example can be found in Akan (Huffman, 1988). In Akan, /na/ and /nã/ contrast exists, but the /a/ in /na/ is quite extensively nasalized phonetically.

I have mentioned in section 3 that the dispersion theory (Flemming 2004,

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<sup>17</sup> In the case of anticipatory nasalization, the percentages of selecting the less nasalized vowel tokens were either low or not above chance levels for the relevant stimuli types  $a_0$ - $a_1$ - $a_1$  and  $a_1$ - $a_2$ - $a_2$ .

Spears 2006) alone cannot fully account for language patterns such as the nasalization pattern in French. Now, the implications behind the result of the AXB experiment in this paper, in conjunction with the dispersion theory can fully account for the above-mentioned asymmetry in the neutralization/coarticulation pattern. Since the conclusion derived from the perception experiment states that carryover nasalization is not easily perceived by the listeners even when the degree of nasalization is quite extensive, one can now proceed to claim that enough perceptual distance between extensively nasalized vowels and full (categorically nasalized) nasal vowels is procured in the case of carryover nasalization.

On the other hand, according to the results of the experiment, there would not be enough perceptual distance between extensively nasalized vowels and full nasal vowels in the case of anticipatory nasalization. This is because vowels are relatively more easily perceived as nasalized in the case of anticipatory nasalization.

For example, the perceptual threshold where the nasalized vowel is perceived as nasal (where the coarticulated vowel nasality is no longer significantly parsed out) and becomes confusable with the full nasal vowel may be when the vowel is nasalized to 60% in the case of anticipatory coarticulation, whereas it is when the vowel is nasalized to almost 90% in the case of carryover coarticulation.<sup>18</sup> In sum, oral-nasal contrast is predicted to be preserved more often in carryover context (even when the oral vowel is extensively nasalized in the surface form) because nasalized vowel and full nasal vowel are more distinguishable in carryover context than the two situated in anticipatory context. Carryover nasalization is perceptually not very salient or intrusive, whereas anticipatory nasalization is more salient perceptually, rendering the extensively nasalized vowel not distinctive enough from full nasal vowels.

## 9. Conclusion

In this paper, I have conducted a typological study on contextual vowel nasalization to elucidate the directional asymmetry involved in the process. I have shown that carryover nasalization is the default and extensive form of phonetic coarticulation in many languages and that it often exceeds the degree of anticipatory nasalization as coarticulation. On the other hand, I have also shown that anticipatory nasalization occurs more frequently than carryover nasalization as a phonological assimilation process.

Consequently, I have concluded that the relevant directional asymmetry in contextual vowel nasalization does not involve one direction of nasalization having absolute ascendancy over the other, but rather involves each direction of nasalization having different kinds of ascendancies at different levels of grammar.

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<sup>18</sup> 60% and 90% are tentative numeric values derived from table 4 in section 4. More refined experiments are needed in order to definitively specify this value.

This mismatch between phonetic and phonological tendencies in contextual vowel nasalization was claimed to arise due to an asymmetry in perception: anticipatory nasalization is more easily perceived than carryover nasalization, rendering the extensive degree of anticipatory coarticulation unstable in nature. Therefore, languages will either opt to suppress anticipatory coarticulation below a certain threshold or opt to phonologize it into a more stable assimilation pattern.

This perceptual hypothesis has been validated by the result of an AXB perception experiment which showed that anticipatory coarticulation is more easily perceived than carryover coarticulation.

#### REFERENCES

- BEDDOR, PATRICE S. 2007. Nasals and nasalization: The relation between segmental and coarticulatory timing. *Proceedings of the International Congress of Phonetic Sciences* 16, 249-254.
- \_\_\_\_\_. 2009. A Coarticulatory Path to Sound Change. *Language* 85.4, 785-821.
- BEDDOR, PATRICE S. and CHUTAMANEE ONSUWAN. 2003. Perception of prenasalized stops. *Proceedings of the International Congress of Phonetic Sciences* 15, 407-410.
- BHAT, D. N. S. 1975. Two studies on nasalization. In Larry M. Hyman and John J. Ohala (eds.). *Nasálfest: Papers from a Symposium on Nasals and Nasalization*, 333-352. Stanford, CA: Stanford University Press.
- BLUST, ROBERT. 1997. Nasals and nasalization in Borneo. *Oceanic Linguistics* 36.1, 149-179.
- CHEN, MATTHEW Y. 1973. *Nasals and Nasalization in the History of Chinese*. PhD Dissertation. UC Berkeley.
- CHEN, MATTHEW Y. and HAROLD CLUMECK. 1975. Denasalization in Korean: A search for universals. In Larry M. Hyman and John J. Ohala (eds.). *Nasálfest: Papers from a Symposium on Nasals and Nasalization*, 125-131. Stanford, CA: Stanford University Press.
- CHEN, MATTHEW Y. and WILLIAM S-Y. WANG. 1975. Sound change: Actuation and implementation. *Language* 51.2, 255-281.
- CHEN, NANCY F., JANET L. SLIFKA and KENNETH N. STEVENS. 2007. Vowel nasalization in American English: Acoustic Variability due to Phonetic Context. *Congress of Phonetic Sciences*.
- CLUMECK, HAROLD. 1975. A cross-linguistic investigation of vowel nasalization: an instrumental study. In Larry M. Hyman and John J. Ohala (eds.). *Nasálfest: Papers from a Symposium on Nasals and Nasalization*, 133-152. Stanford, CA: Stanford University Press.
- COHN, ABIGAIL C. 1988. Phonetic rules of nasalization in French. *UCLA Working Papers in Phonetics* 69, 60-67.
- \_\_\_\_\_. 1990. *Phonetic and Phonological Rules of Nasalization*.

- PhD Dissertation. UCLA.
- \_\_\_\_\_. 1993a. Nasalisation in English: Phonology or phonetics. *Phonology* 10, 43-81.
- \_\_\_\_\_. 1993b. A survey of the phonology of the feature [nasal]. *Working Papers of the Cornell Phonetics Laboratory* 8, 141-203.
- DELVAUX, VÉRONIQUE. 2003. *Contrôle et Connaissance Phonétique: Les Voyelles Nasales du Français*. PhD Dissertation. Université Libre de Bruxelles.
- \_\_\_\_\_. 2009. Perception du contraste de nasalité vocalique en français. *Journal of French Language Studies* 19.1, 25-59.
- DELVAUX, VÉRONIQUE, DIDIER DEMOLIN, BERNARD HARMEGNIES and ALAIN SOQUET. 2008. The aerodynamics of nasalization in French. *Journal of Phonetics* 36.4, 578- 606.
- DIAKOUMAKOU, EVANTHIA. 2004. *Coarticulatory Vowel Nasalization in Modern Greek*. PhD Dissertation. University of Michigan.
- FARNETANI, EDDA. 1986. A pilot study of the articulation of /n/ in Italian using electropalatography and airflow measurements. *15e Journées d'Etudes sur la Parole*, 23-26.
- FLEGE, JAMES E. 1988. Anticipatory and carryover nasal coarticulation in the speech of children and adults. *Journal of Speech and Hearing Research* 31, 525-536.
- FLEMMING, EDWARD. 2001. Scalar and categorical phenomena in a unified model of phonetics and phonology. *Phonology* 18, 7-44.
- \_\_\_\_\_. 2004. Contrast and perceptual distinctiveness. In Bruce Hayes, Robert Kirchner, and Donca Steriade (eds.). *Phonetically based Phonology*, 1-64. Cambridge: Cambridge University Press.
- FOWLER, CAROL A. 2000. Perceptual parsing of acoustic consequences of velum lowering from information for vowels. *Perception & Psychophysics* 62.1, 21-32.
- HADEN, ERNEST F. and EDWARD A. JR BELL. 1964. Nasal vowel phonemes in French. *Lingua* 13, 62-69.
- HAJEK, JOHN. 1993. Old French nasalization and universals of sound change. *Journal of French language studies* 3, 145-164.
- \_\_\_\_\_. 1997. *Universals of sound change in nasalization*. Boston, MA: Blackwell Publishing.
- HUFFMAN, MARIE K. 1988. Timing of contextual nasalization in two languages. *UCLA Working Papers in Phonetics* 69, 68-76.
- HYMAN, LARRY M. 1973. Nupe three years later. *Language* 49.2, 447-452.
- \_\_\_\_\_. 1975. Nasal states and nasal processes. In Larry M. Hyman and John J. Ohala (eds.). *Nasálfest: Papers from a Symposium on Nasals and Nasalization*, 249-264. Stanford, CA: Stanford University Press.
- JOHNSON, KEITH. 2003. *Acoustic and Auditory Phonetics*. Cambridge, MA: Blackwell.

- KAGER, RENÉ. 1999. *Optimality Theory*. Cambridge: Cambridge University Press.
- KAWASAKI, HARUKO. 1986. Phonetic explanation for phonological universals: the case of distinctive vowel nasalization. In John J. Ohala and Jeri J. Jaeger (eds.). *Experimental Phonology*, 81-103. Orlando: Academic Press.
- KRAKOW, RENA A. 1994. Nonsegmental influences on velum movement patterns: Syllables, sentences, stress, and speaking rate. *Haskins Laboratories Status Report on Speech Research* SR-117/118, 31-48.
- LINDBLOM, BJÖRN. 1986. Phonetic universals in vowel systems. In John J. Ohala and Jeri J. Jaeger (eds.). *Experimental Phonology*, 13-44. Orlando: Academic Press.
- MAEDA, SHINJI. 1993. Acoustics of vowel nasalization and articulatory shifts in French nasal vowels. In Marie Huffman and Rena Krakow (eds.). *Phonetics and Phonology, Volume 5: Nasals Nasalization and the Velum*, 147-166. New York: Academic Press.
- MALÉCOT, ANDRÉ. 1960. Vowel nasality as a distinctive feature in American English. *Language* 36.2, 222-229.
- MEDEIROS, BEATRIZ RAPOSO DE. 2011. Nasal coda and vowel nasality in Brazilian Portuguese. *Proceedings of the Conference on Laboratory Approaches to Romance Phonology* 5, 33-45.
- OHALA, JOHN J. 1975. Phonetic explanations for nasal sound patterns. In Larry M. Hyman and John J. Ohala (eds.). *Nasálfest: Papers from a Symposium on Nasals and Nasalization*, 289-316. Stanford, CA: Stanford University Press.
- \_\_\_\_\_. 1993. The phonetics of sound change. In Charles Jones (ed.). *Historical Linguistics: Problems and Perspectives*, 237-278. London/New York: Longman.
- OHALA, MANJARI. 1975. Nasals and nasalization in Hindi. In Larry M. Hyman and John J. Ohala (eds.). *Nasálfest: Papers from a Symposium on Nasals and Nasalization*, 317-332. Stanford, CA: Stanford University Press.
- ONSUWAN, CHUTAMANEE. 2003. *Temporal Relations between Consonants and Vowels in Thai Syllables*. PhD Dissertation. University of Michigan.
- PIGGOTT, GLYNE L. 2003. Theoretical implications of segment neutrality in nasal harmony. *Phonology* 20.3, 375-424.
- QUICOLI, A. CARLOS. 1990. Harmony, lowering and nasalization in Brazilian Portuguese. *Lingua* 80, 295-331.
- RUHLEN, MERRITT. 1978. Nasal vowels. In Joseph H. Greenberg (ed.). *Universals of Human Language, Volume 2: Phonology*, 87-103. Stanford, CA: Stanford University Press.
- SCHOURUP, LAWRENCE C. 1972. *A Cross Language Study of Vowel Nasalization*. PhD Dissertation. Ohio State University.
- SCHOUTEN, M. E. H. and L. C. W. POLS. 1979. Vowel segments in

- consonantal context: a spectral study of coarticulation. *Journal of Phonetics* 7.1, 1-23.
- SOLÉ, MARIA-JOSEP. 1992. Phonetic and phonological processes: The case of nasalization. *Language and Speech* 35.1-2, 29-43.
- SPEARS, ABBY. 2006. *Nasal Coarticulation in the French Vowel /i/: A Phonetic and Phonological Study*. PhD Dissertation. University of North Carolina at Chapel Hill.
- STERIADE, DONCA. 2008. The phonology of perceptibility effects: the P-map and its consequences for constraint organization. In Kristin Hanson and Sharon Inkelas (eds.). *The Nature of the Word*, 151-179. Cambridge MA: MIT Press.
- STEVENS, KENNETH N. 2000. *Acoustic Phonetics*. Cambridge, MA: MIT Press.
- TRIGO FERRE, ROSARIO LORENZA. 1988. *The Phonological Derivation and Behavior of Nasal Glides*. PhD Dissertation. MIT.
- USHIJIMA, T. and HIROSE, H. 1974. Electromyographic study of the velum during speech. *Journal of Phonetics* 2, 315-326.
- WALKER, RACHEL. 2003. Reinterpreting transparency in nasal harmony. In Jeroen van de Weijer, Vincent J. van Heuven, and Harry van der Hulst (eds.). *The Phonological Spectrum* 1, 37-72. Amsterdam: John Benjamins Publishing.
- WRIGHT, JAMES T. 1986. The behavior of nasalized vowels in the perceptual vowel space. In John J. Ohala and Jeri J. Jaeger (eds.). *Experimental Phonology*, 45-65. Orlando: Academic Press.
- ZELLOU, GEORGIA E. 2012. *Similarity and Enhancement: Nasality from Moroccan Arabic Pharyngeals and Nasals*. PhD Dissertation. University of Colorado.

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