An acoustic, aerodynamic and perceptual investigation of word-initial denasalization in Korean

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I, Young Shin Kim, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

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김영신 (金英信)

Abstract

Korean nasals /m/ and /n/ are generally considered by Korean phoneticians to be hardly different from the corresponding English sounds, but those in word-initial position are often perceived as plosives by native speakers of English. This had been noted by only a few previous observers, and investigated on a very limited scale.

In this study, various experimental methods were employed in systematic analyses of the production and acoustic form of word-initial /m/ and /n/ from fluent connected speech collected from a relatively large number of informants, and corresponding perception tests were conducted with groups of Korean and English listeners.

Auditory and spectrographic analyses confirmed that the segments were commonly “denasalized”. They display characteristics widely different from those of sonorant nasals, lacking the nasal formants commonly seen in spectrograms; in most cases they were more similar to voiced plosives, many tokens even showing plosive-like release bursts. Spectral analyses confirmed that denasalized nasals are significantly different from sonorant nasals throughout the whole frequency range but remain somewhat different from voiced plosives in the low and high frequency regions. Aerodynamic and accelerometer studies, which examined the consonants in CV combinations, indicated that the denasalized sounds are evidently produced with a pattern of velopharyngeal control which is different from those of sonorant nasals or of plosives. Perception tests showed overwhelmingly that the word-initial denasalized sounds are categorized as nasals by Korean listeners but as plosives by English listeners. When real voiced plosive tokens from another context are artificially moved to word-initial position, Koreans perceive these too as nasals, while English listeners’ responses are not sensitive to the context.

The study shows that denasalization needs to be acknowledged as a major regular feature of spoken Korean, even though it has been largely ignored up to now. Directions for further research are outlined.

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Chapter 1

Introduction

The research topic of this thesis is derived from my experience while teaching Korean courses at Brigham Young University in Provo, Utah about 12 years ago, where most of my students were fluent speakers of Korean, having spent 1.5~2 years in Korea as missionaries. As part of assessments, dictation tests were given in class regularly and during these tests I noticed something I had never done before, which much intrigued me; oftentimes, many students—almost all students were native speakers of American English—were writing ㅂ/p/ for the nasal sound ㅁ /m/ and ㄷ /t/ for the nasal sound ㄴ /n/. For example, the word for 'water' is 물 /mul/, however, many would write 불 'fire' /pul/; and the word for 'rice paddy' is 논 /non/ but they would write 돈 'money' /ton/. When I called out the answers, students said that they were sure they heard /pul/ and /ton/ instead of /mul/ and /non/ and protested! At that time I could do nothing but give them ample ear-training by repeating the words for comparisons as I could not see how /m/ and /n/ could be heard as [p] and [t]: they were clearly nasal vs. plosive to me. Apparently, though, this was not the case to my students.

Once at UCL a few years later and in consulting with my supervisor, it was confirmed that there is a perceived auditory difference in Korean nasals depending on their environment, especially when they are in word-initial position. This is very different from English nasals which perceptually have the same quality regardless of their positions in the phonological context. I thought that this might have something to do with my American students’ misperception on the Korean nasals and that there must be some factors that make these Korean nasals sound plosive to them.

Pilot studies

A variety of trial data were collected through pilot studies: first, using the speech filing software, WASP/SFS, a number of Korean words with an initial nasal consonant were recorded; second, the author talked to her mother in Korea on the phone leading her to say words starting with a nasal followed by different vowels, for about ten minutes; third, some news video clips of the national TV were listened to for nasals that sound differently; lastly, the author had three of her nieces, aged ten, ten and six, make recordings of a list of words starting with a nasal, followed by vowel /a/.

Figure 1.1 is an example of one of these words recorded by the 6 year-old. Compare this to Figure 1.2, part of a nonsense word ‘marber’ [mɑːbə] recorded by a native English speaker. There is a clear difference in the /m/ at the beginning of each figure: in Figure 1.1, the absence of the nasal formants clearly visible in Figure 1.2 is very striking. As a result of these observations, it began to seem that there is some change the Korean nasals go through in their word-initial positions.

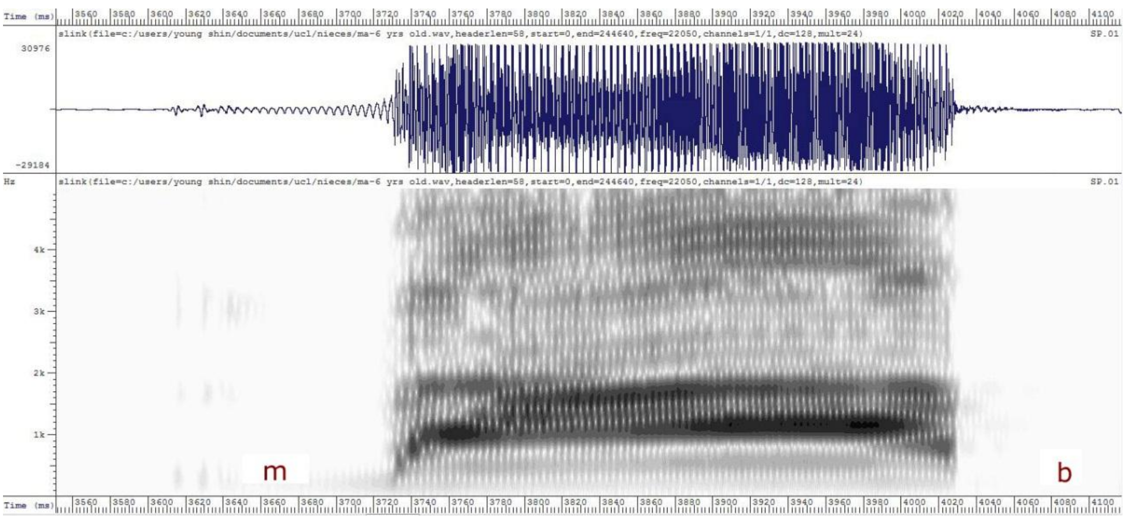

Figure 1.1: Part of waveform and spectrogram of [maːbʌp̚] *magic* uttered by a 6-year-old native Korean speaker.

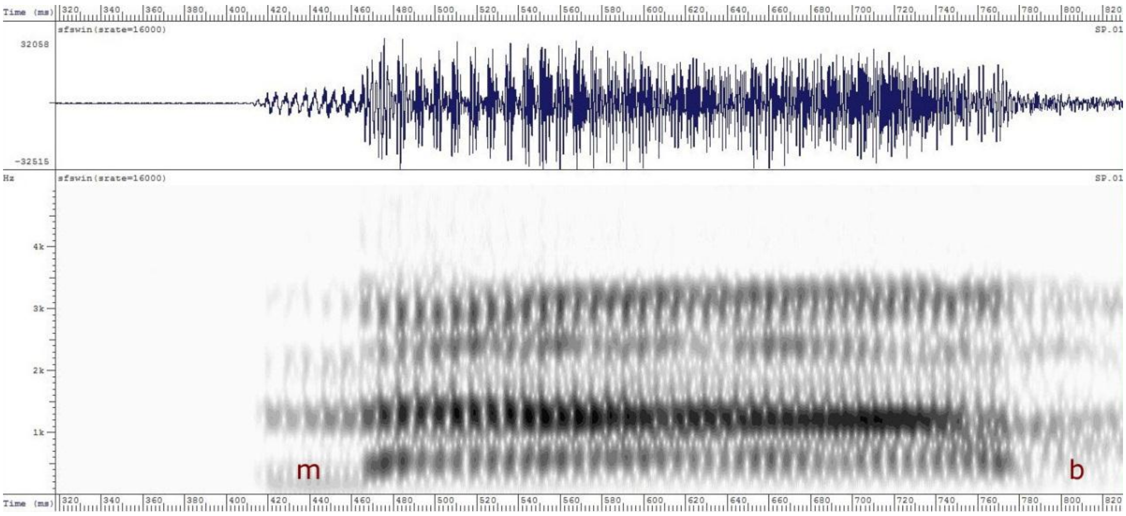

Figure 1.2: Part of waveforms and spectrograms of a nonsense word [mɑːbə] uttered by a native English speaker.

Previous studies

A preliminary review of literature showed that not one Korean researcher had investigated the apparent variation in nasals. Since Hunmin Chongeum (King Sejong, 1443), which was the first comprehensive documentation on Korean phonetics, up to 2006 there had been numerous publications on Korean phonetics and Korean nasals written by Korean scholars but none of them looked into this matter. In fact, many authors of Korean phonetics, Gim (1937) among them, describe Korean nasals as practically the same as English nasals. If that was the case, why did so many of my native English speaker students think that they heard [b] and [d] when in fact I was saying /m/ and /n/? Two reasons could be presumed: one, certain Korean nasals did really sound the same as English voiced plosives; two, native Korean speakers, whether trained in phonetics or not, are simply not sensitive to this sound change.

More recent literature showed that native Korean researchers of phonetics had some difficulty dealing with /m/ and /n/ in the word-initial position: for example, an extensive study done on Korean nasals by Hwang (2002) reports that it is difficult to acoustically characterize Korean nasals in word-initial positions because they are “partly devoiced” and do not show enough energy on the spectrograms (p. 5). However, this observation, although not pursued by Hwang, again indicates something very clearly about these nasals: if they were English nasals, neither would they be partly devoiced nor would they commonly show not enough energy on spectrograms to permit segmentation and measurement.

A few English-speaking researchers (Jones, 1924; Martin, 1951; Chen and Clumeck, 1975), however, had documented this odd behaviour of Korean nasals /m/ and /n/ in part, all of them with slightly different observations. Although highly significant in that they recognized and reported on this otherwise unacknowledged sound change in Korean nasals, these reports do not provide conclusive findings backed by experimental accounts using reliable methods and with a reasonably sized pool of data. Even the most recent reports from other researchers (Yoshida, 2008; Lee and Kim, 2007, both of which carried out an aerodynamic experiment), did not reach conclusive findings.

In sum, it is apparent that the Korean nasals /m/ and /n/ are still problematic and that they need to be clarified more thoroughly by an investigation using a range of reliable methods, and on the basis of a substantial body of data that will provide convincing results.

The current thesis

The main purpose of this thesis is to find out what the sound change that word-initial /m/ and /n/ in Korean go through is (hereafter “denasalization” as named by Chen and Clumeck, 1975) and how the resulting sounds are perceived by listeners with different language backgrounds. The range of approaches employed together is wider than in any previous work, and the data and experiments much more extensive. It covers auditory analyses; acoustic analyses looking at speech waveforms, spectrograms and spectra; a production study using airflow measurement by means of an oro-nasal divided mask; an experiment using a surface nasal accelerometer to measure nasal energy levels; and finally perception tests using natural speech stimuli manipulated by splicing, presented to two language groups of listeners, Korean and English. It is hoped that the combination of methods should produce a coherent picture of denasalization in Korean.

Some preliminary results of the experiments in this thesis have been reported in conference papers (Kim and Ashby 2006, 2008). The current thesis deals with the research questions raised there in considerably more depth.

In addition to the range and scope of the experiments which have been attempted, there is another way in which the present study is different from most others: the target sounds which are studied are not taken from careful forms of words pronounced in isolation, or embedded in brief carrier phrases, but have been segmented from running speech which is meaningful and natural. My own pilot investigations had looked at word-initial nasals in citation forms and the preliminary findings might therefore not very well reflect what happens in real speech.

Research questions and hypotheses

Based on the purpose of this thesis previously stated, the following research questions were raised for investigation:

1. What are the phonetic properties of these sounds?
   a. How can they be characterized and described auditorily?
   b. What are the acoustic properties of these consonants?
   c. What are the aerodynamic characteristics of these consonants?
   d. What happens to the coarticulatory nasality of neighbouring vowels?
   e. How do Koreans—and users of other languages—perceive these sounds?

2. Under what circumstances are these sounds used in Korean?
   a. What are the phonetic and phonological environments for the use of these sounds?
   b. Do the environments in which they occur have any correlation with prosodic features?
3. What are the implications for general phonetic theory?

Hypotheses

General hypotheses based on some of the research questions above were formulated as follows:

1. During the hold phase of denasalized nasal consonants, the continuous energy that is characteristic of sonorant nasals will be absent.
2. During the hold phase of denasalized nasal consonants, the nasal airflow measurement will be zero or close to zero.
3. The vowels immediately following denasalized nasals will have zero or much lower nasality than those following sonorant nasals.
4. Native speakers of Korean will not do well in discriminating sonorant and denasalized nasals while native speakers of English may have little or no problem.

More specific hypotheses were formulated for each of the individual experiments and are introduced below.

Chapter 2

Review of Literature

This chapter provides background information in three parts: part one reviews the phonetics of Korean, part two the phonology of Korean, and part three contains a general review of literature on nasality and an exhaustive review of the few previous studies of nasals and denasalization in Korean.

Part One. Phonetics of Korean

There are two mainstream accounts of Korean phonetics: Hyun Bok Lee (1993) and Ho Young Lee (1996). The former describes Korean with a traditional and conservative approach whilst the latter takes a more contemporary and progressive approach, reflecting modern day Korean used by younger generations more than the former. The main difference is that Lee (1993) distinguishes long and short vowels and provides minimal pairs while Lee (1996) claims that this length contrast is disappearing in modern Korean, especially in the speech of the youth. Another difference is that Lee (1993) categorizes /j/ and /w/ as part of diphthongs whereas Lee (1996) includes them in the consonant phoneme system as semi-vowels. A further difference is, in Lee (1993), /ø/ is categorized as a monophthong while it is completely dropped and replaced with a diphthong /we/ in Lee (1996), which Lee (1993) also does acknowledge as happening in Seoul speakers' speech. As Lee (1996) can be considered to describe current Korean speech more accurately, it has been selected as the basis for the account of the phonetics and phonology of Korean in this thesis. The transcription system and examples also have been adopted from the same source.

2.1 Consonants

There are 22 consonant phonemes in modern Korean as shown in Table 2.1: there is a three-way contrast among bilabial, alveolar and velar plosives and palatal affricates, two types of alveolar fricatives, one glottal fricative, three nasals, one liquid, and three semi-vowels.

Voiceless glottal fricative /h/ is produced with only a little "glottal" friction, and with no constriction or narrowing of the vocal tract, except when followed by /i, o, u/ where there is strong local friction in the oral cavity. /h/ does not occur in word-final positions, and /ŋ/ does not occur in the word-initial positions.

Manner \ Place		Bilabials	Dental/ Alveolar	Palatal	Velar	Glottal
Plosive	Unaspirated Lenis	p	t		k	
	Unaspirated Fortis	p$^{=}$	t$^{=}$		k$^{=}$	
	Aspirated Fortis	p^{h}	t^{h}		k^{h}	
Affricate	Unaspirated Lenis			tɕ		
	Unaspirated Fortis			tɕ$^{=}$		
	Aspirated Fortis			tɕ^{h}		
Fricative	Unaspirated Lenis		s			h
	Unaspirated Fortis		s$^{=}$			
Nasal		m	n		ŋ	
Liquid			l			
Semi-vowel		w		j	ɰ	

Plosive	pul; p$^{=}$ul; p^{h}ul	fire; horn; grass
	kal; k$^{=}$al; k^{h}al	to grind; to lay (a mat); knife
Affricate	tɕada; tɕ$^{=}$ada; tɕ^{h}ada	to sleep; to squeeze; to kick
Fricative	sada; s$^{=}$ada; hada	to buy; to pack (a suitcase); to do
Nasal	sam; san; saŋ	three; mountain; prize
Liquid	sal	flesh
Semi-vowel	jaŋ; waŋ	sheep; king
	wi; ɰidʑaŋ	stomach; chairman

Table 2.1: Phonemes in Korean and examples.

2.2 Vowels

Monophthongs

There are eight monophthongs, /i, u, o, ʌ, e, ɛ, a, ɯ/, in Korean; however, young native-Seoul speakers do not discriminate /e/ and /ɛ/, thus, for them there are only seven vowel phonemes. Here are some minimal pairs of Korean monophthongs:

kiɾɯm; kuɾɯm; koɾɯm; kʌɾɯm	oil; cloud(s); pus; fertilizer
seda; sɛda	to count; to leak
kam; kɯm	persimmon; gold

In careful or conscious speech, vowel length has a distinctive function in Korean and minimal pairs with a difference only in the vowel length can be found:

pam; paːm	chestnut; night
sagwa; saːgwa	apology; apple

In most cases, a long vowel appears in the first syllable of a word, however, in some compound words, it appears in the first syllable of the second element of the compound word.

kadʑʌŋ baːŋmun; seːgje dɛːdʑʌn	home visiting; world war

Vowel length in Korean is derived from the high tone of ancient Korean, however, distinctive use of vowel length is disappearing among young speakers of the Seoul dialect.

Diphthongs

There are generally said to be 12 diphthongs in Korean involving three types of semi-vowels: /j/-types: /ja, jʌ, jo, ju, je, jɛ/; /w/-types: /wa, wʌ, we, wɛ, wi/; /ɰ/-type: /ɰi/ (/we/ and /wi/ are sometimes pronounced as monophthongs [ø] and [y]).

The treatment of these sequences as diphthongs is based on the orthography of Korean. The approximants can alternatively be considered as consonants in the phonology of Korean. Some examples and minimal pairs involving these diphthongs are:

jaŋ; jʌŋ; joŋ; juŋ; je; jɛ	sheep; zero; dragon; cotton flannel; yes; this child
waŋ; wʌn; wenson; wɛ; wi	king; wish; left hand; why; up
ɰisa	doctor

2.3 Allophonic rules in Korean

The following are some major allophonic rules of Korean:

- Plosives are not released when followed by another homorganic obstruent or in word-final positions
- Plosives get an inaudible release when followed by another non-homorganic obstruent except /h/;
- When a plosive is preceded by a homorganic nasal, the oral obstruction is maintained, and the sound is produced with a nasal approach.
- /p, t, k/ become [b, d, ɡ] between voiced sounds within the same rhythmic unit, and they can optionally become fricatives between vowels.
- /p, p⁼, pʰ/ become neutralized to [p] then become fortis and unreleased as [p˺] in word-final positions or before a bilabial plosive;
- /p, p⁼, pʰ/ become neutralized to [p] then become fortis with an inaudible release as [p] before a non-homorganic obstruent except /h/.

Allophones of Korean nasals /m, n, ŋ/

As nasals form the subject of this thesis, a little more detail is given of allophones of nasals as usually recognised (according to Lee (1996)).

1. Voiced bilabial nasal /m/ becomes:
    - palatalized to [mʲ] before /i, j, tɕ, tɕ⁼, tɕʰ/

- labialized to [m^w] before rounded vowels /u, o, we/ and /w/
- labial-palatalized[1] to [m^ɥ] before /wi/ and /j/
- /m/+/h/ becomes [m^ɦ] or /h/ gets elided: i.e. the outcome is a nasal with breathy voice or a nasal with breathy offglide

2. Voiced alveolar nasal /n/ becomes:

- palatalized to [n^j]/[ɲ] before /i, j, tɕ, tɕ$^=$, tɕ^h/
- labialized to [n^w] before rounded vowels /u, o, we/ and /w/
- labial-palatalized [n^ɥ]/[ɲ^w] before /wi/ and /j/
- elsewhere: [n]
- /ŋ/+/h/ becomes [n^h]when /h/ is weak

3. Voiced velar nasal /ŋ/ becomes:

- palatalized to [ŋ^j] before /i, j, tɕ, tɕ$^=$, tɕ^h/
- labialized to [ŋ^w] before rounded vowels /u, o, we/ and /w/
- labial-palatalized [ŋ^ɥ] before /wi/ and /j/
- elsewhere: [ŋ]
- /ŋ/+/h/ becomes [ŋ^h]when /h/ is weak

Part Two. Phonology of Korean

In this section, the phonology of the Korean language is reviewed, following mainly *Korean Phonetics* by Lee, H. Y. (1996).

2.4 Syllable and syllabification

In Korean, a syllable is a unit of sound which consists of one vowel and zero or more consonants. Through establishing the syllable units, one can explain the phonotactic constraints, phonological rules, and the tone and stress patterns of a language. Here is an example of syllabification:

고장 [ko.dʑaŋ]

[1] Labial-palatalization of nasals is due to /wi/ (together with /i/, not just /w/ alone), which is sometimes pronounced as [ɥi] and sometimes [ø] or [y] – see also 'Diphthongs' on p. 22.

There are two indications that the word has to be syllabified this way. One is that there can be a pause between [o] and [dʑ] and the other is that a round vowel labializes the consonants within the same syllable, and [o] labializes [k] but not [dʑ] thus the syllable must be divided before [dʑ].

Syllable structure of Korean

Korean syllables are composed of onset, nucleus, and coda. The nucleus can stand alone and form a syllable, but onset and coda are optional. Thus, the syllable structure of Korean can be expressed as below:

(Onset) Nucleus (Coda)

The nucleus contains only one vowel. Traditionally, semi-vowels used to be considered to belong to the nucleus. However, not only because they appear in consonant positions, but also because they do not affect the syllable weight in Korean, it is more reasonable to consider them as onset. This type of analysis means that there can be up to two consonants in the onset but the second one must be a semi-vowel.

Based on this, 6 types of syllable structure can be set up:

1. Vowels: [i, ɛ, ʌ, o, u]
2. C+V: [so, ɕi, nʌ, kʰi, jo, je, jɛ, wɛ, hɛ]
3. C+C+V: [kje, kwa, mjo, pjʌ, pʰjo, hjo, hwa]
4. V+C: [al, il, un, ɯn, ip̚]
5. C+V+C: [sal, pap̚, kuk, nal, tam, tɕoŋ, tɕʰoŋ, kʰoŋ, tʌk̚, hak̚]
6. C+C+V+C: [hjʌŋ, kwaŋ, pjʌl, pjʌk̚, k˭waŋ]

The template of the syllable structure of Korean is thus: $\mathbf{C_0^2\,VC_0^1}$

2.5 Phonological environments for Korean nasals

The combination of phonotactic constraints and certain obligatory assimilation processes means that Korean nasals can appear in the following environments (Hwang, 2002).

1. Between vowels: VNV
2. Between a vowel and a consonant: VN.C (C→ Plosives, Fricatives, Nasals)
3. Word-initially followed by a vowel: #NV

   /ŋ/ cannot be syllable-initial

   /m/ cannot be followed by /ɯ/ in the word-initial position

   /n/ cannot be followed by /i/ or /j/ word-initially

4. VC.N is not allowed unless C is nasal as well.

   V + obstruent + N is not allowed. The obstruent is assimilated to the nasal.

   V + /l/ + /m/ is allowed.

   V + /l/ + /n/ is not allowed: Assimilation producing two liquids or two nasals is necessary.

   V + N + N is allowed.

2.6 Stress in Korean

Opinions are divided as to whether Korean exhibits what may be termed “stress”. There are certainly clear prominences to be heard in utterances as short as two syllables; some assume that these prominences are the realization of stress, and proceed to debate rules for the location of stresses in words. Others deny that there is any word-level stress in Korean. Among these, Jun’s Accentual Phrase theory (1993), which characterises prosodic prominence in Korean as resulting from phrasal tonal patterns, has been most widely accepted for dealing with the matter.

Early documents on middle Korean such as Hunmin Cheongeum (Sejong, 1443) show that the language formerly had a distinctive tonal system. Tone contrasts were marked in the writing system by dots on the left side of a syllable: two dots (Rise – from Low to High), one dot (High) and none (Low). These dots disappear from literature by the 17th century and the Rise tone was replaced by vowel length, though South Eastern regional dialects still have this tonal quality in their speech (see Cha, 2001 for a review). Gim (1937), although he believed that there is no word stress, only sentence stress, wrote that the stress agrees with the length of the vowel in Korean (1937: 111).

The account of stress in the current chapter is based on Lee (1996), which presents the view that Korean is a fixed stress language and there are certain rules that govern the assignment of stress. Lee was selected as a basis for the general background account of Korean phonetics and phonology required here since it gives the most comprehensive review of Korean phonetics based on current colloquial speech; for example, the loss of long vowels in young Seoul Korean speakers is well documented in his account.

However, the category of stress as such is not crucial to the present investigation, and syllables described as stressed might alternatively be characterised as “initial in an accentual phrase or higher-level domain”. The current research does explore (in Chapter 4), to a certain extent, claims of a possible link between denasalization in Korean and domain-initial strengthening (Cho & Keating, 2000) in the light of Jun’s Accentual Phrase theory. In short, retention of the term “stress” in the following account is more for pragmatic convenience in giving an overview of Korean phonetics rather than reflecting the author’s stance on any of the claims made by previous researchers.

Stress and Accents in Korean

Although Korean is a fixed stress language and stress does not have a distinctive function in simple words, there are compound words and phrases which differ in meaning depending on the presence or the location of stress. In this case, the stress has an “accentual function”:

a.	ˈtɕal| ˈmotʰada	to be not skilful
	ˈtɕalmotʰada	to make a mistake
b.	ˈnɯlgɯn| ˈnamdʑawa jʌdʑa	old man and old woman
	ˈnɯlgɯn namdʑawa| jʌdʑa	old man and woman (age unknown)

Also, stress in Korean has a “rhythmic function,” which means that in a word group there is one stressed syllable and zero or more unstressed syllables, and the intonation pattern for the whole word group depends on the location of the stressed syllable.

Stress assignment rules of Korean

In the syllable structure of Korean, nucleus and the coda form a rhyme. When a rhyme consists of only one short vowel, it is called a ‘light’ syllable. When a rhyme contains one long vowel or any one vowel plus a coda (closed syllable), it is called a ‘heavy’ syllable.

1. The first syllable of a word is stressed;

monosyllabic words: ˈsan; ˈkaŋ; ˈtɕip˺	mountain; river; house
two-syllable words: ˈhakk͈jo; ˈsaːɾam	school; person
three-syllable words: ˈhaks͈ɛŋtɕ͈ɯŋ; ˈkɛguɾi	student ID; frog
four-syllable words: ˈp͈algɛdʑida; ˈtwit͈aɾɯda	to turn red; to follow

2. If the first syllable of a word made up of three or more syllables is light, then the stress could be shifted to the second syllable:

three-syllable words: tɕaˈdoŋtɕʰa; kɛˈguɾi;	car; frog
four-syllable words: aˈɾɯmdaun; koˈsokt͈oɾo	beautiful; highway

3. Two or more stresses can be assigned to a compound word according to the number of morphemes;

ˈseːgjɛˈtɛːdʑʌn; ˈkjowʌnˈtɕagjʌktɕ͈ɯŋ	world war; teacher's license
ˈkuŋnipˈkugʌ ˈjʌːnguwʌn	National Korean Language Research Centre

4. Auxiliary words—particles, bound nouns, and auxiliary verbs—are not stressed.

Accent assignment rules of Korean

1. When compound words with more than two stresses are spoken in a slow and careful manner, all stresses are phonetically realized. However, in fast and casual speech, two or more morphemes in the compound word are grouped together and the first syllable of that word group is stressed.

Slow		*Fast*	
ˈseːgjɛødɛːdʑʌn	→	ˈseːgjɛdɛdʑʌn	world war
ˈkjowʌnˈdʑagjʌktɕ͈ɯŋ	→	ˈkjowʌndʑagjʌktɕ͈ɯŋ	teacher's license
ˈkuŋnipˈkugʌˈjʌːnguwŋn	→	ˈkuŋnipˈkugʌjʌːnguwʌn	National Korean Language Research Centre

2. The same also applies at the phrasal level, that is, when two phrases are combined into the same word group in connected speech, the second phrase loses its stress and only the first phrase is accented.

ˈhakk͈joesʌ| ˈjʌlɕ͈imɦi| ˈkoŋbuhɛt͈a|	at school| hard| studied|
ˈhakk͈joesʌ| ˈjʌlɕ͈imɦi koŋbuhɛt͈a|	studied hard at school (subject omitted)

2.7 Phonotactic constraints of Korean

Certain phonotactic constraints and sandhi (word-boundary) processes are given here because they are relevant to understanding the structures and sequences used in the data.

1. /ŋ/ and /l/ cannot occur word-initially, except for some loan words which start with an /l/: [ɾadio] radio; [ɾamjʌn] ramyon noodles; [ɾʌɕia] Russia
2. The onset can have up to two consonants in which case the second one must be a semi-vowel.
3. Word-initially, a bilabial consonant cannot be followed by /ɯ/.
4. /j/ cannot be followed by either /i/ or /ɯ/, /w/ cannot be followed by /u, o, ɯ, ɰ/ and /ɰ/ can only be followed by /i/.
5. /n/ cannot be followed by /i/ or /j/ word-initially, except for a limited number of words: [njamnjamgʌɾida] to smack [njus$^{=}$ɯ] news
6. In any sequence of obstruent+lenis obstruent, the second becomes fortis:

[hak˺] + [sɛŋ] → [haks$^{=}$ɛŋ]	student
[kuk˺] + [pap˺] → [kukp$^{=}$ap˺]	rice in soup

7. Obstruent+Nasal sequences are not allowed and the obstruent is replaced by a nasal:

[hak˺] + [mun] → [haŋmun]	study; learning
[hak˺] + [njʌn] → [haŋjnʌn]	year (in school)

8. Obstruent+liquid sequences are not allowed and both are replaced by nasals:

[pɛk˺] + [ɾo] → [pɛŋno]	a heron

9. Nasal+liquid sequences are not allowed and either both become nasals or both become liquids:

[ɕin] +[ɾa] → [ɕilla]	Shilla
[tal] + [nim] → [tallim]	moon (poetic expression)
[ɯmun] + [ɾon] → [ɯmunnon]	phonology

10. Lenis obstruents become fortis aspirated, combining with a following /h/:

/p, t, k, tɕ/ + /h/ → [pʰ, tʰ, kʰ, tɕʰ]

[pʌp˺] + [hak˺] → [pʌpʰak˺]

Part Three. Nasality

2.8 Nasality and the Velum

Nasality, and its control by velic action, are well established concepts in descriptive phonetics, and the general phonetic possibilities for nasals have been reasonably well understood in the West since the mid seventeenth century (Kemp 1981). This section provides overall accounts of the velum and nasality in general mainly based on Laver (1994). Other references are cited as appropriate.

The velum

The velum, also called the soft palate, is the soft fleshy part at the back of the roof of the oral cavity past the hard and bony part, the hard palate. At the end of the rear part of the velum, the tiny hanging-down tip, which is visible through the open mouth, is called the uvula. Unlike other passive articulators which are immobile, the velum can be moved up and down, creating an alternative passage for the pulmonic egressive airstream, in which sense it is also considered as an active articulator (Abercrombie, 1967: p. 43).

Understanding this up- and downward movement of the velum may be better achieved by understanding the configuration and functions of the structures involved (see also Figure 2.1). Here is an anatomical description given by Romanes (1986):

> "The soft palate is a flexible, muscular flap which extends postero-inferiorly from the posterior edge of the hard palate into the pharyngeal cavity. It is also attached to the lateral walls of the pharynx, and has the uvula hanging down from the middle of its free posterior border, which is continuous with the palatopharyngeal arch on each side. The soft palate is a flap valve which, when raised and drawn posteriorly against the posterior pharyngeal wall, shuts off the nasal part of the pharynx. This permits…coughing without air escaping through the nose, and swallowing without regurgitation into the nose"

(p. 144).

In other words, the basic biological functions of the soft palate depend on just two settings: open and shut. If speech did turn out to involve carefully controlled degrees of opening, it would represent a considerable specialization of control.

When the velum is raised during speech production, the airstream can flow out of the vocal tract only through the mouth; speech sounds produced this way are called oral. However, when it is lowered and the air escapes through the nose, nasal or nasalized sounds are produced. It is said that there is a velic closure when the velum is shut, and a velic opening when it is open. If the air flows through the velic opening only and not through the oral cavity, then a nasal stop is produced; a nasal 'stop' in the sense that the airflow is completely blocked in the mouth like it is for oral stops, although some are not in favour of this term, pointing out the continuous airflow through the nasal cavity whereas the word 'stop' has the connotation of a complete halt to it (Ladefoged and Maddieson, 1996). Unlike an oral stop, a nasal stop has a continuous flow of air into the atmosphere; the intra-oral air pressure during the hold phase does not build up enough to give a nasal an obstruent quality. In this sense, nasals are similar to approximants rather than stops and are classified as sonorant (Ashby and Maidment, 2005; p. 55).

Nasality as a Distinctive Feature

Phonological classification of sounds in terms of nasality may lead one to think that there are only two velic position values, [+nasal] or [-nasal]; however, physiological conditions of the velopharyngeal mechanism system required for providing or preventing coupling of the oral and nasal cavities effectively may involve more than just two distinctive positions of the velum. Bell-Berti (1993) cites a few studies that suggest various velum height values depending on the type of a segment: lowest for nasal consonants and the second lowest for nasal vowels; higher for high vowels than low ones; and higher for obstruent consonants than high vowels (p. 64).

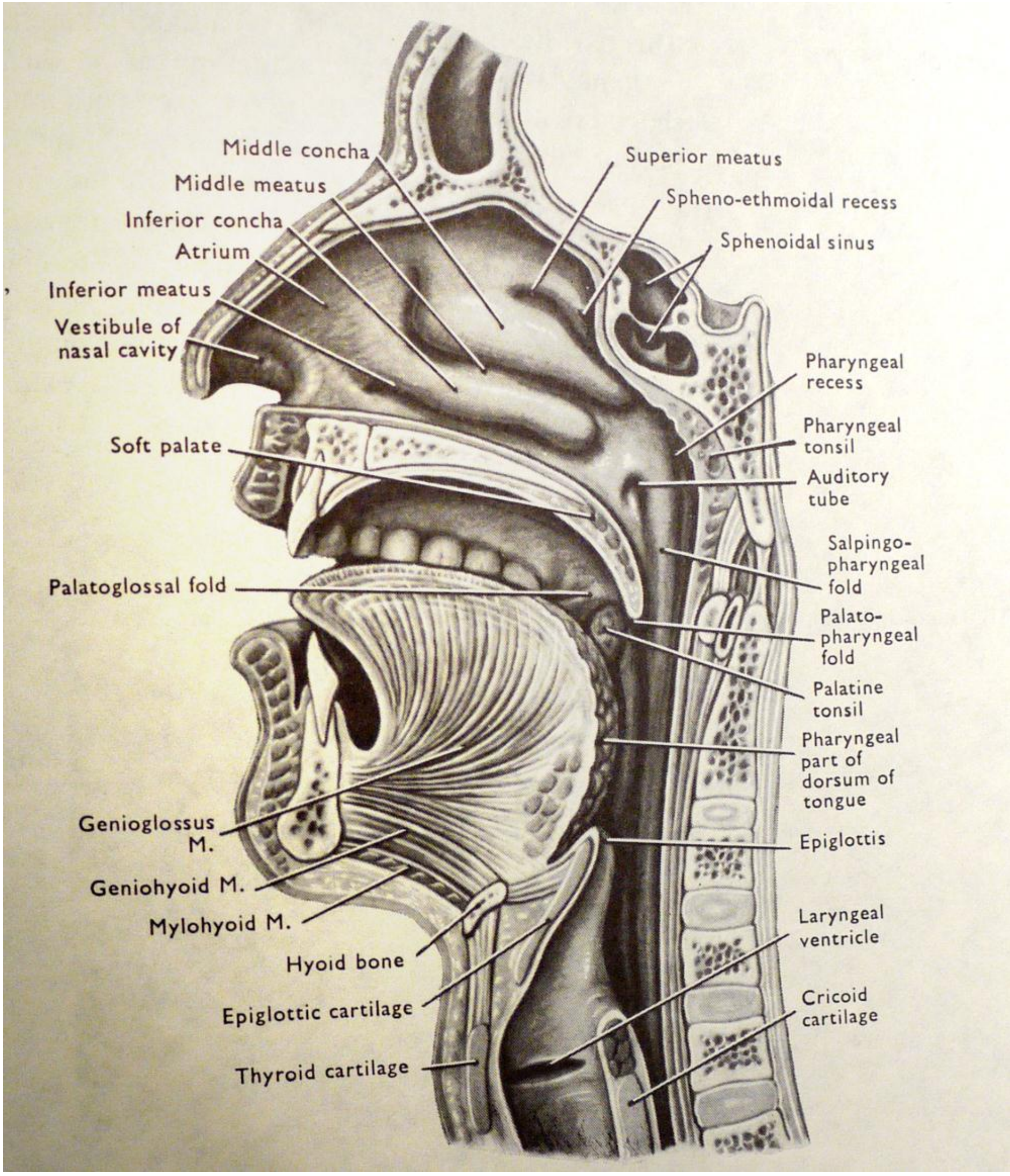

Figure 2.1: Paramedian section through the nose, mouth, pharynx and larynx showing the soft palate in an open position, adapted from Romanes (1986:141).

Velopharyngeal settings

Laver (1994) categorizes velopharyngeal settings into three; neutral, nasal, and denasal. A 'neutral' setting refers to when the velum is tightly shut and thus sounds which are phonologically oral are made as oral as the physiology permits; the 'nasal' setting applies to different degrees of nasality. The term 'denasal' refers to a lower degree of perceived nasality than would otherwise be expected (see below).

Voicing

Normally nasals are produced with vibration of vocal folds, however, some South-East Asian languages: Burmese for example, have been reported to have phonemically contrasting nasals made with the glottis open, resulting in voiceless nasals (Ladefoged and Maddieson, 1996). Voiceless nasals are transcribed with a diacritic, a small circle underneath or over a segment as in [m̥] or [ŋ̊].

2.9 Nasals and Nasalized Consonants

Conventionally, 'nasals' refers to nasal stop consonants which are produced the same way as their oral stop counterparts with only difference in the position of the velum. They are articulated with a complete obstruction of the air in the oral cavity but with it continuously flowing through the nasal cavity via the velic opening. Because the air keeps flowing out of the vocal tract through the nose during the medial phase of a nasal consonant, the intra-oral air pressure does not rise as it does during an oral stop articulation. For this reason, nasals fall under sonorants, not obstruents. Consonants other than stops produced with a velic opening are called 'nasalized' consonants and vowels produced the same way 'nasalized' vowels.

Nasals are made at various places of articulation and at least two or three nasals, four in some, can be found in most languages in the world; for example, English has three—bilabial, alveolar, and velar—and French four—bilabial, dental, palatal, and velar (Laver, 1994; Ashby and Maidment, 2005).

There are two main elements involved in nasal stop articulation: oral occlusion and lowering of the velum. If these two conditions are matched in terms of the onset, duration, and the offset, then the velum keeps its open position throughout the medial phase of a nasal. However, a mismatch of the two can occur in which case four possibilities of 'complex oral/nasal stop articulation' may arise depending on the duration of the oral/nasal components as shown in Figure 2.2 (Laver, 1994; p. 228).

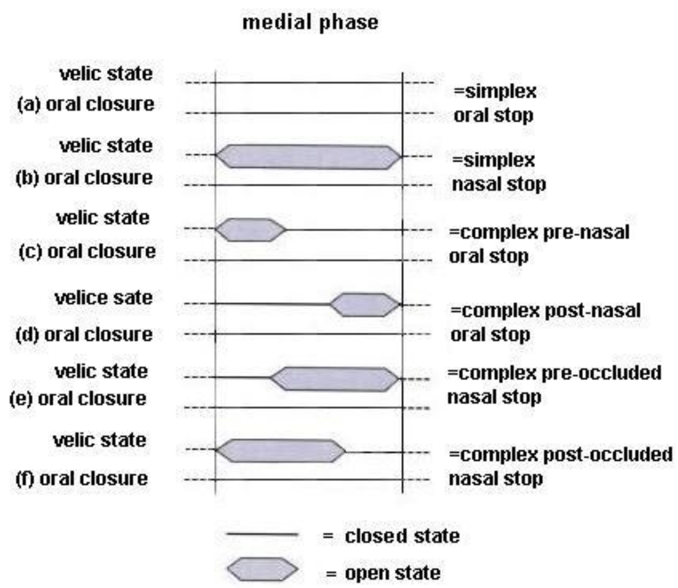

Figure 2.2: The timing relationships of oral closure and velic state during the production of (a) a simplex oral stop; (b) a simplex nasal stop; (c) a complex pre-nasal oral stop; (d) a complex post-nasal oral stop; (e) a complex pre-occluded nasal stop; and (f) a complex post-occluded nasal stop (adapted from Laver, 1994; p. 228).

2.10 The Velum and Prosody

The position of the velum during articulation of a speech sound has been reported to be affected by the stress of a syllable: the velic position is lower for a nasal consonant in a stressed syllable than in an unstressed syllable; however, it is higher for an oral consonant or an oral vowel in a stressed syllable than in an unstressed syllable; and higher for a nasal consonant in a syllable-initial position than in a syllable-final position (Bell-Berti, 1993).

More recent studies have, however, found that the hierarchy of the domain that a domain-initial nasal consonant is in affects the height of the velum; the velum is in the higher position for a nasal consonant in the initial position of a higher prosodic domain than a lower one (Fougeron and Keating, 1997; Cho and Jun, 2000; Cho and Keating, 2001). Cho and Jun (2000) explain this as follows:

> ……what is strenghthened domain-initially is 'consonantality' of the segment, thus enhancing the syntagmatic contrast with the following vowel. For example, articulatorily, consonants become more consonant-like domain-initially by way of more extreme oral constriction. …… (p. 2).

2.11 Acoustics of Nasals

Damping

Nasal sounds are more damped than oral sounds because of a number of factors: first, the soft walls of the nasal cavity which absorb voicing energy much more than the harder walls of the oral cavity; second, the nasal cavity has a larger area and volume than the oral cavity leading to more damping losses; third, there are side chambers (sinuses) within the nasal cavity, and further energy is lost in them (Johnson, 2003).

Damping during the hold phase of nasal consonants produces a characteristic acoustic form showing weak formant structures in the high frequency regions and stronger energy levels in the low-frequency regions. At the release of the oral constriction, however, the amplitudes of the formants sharply increase as the oral cavity, which damps the signals much less than the nasal cavity, becomes the main resonator again (Clark, Yallop, and Fletcher, 2007).

Formants and Anti-Formants

There are three tubes involved in production of nasal consonants: the pharynx, the nasal cavity, and the oral cavity. The pharynx and the nasal cavity are linked at the velopharyngeal port to form one main resonator, while the oral cavity, sealed by an occlusion at one point, functions as a side chamber. These conditions contribute to the spectral characteristics of nasal murmurs: the prominent F1 in the low frequency regions and low energy peaks in the higher frequency regions above 700 Hz (Pickett, 1980). The formants of nasals appear as peaks on the spectrum around the following frequency regions in general: 250Hz, 1,000Hz, 2,000Hz, and 3,000Hz (Clark, Yallop, & Fletcher, 2007).

The oral cavity plays the key role in reduced nasal energy in F2 and higher frequency regions. During the hold phase of a nasal consonant, the signals from the glottis close to the resonant frequency of the oral cavity resonate in it, but because the oral cavity is blocked by an obstruction, those frequency components of the signals are absorbed in it. These resonant frequencies are called “anti-resonances,” “anti-formants,” or “zeros” (Johnson, 2003).

Anti-formants on the spectrum appear as valleys and all peaks above those anti-formants display reduced amplitudes. Johnson (2003) cites Fujimura as explaining that this effect is not universal to all anti-formants but it depends on a side cavity that causes the “separation” of formants and anti-formants (p. 155), which results in higher level of energy on the low end of the spectrum of nasals. Wider bandwidth (heavier damping) of nasals also contributes to the reduction of their formant energy levels and thus the spectrograms of nasals are lighter than those of adjacent oral vowels.

Under some conditions, anti-formants can appear as weakening of specific harmonics on spectrograms, but commonly they may not readily be seen at all, as the degree of energy absorbed in the oral cavity varies depending on the size of the velopharyngeal aperture (Seong, 1996).

The frequencies of anti-formants can be used as cues for places of articulation for nasals as they differ by the length of the resonating body, the oral cavity: lower anti-formant for a bilabial nasal than an alveolar one because the oral cavity is longer because of the place of articulation (Johnson, 2003). Fujimura (1962) suggests the following values for anti-formant frequencies of three intervocalic English nasal consonants: 750Hz and 1,200Hz for [m]; 1,400Hz and 2,200Hz for [n]; and above 3,000Hz for [ŋ]. Anti-formants AF2 and AF3 of the bilabial nasal and AF3 and AF4 of the alveolar nasal appear as a cluster. In a vocal tract of a length such that the oral cavity is 8cm, the anti-formants of each nasal consonant is as follows: 1,000Hz for [m]; 1,700Hz for [n]; and 3,000Hz for [ŋ]. Another cue for places of articulations of nasal consonants is the direction of the F2 transition; it goes toward the lower frequency for bilabial and goes towards higher frequency for velar, there is no or very little transition for alveolar. The portion of the signal just before the release of the oral occlusion of a nasal consonant, and around the start of the transition, are the most prominent perceptual cues for place of articulation (Kurowski & Blumstein, 1993).

A few studies had dealt with Korean nasals before Kim and Ashby (2006), for example, Seong (1996; 2000) and Hwang (MA thesis, 2002) all of which looked at nasals in medial position. According to Hwang, it is not possible to acoustically characterize word-initial Korean nasals because they are partly devoiced and their spectrograms do not show enough energy (p. 5). Seong (1996) did not look at word-initial nasals or denasalization but gave acoustic accounts for intervocalic nasals in Korean using [ama], [ana], and [aŋa]. His suggested anti-formant frequencies of these nasals are: 490~900Hz, 2,900~3,400Hz, and above 3,800Hz for [m]; 580~1,050Hz and 2,850~6,100Hz for [n]; and above 2,850Hz for [ŋ].

2.12 Aerodynamics of Nasals

The Velum and the Nasal Airflow

The velum functions as a valve between the pharynx and the nasal cavity, letting the air from the lungs flow into the nasal cavity or preventing it from doing so. When this valve is open and the air flows through the nasal cavity, nasal sounds are produced; when it is shut, oral sounds are produced.

The amount of airflow in the nasal cavity is a consequence of velic function and an individual can be clinically classified as having either “hypernasality” if they have an excessive amount or “hyponasality” if they do not have enough. Krakow and Huffman (1993) point out that nasal airflow with vary according to the overall flow through the whole vocal tract and the amount of airflow in the oral cavity

An experimental study by Warren, Dalston, and Mayo (1993) provides some important conclusions regarding the relationship between the nasality and the velic functions. First, the velic opening must be larger than 0.2 cm^2 for a speech sound to be perceived as nasal, if smaller than that, the sound would be considered as hyponasal (p. 139). Even if the velic function is normal, however, the nasal cavity can be blocked in such a way that the air does not resonate in it properly, in which case the supposed nasal segment does not sound sufficiently nasal. So both velopharyngeal adjustment and patency of the nasal cavity itself affect the perception of nasality of a sound (pp. 119-120). Second, the duration of velic opening can affect the perceived nasality of a speech sound more than the extent of the opening (p. 143). Also, which part of the nasal cavity is blocked may have consequences for the degree of nasality: while frontal blockage would reduce the nasality, if the rear part of the nasal cavity is blocked, there would be no nasal resonance at all (pp. 143-144).

Observation of velum activity

As velum movement is directly related to the nasality of speech sounds, researchers have used various methods to observe its activities both directly and indirectly. Often special equipment is involved, some relatively easy to obtain and set up, while others are both costly and complex to use. Methods need to be carefully selected according to the characteristics and the purpose of research or diagnoses.

There are various direct and indirect assessment tools for the velopharyngeal function (for a review, see Baken, 2000). Indirect methods include acoustic measures and airflow/pressure measures. Both acoustic and airflow/pressure measures are generally non-invasive, allowing the subject to produce speech as they would normally do, although some techniques may be more complicated and even involve equipment that needs to be in contact with the subject’s face.

Some of the acoustic measurement tools and methods that have been tried include: determinations of vocal tract damping, an oral-and-nasal sound pressure system (so called “Nasometer”), spectral measurements on conventional microphone recordings, especially A1-P1 (relative amplitude of the first formant and first nasal pole), and accelerometry on the exterior of the nose.

Different airflow/pressure measurement tools and methods include: a nasal airflow measurement system using a nasal mask, volume measures, and oral breath pressure ratio.

Direct methods normally require complex and expensive equipment some of which is invasive as they involve insertion of the equipment into the nares or deep into the oral tract near the velopharyngeal opening. Some of these tools are (see Table 2.2); electromyography (highly invasive), X-ray, X-ray microbeam, and endoscopy (rigid and flexible). None of these direct methods were available for the present study.

	Method	Notes
Invasive	Electromyography	Highly invasive; painful (needle electrodes); often disruptive of normal speech behaviours
	X-ray (often combined with cinefluoroscopy, videofluoroscopy, or computed tomography)	Significant health risk associated with prolonged exposure to ionizing radiation; lack standardization of technique, of procedure, and of interpretation that limits clinical utility
	X-ray microbeam	Difficult to attach pellets to the velum; the pellet placement triggers a strong gag reflex; tremendously expensive
	Endoscopy (often combined with multi-view video fluoroscopy and other aerodynamic measures)	Rigid Endoscopy (oral insertion) – a gag is caused by the contact of the instrument to the vocal tract; Flexible Nasendoscopy (nasal insertion) – more invasive than oral insertion and can cause great anxiety to the patient
Non-Invasive	Ultrasonography	No discomfort for the patient; minimal health hazard; rapid data collection; portable; not costly compared to other imaging devices
	Magnetic Resonance Imaging (MRI)	Not many studies have been done on the velopharyngeal activities using MRI; Producing one image can take several seconds to several minutes; promising for monitoring velopharyngeal behaviour

Table 2.2: Comparison of direct methods for assessment of velopharyngeal activities (adapted from Baken, 2000).

2.13 Denasalization

When a nasal consonant is produced without the nasality needed for it to be contrastively distinguished as a nasal, it is said that the nasal is denasalized. This may occur as a result of a blockage or through less than usual opening of the velopharyngeal port, leading to reduced nasal airflow and reduced nasal resonance. According to Laver (1980), a positive airflow in the nasal cavity does not have to be a mandatory requirement for a sound to be perceived as nasal because the nasal cavity could be vibrated without any air flowing in it (p. 88). It seems then that the denasal quality depends on the listeners' perception. Laver (1994) says: "a denasal setting can only exist in relation to listeners' expectations about due nasality" (p. 413).

Denasalization in languages of the world

Acehnese, an Indonesian language of northwest Sumatra, is an example of a language with denasalized nasals. Lawler (1977) describes the "funny nasals" as follows:

> ……These latter are nasal consonants pronounced in the appropriate place with significantly reduced airflow, probably produced by partial closure of the velum; they are 'slightly longer' than ordinary nasals, and do not produce the same allophones of vowels in their environment as do the plain nasals. They appear to be reflexes of certain nasal+voiced stop clusters in Proto-Indonesian, but no longer do they consist of a prenasalized stop. They are extremely difficult to produce and detect. Stress is on the last syllable, and normal delivery is at an extremely high rate of speed, with copious fast speech rules operating; I have not even attempted to represent these. As should be evident, the phonology of this language would repay some study.

Another Indonesian language, Gayo, as documented by Eades and Hajek (2006), also has denasalized nasals. The authors describe these nasals as "non-nasal nasals" compared to "nasal nasals" and record that these non-nasal nasals no longer exist in young people's speech and are not marked in orthography or transcription. They also note that "non-nasal nasals" in Gayo are phonemes in older speakers' speech, while the "funny nasals" in Acehnese as recorded by Durie (1985) are allophones of plain nasals.

Ladefoged & Maddieson (1996) call this type of nasals “orally released nasals,” claiming that the characteristics of these nasals are derived from the exact timing of onset of velum lowering and oral closure and velum raising and oral release, in addition to the lesser degree of the velic opening than that of nasal nasals, as an effort to prevent the nasality from spreading to the following vowel (p. 106). This consequently lengthens the duration of their hold phase longer than that of normal nasals they predict, which is in accordance with Lawler’s (1977) observation on the nasals in question as ‘slightly longer’ than ordinary nasals above.

A similar account of this type of phenomenon is given by Ohala (1997) in which the oral portion of the segment is named an “emergent stop.” In this account, an early velic closure results in an appearance of a stop so it can prevent a coupling of the nasal cavity for the following oral vowel. This, therefore, is more likely to occur if the adjacent vowel is distinctively oral or has low F1 and/or F2. This is where Ohala (1997) agrees with Chen and Clumeck (1975) that the Korean nasals in word-initial positions followed by a high vowel create an intrusive stop due to the nature of the high vowel requiring the velum to rise, thus becoming “post-stopped nasals” (pp. 3, 4):

> …c. Korean: [mul] ~ [m^{b}ul] water (Chen and Clumeck, 1975)
>
> (cited in Ohala (1997)).

Nasals in some Chinese dialects are reportedly in the process of denasalization. In a report of an experiment with four dialects, Hu (2007) concludes that denasalization in southern Min has advanced to the extent that its post-oralized nasal consonants are largely oral, whereas in other three dialects, Shanxi, Cantonese and Hakka, nasality persists until the oral release begins.

Another language with denasalized nasals is Karitiana, a Tupi language in Brazil. Demolin (2007) cites Storto (1999) and Storto and Demolin (2005) as reporting that the nasals in this language are realized as voiced stops word-initially. There are no voiced stops in the phonemic inventory of this language and the nasals become voiced stops in the word-initial position. They remain voiced, even though the language has a general initial devoicing rule. The authors also note that they detected traces of nasality before the oral portion of the segments, which they regard as “an articulatory manoeuvre to facilitate voicing in the initial stop" (p. 274). As will be seen, there are some striking parallels between the situation reported for Karitiana and the one reported in this study for Korean.

Previous studies on Denasalization in Korean

Despite an extensive literature search, very few previous mentions of denasalization in Korean have been identified: Martin (1951), Chen and Clumeck (1975), Ohala and Ohala (1993), and Ohala (1997). Martin (1951) describes post-oralized nasals in Korean as follows:

> In the environments /mw, mu, mo/, the nasal component sometimes ends slightly before the lip closure is replaced by lip rounding, resulting in a momentary voiced stop: [m^b]. Since this stop is in free variation with zero in a limited environment, the fourth criterion of 1.1 is applicable: [m^b] and [m] are free variants of /m/ before /w, u, o/…….In a similar way, the phoneme /n/ is occasionally [n^d] before a front vowel…… (p. 523)

It should be noted that a specific environment is given here as a condition for occurrence of this different type of nasals: 1) before /w, u, o/ for /m/; 2) before a front vowel for /n/. It is presumed that this account is solely based on the author's auditory and perceptual judgements as there is no mention of an experiment.

Chen and Clumeck (1975) are perhaps the first to call what happens in Korean nasals "denasalization." They carried out an auditory experiment with one male informant from Seoul, who had been living in the US for about six months. The informant read a list of 15 words and another list of 30 words with word-initial /m/ and /n/ followed by all vowels allowed after these nasals in Korean. Then the authors, native speakers of English and trained phoneticians, listened to the words repeated five or six times by the informant to mark them for nasality. Following are their conclusions after their observation:

1. Korean word-initial nasals are perceived differently depending on the height of the following vowels: the higher the following vowel, the more denasalized the nasal is perceived;

2. /n/ tends to be perceived as non-nasal much less than /m/;
3. If there are historical consequences of articulatory correlation between vowel height and nasalization, it takes the order of high>mid>low vowel that follows the consonant;
4. Denasalization must be much more common among languages in the world than has been publicized as it is caused by physiological constraints of the human body.

These appear to be ambitious conclusions in the light of the very small scope of their work, based on one speaker and impressionistic judgments of 45 words spoken in isolation.

While Martin (1951) limits the environment for denasalized /m/ to before /w, u, o/, Chen and Clumeck conclude that this happens before any vowel with a difference in the degree of nasalization of the nasal consonant depending on which vowel it is followed by. They agree, however, that /n/ is less denasalized than /m/.

After Chen and Clumeck (1975), Ohala and Ohala (1993, 1997) gave their account of denasalized Korean nasals as “intrusive stops” or “emergent stops,” claiming that the change of the nasality is caused by the neighbouring segments which require the velopharyngeal port to shut in order to ensure their orality. If correct, this might imply that denasalization should not occur in the neighbourhood of another nasal (a prediction contradicted by evidence presented here).

Chen and Clumeck’s study is important in that it was the first attempt at looking at denasalization systematically, dealing with all possible environments for the nasal consonants in question, however, no further studies had been done since their report (Ohala and Ohala’s study in 1993 is not counted because it is not directly focused on Korean nasals) until Kim and Ashby (2006), which investigated the subject more in depth with different methods and technologies, using connected speech rather than words in citation forms: auditory judgements, spectrogram analyses, airflow measurements, laryngography, and energy level measurements using acoustic analysis software to aggregate results over large numbers of tokens.

Yoshida (2008) investigated the degree of denasalization of Korean nasals /m/ and /n/ in different prosodic positions. He claims that denasalization is ‘incomplete’ in that the nasality does not disappear but only weakens as the tier goes up in the prosodic hierarchy. Refusing on this basis to call the phenomenon ‘denasalization’, he argues that ‘nasality weakening’ is correlated to the prosodic hierarchy, as Cho and Keating (2001) claimed, being stronger at the initial position of higher level domains compared with lower level domains. Not every level of domain is claimed to be significantly different from the adjacent ones. Yoshida claims that (Ui[2] and IPi[3]) are alike, as are (APi[4] and Wi[5]), with S[6]i forming a third category. No strong support for differences linked to domain types has been found in the present study.

Lee and Kim (2007) reported that anticipatory nasalization is stronger than carryover nasalization in Korean, and carryover nasalization is stronger when the nasal is in the word-medial position than when it is in the word-initial position. Their method of measuring the level of nasality was to measure the length of the vowel that is nasalized. They claimed that, although carryover nasalization in the vowel following a word-initial nasal was lower than that in the vowel followed by a nasal, the mean percentage of nasalized portion of the whole duration was 40%, which they insisted cannot be considered ‘denasalization’.

The results they report are broadly in line with what might be expected if their data did indeed exhibit denasalization which they failed to recognise. A major criticism of their study is that, even though they used an airflow measurement system with oral and nasal masks, they did not report any actual measurement of the airflow, and, as with the other previous studies, the number of tokens used was very limited (less than 20 for each of /m/ and /n/ across 3 subjects). Their claim that “anticipatory nasalization is stronger than carryover nasalization in Korean” is extensively contradicted by evidence presented in the present study.

All in all, although the phenomena investigated in this study have not gone entirely unnoticed up to now, existing studies have been few in number and very limited in size. Some have also used unsatisfactory methods, and failed to report quantitative findings in detail. In some cases it seems likely that the researchers must

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[2] Utterance-initial
[3] Intonational Phrase-initial
[4] Accentual Phrase-initial
[5] Word-initial
[6] Syllable-initial

have had data in which denasalization was apparent, though they failed to appreciate in full what they were dealing with.

Chapter 3

Auditory and acoustic characteristics of denasalized nasals in Korean

3.1 Introduction

Korean nasals /m/ and /n/ in word-initial position have not been documented much in the phonetics literature as reviewed in the previous chapter. Not one Korean researcher has acknowledged the denasalization phenomenon. On the contrary, they have regarded these Korean nasals as the same as English nasals or stated that their acoustic characteristics are impossible to study due to their short duration in the word-initial position. A few other researchers, none of them native speakers of Korean, have recognized the unusual realization of these consonants although no one has so far provided substantial data or conclusive findings.

Some of the findings from these previous studies claimed that Korean nasals /m/ and /n/:

- are practically the same as English nasals (Gim, 1937);
- become [m^b, b] and [n^d, d] before high vowels and sometimes [o] (Jones, 1924);

- become [m^b] before [w, u, o] and [n^d] before a front vowel (it is implied that this happens word-medially as well in the example provided– [taninta] 'goes back and forth');
- are perceived differently depending on the height of the following vowels: the higher the following vowel, the more denasalized the nasal is perceived;
- have realizations such that it is impossible to measure the duration or observe acoustic characteristics in word-initial position owing to the absence of energy and short duration (Hwang, 2002).

The current experiments aimed to challenge these claims as well as to find out the reason native English speakers perceive these nasals as plosives.

If these denasalized nasals are in fact similar to voiced plosives rather than sonorant nasals, then the spectrograms will also show this: there may not be any continuant energy flow during the hold phase and a plosive-like burst may be evident on the release of the consonant. Also, the energy level during the hold phase will be much lower than that of sonorant nasals and close to or same as voiced plosives.

Since these Korean nasals /m/ and /n/ have only been observed either in citation forms or within short artificial sentences in previous studies, they were observed in readings of a summary of a well-known story and news excerpts in this experiment to generate as natural a setting as a spontaneous speech. This is to eliminate the possibility that the unusual realization is found only in emphatic citation forms.

There is an IPA diacritic (provided within the extIPA symbol set) to mark 'denasal', consisting of a cancelled tilde [͊]; its Unicode designation is "Combining Not Tilde Above", and it is located at U+034A in Unicode fonts. But it is visually indistinctive, and extremely inconvenient to use in conjunction with the various software applications used in this study. Instead, throughout this research a zero '0' will be added next to the nasal symbol to show that it lacks nasality, giving [m0] and [n0].

This chapter is structured in two aspects: auditory analyses and acoustic analyses. The auditory analyses provide descriptions on denasalized nasals in comparison to sonorant nasals and voiced plosives in both places of articulation, namely, [m0, m, b] and [n0, n, d]. The acoustic analyses provide results of the energy measurements of the same 6 segments by a 16-channel filterbank analysis within SFS (Speech Filing System).

The following sections are Method, Result 1, Result 2, Discussion and Conclusion.

3.2 Method

3.2.1 Speakers

A total of 8 (4 male and 4 female) native speakers of Korean from different regions of South Korea were recruited (see also Table 3.1): 2 from Seoul, 3 from South West, 1 from Central West and 2 from South East. This was to observe nasals in different accents in order to find out whether denasalization is a feature limited to particular accents. The participants were aged between 22 and 29 and all had been in the UK for less than 12 months at the time of recording. No one had any known impairment with hearing or speaking. Participants were paid a small fee for the recording.

	Regional Accent	Age	Gender	Time spent overseas (mo)
S1	South West	25	M	4
S2	Central West	25	F	11
S3	Seoul	29	M	10
S4	Seoul	22	F	3
S5	South West	25	M	12
S6	South West	27	M	3
S7	South East	23	F	3 wks
S8	South East	23	F	3 wks

Table 3.1: Subjects for acoustic recordings[7]

[7] A table of all subjects who participated in all experiments for the current research is provided as Appendix 4 on p. 163.

3.2.2 Recording materials

Two texts were used: one of a summary of a well-known novel, which contains a wide sampling of /m/'s and /n/'s in the word-initial position, and the other text based on five TV news extracts taken from recordings in which they had originally been broadcast by professional news readers.

The texts furnished a total of 60 words to be observed, with 40 bilabial and 20 alveolar nasals in the word-initial position. Some extra words in isolation with initial nasal consonants mixed with words with a different initial consonant were added for four subjects in the second recording session.

The vowels following the target nasals were /i, e, a, u, o, ʌ/ for bilabial nasals (bilabial nasal cannot be followed by /ɯ/ in Korean) and /e, a, u, o, ʌ/ for alveolar nasals because words with an initial alveolar nasal followed by /ɯ/ or /i/ are very limited. For both /m/ and /n/, /ɛ/ was treated as /e/ as they are not distinctive in young Korean speakers' speech according to Lee (1996). All vowels are monophthongs except for one item with bilabial nasal which is followed by /jʌ/.

3.2.3 Recording

Simultaneous speech and Laryngograph recordings were made in the anechoic chamber at the department of Phonetics and Linguistics, University College London. A strap with two electrodes was wrapped on the outside of each participant's larynx, and the participant was seated in a chair with a microphone at a distance of about 25cm. Recordings were made on a digital audio tape, and later transferred onto a CD as sound files to be analysed on SFS/WASP 1.2, SFS version 4.5.

3.2.4 Annotation

The target segments, [m, m0, b] and [n, n0, d] and the vowels immediately following them, were annotated manually in SFS (Figure 3.1 shows an example). The number of segments annotated was different across subjects because some parts were repeated by the subjects and an extra 15 words in citation were added to each of the subjects 5 to 8. For auditory analyses, however, exactly 60 denasalized nasals, 40 bilabials and 20 alveolars, in the same position for each subject were selected for a controlled comparison.

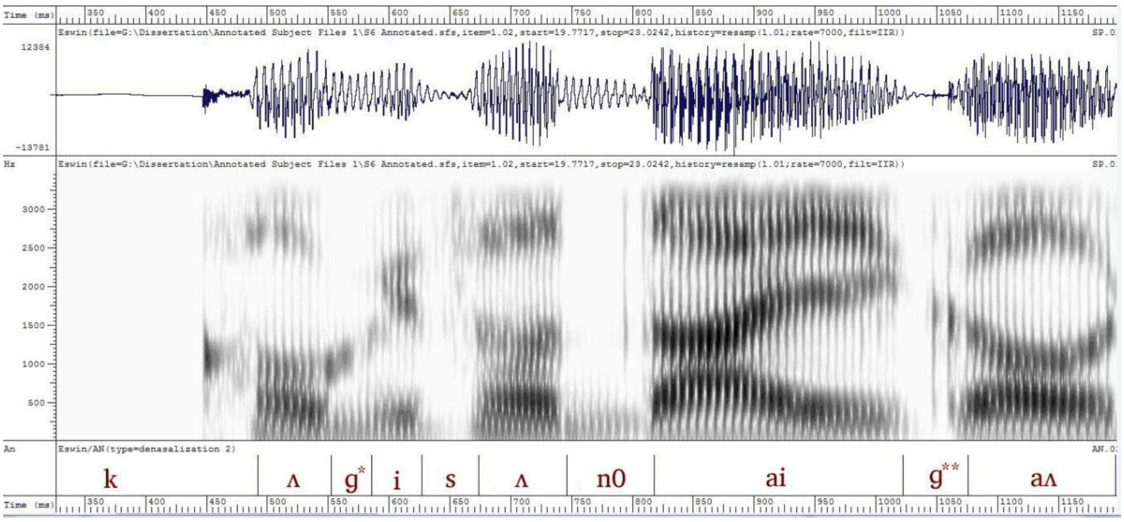

Figure 3.1: An example of a section of an annotated speech file on SFS (* and ** are different realisations of /k/ in intervocalic positions).

3.2.5 Filtering

A filterbank item was added to each recording in SFS using the genfilt program. The item takes the form of 16 filter coefficients, determined at 10ms intervals throughout the recording. Before filtering, the speech was downsampled at 7000 Hz, yielding an effective bandwidth of 3500 Hz. The program genfilt then used 16 bandpass filters linearly spaced between 50 Hz and (Fs/2)-50 Hz (where Fs is the sampling frequency). The resulting filters are centred at:

filter	Hz
1	250
2	450
3	650
4	850
5	1050
6	1250
7	1450
8	1650
9	1850
10	2050
11	2250
12	2450
13	2650
14	2850
15	3050
16	3250

The sixteen time-varying coefficients represent the energy level on a decibel scale as measured in each filter. At any one point in time, the 16 values provide a good picture of the acoustic spectrum.

3.3 Results 1: Auditory analyses

The total number of word-initial nasals accounted for across all 8 participants was 475, which consists of 318 bilabials and 157 alveolars (S3 omitted the first 2 bilabials and S1, S3 and S6 each assimilated one of the alveolars to preceding [l]).

From a simple auditory analysis, 76% of those bilabial nasals were denasalized and 94% of the alveolar nasals were denasalized. Tables 3.2 and 3.3 show the ratio of denasalized and sonorant nasals over the total of segments observed for individual subjects. Figure 3.2 shows bilabial nasal /m/ realized as denasalized in the word-initial position and as sonorant in the word-medial position in [e m0emil]; contrary to what some previous studies said about word-initial nasals being hard to acoustically characterize, the denasalized /m/ shows all of its acoustic features clearly in connected speech, tightly connected to the preceding vowel /e/.

	Accent	Denasal	Sonorant
S1	SW	80%	20%
S2	CW	83%	18%
S3	Seoul	82%	18%
S4	Seoul	80%	20%
S5	SW	63%	38%
S6	SW	88%	13%
S7	SE	68%	33%
S8	SE	70%	30%
All		76%	24%

Table 3.2: Auditory analysis results for word-initial /m/.

	Accent	Denasal	Sonorant
S1	SW	95%	5%
S2	CW	100%	0%
S3	Seoul	89%	11%
S4	Seoul	95%	5%
S5	SW	95%	5%
S6	SW	100%	0%
S7	SE	90%	10%
S8	SE	85%	15%
All		94%	6%

Table 3.3: Auditory analysis results for word-initial /n/.

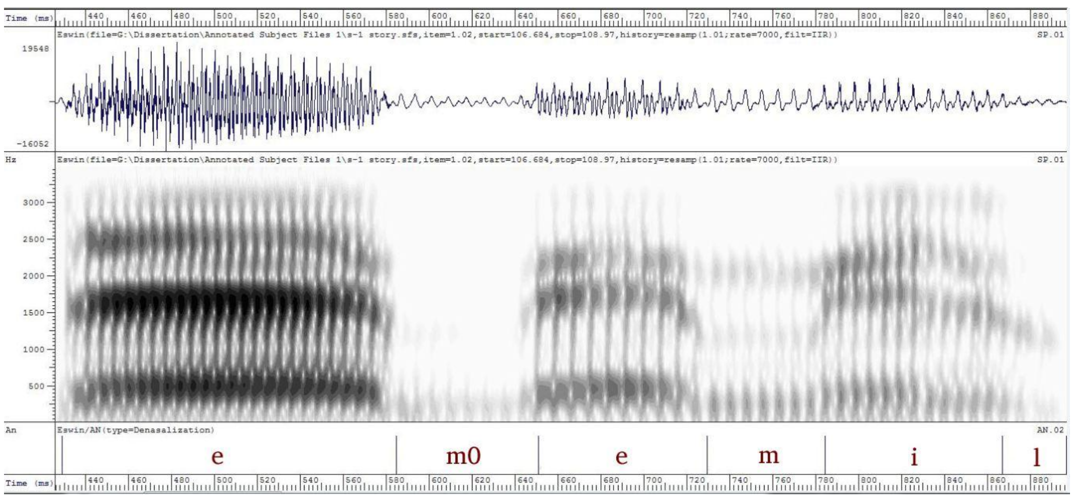

Figure 3.2: S1 male [e m0emil] *buckwheat (flower)*

Table 3.4 shows the ratio of the denasalized segments with a visible burst mark to the total of the word-initial nasals judged denasalized. 21% of the denasalized bilabial nasals and 62% of the denasalized alveolar nasals had a burst mark on the spectrogram. The burst mark indicates something important as it is not a typical feature of a nasal though it is of a plosive. It is not impossible that an acoustic transient of some kind might be caused by a rapid motion of the velum at the release of a nasal but when, as here, it is combined with absence of nasal formants and reduced amplitude during the hold phase, it seems very likely that the velum is not fully open and that the burst results from a value of intra-oral pressure higher than would be the case with a sonorant nasal.

	m0	n0
S1	34%	78%
S2	45%	70%
S3	6%	29%
S4	34%	79%
S5	32%	63%
S6	3%	63%
S7	4%	83%
S8	7%	29%
All	21%	62%

Table 3.4: Proportion of denasalized nasals with a burst mark.

Figure 3.3 is an example of a denasalized alveolar nasal and a voiced alveolar plosive adjacent to each other, showing considerable resemblance: the amplitudes of the waveforms for each segment are the same size; there is absence of typical nasal formants, and a burst mark is shown before the onset of the following vowel. A close-up of the two syllables is shown in Figure 3.3-a. According to the {plosive+nasal → nasal+nasal} assimilation rule in Korean, the segment preceding [n0] ought to have surfaced as a velar nasal [ŋ]. Another instance of the same phrase recorded by the same speaker shows the expected [ŋ] but denasalization of the following word-initial alveolar nasal still occurred (Figure 3.4). The amplitude of the waveform for /k/-turned-into-[ŋ] is noticeably larger than that for /k/-turned-into-[d], but this does not carry over to the immediately following word-initial alveolar nasal. What happens to /n/ instead, shown in Figure 3.4, is that the amplitude reduces dramatically to the size of that of the voiced plosive in the neighbourhood, the nasal formants disappear, and evidently air pressure during its hold phase builds up to produce a burst at the release (see also Figure 3.4-a); all of which make it rather hard to distinguish [n0] from [d].

Denasalization was found regardless of the environment: before and after all vowels and consonants including sonorant nasals and liquids. An example of denasalized bilabial and alveolar nasals before a low vowel [a] is shown in Figures 3.5 and 3.6. In both cases the formants typical of nasal consonants are not seen; the sonorant alveolar nasal in Figure 3.5 provides a good visual comparison.

Denasalization of word-initial /m/ and /n/ was found even after a sonorant nasal. Figure 3.7 shows a denasalized alveolar nasal immediately preceded by a homorganic sonorant nasal. The nasal formants disappear during the /n/+/n/ sequence and there is even something that looks like a small burst at the release of the second /n/.

Figure 3.8 shows a /m/ still realized as [m0] immediately after a sonorant alveolar nasal. As was seen in Figure 3.7, the nasal formants visible for [n] disappear completely in the most of the denasalized nasal hold phase. The contrast is clear between this realization and that of the same phoneme realized as a sonorant nasal between vowels word-medially in the following syllable.

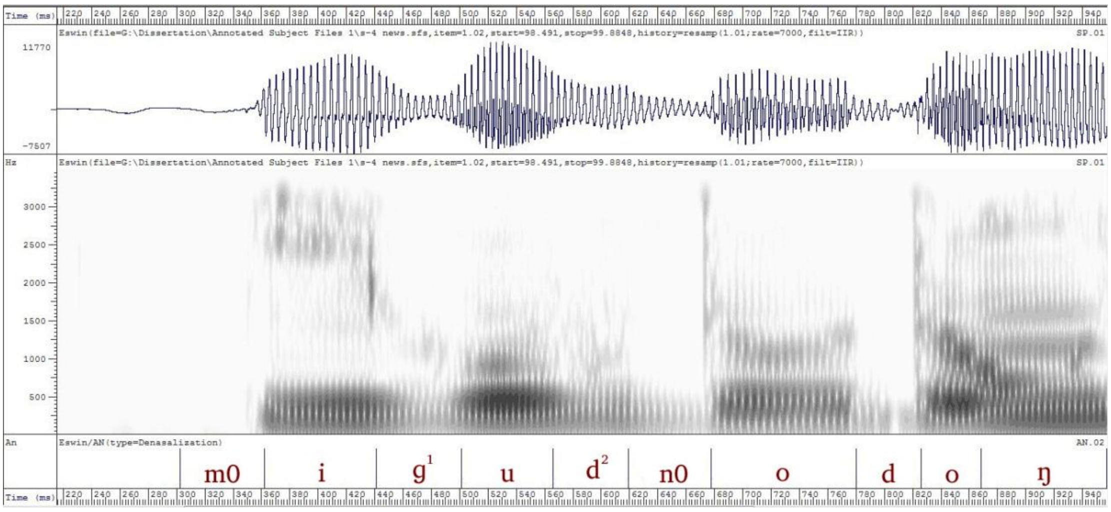

Figure 3.3: S4 female [m0igud n0odoŋ] *American labour* – 1 and 2 are phonetic realisations of /k/ and /t/, realised here as something other than plosives, presumably fricatives. 2 shows some nasal characteristics presumed to be resulted from anticipating the upcoming nasal.

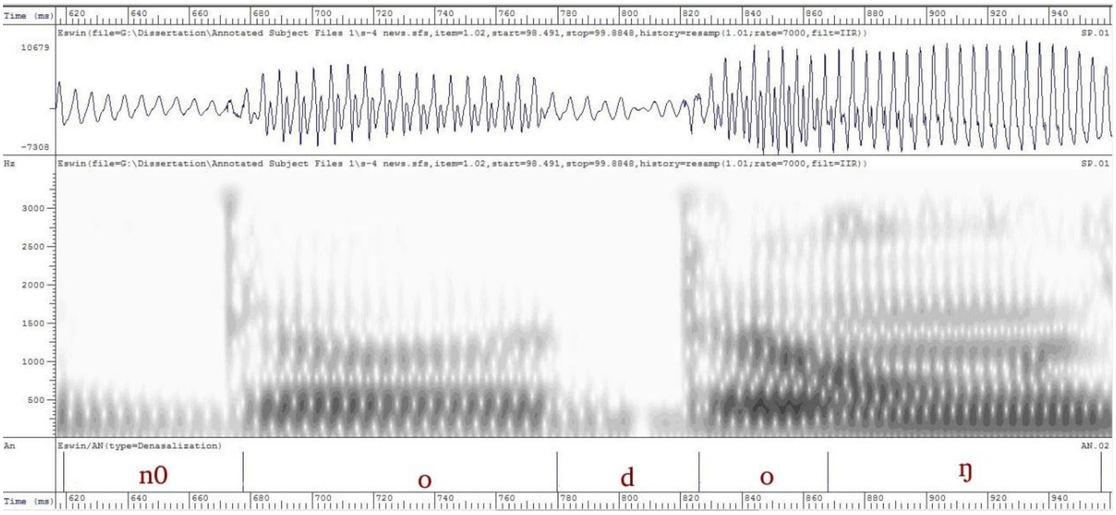

Figure 3.3-a: S4 female [n0odoŋ] *labour*

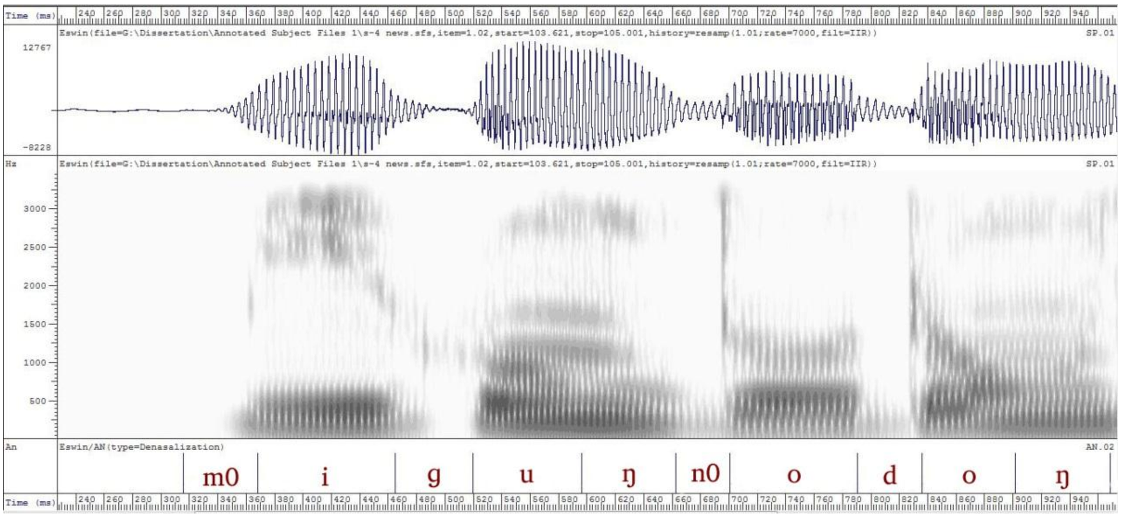

Figure 3.4: S4 female [m0iguŋ n0odoŋ] *American labour*

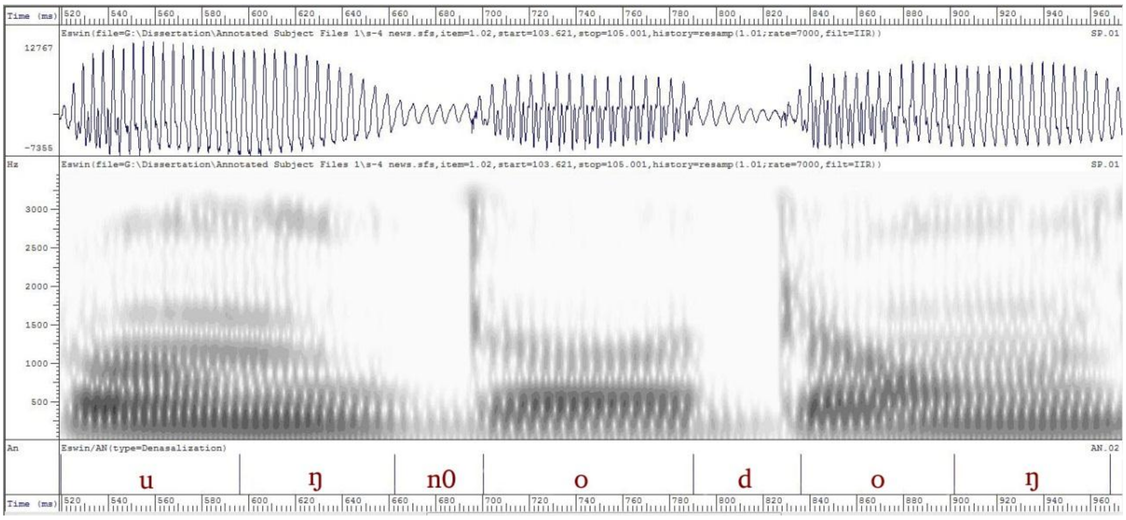

Figure 3.4-a: S4 [uŋ n0odoŋ] *(American) labour*

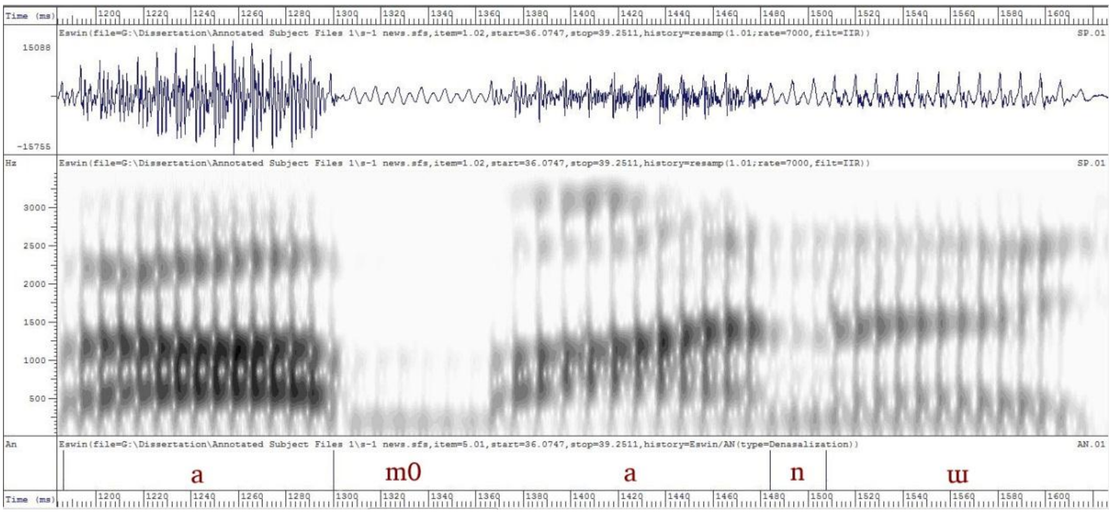

Figure 3.5: S1 male [a m0anɯ] *part. stem. many* (an example of m0+low vowel)

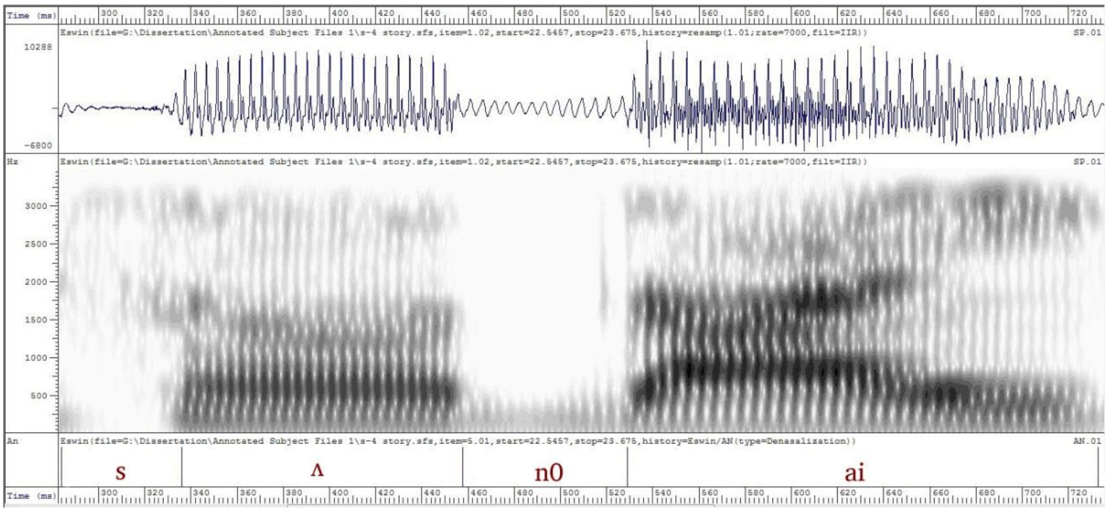

Figure 3.6: S4 female [sʌ n0ai] (*part) age* (an example of n0+low vowel)

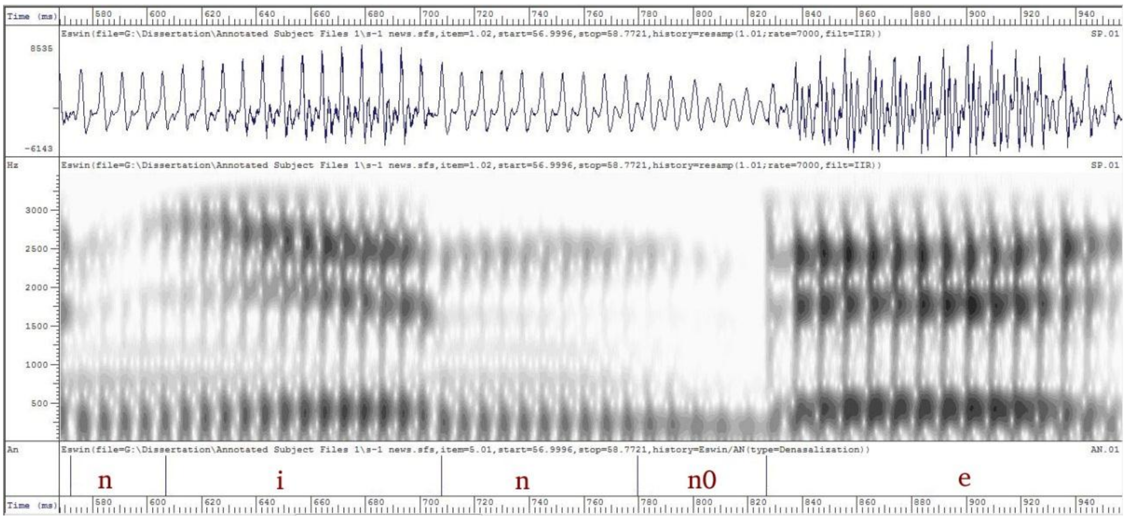

Figure 3.7: S1 m [nin n0e] *(just now) four*

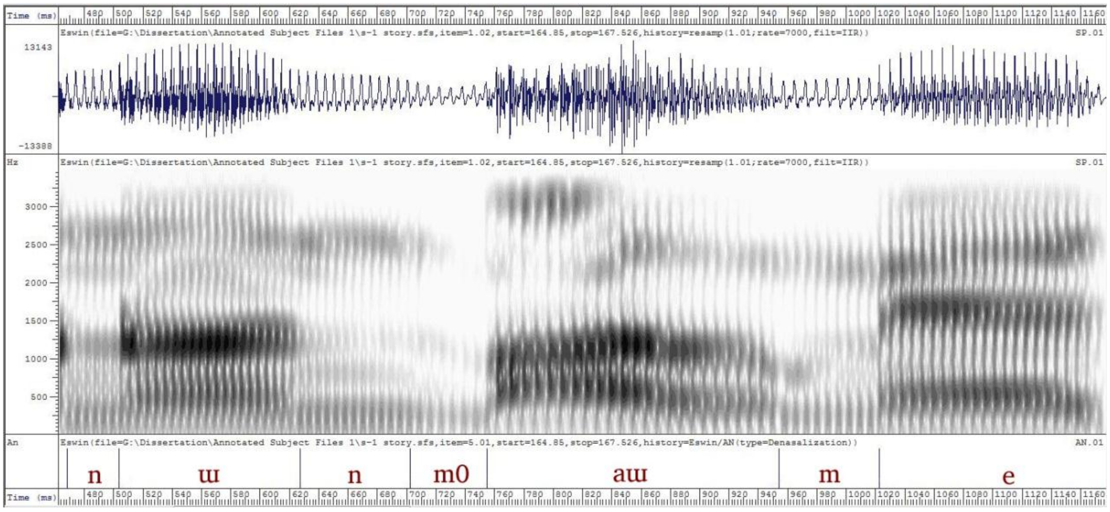

Figure 3.8: S1 male [nɯn m0aɯme] *(subj.) heart (place)*

3.4 Results 2: 16-channel filterbank analyses

The graphs of filterbank output for each subject show considerable similarity (Figures 3.9 and 3.10), which justifies pooling the data across the eight subjects (Figures 3.11 and 3.12). After pooling the subjects, the Kruskal-Wallis nonparametric analysis of variance was conducted separately for each of the 16 filters. It shows that there are significant differences among segments ($p=0.000$ in each of the 16 tests).

In each case, the Mann-Whitney U test has been applied as a post-hoc test (see Table 3.5). As the number of tests is very large, the accompanying table and boxplots give particulars only for a subset. Four representative points (filters 1, 3, 6 and 12) have been selected (250 Hz; 650 Hz; 1250 Hz; 2450 Hz).

Denasalized vs. Sonorant nasals

The comparisons [m]:[m0] and [n]:[n0] show a highly significant difference throughout the frequency range. For both places of articulation, and in each of the 16 filters, the differences are significant with $p=0.000$.

Denasalized nasals vs. Plosives

The comparison [n0]: [d] shows differences in filters 1-4, 10-11, and 15-16, while the comparison [m0]:[b] shows differences in filters 1-4, and 15-16.

From this it appears that Denasalized segments partly resemble plosives but are distinct from them. For both places of articulation, the Denasalized segments show greater energy at low frequencies (up to 850 Hz) and then again at high frequencies (over 3000 Hz).

Denasalized bilabials and Denasalized alveolars

The comparison [m0]:[n0] shows no significant differences in filters 1-6 (up to 1250 Hz), indicating that at low frequencies denasalized segments of either place are essentially alike. This suggests that they share a common mode of production. From filter 7 (1450 Hz) upwards, the comparison [m0]:[n0] yields a significant difference ($p=0.000$) in every case. This indicates that at middle and higher frequencies the two denasalized segments are differentiated by place-of-articulation cues.

Place cues to the [b]:[d] distinction

The comparison [b]:[d] yields a significant difference in 12 of the 16 filters, including all the high frequency filters from 7 (1450 Hz) and upwards. This shows that the filters are selectively responding to the place-of-articulation cues localized in distinct frequency regions. It is likely that these cues include F2 transition information, and the presence or absence of a high frequency burst.

Sonorant nasals distinct

The comparison [m]:[n] yields significant differences in 8 of the 16 filters, with 6 of these grouped into blocks (filters 5-7 and 14-16). This is in line with expectation, since steady portions of sonorant nasals are alike in some respects, but show characteristic patterns of poles and zeroes located at different frequencies.

comparison	n1	n2	p, *U* (Filter 1)	p, *U* (Filter 3)	p, *U* (Filter 6)	p, *U* (Filter 12)
m:m0	290	274	**0.000** *16516.0*	**0.000** *14179.5*	**0.000** *10559.0*	**0.000** *11456.0*
m0:b	274	473	**0.000** *94641.0*	**0.000** *79626.0*	0.508 *62917.5*	0.137 *60572.0*
n:n0	536	192	**0.000** *27294.0*	**0.000** *21701.5*	**0.000** *21106.0*	**0.000** *19913.5*
n0:d	192	880	**0.000** *117030.0*	**0.000** *99628.0*	0.522 *86970.0*	0.058 *11110.0*
m:n	290	536	**0.000** *65136.0*	**0.021** *85085.0*	**0.000** *60862.0*	0.583 *75924.0*
m0:n0	274	192	0.358 *24990.0*	0.196 *28156.0*	0.173 *28254.0*	**0.000** *32439.0*
b:d	473	880	0.052 *221464.0*	**0.000** *234879.5*	0.577 *211946.0*	**0.000** *260699.0*

Table 3.5: Mann-Whitney U test results for correlation of each pair of consonants – [m]:[m0], [m0]:[b], [n]:[n0], [n0]:[d], [m]:[n], [m0]:[n0], [b]:[d] – in four out of 16 filters.

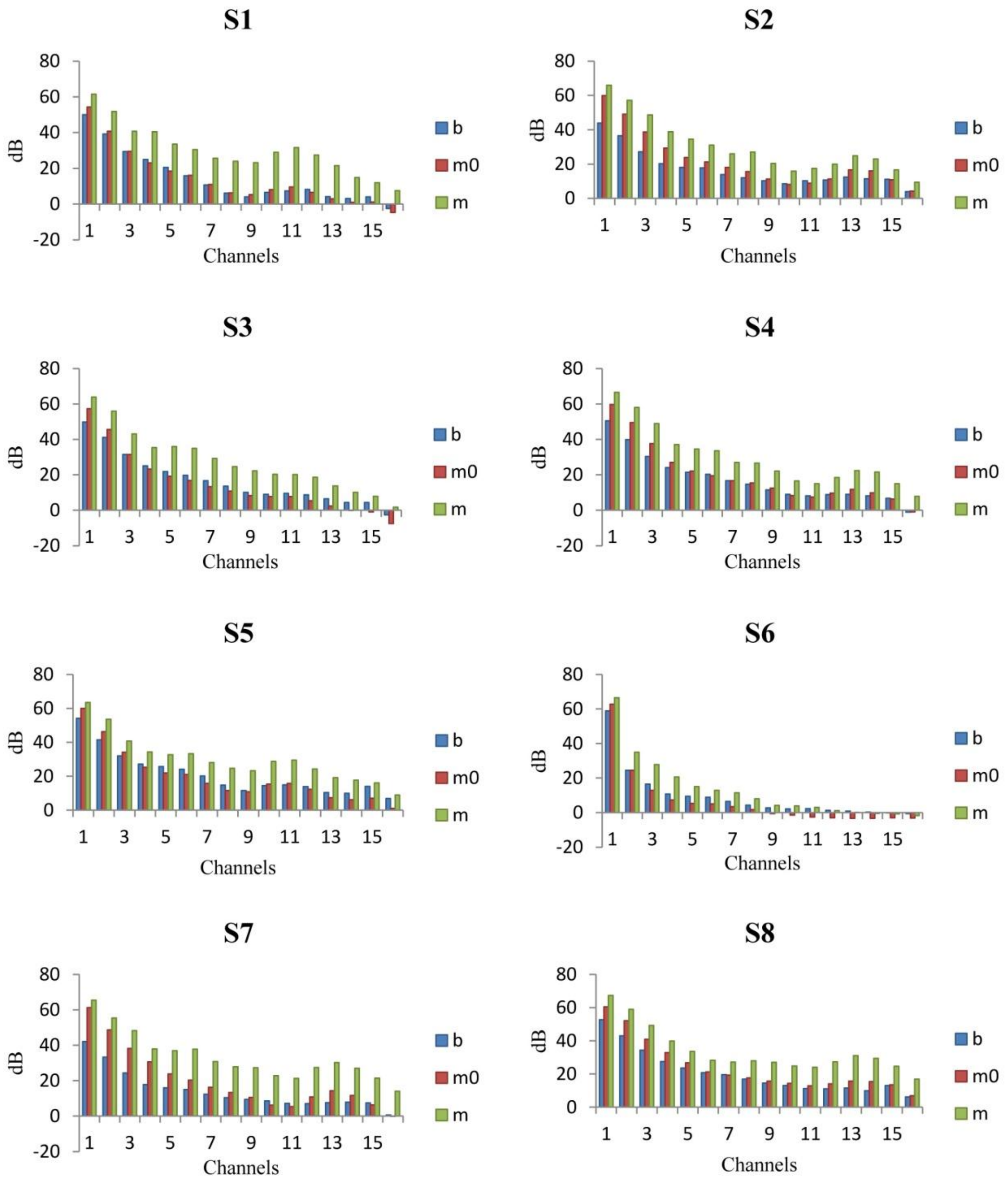

Figure 3.9: Mean energy (dB) of each of 16 filters for each subject: [b, m0, m].

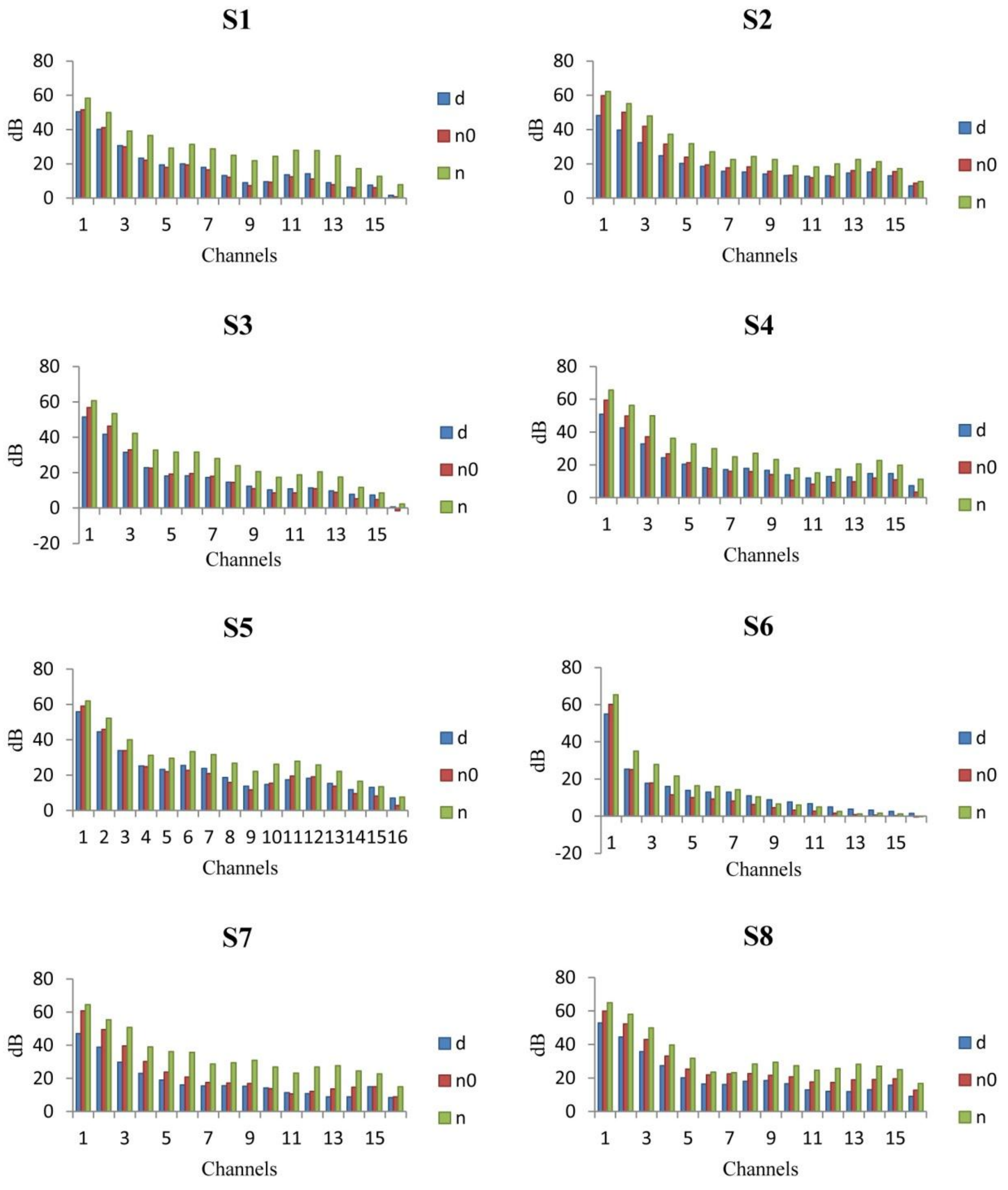

Figure 3.10: Mean energy (dB) of each of 16 filters for each subject: [d, n0, n].

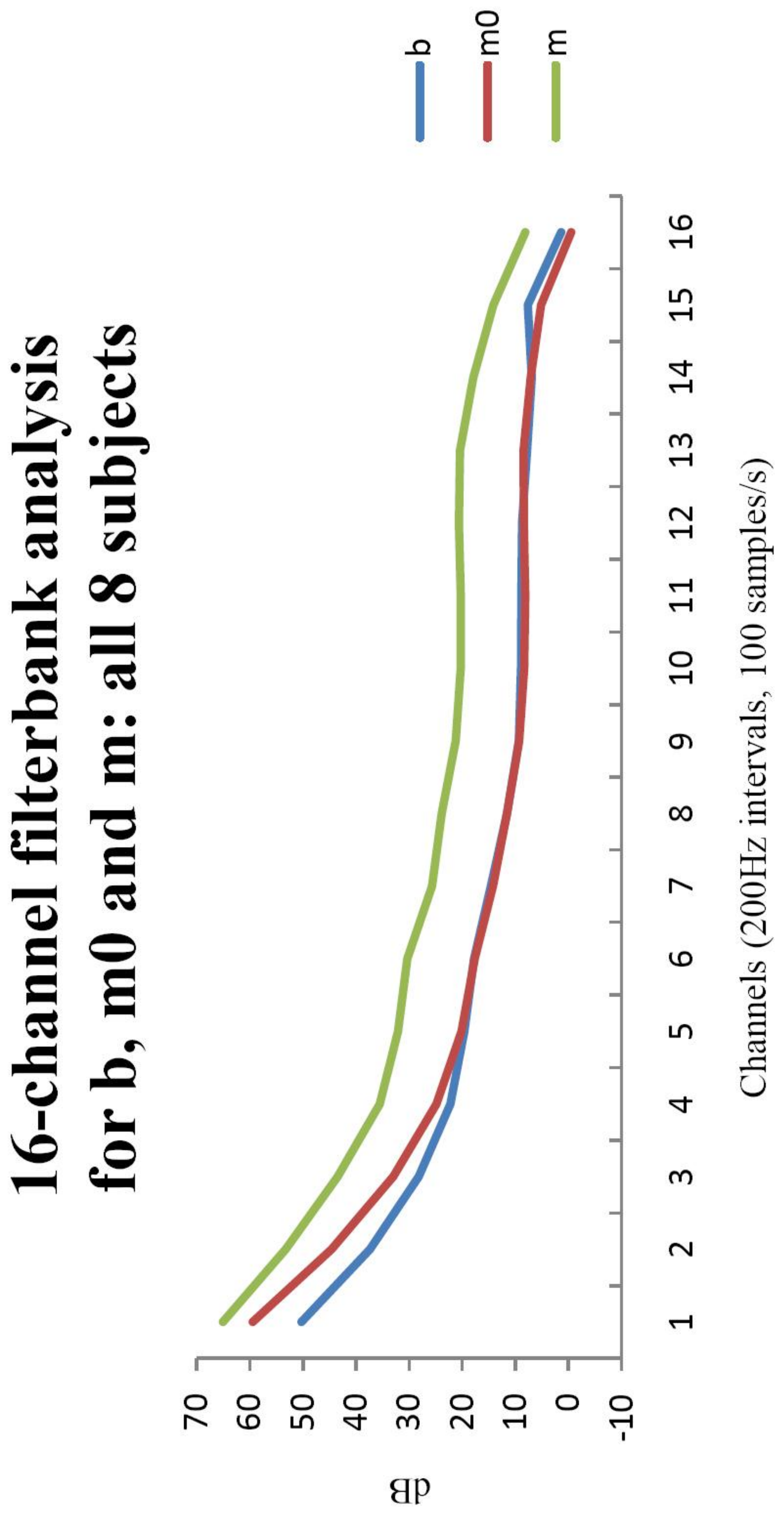

Figure 3.11: 16-channel filterbank analysis for b, m0 and m: all 8 subjects.

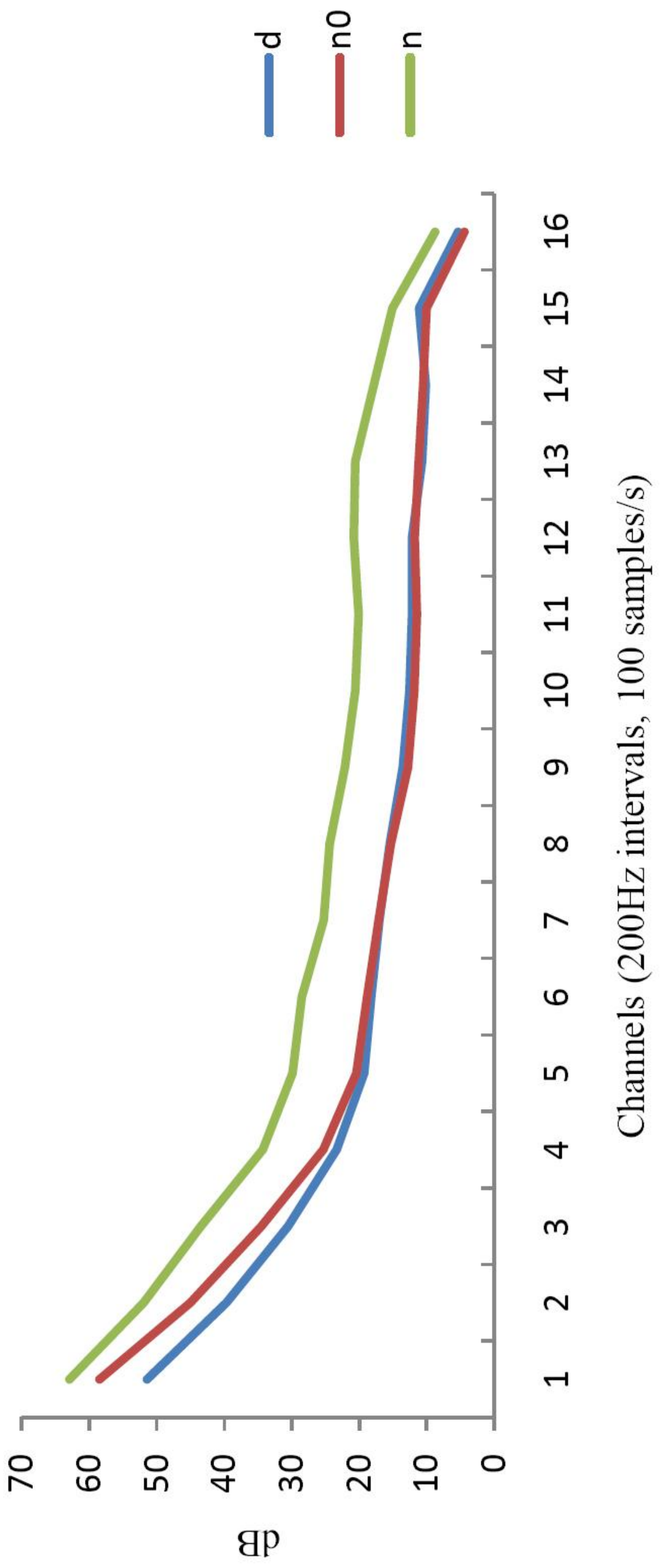

Figure 3.12: 16-channel filterbank analysis for d, n0 and n: all 8 subjects.

3.5 Discussion

Word-initial nasals in Korean were investigated through listening, by systematic observations of large numbers of waveforms and spectrograms, and through spectral analyses in comparison to homorganic word-medial nasals and plosives; [m, m0, b] and [n, n0, d].

The main findings were that a large majority of the word-initial nasals were judged denasalized auditorily (76% of bilabials and 94% of avleolars) and their waveforms and spectrograms showed features that are different from those of word-medial sonorant nasals but similar to those of word-medial voiced plosives: absence of nasal formants, a markedly reduced amplitude of the waveform compared to an adjacent sonorant nasal and, in some tokens, a burst mark at the release of the hold phase.

Also, denasalization occurred to these nasals regardless of the height of the vowels following them, clearly shown in Figures 3.5 and 3.6 with an open front unrounded vowel [a] and this is a result contradictory to observations made by previous researchers (Jones, 1924; Martin, 1951; Chen and Clumeck, 1975) who claimed that denasalization is only relevant to the target segments followed by high vowels.

It should be remembered that connected speech was used for this experiment, in the hope of matching natural speech patterns. The results show that denasalization occurred to both categories of word-initial nasals, /m/ and /n/, seemingly regardless of environment, even when directly preceded by a sonorant nasal at the end of the preceding word (Figures 3.7 and 3.8).

Spectral analyses showed that denasalized nasals, both bilabial and alveolar, are highly significantly different from sonorant nasals in all 16 filters, throughout the whole frequency range of 0 Hz ~ 3,500 Hz. This is clear acoustic evidence of Korean nasals /m/ and /n/ being denasalized, strongly supporting the auditory analysis, and in accord with the main hypothesis. Comparative boxplots of energy measured by four selected filters are shown in Figure 3.13[8].

[8] In this and all subsequent boxplots, the box runs from the 25th percentile to the 75th percentile, and the bold line indicates the median. Whiskers extend to the top and bottom of the range, up to 1.5 box-lengths. After that, values are marked as outliers (circles) and beyond three box lengths as extreme outliers (asterisks). The case-numbers are suppressed on outliers in many instances to avoid cluttering the graph.

The hypothesis for denasalized nasals being similar to voiced plosives was supported in the auditory analyses based on the acoustic features displayed in the waveforms and spectrograms; however, according to the filterbank analyses, they are similar but not identical. The energy level of denasalized nasals at both places of articulation is distinctively lower than sonorant nasals but higher than plosives at lower frequency regions and at the top end of high frequency regions.

3.6 Conclusion

The three types of analyses—auditory, acoustic and spectral—have shown that Korean word-initial bilabial and alveolar nasals are overwhelmingly denasalized and are distinct from sonorant segments in their hold phases, and that denasalized segments from the two places of articulation are closely similar, suggesting a common mode of production. Denasalized segments resemble plosives in certain respects, but are distinct from them.

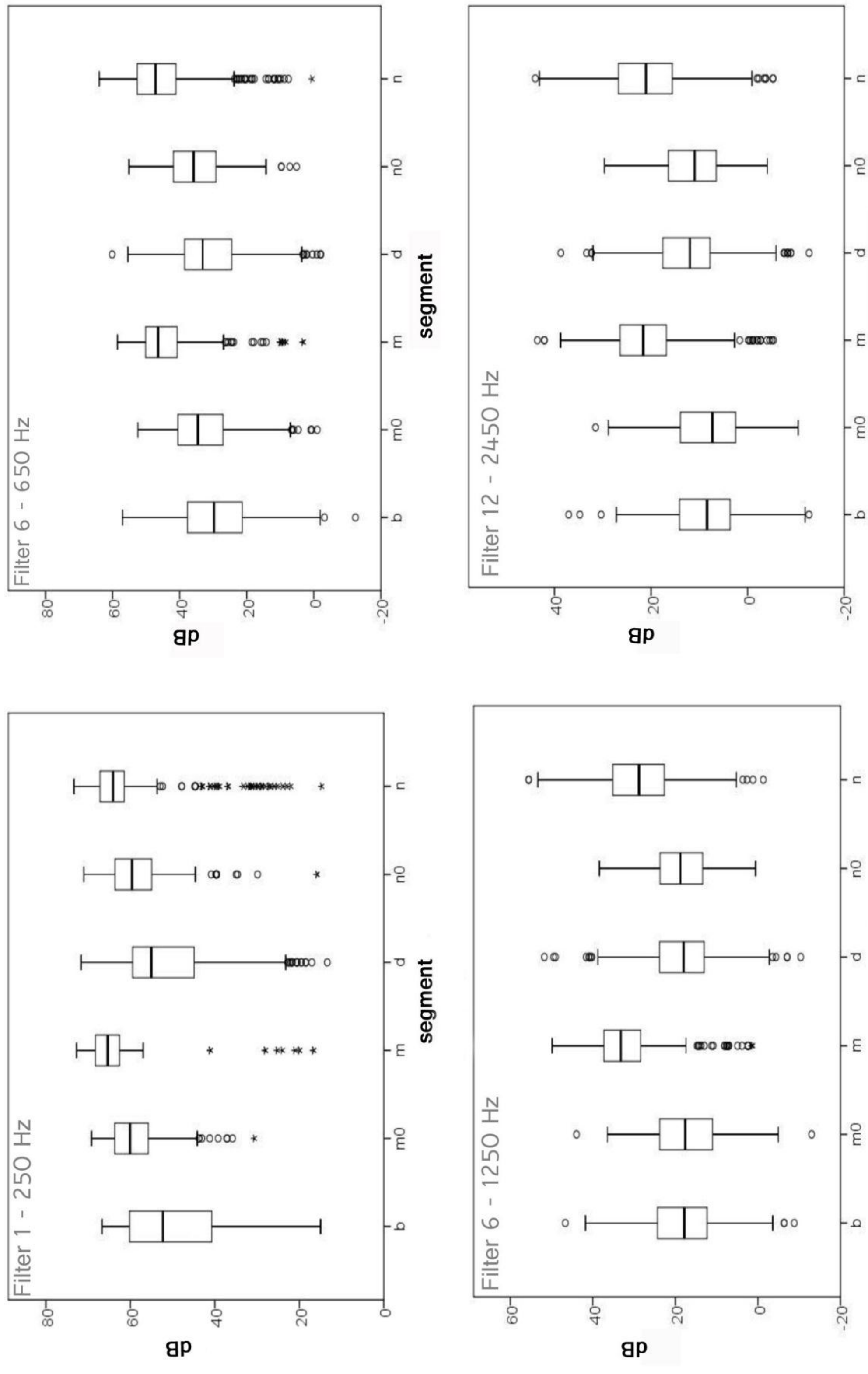

Figure 3.13: Comparative energy in target consonants in four selected filters out of the 16 channel filterbank.

Chapter 4

Aerodynamic characteristics of denasalized nasals in Korean

4.1 Introduction

In the previous chapter, we described the features of denasalized Korean nasals, [m0, n0], in comparison to those of sonorant nasals, [m, n], and voiced plosives, [b, d], based on auditory judgement, and evidence from spectrograms, and spectral analyses applied to the hold phase of the segments. It was found that [m0, n0] are distinct from [m, n] and similar to [b, d] but not identical.

Since nasal consonants are known generally to have co-articulatory effects on neighbouring segments, especially on following vowels (Hardcastle and Hewlett, 1999), an appropriate next step would be to study what effects denasalized nasals in Korean have on following vowels; whether they have the same nasalization effect as sonorant nasals do, and if not, how differently. Also, being perceived as voiced plosives by English speakers, how do they compare in terms of nasal flow of the hold phase and the following vowels?

As reviewed in Chapter 2, quantifying nasal airflow using an oro-nasal mask system is one of the various methods of assessing nasality in speech that are non-invasive, though fairly difficult to set up. One of the main advantages of using this system is that it detects both voiced and voiceless flow and can be considered the best way to directly monitor the activities of the velum and the nasal airstream (Baken, 2000). It is so sensitive that even when there is no respiratory or phonatory activity, it can pick up the small nasal airflows resulting from opening and shutting of the velum (Figure 4.1). This kind of sensitivity makes the data collected with this system, providing that the channeling of air is done accurately with a proper seal of the mask to a subject's face, a reliable representation of the velum activity and nasal airflow during speech production. Also, calibration of the masks allows cross comparisons of the data collected from multiple subjects.

Airflow measurement is the only method used in the present study to monitor speech production. Although it gives only an indirect indication of velopharyngeal function, it is non-invasive and can be used for the collection of large amounts of fairly natural speech data.

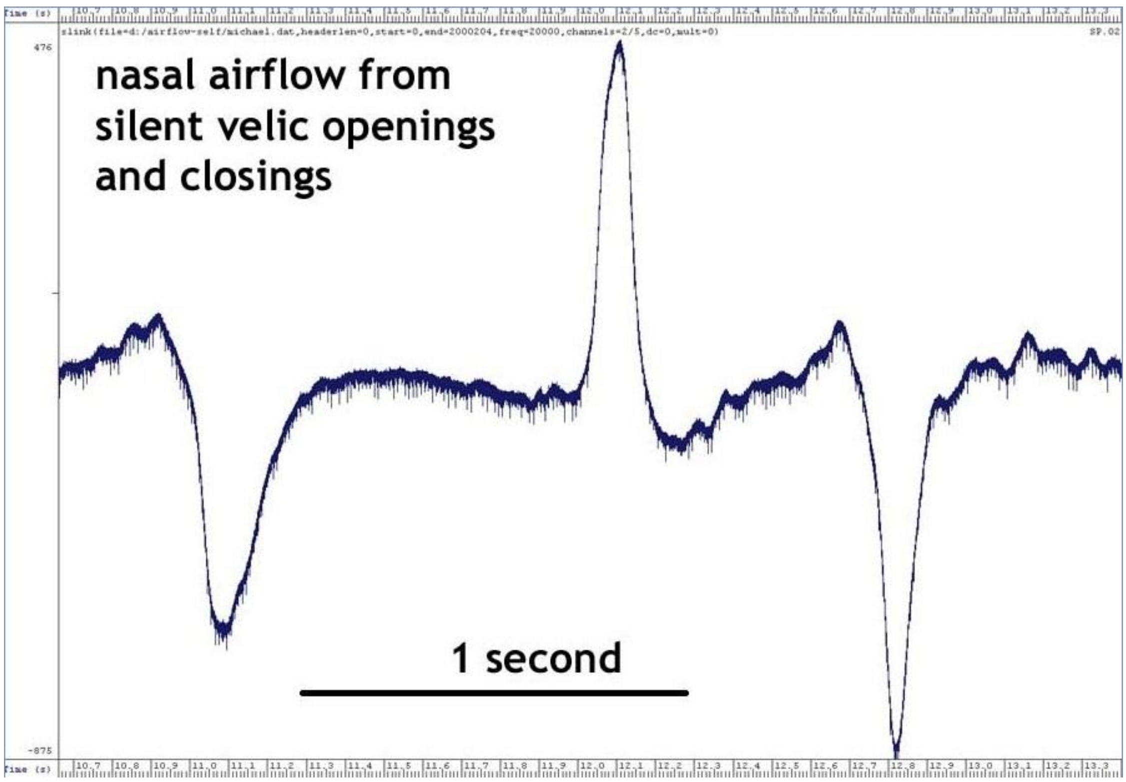

Figure 4.1: Nasal airflow resulting from deliberate silent movement of the velum. The subject maintained closed lips and closed glottis. The downward (negative) excursions correspond with velum opening—that is, they are in the opposite direction to the airflow which they would initiate. Similarly, closing the velum produces a brief outward flow.

There were two aerodynamic studies on Korean word-initial nasals reviewed: Yoshida (2008) conducted an experiment that examined nasals in word-initial position and found that they have two patterns in terms of nasality, falling and rising; Lee and Kim (2007) measured the duration of the nasalized portion of /m/ and /n/ in word-initial position and found that they are nasalized 40% of the whole duration. Both groups of researchers argue that denasalized nasals do not achieve a total cessation of nasality and therefore the term 'denasalization' is not suitable, however, it should be noted that denasalization is a quality that is relative to the perception of listeners (Laver, 1994) and does not necessarily mean complete absence of nasality or nasal flow, which was also revealed in the filterbank analysis of the previous chapter. Yoshida also claimed that 'nasality weakening' is an effect that is in accordance with the 'domain-initial strengthening' posed by Cho and Keating (2001) and claimed that the results of his experiment showed that the degree of nasal weakening is higher in the higher prosodic tier.

The current experiment was carried out to measure the nasal flow during the denasalized consonants and the following vowels together, in comparison to the same sequence of sonorant nasals and voiced plosives. If [m0] and [n0] were indeed different from sonorant nasals, they should on aggregate have lower nasal flow than [m] and [n]; and their nasal flow would be similar to that of [b] and [d]. Also, if denasalization is a domain-initial-strengthening process, greater evidence of denasalization should be found in segments located at the beginning of domains higher in the hierarchy.

4.2 Method

4.2.1 Ethical approval

Ethical approval was granted by the UCL Research Ethics Committee for the use of the masks used in this experiment which need to be in contact with participants' faces during recordings and thus bear hygiene and infection control issues. The manufacturer was consulted on this matter and adequate cleaning/disinfection/maintenance procedures were recommended.

Participants made recordings individually, at appointments separated by a minimum of one hour, during which the mask was washed with antibacterial detergent in accordance with the manufacturer's and supplier's instructions. Immediately before use, the masks were additionally sterilized with alcohol wipes. The experimenter and technical staff followed an appropriate hand-washing routine, and handled the equipment with sterile disposable gloves.

4.2.2 Speakers

Eight native speakers of Korean, aged between 24 and 31, took part in making recordings for this experiment. Five of the participants had standard Korean accents and three had regional accents from the southwest of the country (2 males and 1 female). However, S13 (female) data showed flow levels that were presumed to be caused by incomplete seal of the mask to the face and were excluded from the analyses for that reason. Thus the total number of participants now is 7—5 standard Seoul accents and 2 south-western accents.

All participants were born and raised in Korea and learned English as a foreign language through the public school system for a minimum of 6 years. Though some of them spoke a second language (either English or Japanese) to a good standard, none of them were bilingual from young age. The longest duration of residence in the UK or any other overseas country across participants is 3 years and the shortest 6 months. All participants had normal hearing and speech.

	Accent regions	Age	Gender	Fluency in English	Time spent overseas (mo)
S9	Seoul	29	M	Intermediate	3
S10	Daegu (South)	30	M	Beginner	18
S11	Seoul	23	M	Intermediate	3
S12	Kyeongju (South)	31	M	Advanced	2
S13	Changwon (South)	31	F	Intermediate	3
S14	Seoul	23	F	Intermediate	6
S15	Seoul	25~30	F	Intermediate	2
S16	Seoul	20	F	Intermediate	9

Table 4.1: Subjects for airflow recordings using oro-nasal masks.

4.2.3 Recording materials

Two texts, one of a summary of a well-known novel and the other of five TV news extracts, 25 words in citation and short phrases, and 6 individual sentences were recorded, which took on average around 4 minutes. Participants were given the transcript ahead of the recording so they could achieve a level of fluency that would demonstrate similarity to spontaneous speech.

In total there were 56 bilabial nasals and 30 alveolar nasals in the word-initial position, 36 intervocalic bilabial nasals, 45 intervocalic alveolar nasals, 9 intervocalic bilabial plosives and 13 intervocalic alveolar plosives from each participant's recording. The number of tokens across categories is not the same because the materials were not artificially made up under control but they were selected from well-known texts which contained a number of the main target segments, /m/ and /n/, to facilitate the most natural, spontaneous speech-like recording.

4.2.4 The Masks

The Oro-Nasal Dual-Chamber Mask System by Glottal Enterprises, model names S/T-MA1 (Adult) and S/T-MC (Child), were used. The masks are vented with round openings covered by fine-mesh wire screens and are divided in the middle into the mouth and the nose sections. The adult-size mask has four meshes and the child-size mask has two meshes in each section. The meshes are interchangeable and of a standard specification.

The adult-size mask was used on 7 participants and the child-size mask was used on one female participant for whom the adult-size mask was too big and a complete seal between the mask and the participant's face was unattainable. The output of this participant (S13), however, still showed poor differentiation of oral and nasal flow, probably caused by leakage between the two divisions of the mask. Thus data from this participant was excluded from the analyses.

4.2.5 The Measurement System with Transducers

Glottal Enterprises MS-100S Measurement System with PTW and PTL Transducers was used to measure airflow. PTL was plugged into the nasal flow area and PTW into the oral area of the vented oro-nasal divided mask.

The PTW (Wide band transducer) signal was obtained from Main Output A.

The PTL (Narrow band transducer) signal was obtained from Main Output B.

The differentiated airflow (speech pressure) signal was obtained from SPL unit.

The Lx signal was obtained from Lx out on a Laryngograph Processor.

A speech signal was obtained from a compact microphone attached to the participant's clothes close to the mouth.

Signals were routed to a PC fitted with a Data Translation DT2838 card - a multichannel 16-bit dc coupled A-D unit. The flow waveforms were also taken to an oscilloscope so that the outputs could be regularly zeroed using the controls on the MS-100S unit. Global Lab software was used for acquisition. This created a file with a .DAT extension - raw binary with a header. The file was linked to an SFS file and the header was removed.

Within the .DAT file:

CH1 was the differentiated flow (speech pressure)

CH2 was the wideband flow

CH3 was the Lx signal

CH4 was the speech signal

CH5 was the narrowband flow

When linked to an SFS file:

The differentiated flow (speech pressure) became item 1.01.

The narrowband flow became item 1.02 (nasal flow).

The Lx signal became item 1.03.

The speech signal became item 1.04.

The wideband flow became item 1.05 (oral flow).

Global Lab software was set up using 5 channel configuration file (20KHz sampling rate). All channels have a response from 0 Hz (dc) to 10 kHz.

4.2.6 Annotation

Annotations were created on SFS manually marking the tokens in the three categories for each place of articulation, [m, b, m0] and [n, d, n0], and the vowels immediately following the consonants. There were 56 denasalized bilabial nasals and 30 denasalized alveolar nasals, 36 sonorant bilabial nasals, 45 sonorant alveolar nasals, 9 intervocalic bilabial plosives and 13 intervocalic alveolar plosives in the recording materials. The numbers of segments annotated, however, especially those of sonorant nasals and plosives, vary across subjects due to two main reasons: one, subjects missed or repeated some words/phrases; the other, some segments were realized without a complete obstruction in the oral cavity, which resulted in production of approximants instead of nasals, and fricatives or approximants instead of plosives (Table 4.2). Also excluded from this analysis are segments immediately preceded by a sonorant nasal, [m], [n] or [ŋ], in order to rule out any invasive co-articulatory effect.

subjects	m	b	m0	n	d	n0
S9	20	13	30	19	34	16
S10	7	1	28	11	19	22
S11	6	4	25	8	16	16
S12	15	5	34	10	20	27
S14	11	7	29	20	23	19
S15	8	4	20	9	14	18
S16	7	5	19	11	21	24
Sum	74	39	185	88	147	142

Table 4.2: Number of tokens annotated for each subject file for airflow measurement recording.

A separate set of annotations was created to mark hypothetical prosodic domains to investigate the domain-edge strengthening theory posed by Cho and Keating (2001) regarding denasalization in Korean. The distinction between "sonorant" and "denasalized" segments which had been applied auditorily corresponded to the "Syi" domain (sonorant) as opposed to all the others (Ui, IPi, APi, Wi). The Syi domain was removed from consideration in this second part of the study, since the aim was to look for differences among the remaining domains.

4.2.7 Calibration of flow rates

After digital sampling, the outputs of the flow transducers are in arbitrary units which in principle are proportionally related to flow, with a zero at zero flow. Calibration makes possible the conversion of the arbitrary units into physical units (millilitres per second), and assessment of the linearity of the relationship.

Calibration was performed using a flow source consisting of a controllable centrifugal pump and rotameter calibrated in litres per minute. Because of the difficulties of securing a good seal with the sections of the face-mask, the transducers were tested instead in a specially constructed manifold (a small die-cast box supplied with various air-tight inlets and outlets). Flow from the manifold was through standard meshes of the type fitted in the mask. The number of meshes fitted could be varied.

Acquisition of data during a calibration run was as for an experimental session, and the resulting files were analysed in SFS. The figure 4.2 shows a calibration run of approximately one minute in duration. In this instance, two transducers are being tested together, and the number of meshes fitted is two. The upper panel is a microphone recording with spoken information about the test, and announcements of the rotameter readings. The two lower panels show the output from the pressure transducers; the staircase results from setting flows successively at 1, 3, 5, 7 and 9 litres per minute.

To analyse the calibration data, the transducer outputs were low-pass filtered at 1Hz, and then each step in the calibration run was averaged over a stable 5-second period following the announcement of the rotameter reading. An Excel spreadsheet was constructed tabulating the averaged outputs against the known flow rates, and graphs plotted to which trendlines were fitted. After correcting for small errors in the zero-setting, the resulting calibrations for flow through 2 meshes and 4 meshes as measured in the conditions of the experiment are as shown in Figures 4.3 and 4.4. As is clear from the calibration graphs, the transducers are nearly perfectly linear. The flow in millilitres per second as measured with either of the two transducers employed is approximately 0.07 times the digitized transducer output per mesh. The difference in gradient (very nearly 1:2 as expected) in the two examples shown is caused by the fact that in one case flow was measured through 2 meshes and in the other through 4 meshes.

Although great care was taken with calibration, the resulting estimates of absolute flow rates probably achieve accuracy no better than ±5%, the rotameter itself being the main likely source of error. No useful purpose would have been served by converting all the flow measurements reported here into flow in millilitres per second. If it is desired to know the absolute flow it can be calculated by multiplying the raw flow value by 0.2712, which is the figure for the narrow-band transducer working with four meshes (the configuration used for all the nasal flow measurements). The result is in millilitres per second.

4.2.8 Measurement of the flows

The wideband flow (nasal flow) and the narrowband flow (oral) items were smoothed by low-pass filter at 50Hz before SML scripts were run on SFS to measure the average flow of each of 10 phases over 50 ms before and 10 phases over 50 ms after the onset of the vowel, and at the onset of the vowel for each consonant. This was to ensure coverage of the minimum duration of the consonants observed in the intervocalic position in the ones at the utterance-initial position for which it was impossible to decide on the exact starting point of the hold phase, especially the nasals that were denasalized and voiceless. It should be noted that the filtering applied to the nasal flow output for smoothing the curve and removing noise introduced a phase delay of about 8ms. Figure 4.5 shows a greatly magnified part of a 10 Hz test wave (top), and the same thing after it has passed through the filter (bottom). The cursors are at the corresponding peaks and the time between them is just over 8ms.

The measurements were imported to a spreadsheet and line charts were plotted. Since perceived nasality is affected by both the degree of nasality and the duration of the velar opening (Hajek, 1997), more than one quantity was measured. The area under the nasal flow curve within a specified window (**area**) and the time from the annotation point to the highest nasal flow value within the time window (**peak time**) were measured and tested for significance in difference across target consonants across subjects. The idea behind the peak time variable is that it should provide a single number varying from negative to positive according to whether velic closing began early or late in relation to vowel onset. In addition, the nasal flow at time sample 15 **(flow 15)**—nominally 20 ms into the vowel, but actually 12ms after the vowel onset after allowing for the phase delay mentioned above—was tested to investigate the nasal flow activity immediately after the release of the consonants, which would give a good idea on whether the consonants in question were behaving the same way or not. All of these measures were devised for the current study, as there appears to be no extensive previous work in which a large body of aerodynamic data was quantified and analysed to serve as a model.

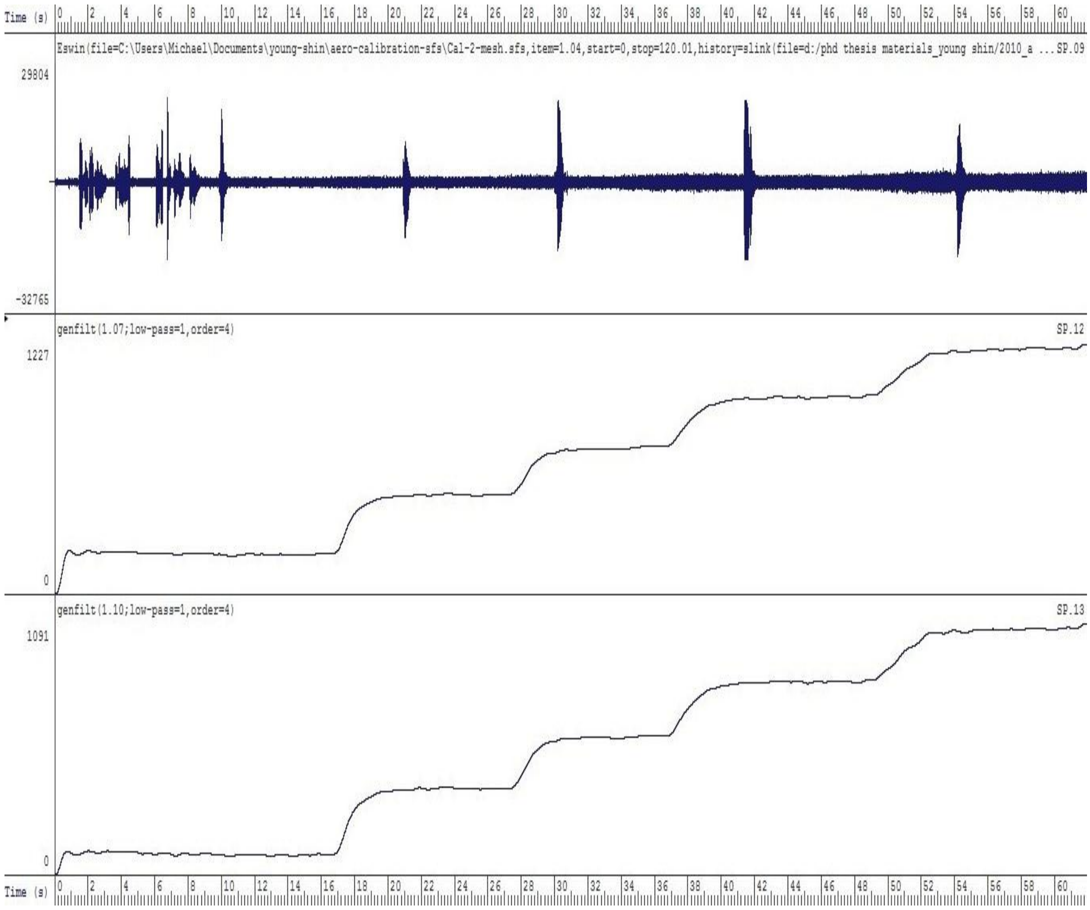

Figure 4.2: Calibration run of the mask model with two meshes linked to two transducers.

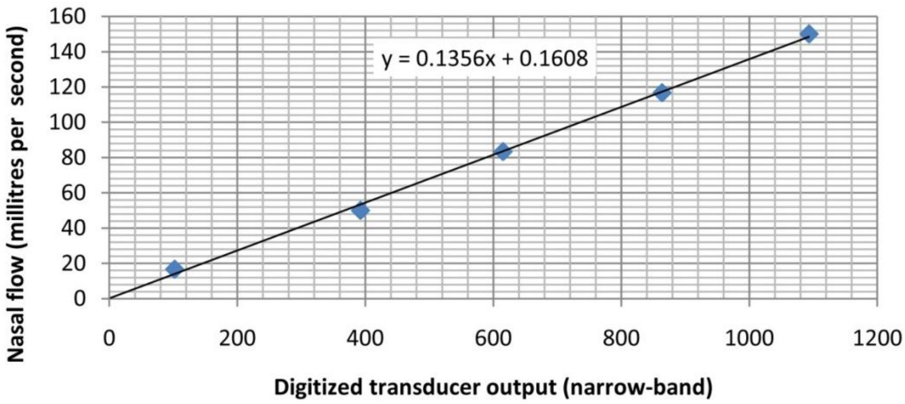

Figure 4.3: Calibration of the narrowband transducer used to measure nasal flow. With 4 meshes, as in the adult size mask, the gradient will be doubled (0.2712).

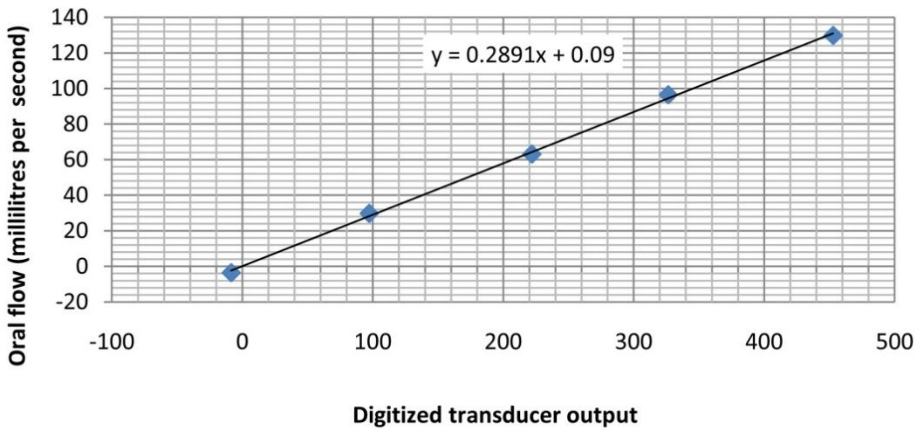

Figure 4.4: Calibration of the wideband transducer, working with 4 meshes.

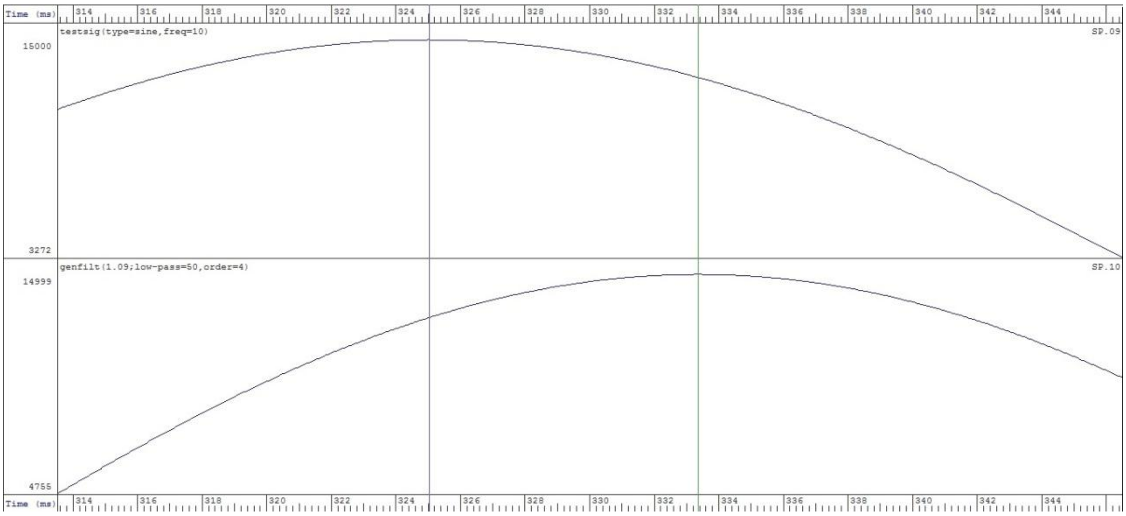

Figure 4.5: Phase delay in the nasal flow output caused by filtering. At top, greatly magnified portion of a 10 Hz test signal representing realistic rate of change in nasal flow. At bottom, output from the measurement system. The left cursor is at the peak of the input wave, and the right cursor at the peak in the output. The delay is almost exactly 8 ms.

4.3 Results 1: Nasal flow

Figures 4.6 and 4.7 respectively show the mean nasal airflow in [m, b, m0] and [n, d, n0] and their following vowels in a 100 ms window for each subject. Similarities are shown across all subjects and S10 and S12 seem to form a subgroup as well: these subjects are the two with a south western accent.

In Tables 4.3 and 4.4, the Kruskal-Wallis test (a non-parametric analysis of variance) is applied 42 times. The 7 subjects, the two places of articulation, and the 3 variables tested, are all independent, and no data point is analysed more than once.

For the two variables **area** (area under the nasal flow curve within a specified window) and **flow 15** (the nasal flow at time sample 15, approximately 12 ms after the vowel onset) the tests show significant differences among the three segment types , at both places of articulation, for each subject considered individually. Out of 28 tests, the least favourable outcome is p=0.025; for 20 of the tests, including all those for alveolars, p=0.000.

For the variable **peak time** (time from the annotation point to the highest nasal flow value within the time window), a significant difference is found in 11 out of 14 instances. For bilabials, results for S9, S11 and S16 show no significant difference by peak time; for alveolars, only S8 fails to show a difference. S16 thus has no significant difference by peak time for either place of articulation. The four peak-time comparisons which failed to achieve significant results in the Kruskal-Wallis test were therefore excluded from the post-hoc tests.

Table 4.5 and 4.6 show the post-hoc tests, performed using the Mann-Whitney test, to examine pairs of segments. Sonorants are compared with denasalized segments (m>m0; n>n0), and denasalized segments are compared with plosive segments (m0>b; n0>d). Again the tests are made for each subject individually. No comparisons are made between places of articulation, since the experimental hypotheses make no quantitative prediction about such a comparison; the variable **peak time** is not tested in comparisons involving [b] or [d], again for the reason that the hypotheses make no prediction.

For the comparisons of sonorants with denasalized segments, the prediction was m>m0 and n>n0 for all three variables. The comparison of denasalized segments with plosives was tested with the predictions m0>b and n0>d, though strictly the hypotheses predict m0≥b and n0≥d.

In total, 64 post-hoc tests have been applied out of 70 possible comparisons. The excluded comparisons either (i) failed to achieve significance in the Kruskal-Wallis test, or (ii) in the case of S10, only one satisfactory example of [b] was identified in the recording, making the m0>b test impossible. This is because S10 generally used lenited (continuant) realizations for [b] which could not be reliably annotated.

The number of post-hoc tests is large, but for the most part they are independent, as the 7 subjects, 2 places of articulation, and 3 test variables are treated separately. Each data point is used at most in two comparisons, so the appropriate Bonferroni correction is by a factor of 2 (that is, tests should be conducted with a criterion of $p \leq 0.025$). However, the hypotheses being tested are all **directional** – that is, it is not merely predicted that, for example, m and m0 should *differ* in nasal flow, but specifically that m should *exceed* m0 in nasal flow. The p values returned by the PASW program are for a two-tailed test, corresponding to a non-directional hypothesis, and must be divided by 2 to yield the one-tailed probability; hence a returned value $p=0.05$ should be interpreted as $p=0.025$. It will be evident that these two factors cancel each other out, and the correct outcome is obtained by directly using the p values reported by PASW.

The post-hoc tests indicate:

For the comparison sonorant>denasalized, a significant difference in the **flow 15** variable is found for all subjects, and for both places of articulation. The least favourable p value is for S10, n>n0, where $p=0.047$; for the 13 other comparisons in this group, $p=0.003$ or better.

For the **area** variable, m>m0 for all subjects, $p=0.026$ or better; n>n0 for five out of seven subjects, with $p=0.001$ or better; two subjects, S10 and S12, show no significant difference on this comparison.

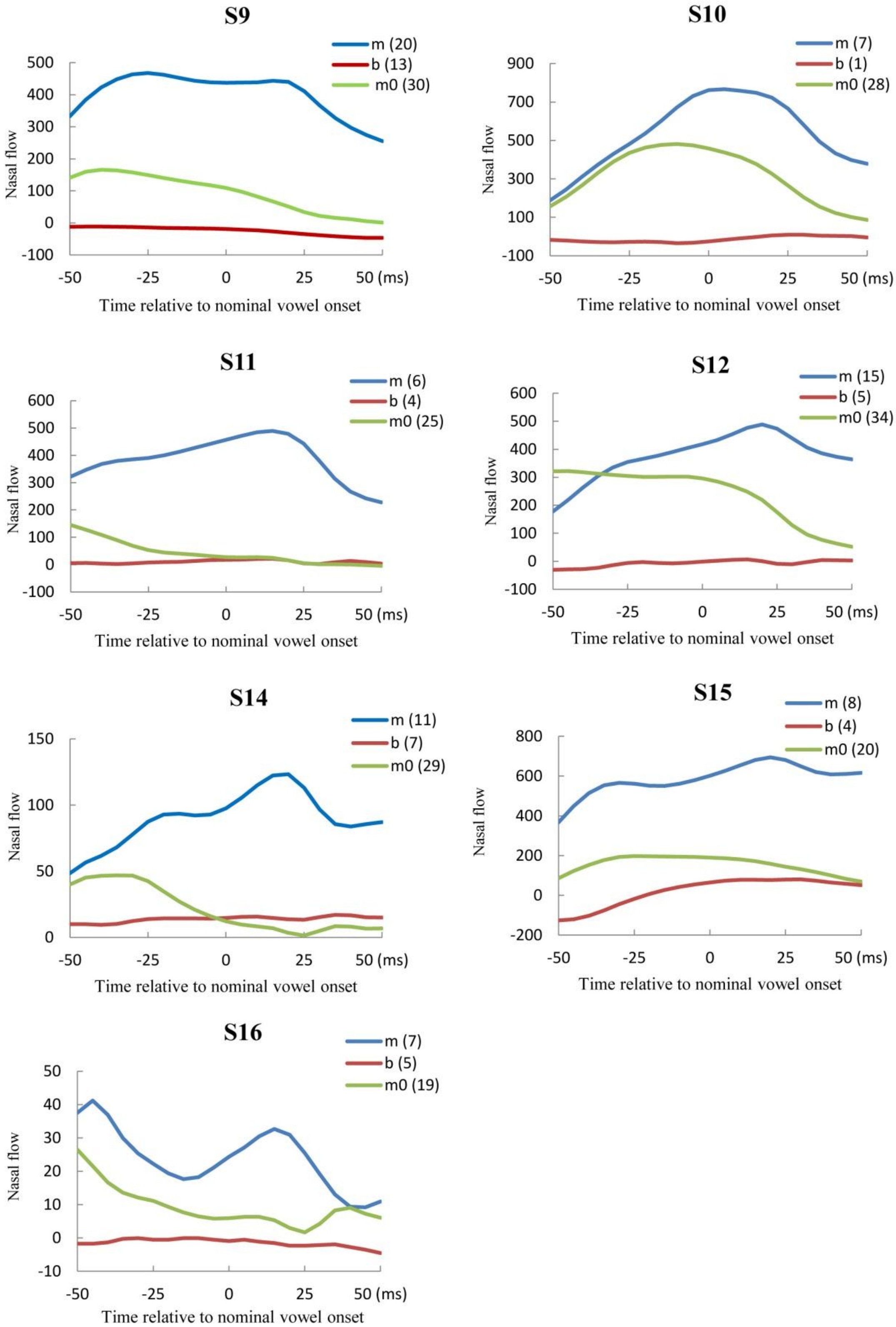

Figure 4.6: Mean nasal airflow in bilabial consonants [m, b, m0] and their following vowels in a 100 ms window centred at the annotation which identifies the nominal vowel onset, for each subject. Each point on each curve is an average based on all available tokens (the number is indicated).

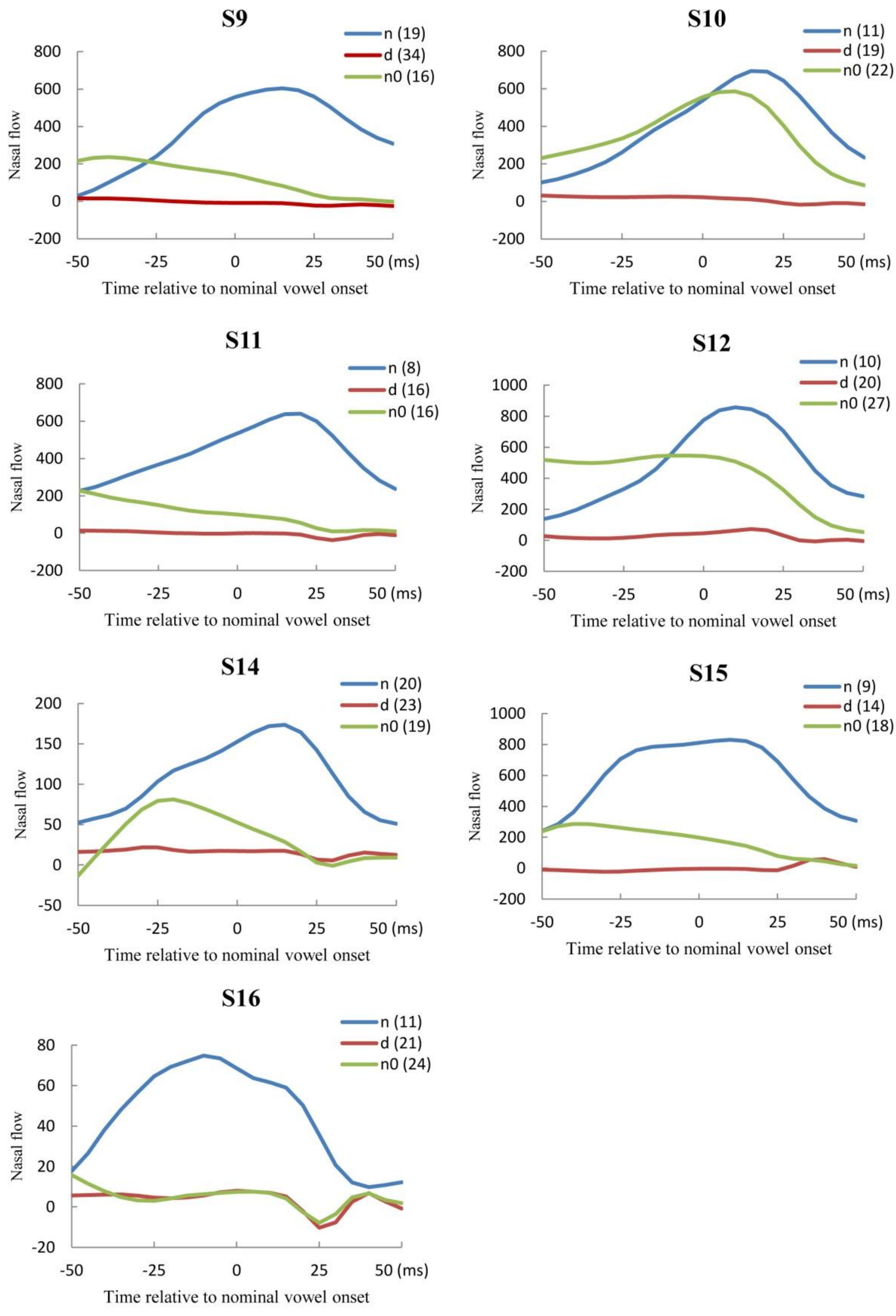

Figure 4.7: Mean nasal airflow in alveolar consonants [n, d, n0] and their following vowels in a 100 ms window centred at the annotation which identifies the nominal vowel onset, for each subject. Each point on each curve is an average based on all available tokens (the number is indicated).

comparison	variable	subject	test	test statistic	df	P
m/m0/b	flow 15	S9	Kruskal-Wallis	49.001	2	0.000
		S10		21.000		0.001
		S11		14.182		0.001
		S12		28.144		0.000
		S14		24.388		0.000
		S15		14.711		0.001
		S16		10.658		0.005
	area	S9	Kruskal-Wallis	49.018		0.000
		S10		29.000		0.004
		S11		15.511		0.001
		S12		20.864		0.000
		S14		19.557		0.000
		S15		13.354		0.001
		S16		7.366		0.025
	peak time	S9	Kruskal-Wallis	1.608		0.448
		S10		36.000		0.009
		S11		2.441		0.295
		S12		9.711		0.008
		S14		7.219		0.027
		S15		6.173		0.046
		S16		2.645		0.267

Table 4.3: Kruskal-Wallis tests (non-parametric analysis of variance) for three variables based on nasal flow for bilabial consonants [m0, m, b].

comparison	variable	subject	test	test statistic	df	P
n/n0/d	flow 15	S9	Kruskal-Wallis	47.245	2	0.000
		S10		35.681		0.000
		S11		22.205		0.000
		S12		32.317		0.000
		S14		37.095		0.000
		S15		22.545		0.000
		S16		17.762		0.000
	area	S9	Kruskal-Wallis	48.860		0.000
		S10		32.261		0.000
		S11		24.532		0.000
		S12		33.953		0.000
		S14		30.709		0.000
		S15		20.268		0.000
		S16		18.847		0.000
	peak time	S9	Kruskal-Wallis	21.035		0.000
		S10		9.514		0.009
		S11		8.660		0.013
		S12		8.961		0.011
		S14		18.904		0.000
		S15		6.995		0.030
		S16		0.997		0.608

Table 4.4: Kruskal-Wallis test (non-parametric analysis of variance) for alveolar consonants [n0, n, d].

comparison	variable	subject	test	U	n1	n2	P
m>m0	flow 15	S9	Mann-Whitney U	7.500	20	30	0.000
		S10		21.000	7	28	0.001
		S11		1.000	6	25	0.000
		S12		54.500	15	34	0.000
		S14		3.000	11	29	0.000
		S15		9.000	8	20	0.000
		S16		15.500	7	19	0.003
m>m0	area	S9	Mann-Whitney U	19.000	20	30	0.000
		S10		29.000	7	28	0.004
		S11		1.000	6	25	0.000
		S12		116.000	15	34	0.003
		S14		16.000	11	29	0.000
		S15		15.000	8	20	0.001
		S16		28.000	7	19	0.026
m>m0	peak time	S9	Mann-Whitney U				
		S10		36.000	7	28	0.009
		S11					
		S12		122.000	15	34	0.004
		S14		72.500	11	29	0.008
		S15		32.000	8	20	0.014
		S16					
m0>b	flow 15	S9	Mann-Whitney U	368.000	13	30	0.000
		S10					
		S11		51.500	4	25	0.924
		S12		165.000	5	34	0.001
		S14		76.500	7	29	0.317
		S15		49.000	4	20	0.486
		S16		57.500	5	19	0.477
m0>b	area	S9	Mann-Whitney U	382.000	13	30	0.000
		S10					
		S11		61.000	4	25	0.487
		S12		170.000	5	34	0.000
		S14		102.000	7	29	0.984
		S15		54.000	4	20	0.278
		S16		60.000	5	19	0.374

Table 4.5: The Mann-Whitney post-hoc test results for bilabial consonants [m, m0, b].

comparison	variable	subject	test	U	n1	n2	P
n>n0	flow 15	S9	Mann-Whitney U	2.000	19	16	0.000
		S10		69.000	11	22	0.047
		S11		2.000	8	16	0.000
		S12		46.000	10	27	0.002
		S14		13.000	20	19	0.000
		S15		7.000	9	18	0.000
		S16		22.500	11	24	0.000
n>n0	area	S9	Mann-Whitney U	17.000	19	16	0.000
		S10		114.000	11	22	0.789
		S11		9.000	8	16	0.001
		S12		85.000	10	27	0.087
		S14		53.000	20	19	0.000
		S15		17.000	9	18	0.001
		S16		20.000	11	24	0.000
n>n0	peak time	S9	Mann-Whitney U	21.000	19	16	0.000
		S10		71.500	11	22	0.059
		S11		20.500	8	16	0.007
		S12		59.000	10	27	0.009
		S14		50.500	20	19	0.000
		S15		71.000	9	18	0.600
		S16					
n0>d	flow 15	S9	Mann-Whitney U	444.000	34	16	0.000
		S10		411.000	19	22	0.000
		S11		199.000	16	16	0.007
		S12		483.000	20	27	0.000
		S14		197.500	23	19	0.595
		S15		189.500	14	18	0.016
		S16		242.500	21	24	0.829
n0>d	area	S9	Mann-Whitney U	480.000	34	36	0.000
		S10		403.000	19	22	0.000
		S11		219.000	16	19	0.001
		S12		515.000	20	27	0.000
		S14		264.000	23	19	0.250
		S15		188.000	14	18	0.019
		S16		253.000	21	24	0.982

Table 4.6: The Mann-Whitney post-hoc test results for alveolar consonants [n, n0, d].

4.4 Results 2: Denasalization and prosodic domains

The results just reported are for a division of the tokens into two classes:

i. a set of denasalizing contexts which have in common that the target segment is in word-initial position, regardless of whether that word is utterance-initial (Ui), intonational-phrase initial (IPi), or accentual phrase-initial (APi)
ii. a set of non-denasalizing contexts in which the target segment is syllable initial (Si) but not word-initial

A further set of annotations had been added to the data permitting comparison among the various domains in (i). In addition to the domains recognised in the prosodic hierarchy, a separate Wi annotation was used for those tokens in words spoken as citation forms in isolation. In theory, they are instances of Ui, but simple examination of the data showed they were commonly very different (this is confirmed in the tests below).

The Si context was excluded from consideration, and then for each of the seven subjects individually, the Kruskal-Wallis test was applied to the remaining domains, for all of the 22 variables *peak time* and *flow_1* to *flow_21* inclusive (each of which in turn is a mean across relevant tokens from that subject). This produced 154 independent results. The quantities *flow_,1 flow_2,… flow_21* are nasal flow measured at the 21 points, spaced 5 ms apart, which define the 100 ms window. Between them they represent the last 50 ms of the “hold” phase of the target segment and the first 50 ms of the vowel. The reason for using all 21, rather than a single representative (*flow_15*) as above, is that in this comparison it is not desired to separate denasalized from nasal but to look for sub-types within the denasalized class. The internal time-structure of the denasalized segments is one way they might vary in relation to domain type.

The results are as follows:

Subject 9: no significant differences

Subject 10: there is a marginal difference (p=0.049) in *flow_1* only

Subject 11: there are significant differences in *flow_1* to *flow_16* inclusive. This appears to be related to much greater variability in the Wi class

Subject 12: there are significant differences in *flow_1* to *flow_7* inclusive. This appears to be related to higher flow in the Wi class

Subject 14: there are significant differences in *peak time* and in *flow_15.* Ui and Wi have similar early peaks, and Ui has very little scatter. Similarly in *flow_15*, Ui and Wi are low, and Wi has little scatter.

Subject 15: there are significant differences in *flow_1*, *flow_4* to *flow_7* inclusive, and *flow_9.* The gaps in these sequences only just miss significance.

Subject 16: there are significant differences in *flow_1* to *flow_7* inclusive, *flow_11* to *flow_16* inclusive, and also in *flow_21*.

The generalisations to be drawn from this are:

- there are considerable differences among speakers
- flow differences, where present, *precede* the vowel onset (and are thus in the "steady" hold phase of the segment, as anticipated)
- the Wi category is in several cases markedly apart from the others.

Since it is unclear what prosodic domain (if any) is appropriate for words spoken in isolation, the Wi (citation form) tokens were excluded, leaving unproblematic cases of Ui, IPi and APi, and the tests repeated. The results are:

Subject 9: *flow 7* is higher for Ui

Subject 10: *flow_21* is higher in APi.

Subject 11: *flow_2* to *flow_7* are ordered: highest in Ui, intermediate in IPi, and lowest in APi (see Figure 4.11)

Subject 12: *flow_1* to *flow_3* are ordered: highest in Ui, intermediate in IPi, and lowest in APi (see Figure 4.12)

Subject 14: *peak time*—is lower for Ui

Subject 15: there are differences in *flow_5* to *flow_11*: lower flow in Api

Subject 16: there are differences in *flow_2*, and in *flow_13*, *flow_14*. These appear to be linked with higher nasal flow in Ui than in IPi or APi

According to the domain-edge strengthening hypothesis, more denasalization (and hence lower flow) should be found at a high-ranking domain edge (Ui) than at a low one (APi). It is plain that the results give no indication of a systematic relationship of this kind. In fact, in 20 out of 22 cases just examined where a significant difference is found, it is in the contrary direction to that prediction, and this is well illustrated by Figures 4.14 and 4.15.

4.5 Discussion 1: Denasalized and nasal segments

Nasal flow of the two groups of consonants in question, [b, m0, m] and [d, n0, n], was measured in three different aspects: the total volume of the nasal flow within a given time frame (estimated by the **area** under the nasal curve in the sequence of CV), the nasal flow level immediately after the onset of the vowel (**flow 15**) and the time to the peak nasal flow measured from the vowel onset (**peak time**).

The main result was that, for both places of articulation, the three types of consonants were significantly different in terms of **area** and **flow 15** in all 7 subjects, which strongly supports the hypotheses across the board (Figures 4.8 ~ 4.11). A measure of nasal flow at a specified point early in the vowel separated the sonorant and denasalized classes at both places of articulation and for all seven subjects. The **area** variable was slightly less effective in separating the sonorant and denasalized classes. This corresponds to differences between subjects in the variation of nasal flow over time. S10 and S12 have relatively high nasal flow for denasalized segments *before* release into the vowel.

The comparison based on the **peak time** variable reached significance in 8 out of 14 comparisons, suggesting that the measure may capture an aspect of the sonorant/denasalized difference for at least some of the subjects (Figures 4.12 and 4.13).

For the comparisons m0>b and n0>d, there is little to choose between the **flow 15** and the **area** variables, as both produced a similar pattern of results. For m0>b, only S9 and S12 showed a difference; for n0>d, all subjects showed a difference except S14 and S16. These results were consistent with the hypothesis that m0 and n0 have nasal flow intermediate between m/b and n/d respectively, and that for each the range of realisation includes the possibility that m0=b and n0=d.

The overwhelming overall conclusion is that denasalization is produced by velic action. At the time of vowel onset following a denasalized segment, all subjects have significantly lower nasal airflow than at the corresponding point following a sonorant nasal. Complete or partial closure of the velum is the only explanation so far available for how this might be achieved.

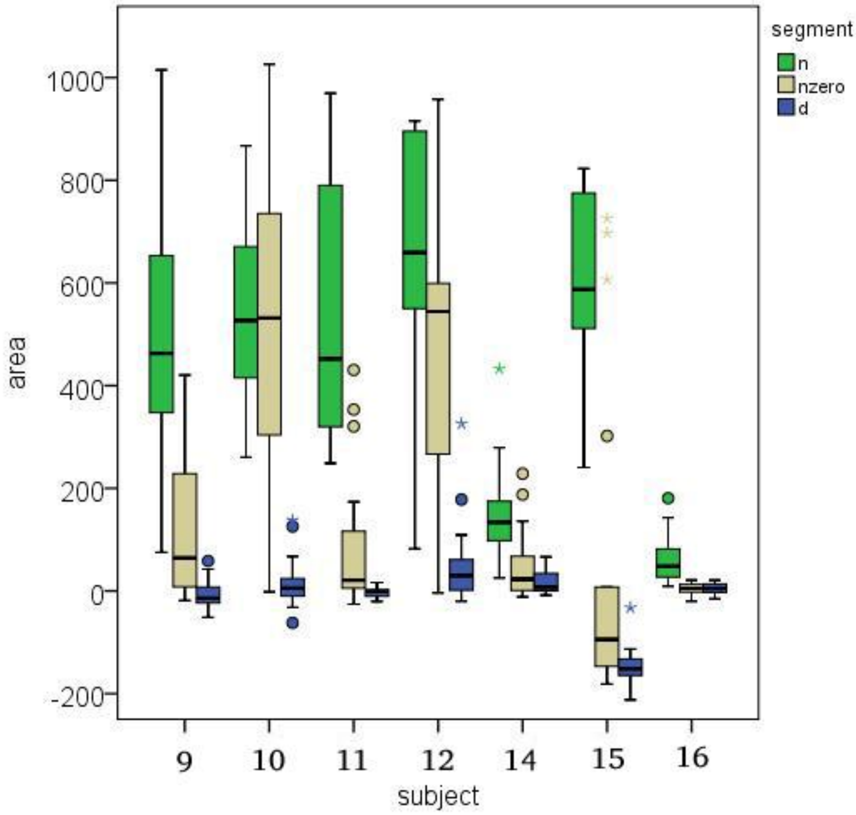

Figure 4.8: Mean area under nasal flow curve for alveolar consonants [n, n0, d].

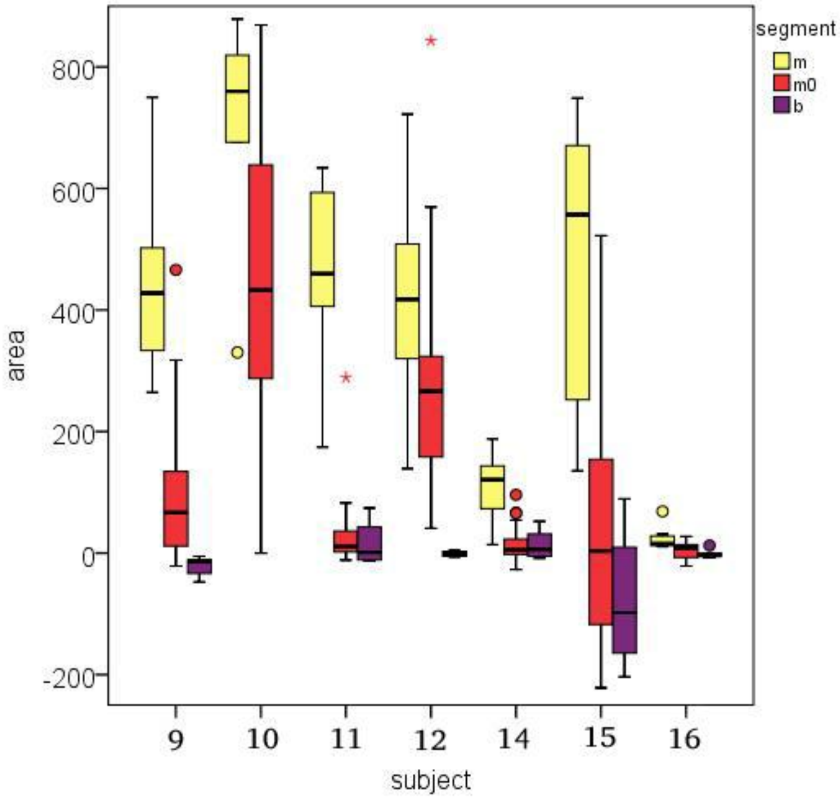

Figure 4.9: Mean area under nasal flow curve for bilabial consonants [m, m0, b].

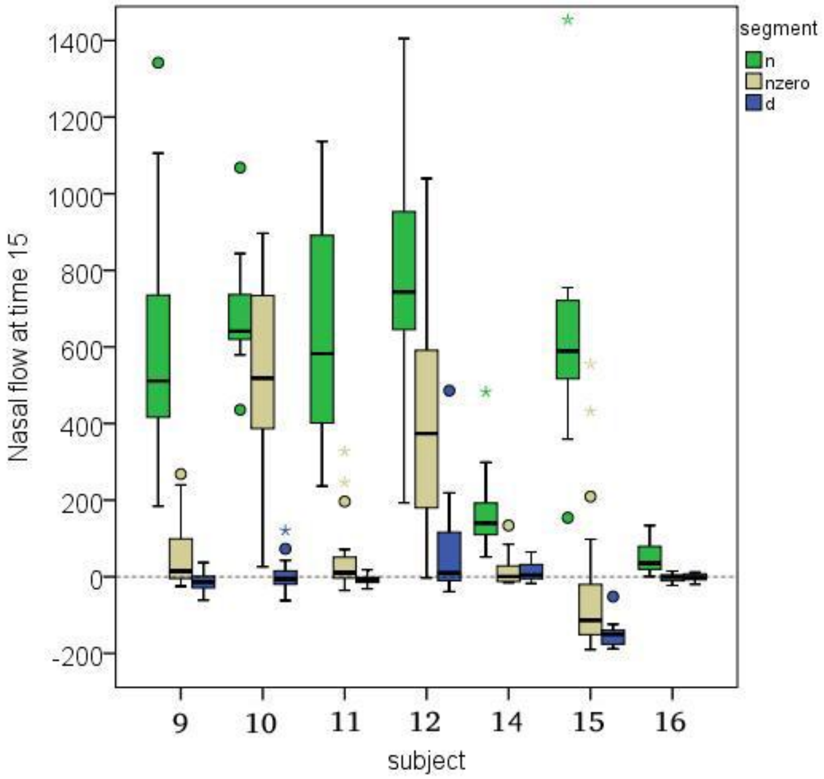

Figure 4.10: Nasal flow at time 15 (approximately 12ms after vowel onset) for alveolar consonants [n, n0, d].

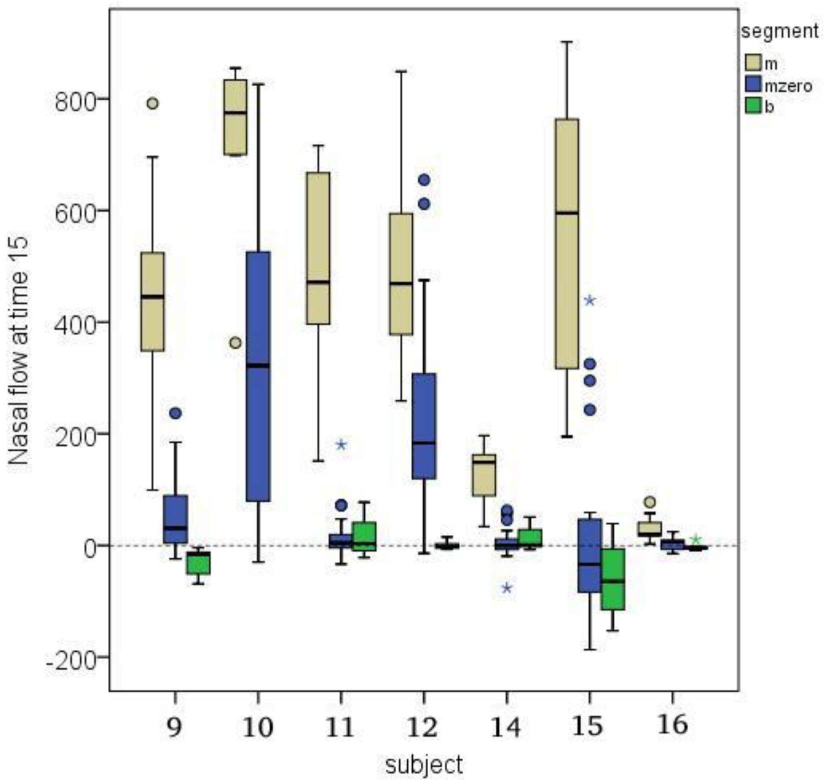

Figure 4.11: Nasal flow at time 15 (approximately 12ms after vowel onset) for bilabial consonants [m, m0, b].

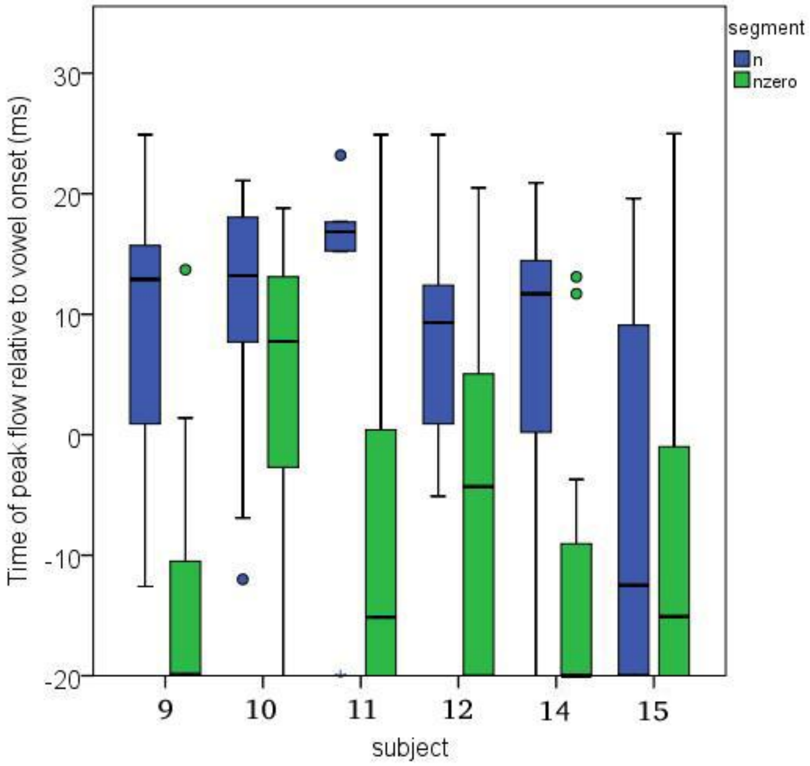

Figure 4.12: Time to peak nasal flow from vowel onset for alveolar consonants [n, n0].

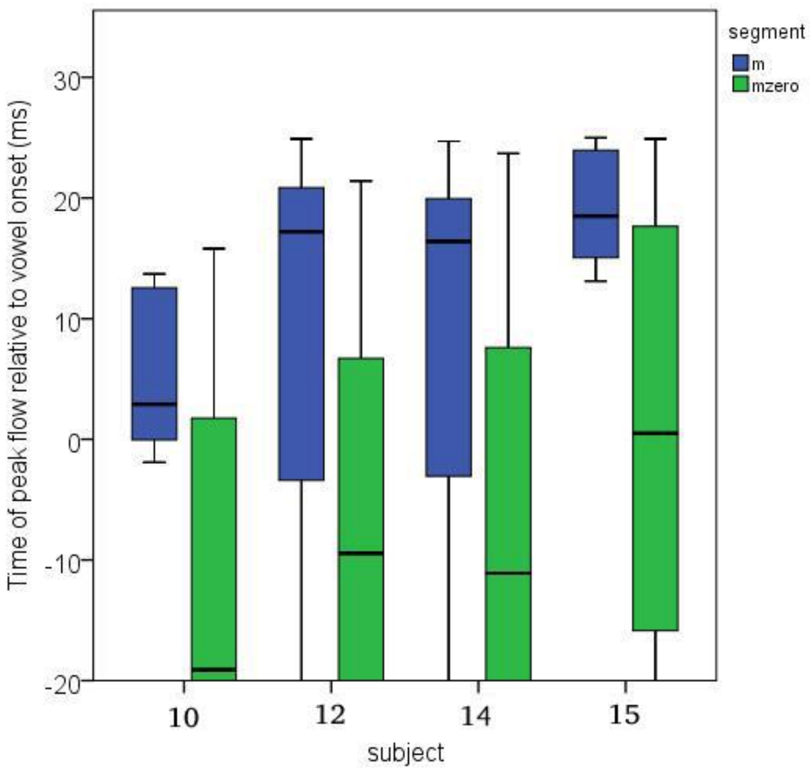

Figure 4.13: Time to peak nasal flow from vowel onset for bilabial consonants [m, m0].

4.6 Discussion 2: Denasalization and prosodic hierarchy

The main finding of this part of the analysis is that the aerodynamic data does not show evidence of proportional denasalization linked to domain hierarchy, which is contrary to what some of the previous researchers reported (Yoshida, 2008; Fougeron, 2001; Cho & Keating, 2001). It would not be difficult to select a small number of examples which appear to illustrate the hypothetical hierarchy, but when all the data are considered a contrary pattern emerges. There is thus no support in this data for the widely posited hierarchy of prosodic domains (See Figures 4.14 and 4.15).

One possible explanation of the flow differences observed in this study is that they may be linked to the speech breathing pattern of the speakers. No account has been taken of the location of in-breaths in relation to prosodic domains, but on average it is likely that the Ui position will follow breathing pauses, and relatively unlikely that the APi position can do so. Hence lung volume and subglottal pressure will generally be higher for the Ui position than for the APi position. Thus the generally downward trend in nasal flow across Ui, IPi and APi may reflect simply position within the breath group. If correct, this suggests that any attempts to study the production of prosodic structures need to take account of speech breathing.

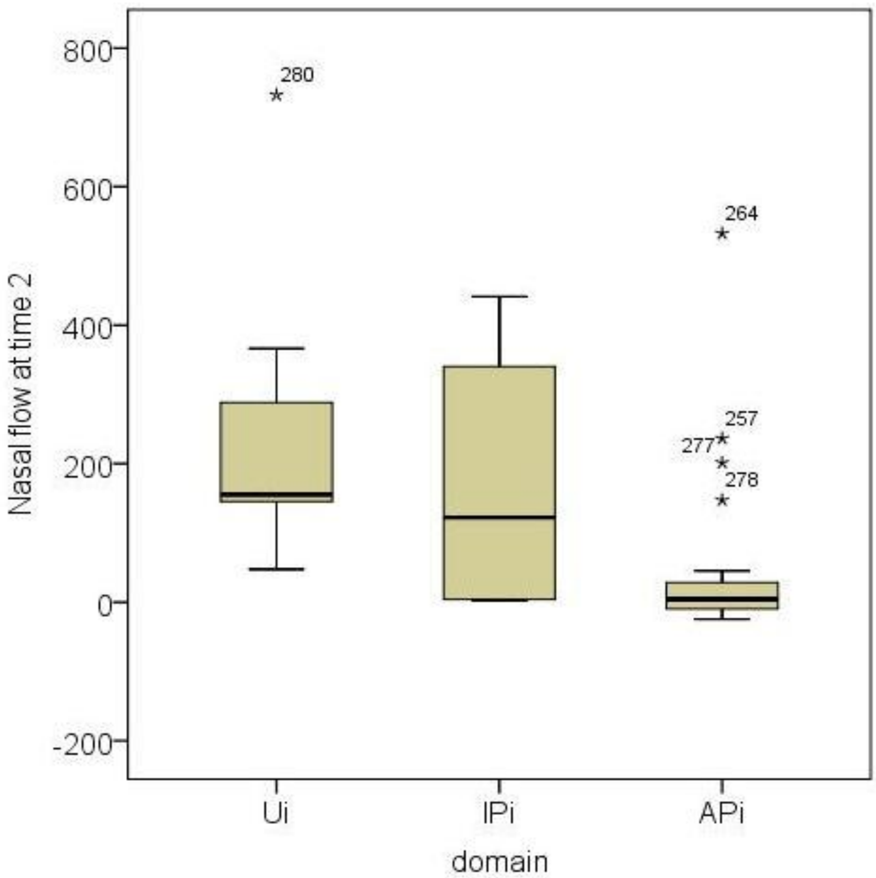

Figure 4.14: Mean nasal flow at time-point 2 (about 45 ms before offset) of word-initial nasals in Ui, IPi and APi positions – Subject 3. The APi domain, which is supposedly the lowest-ranking of the prosodic domains, appears to have the highest degree of strengthening.

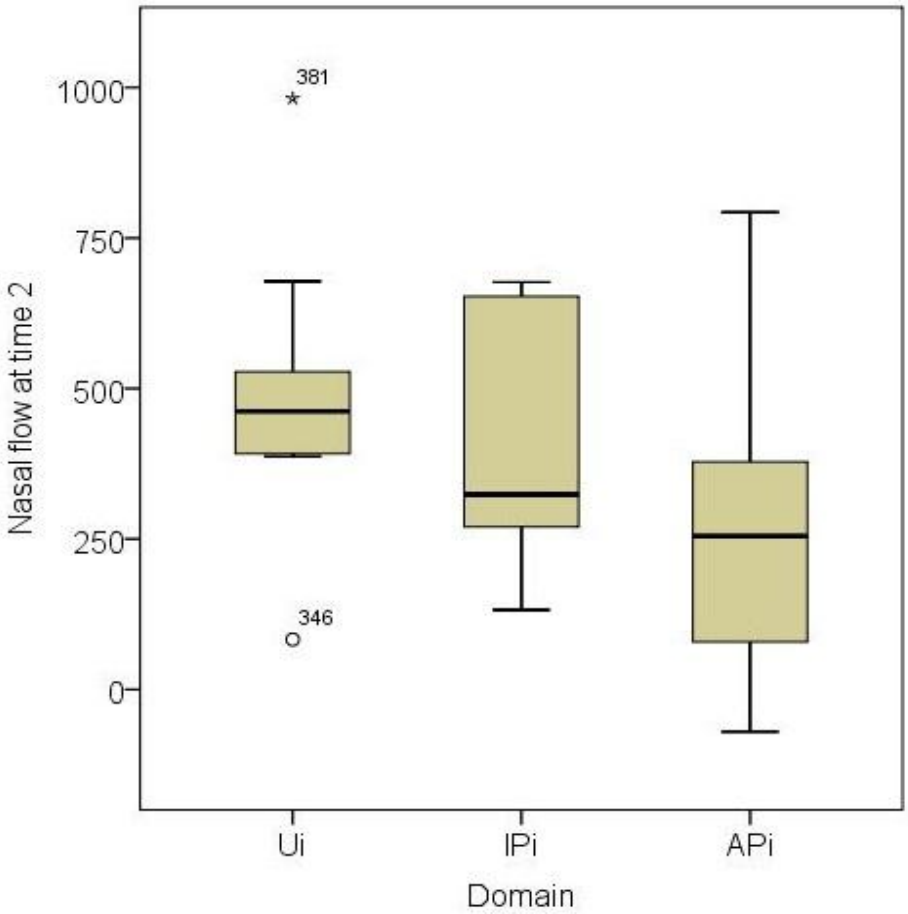

Figure 4.15: Mean nasal flow of word-initial nasals in Ui, IPi and APi positions – Subject 4. Again, the largest degree of denasalization is found in APi.

Chapter 5

An accelerometer study on denasalization in Korean

5.1 Introduction

This chapter presents further data on denasalized nasals in Korean [m0] and [n0], based on an experiment conducted with a nasal accelerometer. An accelerometer, attached to the exterior of the nose, senses vibration in the nasal tract during phonation of nasals and nasalized sounds (Moon, 1990). In a sense, it is intermediate between an acoustic device and a device to directly monitor articulatory activity. It senses acoustic energy, but only when this is transmitted through the tissues and skin of the particular point to which it is attached. It is insensitive to airborne sound. Like airflow masks, it is one of the non-invasive ways of measuring nasality and, what is better, is much more inexpensive than masks.

In the previous chapter, nasals and the following vowels were investigated in comparison with two other classes of sounds, sonorant nasals and voiced plosives. It was found that denasalized nasals are significantly different from sonorant nasals in terms of the volume of nasal airflow in the region of 50ms before and after the onset of the vowel. In the current experiment we were also interested in the vowels that *precede* denasalized nasals. Although denasalization seems only to occur in the word-initial position and often preceded by a pause, in real–life speech denasalized segments are commonly closely connected to the previous sounds within complex sentences and phrases, including vowels. Thus there is an opportunity to find out what happens to the vowels that come before denasalized nasals.

Nasal consonants in general commonly give rise to coarticulatory nasality in adjacent vowels. This is of two kinds: anticipatory nasalization and carryover nasalization. The nasalization naturally has specific effects on the spectra of the affected vowels. However, the automatic detection of these effects is very difficult. For example, if nasal coupling introduces a pole-zero pair into the vowel spectrum around 1 kHz (Stevens 1999: 316) it might be relatively easy to detect in a close front vowel, where both F1 and F2 are remote from this region, but completely obscured by F1 energy in a more open vowel. By contrast, if we have access to the speaker we can attach an accelerometer and obtain a reliable indication of nasal resonance regardless of vowel type. It is thus an ideal method of collecting data on nasalization.

The hypotheses of the present study are similar to those for the airflow experiment. Denasalized segments should have significantly lower nasal energy in their hold phase than sonorant nasals, probably similar to, and overlapping, the levels of voiced plosives but not identical. If denasalized segments are, as it seems, produced by a maneuver with smaller velic opening than sonorant nasals, then the extent of coarticulatory nasalization of vowels adjacent to denasalized segments should be less than for those adjacent to sonorant nasals.

5.2 Method

5.2.1 Speakers

Four subjects, aged between 20 and 26, took part in making recordings for this experiment (see also Table 5.1). All speakers were female and were born and lived in Korea almost all their lives, speaking Korean as their mother tongue and having spent only a few weeks outside their country except for one who had lived in the UK for 9 months at the time of recording. No participant had any known impairment with hearing or speaking. All participants signed a Consent and Data Protection Form and Project Information Form prior to the recording.

	Regional Accent	Age	Gender	Time spent overseas	English Proficiency
S17	Seoul	26	F	7 weeks	Intermediate
S18	Seoul	21	F	7 weeks	Intermediate
S19	Seoul	19	F	9 months	Advanced
S20	Southwest	24	F	3 weeks	Beginner

Table 5.1: Subjects for accelerometer recordings

5.2.2 Recording materials

The same recording materials as for the aerodynamic study were used for this experiment.

5.2.3 Apparatus and Procedures

Recording equipment

The recording was made in a sound-proof phonetics lab at Chandler House, University College London. The apparatus used included a miniature accelerometer (Model BU-1771 by Knowles Electronics), a PC with multi-channel recording software (Adobe Audition) and a microphone with a windshield.

Preparation for recording

The accelerometer was attached to each subject's nose using thin double-sided adhesive tape to a spot in the exterior of the nose directly below the nasal cartilage as recommended and illustrated by Lippmann (1981). Trials were also made with a cosmetic glue, but the double sided tape was preferred by subjects. The tiny attachment point can easily support the weight of the accelerometer itself. It weighs only 0.28 grams and is rather less than 6 mm x 8 mm. But the considerably greater weight of the connecting cable was taken by surgical tape on the nose. The cord was then routed upwards and fixed with more surgical tape between the eyebrows and on the forehead, and then routed behind the subject's ear to relieve any strains caused by tugging on the cord. This arrangement let the accelerometer stay comfortably attached to the subject's nose throughout the recording, and subjects were free to move their heads naturally. There is no audible effect on subjects' speech.

Annotation

The output signals from the accelerometer and the microphone are both in the audio range and were recorded in separate channels using Adobe Audition. The resulting .wav files were transferred to SFS and extensively annotated. All consonants were itemised individually with main target consonants being [m, m0, b] and [n, n0, d], and all vowels were itemised according to their preceding and following consonant, under the categories of sonorant nasals, [m, n], denasalized nasals, [m0, n0], voiced plosives, [b, d], and all other voiced and voiceless oral consonants, marked as *G* and *K*. When combined, [m] and [n] were represented by *N*, [m0] and [n0] by *N0* and other consonants including [b] and [d] by *C*. Thus the vowels divided into 8 subgroups according to their environment were: CVN, CVN0, CVC, N0VC, N0VN, NVN, NVN0 and NVC.

Measurement of nasality

After annotation was complete, an SFS program 'vdegree' was run to produce energy tracks on a dB scale for each of the two channels, microphone and nasal accelerometer. A specially devised SML script was then run to process the files in two steps: Step 1— to improve the selectivity in the extraction of the nasal energy from the accelerometer signals; and Step 2 — to measure the average nasal energy of each consonant and vowel over ten time-normalised stages between corresponding pairs of annotations.

Step 1 was taken because, although fixed to the nose, the accelerometer is partly sensitive to the whole speech energy in so far as this is conveyed through tissue vibrations, in the manner of a contact microphone. Call this overall signal *L*, and the specifically nasal component *N*. The energy track from the accelerometer thus represents *(L+N)*. An independent estimate of *L* is obtained from a conventional microphone detecting airborne sound. Subtracting the microphone level from the accelerometer level thus isolates the nasal component effectively, since $(L+N)-L = N$.

In essence, then, the analysis script must subtract the microphone level from the accelerometer level at each sample point:

$$N = (\text{accelerometer} - \text{microphone})$$

But for graphical purposes it is useful to have an output that is negative-going with increasing nasality, recalling the downward movement of the opening velum:

$$-N = -(\text{accelerometer} - \text{microphone})$$

By the rules of algebra, "minus (accelerometer minus microphone)" is the same as "microphone minus accelerometer", and that is the quantity which the SML scripts were written to derive.

5.3 Results

The results for 4 subjects (Figures 5.2 to 5.5) were so similar that it was reasonable to pool them together. Based on the merged data, the mean nasal energy over 10 normalised time phases for each of the target consonant groups and the vowels immediately adjacent to them[9] are shown in Figure 5.1. The consonants are displayed both before and after the vowel phase in order to effectively visualize co-articulatory transitions between segments in the form of CVC. Note that a smaller or negative going value indicates *more* nasality in relation to the oral level; i.e. the lower the y-axis value, the higher the relative nasality. It is evident from this display that the main coarticulatory effect in Korean is *carryover* nasality. It is strongly evident with sonorant nasals but not with denasalized segments.

Consonants

The Kruskal-Wallis nonparametric analysis of variance was carried out to see if the differences apparent on the graph were significant. The tests results revealed that the difference was significant (p=0.000) at all ten of the sample points. The post-hoc tests (Mann-Whitney U) showed that [m, n] and [m0, n0] were distinct (p=0.000) at all ten sample points, and [b, d] and [m0, n0] are distinct at the first three sample points (p=0.000; p=0.000; p=0.015) and at the last (p=0.044).

From this it appears that denasalized segments are robustly distinct from sonorant nasals. Denasalized segments resemble plosives to some degree, but are not identical with them.

[9] C includes not only [b] and [d] but all other consonants as well

Vowels preceded by N, N0 and C

Three vowel groups categorized by their preceding consonants, sonorant nasals (NVC, NVN0 and NVN), denasalised nasals (N0VC and N0VN) and other consonants (CVC, CVN and CVN0) were tested for significance in difference. The Kruskal-Wallis nonparametric analysis of variance shows that there is a difference (p=0.000) at all ten of the sample points in the vowel duration. The post-hoc tests (Mann-Whitney U) showed:

- vowels following N and N0 are different throughout their duration (at all ten sample points p=0.000)
- vowels following N and C are different throughout their duration (at all ten sample points p=0.000)
- vowels following N0 and C are different throughout their duration (at all ten sample points p=0.000)

From this it appears that the occurrence of N, N0 or C as onset is robustly cued throughout the syllable, and it is unsurprising that the three types are auditorily distinct.

Vowels following sonorant nasals: NVN0, NVN and NVC

Vowels preceded by N but followed by different types of segments were analyzed. The Kruskal-Wallis test showed that there was a difference (p=0.000) at all ten of the sample points. In post-hoc tests by Mann-Whitney U:

- NVN and NVN0 were not distinct at any of the ten sample points
- NVN0 and NVC were not distinct at the first 5 sample points, but they are for sample points 6-10 (p=0.048; p=0.026; p=0.015; p=0.008; p=0.004 respectively: showing that they are progressively diverging)
- NVN and NVC were distinct at all ten sample points (p=0.000)

From this it appears that denasalized segments have similar effects on co-articulatory anticipation of nasality as sonorant nasals do. All vowels *preceded* by N are nasalized but a following C causes progressive reduction of this nasality, which is detectable throughout the vowel.

Vowels followed by sonorant nasals (a): CVN and N0VN

Vowels followed by N but preceded by C and N0 were tested for significance in difference by the Mann-Whitney U test. From sample point 2 onwards, CVN and N0VN are distinct (p=0.000) with more nasality in the N0VN case. This appears to suggest that anticipatory nasality occasioned by the following N links, as it were, to the latent nasality of N0, producing a greater anticipatory effect.

Vowels followed by sonorant nasals (b): N0VN and NVN

Vowels followed by N but preceded by N0 and N were tested. NVN and N0VN are significantly different at all 10 time points, with some indication that they are becoming more alike at the very end.

Total N=298. For times 1 to 8, p=0.000; at time 9, p=0.002; and at time 10, p=0.045 (that is, just below the threshold of 0.05)

Vowels surrounded by C and N0: CVC, N0VC, CVN0

CVC, N0VC and CVN0 were tested to see if C and N0 behave the same way. The Kruskal-Wallis test shows that there is a difference at points 6-10 inclusive (p=0.021, p=0.001, p= 0.000, p=0.000). In post-hoc tests by Mann-Whitney U:

- CVC and N0VC were distinct at sample point 1 (p=0.023), and then at points 5-10 inclusive (p=0.019; p=0.005;p=0.000;p=0.000;p=0.000; p=0.000), which appears to show the effect of a strong velum closing movement following N0, as if there were a deliberate avoidance of nasality, greater than in the CVC context;
- CVC and CVN0 were not distinct at any of the ten sample points;
- N0VC and CVN0 were not distinct at 9 of the ten sample points; at time 10, p=0.034, which may show some anticipatory nasality caused by the following N0.

5.4 Discussion

One of the main results of the current study is that denasalized nasals are significantly different from sonorant nasals. This was true for both bilabials and alveolars, for both of which the mean nasality in the hold phase, measured in each of 10 equally spaced time frames of each segment, proved that N and N0 were robustly distinct. The results also showed that denasalized nasals were partially the same as voiced plosives but not identical, distinctive at the first three and the last sample points of the hold phase. This finding is almost the same result as that of the aerodynamic analysis in the previous chapter, which partly supports the hypothesis that denasalized nasals are similar to voiced plosives.

Turning to the various categories of vowels, it was found that, the vowels preceded by N, N0 and C were all proved to be distinct from one another as well, which strongly accounts for the difference in perceived qualities by some listeners, for example, native speakers of English. This analysis is noteworthy in that it looked at the vowels separately from the consonants and for the whole duration, all 10 time points of the entire phase, the three types of vowels were distinctive. This means that the type of onset is evident from the whole duration of the vowel, i.e. the differences really affect the whole CV sequence.

The results from comparison of vowels preceded by N but followed by N and N0 suggested that denasalized nasals might behave the same way as sonorant nasals do in terms of anticipatory nasalization of the preceding vowel (of the previous word in the coda position in case of denasalized nasals as they occur only in the word-initial position). This is an interesting point as, when the vowels follow a denasalized nasal, the nasality is distinct from when they follow a sonorant nasal, and N and N0 are distinct from each other throughout the whole hold phase. Without reading too much into this finding, it may point to the possibility of a difference between the surface nasality of a segment and its underlying or notional nasality. And it also means that the nasality of the vowel in NVN0 rises as high as N, and then drops to the distinct level once the hold phase of N0 starts.

Vowels CVN and N0VN proved to be distinct from each other from the sample point 2 throughout: during the first part of the vowel, it behaved the same way as when preceded by C but the rest of the vowel showed distinctively higher nasality. If we look at the results of comparison between N0VN and NVN, which proved to be highly significantly different in all of the duration, with the last two points where the difference is much less dramatic (close to that of NVN) but still significant, we can see that 'distinctively higher nasality' of N0VN than that of CVN does not mean that it is as nasal as that of NVN but that it is still distinct from it.

Vowels in CVC and N0VC significantly differed from each other at the sample point 1 and from 5 throughout, which suggested that for N0 there was a radical change in the velum position at sample point 2 that brought down the nasality level of this consonant to the same level as C, which is a similar pattern to the comparison of CVN and N0VN.

In summary, the results of this experiment showed the following:

- [m0, n0] are significantly different from [m, n];
- [m0, n0] are similar to [b, d] but not identical;
- NVN and NVN0 are practically the same;
- NVN0 and NVC are same in the first half but different in the second half ;
- NVN and NVC are significantly different;
- CVN and N0VN are the same in the first section but the rest significantly different;
- N0VN and NVN are significantly different;
- CVC and N0VC different in the first section and in the second half, which means that there is a sudden change in nasality (velum height) immediately after the vowel onset;
- CVC and CVN0 are the same; N0VC and CVN0 are the same except for the last section, which might be a sign of anticipatory nasality for N0 for CVN0.

Overall, the hypotheses raised at the outset are all comprehensively supported. In addition, there is some suggestive evidence from coarticulatory patterns that denasalized segments remain phonologically 'nasal' even when phonetically denasalized. This deserves further investigation in future.

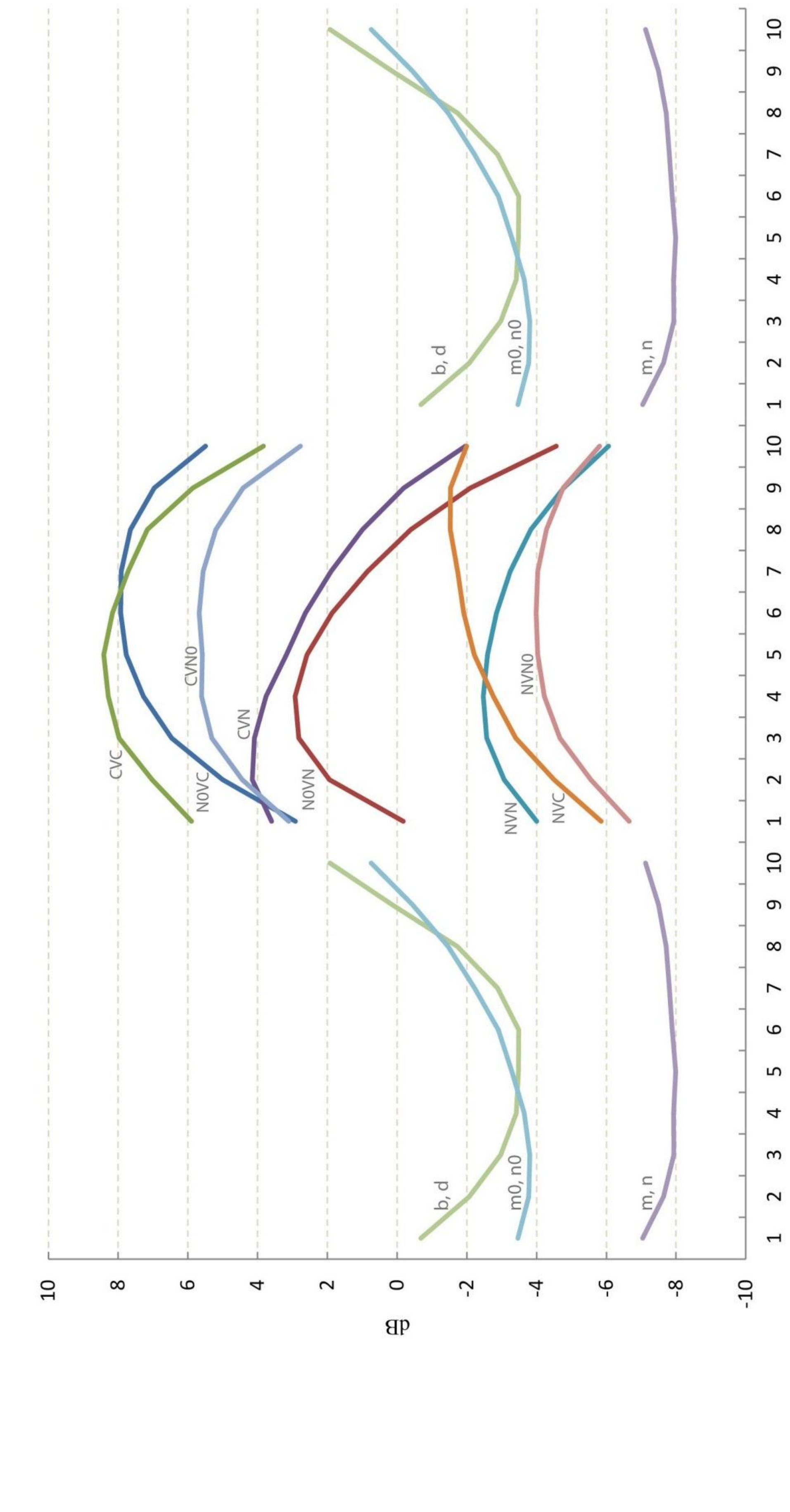

Figure 5.1: Mean nasal energy detected by a nasal accelerometer for consonants and their following vowels – data pooled from 4 subjects

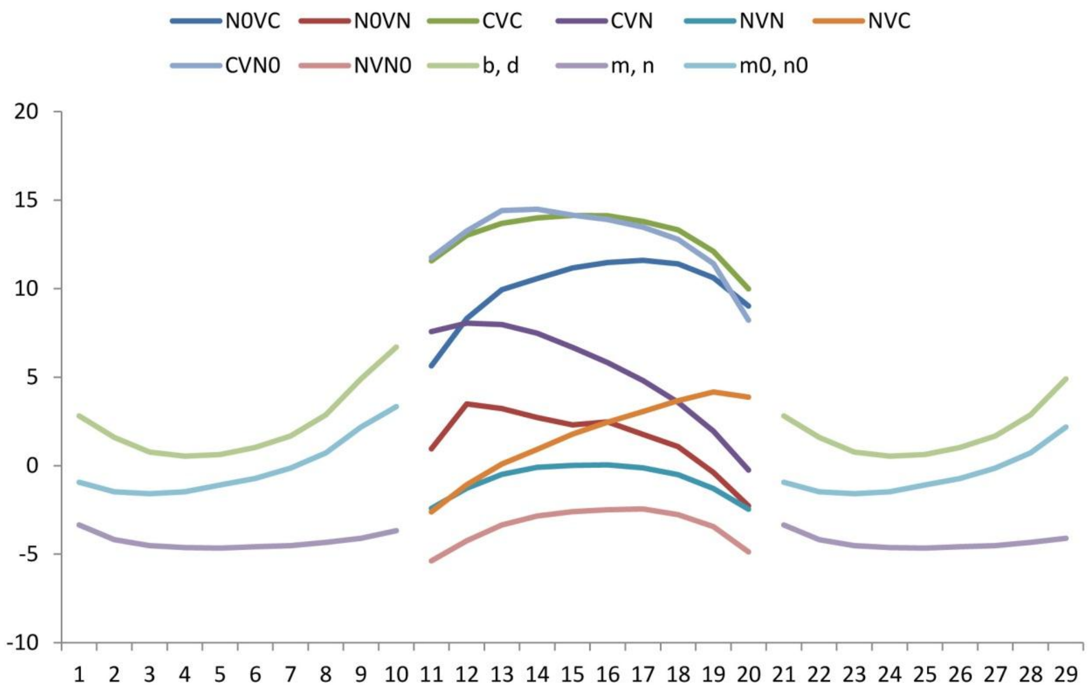

Figure 5.2: Mean nasal energy (db) detected by a nasal accelerometer – Subject 17. Data have been aggregated into a composite consonant-vowel-consonant sequence, and all segments time-normalized.

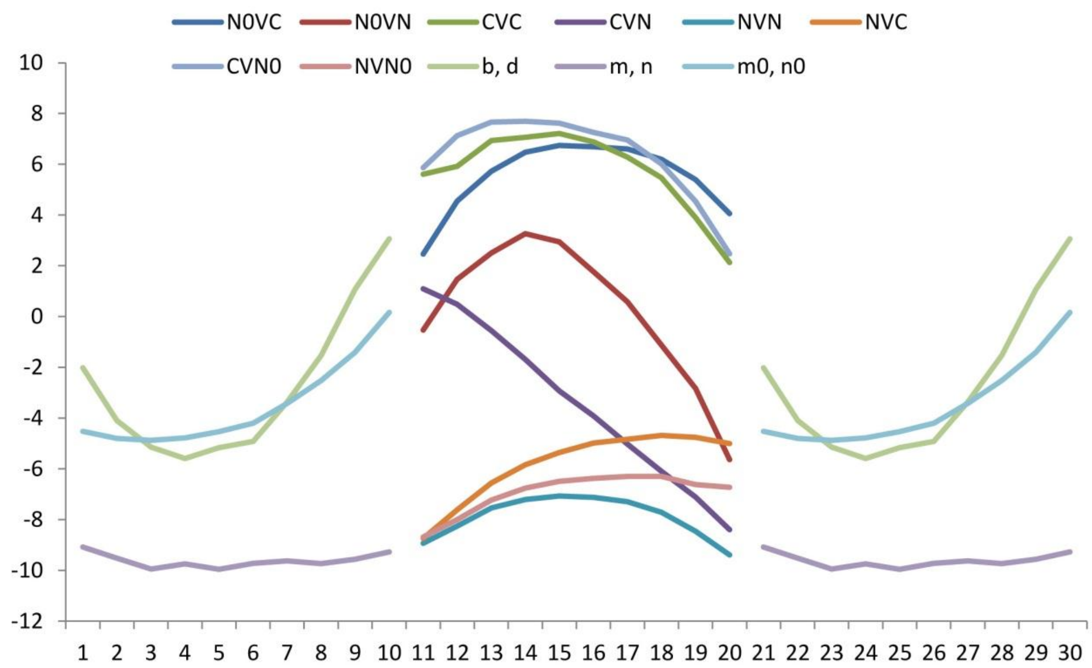

Figure 5.3: Mean nasal energy (db) detected by a nasal accelerometer – Subject 18. Data have been aggregated into a composite consonant-vowel-consonant sequence, and all segments time-normalized.

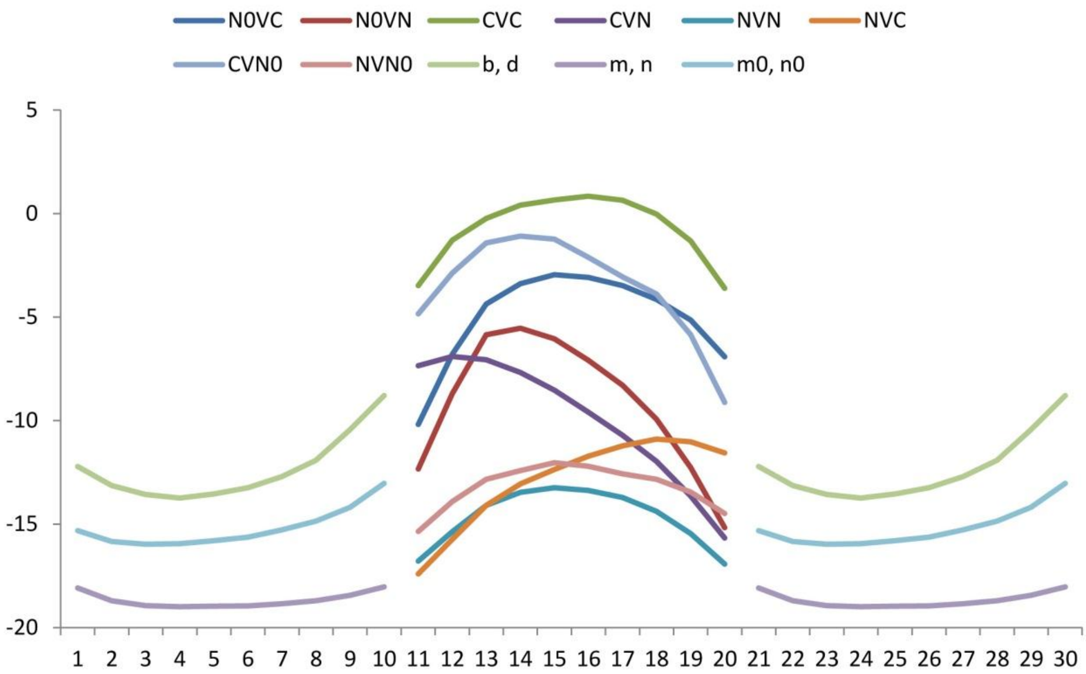

Figure 5.4: Mean nasal energy (db) detected by a nasal accelerometer – Subject 19. Data have been aggregated into a composite consonant-vowel-consonant sequence, and all segments time-normalized.

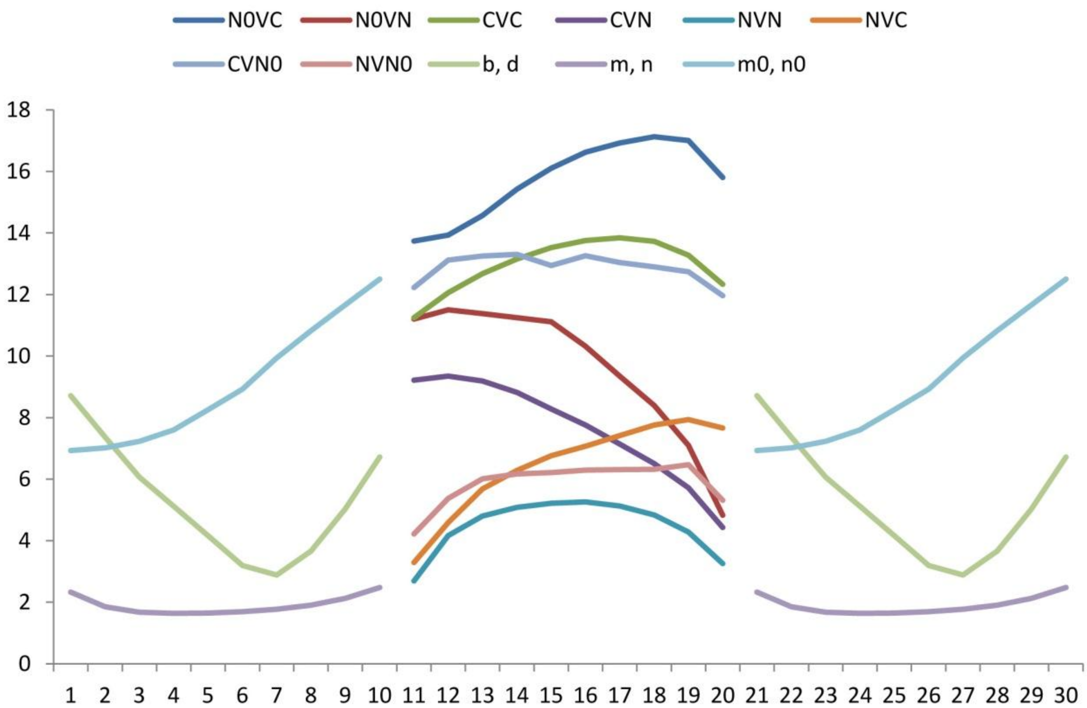

Figure 5.5: Mean nasal energy (db) detected by a nasal accelerometer – Subject 20. Data have been aggregated into a composite consonant-vowel-consonant sequence, and all segments time-normalized.

Chapter 6

Perception of denasalized nasals in Korean

6.1 Introduction

So far we have discussed the physical properties of denasalized nasals [m0, n0] along with two other pairs in comparison, [m, n] and [b, d]. Through four different types of analyses, it was revealed that denasalized nasals are different from sonorant nasals and similar to voiced plosives, though not completely the same. It was also found that denasalization in Korean has little correlation with the different domains in the prosodic hierarchy and moreover is apparently independent of the height of the following vowels.

These overwhelmingly consistent results in the production and acoustic aspects take us to the other side of speech: its perception. As the degree of perceived nasality is reported to increase proportional to the amount of nasal airflow (Warren et al., 1993), it is expected that denasalized nasals, which are significantly lower in nasality than sonorant nasals, will be categorized as perceptually different from them. All of the previous researchers who documented denasalized nasals in Korean connected the perceived nasality to the height of the following vowels (Jones, 1924; Martin, 1951; Chen and Clumeck, 1975); however, more recently Hajek (1997) reported that there is no clear connection between articulatory adjustments such as vowel height and the perception of nasalization.

Although the results of production data analyses in the previous chapters did not support the claims that denasalization is correlated to the height of the vowels or to the position in the prosodic hierarchy, the perception data might indeed prove it true. After all, the true meaning of denasalization lies in the perception in the strict sense, as Laver (1994) notes, not in the physical properties of the segments.

The motivation of the current perception tests was to find out whether there is a significant difference in perception of denasalized nasals by English speakers compared to Korean speakers, as the whole research undertaking was triggered at the outset by the surprising misperceptions of my American students, native speakers of English, many of whom frequently perceived the segments in question as plosives.

The following are the hypotheses for the current perception experiments:

H1. Denasalized segments, categorised as nasals by Korean listeners when heard in domain-initial context, will be categorized as voiced plosives by English listeners.

H2. Denasalized segments, removed from initial position and placed in intervocalic position, will be categorized as plosives by both Korean listeners and English listeners.

H3. Plosive segments, removed from intervocalic position and placed in initial position, will be categorized as nasals by Korean listeners and as plosives by English listeners.

H4. Sonorant nasal segments re-spliced into intervocalic position will be categorized as nasals by both Korean and English listeners.

H5. For all comparisons, similar results will be found for the bilabial and alveolar places of articulation.

H6. The height of the following vowel will not affect categorization results for either group of listeners.

6.2 Method

6.2.1 Speakers

A total of 10 native Korean speakers (KS: Korean Speakers; KS9 [10] and KS11 previously provided airflow recordings and KS19 accelerometer recordings) and a total of 10 native English speakers (ES: English Speakers) with normal hearing and speech participated in this experiment as listeners (see also Tables 6.1 and 6.2).

All but two of the ES had some (first year linguistics students) or advanced training (final year and research students in speech therapy and phonetics) in phonetics. There were 8 female and 2 male, aged between 18 and 44.

None of the KS had any formal training in phonetics except for one participant (a research student in phonetics). All KS, however, are trained in listening to English conversations and spoken passages as part of their education in Korea. There were 6 male and 4 female, aged between 19 and 35.

	Regional Accent	Age	Gender	Months in UK
KS9	SEOUL	29	M	9
KS11	SEOUL	23	M	9
KS19	SEOUL	20	F	15
KS21	SEOUL	31	M	12
KS22	SEOUL	26	F	4
KS23	SEOUL	27	F	6
KS24	SW	33	M	3
KS25	SEOUL	27	M	11
KS26	SEOUL	30	F	6
KS27	SEOUL	35	M	12

Table 6.1: Korean participants for the listening tests

	Regional Accent	Age	Gender	Phonetics training
ES1	SBE	19	F	Y
ES2	SBE	18	F	Y
ES3	SBE	38	M	Y
ES4	SBE	38	F	Y
ES5	SBE	44	F	N
ES6	SBE	40	M	N
ES7	SBE	32	F	Y
ES8	SBE	22	F	Y
ES9	SBE	22	F	Y
ES10	SBE	24	F	Y

Table 6.2: English participants for the listening tests.

[10] Subject numbers are in continuation from the previous experiments. 'K' has been added for this chapter in order to give clear distinction from ES (English speakers).

6.2.2 Stimuli

Stimuli were constructed in Praat (Boersma and Weenik 2011) by cutting and splicing natural recordings previously made of fluent speech from a female Korean speaker, who was chosen at random from those who had already furnished accelerometer recordings.

Construction of stimuli was done by trial and error until the intended number of stimuli of acceptable quality had been made. In this way, all resulting stimuli have the same number of cuts and splices, and any unnaturalness resulting from the splicing process should be randomly distributed among the various categories of stimulus. The stimuli seem somewhat abrupt when heard in isolation, since they have syllable durations representative of fluent speech (from which they have been cut).

Stimuli Set 1: VCV (with the target consonant in the medial position)

A total of 80 target consonants ([b, d, m0, m, n0, n]), along with their following vowels (ranging Open to Close and Front to Back), were cut from the recording to yield CV fragments. These were then spliced into position following a constant V portion, [e], giving a range of VCV stimuli. There were 80 VCV stimuli and these were repeated three times in the listening test.

Stimuli Set 2: CVCV (with the target consonant in the onset position)

A total of 41 CV forms were put together with four different types of unrelated CV(C) sequences to produce CVCV(C) stimuli. One item, however, did not produce a natural-sounding sample when spliced with two of the CV(C), and these two combinations were removed.

In the CVCV stimuli, [m] and [n] were excluded so as not to bias the results for [b] and [d], which were also predicted to be perceived as [m] and [n] by native Korean speakers in the word-initial position. Instead, [p] and [t] were included to investigate whether the listeners discriminate them from [b] and [d] when they are all in the word-initial position. The total number of CVCV stimuli was now 162 and these were repeated twice in the listening test.

6.2.3 Apparatus and Procedures

Apparatus

A PC with the Praat programme, a mouse and a headset were used for the listening tests. The tests were done in one of the UCL phonetics lab booths or in a quiet room with no background noise.

Identification tasks

Each participant was given instructions and a short practice session before the actual tests. They were asked to choose the answer spontaneously, judging by the first impression (Screenshots of the tests are shown in Figures 6.1 to 6.4). KS were especially asked to remind themselves that this was Korean, which was to prevent them from switching their mode to listening to English.

The tests were presented in the order VCV and then CVCV. The VCV stimuli were repeated three times and the CVCV twice and Praat presented them in a (different) random order for each listener. The results table showed that Praat presented a set of stimuli once in a random order before repeating the set, again in a random order. In practice, neither Korean nor English listeners had any difficulty in categorising the stimuli. In cases where the outcome is unproblematic—as for example in the case of sonorant nasal segments reported as nasals—identification rates approach 100%; there is also a good degree of inter-listener agreement. The average time consumed for completing the VCV test was approximately 10 minutes and 15 minutes for the CVCV. All participants progressed through the tests at about the same rate, and no participant took an unusually long time or stopped in the middle of the tests.

Analysis of the data

The results were obtained in text files and then were imported to Excel and SPSS for analyses. Two errors were discovered early on: one was the CVCV results for KS11; they were saved twice, once as VCV and the other time as CVCV. Thus the responses to the VCV test by KS11 were lost and the total number of responses by this group in this category was now 2160 (80 stimuli x 3 repetitions). Another error was that three of the spliced VCV stimuli were in fact identical sound files saved in different names.

Thus results for two of them were eliminated from the analysis, changing the total number of VCV responses across all KS to 2106 from 2160 (9 subjects). The same was applied to the EP, changing the total number of VCV responses to 2340 from 2400 (10 subjects). The total number of responses for the CVCV task was 3240 for both ES and KS groups.

The results were analysed in Excel to obtain the response rates and probability of “nasal” and “plosive” response for each group of listeners. Subsets of the data were then tested as required using an online implementation of certain non-parametric tests. SPSS (PASW) was used to generate crosstabulations of the data.

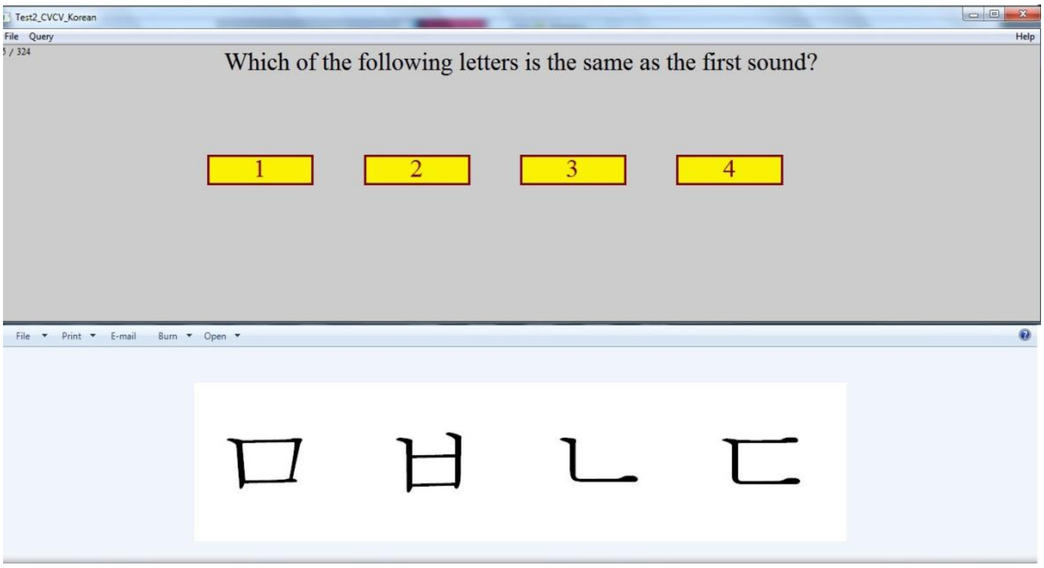

Figure 6.1: A screen shot of the CVCV perception test for Korean speakers

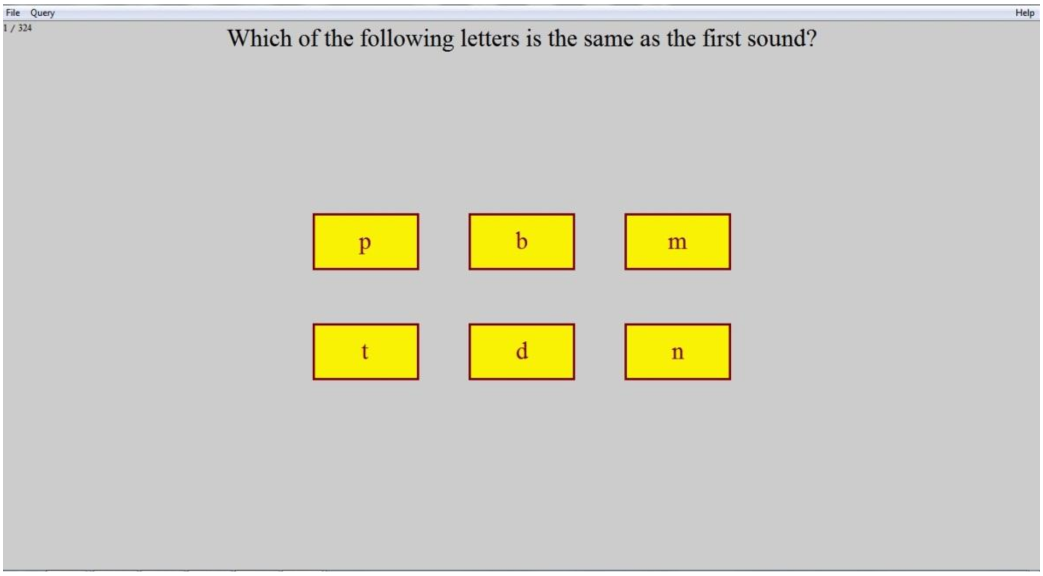

Figure 6.2: A screenshot of the CVCV perception test for English speakers

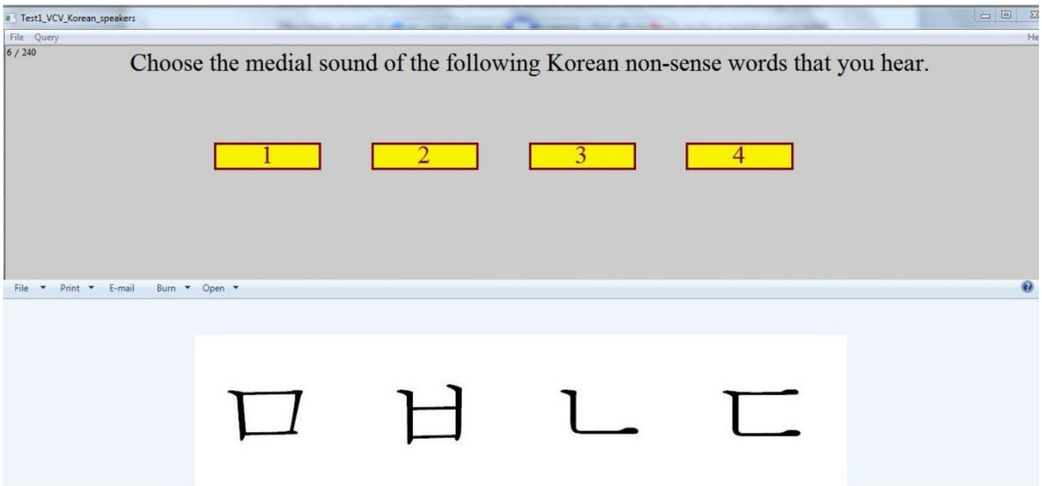

Figure 6.3: A screenshot of the VCV perception test for Korean speakers

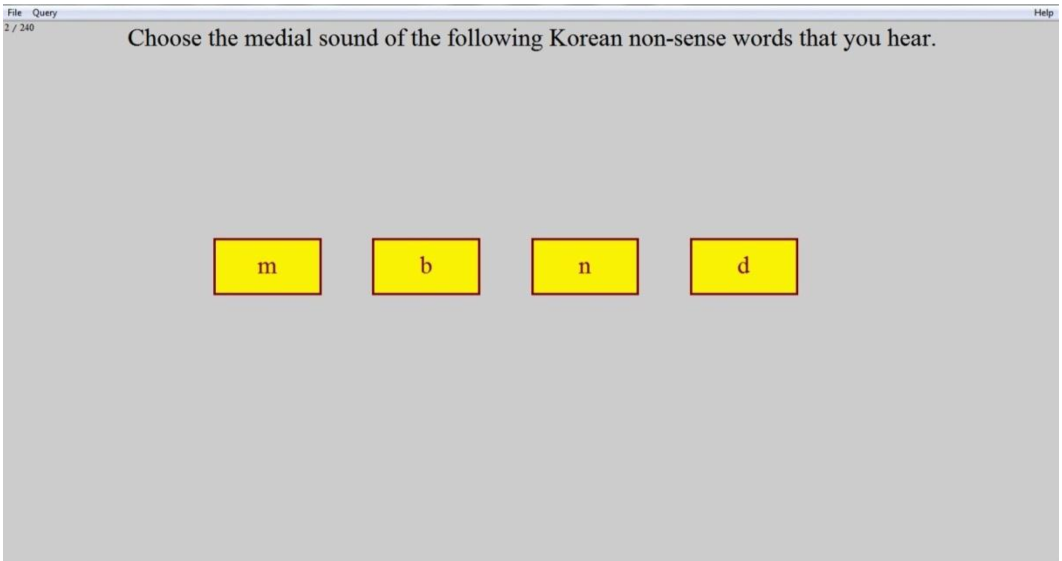

Figure 6.4: A screenshot of the VCV perception test for English speakers

6.3 Results

The overall results can be summarised in the form of eight confusion matrices (Table 6.3). The rows represent the sound type on which the stimulus was based—[m], [n], [m0], [n0], [b], [d], [p] and [t]; bear in mind that [b] and [p] are allophones of a single phoneme /p/, and [d] and [t] are likewise allophones of /t/. The response categories (columns) are those made available to the subject groups.

In the discussion which follows, responses are mostly pooled into "Nasal" and "Plosive" categories, and Table 6.4 therefore presents the same results with the response categories pooled in this way.

The results for alveolar stimuli will be dealt with first. The hypotheses are considered in turn, and for convenience the suffixes "a" (=alveolar) and "b" (=bilabial) are added to indicate when the discussion is limited to evidence from stimuli with a given place of articulation.

H1a: denasalized segments, categorised as nasals by Korean listeners when heard in domain-initial context, will be categorized as voiced plosives by English listeners. (By implication, the null hypothesis is that—being phonologically "Nasals"—they will be categorised as nasals by English listeners).

In 400 trials with n0 stimuli, 310 (73%) were categorized as nasals by Korean listeners, as opposed to 90 (23%) as plosives. In 400 trials with the same n0 stimuli for English listeners, only 8 (2%) were categorized as nasals, while 392 (98%) were categorised as plosives. There is thus a very clear majority exactly in accordance with prediction, and H1 is strongly supported.

Although the results overwhelmingly support H1, the number of contrary results is not zero. It should be noted that Hypotheses 1 – 4 are all in the nature of *categorical* predictions. For example, H1 predicts that 100% of denasalized segments will be reported as Nasal by Korean listeners and 0% as Nasal by English listeners. It is necessary to explain, then, why 90, rather than zero, Plosive responses were given by Korean listeners, and similarly why 8, rather than zero, Nasal responses were given by English listeners. Plainly, random factors may account for some of the unexpected

stimulus * response * place * listener group * type Crosstabulation

Count

type	listener group	place			response b	d	m	n	p	t	Total
CVCV	English	alveolar	stimulus	d	36	609	3	17	9	6	680
				n0	3	380	0	8	0	9	400
				t	2	2	0	1	3	792	800
			Total		41	991	3	26	12	807	1880
		bilabial	stimulus	b	410	8	46	7	8	1	480
				m0	324	10	138	4	4	0	480
				p	28	0	0	0	371	1	400
			Total		762	18	184	11	383	2	1360
	Korean	alveolar	stimulus	d			5	493	5	177	680
				n0			0	310	3	87	400
				t			1	0	25	774	800
			Total				6	803	33	1038	1880
		bilabial	stimulus	b			433	4	41	2	480
				m0			462	5	11	2	480
				p			4	0	390	6	400
			Total				899	9	442	10	1360
VCV	English	alveolar	stimulus	d	27	268	0	5			300
				n	0	1	2	357			360
				n0	22	400	3	55			480
			Total		49	669	5	417			1140
		bilabial	stimulus	b	170	3	7	0			180
				m	0	1	350	9			360
				m0	557	14	136	13			720
			Total		727	18	493	22			1260
	Korean	alveolar	stimulus	d	11	228	3	28			270
				n	0	0	2	322			324
				n0	12	297	4	119			432
			Total		23	525	9	469			1026
		bilabial	stimulus	b	147	1	14	0			162
				m	2	1	317	4			324
				m0	299	4	341	4			648
			Total		448	6	672	8			1134

Table 6.3: Crosstabulation of stimulus, response, place, listener group and type (VCV, CVCV)

stimulus * response category * place * listener group * type Crosstabulation

Count

type	listener group	place			response category: nasal	response category: oral	Total
CVCV	English	alveolar	stimulus	d	20	660	680
				n0	8	392	400
				t	1	799	800
			Total		29	1851	1880
		bilabial	stimulus	b	53	427	480
				m0	142	338	480
				p	0	400	400
			Total		195	1165	1360
	Korean	alveolar	stimulus	d	498	182	680
				n0	310	90	400
				t	1	799	800
			Total		809	1071	1880
		bilabial	stimulus	b	437	43	480
				m0	467	13	480
				p	4	396	400
			Total		908	452	1360
VCV	English	alveolar	stimulus	d	5	295	300
				n	359	1	360
				n0	58	422	480
			Total		422	718	1140
		bilabial	stimulus	b	7	173	180
				m	359	1	360
				m0	149	571	720
			Total		515	745	1260
	Korean	alveolar	stimulus	d	31	239	270
				n	324	0	324
				n0	123	309	432
			Total		478	548	1026
		bilabial	stimulus	b	14	148	162
				m	321	3	324
				m0	345	303	648
			Total		680	454	1134

Table 6.4: Crosstabulation of stimulus, response category, place, listener group, type

responses. In what follows, for each particular hypothesis which is supported by the data, the goodness-of-fit of the categorical model embodied in the hypothesis is further evaluated using a chi-square test (Siegel and Castellan 1988: 45–51), as implemented in Preacher (2001). Essentially, this determines whether the number of contrary responses is small enough to be ascribed to unpredictable random factors; if not, it must be concluded that one or more factors must be in operation determining the listeners' responses.

The goodness-of-fit test compares the *observed* categorical frequencies with the *expected* frequencies, but a difficulty arises over small expected frequencies. Following Siegel and Castellan (1988: 49), when the degrees of freedom (*df*) are =1 (as they are in the present comparisons) the smallest *expected* frequency should be at least 5. Hence we set 5, rather than zero, as the expected frequency in the contrary category.

Returning to the evaluation of H1, for Korean listeners, the goodness-of-fit test shows that the 90 categorizations as Plosive are more numerous than would be predicted by chance alone. Chi-square= 1463.291; *df*=1;p=0 (i.e. too small to be calculated); for English listeners, 8 Nasal responses out of 400 is not significantly different from the model baseline of 5 out of 400; chi-square= 1.823;df=1;p= 0.17698215.

We conclude that H1 accounts for all of the English listeners' responses, and the great majority of the Korean listeners' responses. One or more unknown factors must however be in operation increasing the number of Plosive responses from Korean listeners. These remain to be discovered, but may be conjectured to include:

- particular Korean listeners may be affected by English
- weakening of the domain-initial cues by the splicing procedure
- particular stimuli may exhibit atypical configurations of acoustic cues

H2a: denasalized segments, removed from domain-initial position and placed in intervocalic position, will be categorized as plosives by both Korean listeners and English listeners.

Out of 432 trials with n0 stimuli in VCV context, Korean listeners categorised 309 (72%) as plosive, and 123 (28%) as nasal. For English listeners, 480 trials with n0 stimuli resulted in 422 (88%) categorizations as plosive and 58 (12%) as nasal. (The different numbers of trials result from an error causing loss of the data for one Korean subject). The majority of responses are therefore in accordance with the hypothesis.

The goodness-of-fit tests show that for both groups of listeners the number of contrary responses is too great to be ascribed to chance. For Koreans, chi-square= 2817.409; *df*=1;p=0. For the English listeners, chi-square= 611.368; *df*=1;p=0.

A further chi-square test was used to examine if the rate of response was the same for Korean and English listeners. The test shows that the denasalized n0 stimuli are judged as nasal significantly more often by Korean listeners than by English listeners; chi-square (with Yates' correction) =37.367; df=1; p=0.

Hence we may conclude that H2 is accepted, subject to modifications. On the whole, denasalised n0 stimuli when transferred to intervocalic position are categorised as "Plosive" by both Korean (72%) and English listeners (88%), in accordance with the hypothesis. However, a minority of the stimuli were reliably categorised as "Nasal" by English listeners, and a significantly greater proportion categorized as "Nasal" by Korean listeners. This appears to indicate that some of the stimuli must have included sufficient cues to nasality for all subjects, and that some factor or factors rendered the Korean subjects more likely to respond "Nasal" than the English subjects.

H3a: plosive segments, removed from intervocalic position and placed in initial position, will be categorized as nasals by Korean listeners and as plosives by English listeners

Of 680 trials using [d] stimuli in CVCV with Korean listeners, 498 (73%) were classified as Nasal and 182 (27%) as Plosive. The same 680 trials with English listeners yielded 660 (97%) plosive responses and 20 (3%) Nasal. Thus overall the results are in accordance with the hypothesis, though again the goodness-of-fit tests show that the numbers of contrary responses are too great to be ascribed to chance. For Koreans, chi-square= 6312.213; df=1; p=0. For the English listeners, the 20 Nasal responses are significantly more numerous than the model baseline of 5; chi-square= 45.333; df=1;p=0.

Hypothesis H3 depended on a particular assumption about the allophonic variation affecting Korean lax plosives in intervocalic position. In this position, they are supposed to be realized as fully voiced oral plosives. While this is true by and large, it is known to be a simplification (Seo, 2005); sometimes complete closure is not achieved, and vocal fold vibration may also cease. Hence a sample of real intervocalic tokens, as used in this study, is likely to show a range of acoustic properties.

H4a: sonorant nasal segments respliced into intervocalic position will be categorized as nasals by both Korean and English listeners

For Korean listeners, in 324 trials, all were categorised as Nasal and none as Plosive. In 360 similar trials with English listeners, 359 were judged Nasal and only 1 Plosive. The number of contrary responses is less than the model baseline in both cases, and hence H4 can be accepted in full.

The results for the sonorant nasal stimuli demonstrate that splicing a nasal segment into a VCV structure with an alien vowel does *not* by itself cause any categorisation shift from nasal to plosive. It follows that the change in categorisation which is observed for the denasalized tokens spliced into the same position cannot be explained as an artefact caused by the splicing procedure.

We now consider the same hypotheses in the light of evidence from stimuli with bilabial segments.

H1b: denasalized segments, categorised as nasals by Korean listeners when heard in domain-initial context, will be categorized as voiced plosives by English listeners. The null hypothesis is that they will be categorised as nasals by English listeners.

In 480 trials with m0 stimuli in CVCV, Korean listeners categorized 467 as Nasal and only 13 as Plosive. In a corresponding 480 trials with English listeners, 142 were reported as Nasal, while 338 were categorized as Plosive. This result strongly supports the experimental hypothesis.

As was the case with alveolar stimuli, the number of contrary responses, though small, is not negligible for either listener group. For Korean listeners, the rate of 13 Plosive responses out of 480 is significantly greater than a model using a minimum of 5, as assessed by a chi-square goodness of fit test; chi-square= 12.935; *df*=1;p= 0.00032254. For English listeners, chi-square= 3793.314; *df*=1;p=0. We must conclude that for both groups of listeners the number of contrary responses is greater than chance, and that some additional factor or factors must be at work.

H2b: denasalized segments, removed from domain-initial position and placed in intervocalic position, will be categorized as plosives by both Korean listeners and English listeners.

In 648 trials with m0 stimuli, Koreans categorized 345 as Nasal and 303 as Plosive. In 720 corresponding trials with m0 stimuli, English listeners categorised 571 as Plosive and 149 as Nasal.

The results for Korean listeners certainly demonstrate that a substantial number of underlyingly "Nasal" segments are reported as Plosive, though only about 47% of trials are fully accounted for. For English listeners, 79% of the results are in accordance with the hypothesis, though the 149 contrary responses cannot be ascribed to chance (chi-square=4176.201; *df*=1; p=0).

We must conclude that for both language groups, the hypothesis is supported, but categorization of the m0 stimuli was probably affected by yet further additional factors compared with the categorization of the n0 stimuli, since rates of response to m0 and n0 stimuli were significantly different for both language groups. For English listeners, chi-square=14.961; *df*=1; p=0.00010976; for Koreans, chi-square= 64.757; *df*=1; p=0.

H3b: plosive segments, removed from intervocalic position and placed in initial position, will be categorized as nasals by Korean listeners, and as plosives by English listeners

In 480 trials with [b] stimuli, Korean listeners categorized 437 as Nasal and 43 as Plosive. In 480 corresponding trials, English listeners categorised only 53 as Nasal, and 427 as Plosive. This complementary pattern of responses is very strong support for the experimental hypothesis.

The goodness-of-fit tests show that the numbers of contrary responses again exceed the model baseline. For Koreans chi-square=291.84; df=1; p=0; for English listeners, chi-square= 465.651; *df*=1; p=0.

H4b: sonorant nasal segments respliced into intervocalic position will be categorized as nasals by both Korean and English listeners

For Korean listeners, out of 324 trials, 321 were categorized as Nasal, and 3 as Plosive. For English listeners, in 360 trials, 359 were categorized as Nasal and 1 as Plosive. For both listener groups, the results are entirely in accordance with prediction. The numbers of contrary responses are less than the model baseline of 5, and so the goodness-of-fit test is not applicable.

H5: Comparing the responses for alveolar and bilabial stimuli

Since it is hypothesized that denasalization affects bilabial and alveolar segments equally, the rates of response for each stimulus type should be the same for the two place categories. Even where the categorization of a particular stimulus type is found to differ from the predictions, the *proportion* of responses in the two categories is expected to be the same for alveolar and bilabial stimuli. This can be tested by using, for each combination of stimulus type and listener group, a chi-square test in which the two place categories are treated as related samples.

The results of the 6 tests are as follows. The chi-square values quoted are with Yates' correction. In all tests, *df*=1.

H1: Korean 310-90; 467-13 chi-square 80.793 p=0

H1: English 392-8; 388-142 chi-square 115.456 p=0

H2: Korean 309-123; 303-345 chi-square 63.752 p=0

H2: English 422-58; 571-149 chi-square 14.364; p= 0.00015066

H3: Korean 498-182; 437-43 chi-square 64.052; p=0

H3: English 660-20; 427-53 chi-square 29.951 p=4e-8

H5 is comprehensively rejected by these tests. In every comparison, and for both listener groups, there is a significantly different rate of response for alveolar and bilabial stimuli.

In relation to H1 and H2, both listener groups are more likely to judge denasalized alveolars as Plosive than they are denasalized bilabials. Correspondingly, they are more likely to judge denasalized bilabials as Nasal than they are denasalized alveolars. This is true when the overall categorization of the listener groups is in the contrary direction (H1) and when it is in the same direction (H2).

Similarly, in relation to H3, where the overall categorization of the listener groups is in the contrary direction, both listener groups are more likely to respond with the Nasal categorization for bilabial stimuli than for alveolar stimuli.

To investigate whether the listener groups are distinct, for each subject, it was decided to calculate a measure of Korean-ness (that is, the probability that responses will be given in accordance with the Korean response in the model, for those judgements in which predictions differ for the two language groups). It can be called *K*.

K=number of Nasal responses to m0, n0, b and d stimuli in the CVCV test, divided by the number of trials (204 for each subject).

For the ten Korean subjects, the *K* values cover a range 0.54 to 0.94; for the ten English subjects, the *K* values cover the range 0.02 to 0.23; in other words, the *K* values for the two groups are completely disjoint. Unsurprisingly, Mood's median test (http://www.fon.hum.uva.nl/Service/Statistics/Median_Test.html) confirms that the two groups are different (Median = 0.385, p <= 1.08e-05) (Figure 6.5).

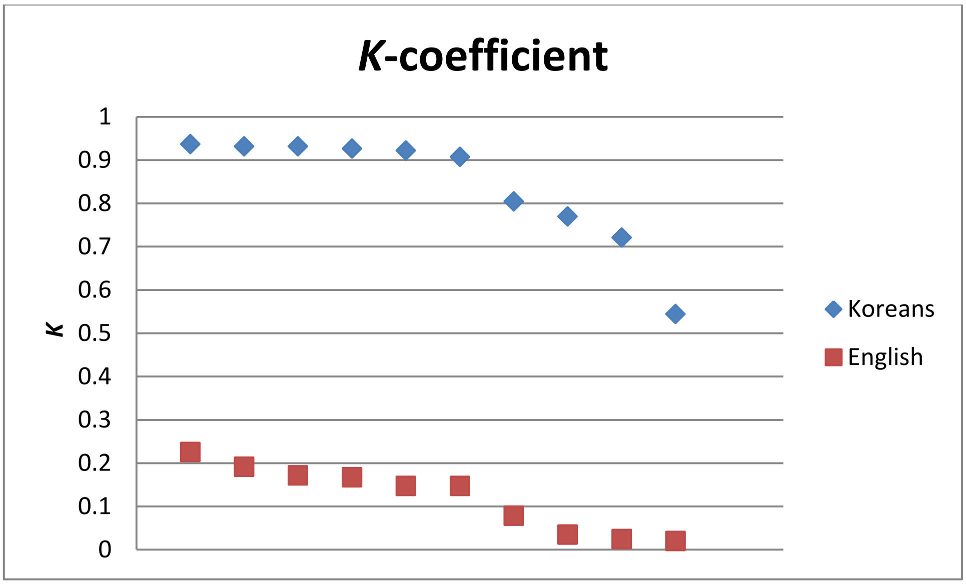

Figure 6.5: The calculated K values for the 20 subjects. While it is clear that the two language groups are completely distinct, there is evidence for variation within each group. Six of the Koreans have *K* over 0.9, while four have K of 0.8 or less. One Korean subject, with *K*=0.54, appears to be something of an outlier.

H6: The height of the following vowel will not affect categorization results for either group of listeners

Previous work (Jones, 1924; Martin, 1951; Chen and Clumeck, 1975) claimed that denasalization was greater before close vowels. If so, this predicts that English listeners should have a greater tendency to give Plosive judgments for m0 and n0 stimuli before high vowels than before others, in both VCV and CVCV conditions. This leads to four individual comparisons, and one overall test:

(In all tests, *df*=1)

m0CVCV the observed rate of Plosive responses is *higher* for close vowels than others, but the difference is not significant; Yates' chi-square=1.016;p=0.32

m0VCV the observed rate of Plosive responses is *lower* for close vowels than others, but the difference is not significant; Yates' chi-square= 1.046;p=0.31

n0CVCV the observed rate of Plosive responses is *higher* for close vowels than others, but the difference is not significant; Yates' chi-square= 1.201;p=0.27

n0VCV the observed rate of Plosive responses is *lower* for close vowels than others, and the difference is significant; Yates' chi-square= 6.269;p=0.012

For all responses combined, the observed rate of Plosive responses is *lower* for close vowels than others, and the difference is significant; Yates' chi-square= 5.449;p=0.02.

We conclude that in the present experiment vowel height has no systematic effect on the judgments of English listeners. The only significant effect is found for n0VCV, and is in the contrary direction to that predicted by previous researchers. It is large enough to dominate the overall comparison. The English subjects' responses therefore do not indicate any greater degree of denasalization before high vowels than before others.

For Korean listeners, the effects of a putative link between vowel height and degree of denasalization are more difficult to model, since any height-related physical differences among m0 and n0 tokens would presumably be matched by corresponding differences in the perceptual categorization criteria for nasals. Since every m0 or n0 stimulus used in the experiment is accompanied throughout by its original following vowel, no differential predictions result for stimuli incorporating m0 or n0 tokens. However, if Koreans are more tolerant of denasalization before high vowels, it should follow that a higher proportion of Nasal responses should be given for [b] and [d] stimuli with high vowels than with others. This leads to four comparisons (in all tests, *df*=1):

- bCVCV the observed rate of Nasal response is significantly higher for close vowels than for others; Yates' chi-square= 4.005; p=0.045
- dCVCV the observed rate of Nasal response is significantly higher for close vowels than for others; Yates' chi-square= 5.82; p=0.016
- bVCV the observed rate of Nasal response is somewhat lower for high vowels than for others, but the difference is not significant; Yates' chi-square= 0.391; p=0.53
- dVCV the observed rate of Nasal response is significantly higher for close vowels than for others; Yates' chi-square= 40.289; p<<0.0001

These results seem to indicate that Korean listeners are more likely to categorize a non-nasal stimulus as Nasal when a high vowel follows than when a non-high vowel follows. Evidently, this claim about Korean listeners would have to be modified if a similar pattern were to be found for English listeners, but tests reveal that English subjects do not show this pattern. Numbers of [b] and [d] trials had to be combined, because of very low observed Nasal frequencies, leading to two comparisons; for both *df*=1.

- CVCV the observed rate of Nasal response is significantly *lower* for close vowels than for others; Yates' chi-square= 13.376; p= 0.00025
- VCV the observed rate of Nasal response is somewhat lower for high vowels than for others, but the difference is not significant; Yates' chi-square= 0.71; p=0.40.

Overall, the tests for links with vowel height tend to suggest (1) that tokens of m0 and n0 taken from high vowel environments were not physically more denasalized than tokens from other vowel environments; (2) Korean listeners have a criterion for categorization as Nasal which is somewhat sensitive to vowel height.

6.4 Summary

This experiment aimed to investigate whether denasalized nasals are in fact perceived as non-nasal by English listeners in both CVCV and VCV context and as non-nasal in VCV but as nasal in CVCV by Korean listeners. It also: looked into voiced plosives in both contexts to see if both groups of listeners responded as predicted in the hypotheses—as nasals in CVCV by Korean listeners but as plosives by English listeners, and as plosives by both groups in VCV; analysed whether alveolar and bilabial nasals are perceived as plosive at the same rate; and finally whether listeners' judgement is correlated with the height of the vowels following the target nasals. Part of the results of the current experiment is shown in Table 6.5.

	alveolar (%)				bilabial (%)			
	KS		ES		KS		ES	
	Nasal	Plosive	Nasal	Plosive	Nasal	Plosive	Nasal	Plosive
H1	78	23	2	98	97	3	30	70
H2	28	72	12	88	53	47	21	79
H3	73	27	3	97	91	9	11	89
H4	100	0	100	0	99	1	100	0

H1. Denasalized nasals in CVCV will be perceived as Nasal by KS and as Plosive by ES.
H2. Denasalized nasals in VCV will be perceived as Plosive by both KS and ES.
H3. Voiced plosives in CVCV will be perceived as Nasal by KS and as Plosive by ES.
H4. Sonorant nasals in VCV will be perceived as Nasal by both KS and ES.

Table 6.5: Responses to denasalized segments for each hypothesis by language group (%)

Overall, the hypotheses 1~4 were strongly supported: denasalized nasals were perceived as nasal by Korean listeners and as plosive by English listeners in the word-initial position (CVCV); denasalized nasals were judged as plosive by both groups of listeners in the intervocalic position (VCV); voiced plosives were categorized as nasal in CVCV by Korean listeners; and nasals were judged as nasal in VCV almost 100% by both groups of listeners. The only exception was denasalized bilabials in VCV, which were perceived as plosive in only 47% of the trials; however, this is still a substantially greater rate than the null hypothesis of 0% plosive response, thus the hypothesis is regarded as strongly supported.

Hypothesis 5 that denasalized alveolar and bilabial nasals would be judged denasalized in the equal proportion was not supported by the results. Denasalized alveolar nasals were more likely to be judged as denasalized than denasalized bilabial nasals were. This result does not support our hypothesis but is also opposite of what some previous researchers reported, which says that bilabial nasals are more likely to be judged as plosive.

Hypothesis 6 was that the height of the vowel following word-initial nasals would not affect the degree of being perceived as denasalized, which is in contrast with previous researchers' reports. The test results showed that both denasalized alveolar and bilabial nasals with a following high vowel were not judged as denasalized more often than those with a following non-high vowel; however, there seem to be some cues that Korean listeners, but not English listeners, use when judging a segment as nasal.

Going back to Table 6.3, we can see that the response rates are not absolute 100% or 0% as underlyingly predicted in the hypotheses. This could have resulted from several possible factors: one, some Korean listeners might have had their English listening skills affect their judgement; two, some stimuli might have lost domain-initial cues or had them weakened during splicing; three, some stimuli may have some unusual acoustic characteristics, for example, voiced plosives were not always realized as fully voiced plosives but sometimes approximants or fricatives, and sometimes even voiceless; and denasalized nasals were also sometimes realized as voiceless; and there are presumed to be some other unknown influences.

Figure 6.1 showed a coefficient of Korean-ness of each listener's judgement based on their Nasal response to denasalized nasals [m0, n0] and voiced plosives [b, d]. It effectively shows how 'Korean' each participant's perception was and it also displays how much one participant's judgement was straying towards that of English speakers' in this task.

Chapter 7

Discussion and Conclusions

7.1 Summary of findings of each experiment

Auditory and Acoustic analyses

- A large majority of word-initial Korean nasals /m/ and /n/ (76% of bilabials and 94% of alveolars) are judged 'denasalized' by the author in her capacity as trained phonetic observer. Examination of waveforms and spectrograms confirms that they have acoustic features that are strikingly different from those of sonorant nasals and resembling those of voiced plosives.
- Spectral energy levels in the "hold" phases of denasalized nasals are consistently lower than those of sonorant nasals throughout the range 0 Hz~3500 Hz. The denasalized segments appear to occupy an intermediate position between sonorant nasals and voiced plosives
- Denasalization appears to occur regardless of the height of the following vowel, contrary to previous reports.

Aerodynamic analyses

- The integrated nasal airflow in a window centred on the CV boundary is lower for denasalized segments than for sonorant nasals but higher than for voiced plosives. Assuming that 'plosive' and 'sonorant nasal' represent the low and high ends of a scale of velic opening, denasalized segments must have an intermediate degree (or a pattern of change such that its average value is an intermediate one).

- The instantaneous nasal airflow in the early part of a following vowel is significantly lower following denasalized segments than following sonorant nasals. Thus the carryover coarticulation of nasality which is found with sonorant nasals is greatly attenuated.
- Denasalization has been observed only in syllables which are both stressed and word initial. To that extent, it can perhaps be called a 'domain-initial strengthening process'. However, the claim that degree of denasalization is linked proportionally to a putative hierarchy of prosodic domains was not supported.

Accelerometer signals analyses

- In at least certain syllable types, denasalized nasals have similar effects to sonorant nasals on the vowels preceding them (similar anticipatory nasalization).
- Denasalized nasals have significantly lower nasalization effects than sonorant nasals do on the vowels following them (reduced carryover nasalization).
- Vowel types CVN and N0VN are the same in the section right after the onset of the vowels (1 of 10 sections) but significantly different in the rest. This appears to suggest some kind of coarticulatory linkage between N0 and N across the vowel, even though the nasality of N0 does not surface locally.
- Comparison of the nasal energy levels of the vowel types CVC and N0VC suggests that there may be a rapid upward movement of the velum shortly after the onset of the vowel in N0VC, possibly reflecting a specific denasalization gesture.
- Vowel types CVC and CVN0 are alike, as are vowel types NVN and NVN0. This may arguably be taken to imply that a denasalized segment (N0) has the potential to contribute anticipatory nasality to a vowel, but this is somehow suppressed unless a sonorant nasal N also precedes that vowel.
- Vowel types N0VC and CVN0 are alike except for the last 10% of their duration. This is presumed to result from some degree of anticipatory nasalization for N0.

Perception experiments

- Denasalized segments, categorised as nasals by Korean listeners when heard in domain-initial context, are categorized as voiced plosives by English listeners.
- Denasalized segments, removed from initial position and placed in intervocalic position, are categorized as plosives by *both* Korean listeners and English listeners. This indicates that the Korean listeners' categorization is context-sensitive: exactly the same portion of signal is judged as 'nasal' when presented in word-initial position, but 'plosive' when presented in intervocalic position.
- Plosive segments, removed from intervocalic position and placed in initial position, are categorized as nasals by Korean listeners and as plosives by English listeners. This is complementary to the previous observation, and confirms that Korean listeners are making a context-sensitive category choice, while English listeners make the same judgment regardless of context.
- Denasalized alveolar nasals are judged as plosive more often than denasalized bilabial nasals are. For reasons not yet fully determined, denasalized alveolar segments resemble realizations of alveolar plosives rather more than denasalized bilabials resemble bilabial plosives.
- The height of the following vowel does not greatly affect categorization results for either group of listeners, although there are indications that Korean listeners' judgements of vowel nasalization might be partly dependent on vowel height.

7.2 Status of denasalization

Korean nasals /m/ and /n/ have only ever been described by native Korean phoneticians as effectively the same as English nasals, but they are problematic for native speakers of English, who commonly perceive them as plosives. Koreans not only fail to notice them, but may even deny that the effect exists at all.

It appeared that there had been no in-depth investigation into the issue and the few researchers who reported on these nasals—mostly native speakers of English—had made only limited investigations. Hence the purpose of the current thesis was to identify and characterize these nasals by providing reliable and fairly extensive empirical data using a range of different methods.

Three main hypotheses were tested: one, nasals /m/ and /n/ are denasalized in word-initial position and are significantly different from sonorant nasals; two, denasalized nasals are similar to or same as voiced plosives in terms of nasality level during the hold phase and also nasalization of the following vowel; three, native speakers of English will perceive denasalized nasals as plosives while native speakers of Korean will have no problem categorizing them as nasals.

In all five aspects of the study which throw light on the nature and production of these sounds—auditory and spectrograms analyses, spectral analyses, aerodynamic and accelerometer analyses—it was confirmed that Korean nasals /m/ and /n/ are significantly different in word-initial position from those in word-medial position between vowels: denasalized nasals had distinctively lower level of nasal energy and flow not only throughout the whole hold phase but also into the vowel following.

As to their similarity to voiced plosives, not all experiments had the same results. Auditory analysis revealed high resemblance of denasalized nasals to voiced plosives, and simple inspection of spectrograms also supported this apparent resemblance, with absence of nasal formants and often a visible burst mark, these being typical features of voiced plosives realized with a complete oral obstruction. However, the three quantitative analyses—spectral, aerodynamic and accelerometer—revealed that they are similar but not identical: denasalized nasals had higher energy in the lower and top end frequency regions; had significantly higher mean nasal flow in the given time frame covering the consonant and the vowel (CV) and also at a point shortly after the vowel onset; and had significantly higher nasal accelerometer output in the first three and the last sections out of 10. English listeners respond to this array of characteristics by judging them mainly as plosive rather than nasal, and these very same characteristics must give native Korean speakers acoustical cues that signal 'nasal' instead of 'plosive', at least in the word-initial position (CVCV).

The perception test results showed strong contrasts between the two groups of listeners, Korean (KS: Korean speakers) and English (ES: English speakers). To recapitulate the striking extent of the contrast, Table 7.1 re-summarizes the results in response rates (%) to denasalized stimuli and voiced-plosive stimuli. All hypotheses which predicted the differential reactions of the two groups of listeners were strongly supported.

Even what appears to be the least favourable outcome for the perception-test hypotheses, the response of Korean listeners to [m0] in VCV, has a 'plosive' response rate of 47%, which vastly exceeds the null hypothesis prediction of 0%.

There can be little doubt that the production and perception of denasalized segments are broadly similar for the two places of articulation, bilabial and alveolar. However, they are not identical—serving as a reminder that descriptive categories such as 'nasality' and 'place of articulation' are only abstractions. The physical and perceptual factors which they stand for can only be partly separated, and may interact in unforeseen ways. As for the nature of the differences found, claims made by previous researchers that alveolar nasals are less likely to be judged denasalized than bilabial nasals were not supported: on the contrary, they were more likely (98%) judged denasalized than bilabials (70%) by English listeners.

Lastly, on the much-discussed issue of possible links between nasality and vowel height, the results of both production and perception tests do not show any link between degree of denasalization and the height of the following vowel. Small-scale impressionistic studies (Jones, 1924; Martin, 1951; Chen & Clumeck, 1975), which claimed this were based on a very limited number of samples in citation forms or artificial carrier sentences.

Stimuli	m0		n0		b		d	
Response	Nasal	Plosive	Nasal	Plosive	Nasal	Plosive	Nasal	Plosive
CVCV ES	30%	70%	2%	98%	11%	89%	3%	97%
CVCV KS	97%	3%	78%	23%	91%	9%	73%	27%
VCV ES	21%	79%	12%	88%	4%	96%	2%	98%
VCV KS	53%	47%	28%	72%	9%	91%	11%	89%

Table 7.1: Summary of response rates (%) to denasalized-nasal and voiced-plosive stimuli by English and Korean native speakers showing clear complementary patterns of response.

Overall, the results of the experiments presented in the current thesis strongly support our three main claims: denasalization is widely prevalent in word-initial nasals /m/ and /n/ in Korean, including the vowel that follows immediately after; denasalized nasals resemble voiced plosives acoustically and aerodynamically, though they are not exactly the same; denasalized nasals are perceived as plosives by English speakers and as nasals by Korean speakers in the word-initial position.

7.3 Limitations and future directions

This study was begun against a background in which denasalization was not a widely acknowledged feature of Korean. It does not figure in any established description of the language, and the author had an international conference paper rejected by a reviewer (presumably Korean) on the grounds that the putative 'denasalization' was illusory. But the illusion is entirely the other way around: when Korean is approached objectively, denasalization is revealed as a classic example of an allophonic variation which is immediately conspicuous to an outside observer but overlooked by the native speaker, who is effectively deaf to it. This affected the present study in that the overriding goal became that of establishing beyond question that the phenomenon does exist, and that it merits the term 'denasalization'. Had it already been established as a recognised feature of the language, which could be taken for granted as a starting-point, there would have been an opportunity to do more sophisticated studies of its perception and production.

In the aspect of production, both denasalized nasals and sonorant nasals could be investigated in much more detail if detailed imaging such as high-resolution real-time MRI movies were available. This technique would in principle allow us to observe the movement of the velum directly, providing detailed measurements of the height, the duration and the size of its opening for each segment. Ideally, the data would be used to drive a quantitative three-dimensional model of the velopharyngeal port. This, however, would be a major research project in itself, requiring a team of people and considerable resources, whereas the current main focus was a linguistic-phonetic one. Given the resources available, it was necessary to infer something about production from airflow measurements. It is hoped to attempt some imaging studies in future if opportunities become available.

We also have suggested that Korean speakers use different cues in judging nasals that English speakers do not detect. There is an opportunity, therefore, to make a detailed study of all the factors used by both groups (leaving aside the big context-sensitive effect that the present study documents for the first time). This could be done best with synthetic stimuli. There have been relatively few studies of the nasal-oral stop continuum using synthetic stimuli. Mandler (1976) made use of a terminal analog (formant) synthesizer, while Abramson et. al (1981) employed an articulatory model in which velum opening could be directly manipulated. But for either approach, difficulties arise in connection with the problematic segment types investigated in this thesis. The author devoted considerable time and efforts to produce a Korean oral-nasal stop continuum using available vocal tract simulators. However, it proved impossible in reasonable time to produce stimuli of sufficient naturalness. That could in part be due to the fact that the sounds we are dealing with are outside the range of types that current articulatory synthesizers are designed to model. It is hoped to undertake further work on this.

Although we have confirmed that Korean nasals /m/ and /n/ are acoustically and aerodynamically denasalized and they are perceived as plosives by native speakers of English, *why* these nasals undergo this is yet to be determined.

The denasalization is found only in stressed word-initial syllables and therefore has a potentially demarcative function, like stress itself, in indicating the beginning of a word. It would be interesting to devise a perception test in which denasalization could be shown to aid in the comprehension of particular phrases by signalling word-boundary location. If so, it would mean that Korean listeners could make use of denasalization as a cue to constituency in the perception of connected speech, while disregarding it as a cue to segment identification.

Why a particularly conspicuous type of “strengthening” might be applied only to stressed syllables beginning with nasals is unexplained, however. It may be relevant that several assimilation and sandhi processes noted in Chapter 2 give rise to nasals or sequences of nasals at syllable junctions. If nasals are multiplied and inserted in this way by automatic processes, their value as part of the distinctive form of lexical items may go down, so that there could be a perceptual advantage in signalling word-initial nasals very clearly. A first step towards exploring this idea further would be to determine the text-frequency of nasals in Korean compared with various other languages. It is also possible to imagine a type of perceptual experiment in which listeners might show a stronger preference for a denasalized realization of an initial consonant in a context with relatively more sonorant nasals in the neighbourhood to prompt the differentiation.

Much more speculatively, a different type of explanation might be some tendency towards the avoidance of nasality in prominent locations. ‘Nasality’ can be a long-term-feature of a person’s voice, or of an accent, and for both has a generally negative set of connotations. Overtly nasal speech may be judged as revealing lower intelligence, dishonesty, having ulterior motives to get something they want (especially women), and ‘nasal’ speakers as being immature or even boring (Addington, 1968). Since Korean has extensive carryover coarticulation of nasality, any word beginning with a fully sonorant nasal would have its most prominent syllable extensively nasalized. Partial denasalization of initial consonants would therefore have a relatively large effect on the overall ‘nasal’ effect of Korean. There are no risks to intelligibility, since Korean has no voiced plosives in initial position with which the denasalized segments might be confused. It might be possible to test this idea experimentally by obtaining subjective ratings of corresponding utterances in which only the nasality of prominent initial syllables was manipulated.

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http://www.koreanclass101.com/2008/05/28/picture-video-vocab-6-the-bus/ A forum in an online Korean lessons website. Learners of Korean do experience difficulty recognizing denasalized nasals and one can see that native Korean speakers do not recognize this problem.

Appendix

A.1 Recording materials scripts in Korean

이야기

메밀꽃 필 무렵

봉평장의 파장 무렵, '왼손잡이'인 드팀전의 허 생원은 장사가 시원치 않아서 속이 상한다. 조 선달에 이끌려 충주집을 찾는다. 거기서 나이가 어린 장돌뱅이 '동이'를 만난다. 허 생원은 대낮부터 충주집과 짓거리를 벌이는 '동이'가 몹시 밉다. 머리에 피도 안 마른 주제에 계집하고 농탕질이냐고 따귀를 올린다. '동이'는 별 반항도 하지 않고 그 자리를 물러난다. 허 생원은 마음이 좀 개운치 않다.

조 선달과 술잔을 주고받고 하는데 '동이'가 황급히 달려온다. 나귀가 밧줄을 끊고 야단이라는 것이다. 허 생원은 자기를 외면할 줄로 알았던 '동이'가 그런 기별까지 하자 여간 기특하지가 않다. 나귀에 짐을 싣고 대화장을 향해 산길을 가게 된다. 그들이 가는 길가에는 달빛에 메밀꽃이 흐드러지게 피어 있다.

달빛 아래 펼쳐지는 메밀꽃의 정경에 감정이 동했음인지 허 생원은 조 선달에게 몇 번이나 들려준 이야기를 다시 꺼낸다. 한때 경기가 좋아 한밑천 두둑이 잡은 적이 있었다. 그것을 노름판에서 다 잃어버렸다. 그리고 그는 평생 여자와는 인연이 없었다. 그런데 메밀꽃이 핀 여름 밤, 그날 그는 토방이 무더워 목욕을 하러 개울가로 갔다. 달이 너무도 밝은 까닭에 옷을 벗으러 물방앗간으로 갔다. 그리고 거기서 성 서방네 처녀를 만났다. 성 서방네는 파산(破産)을 한 터여서 처녀는 신세 한탄을 하며 눈물을

보였다. 그런 상황 속에서 허 생원은 처녀와 관계를 맺었고, 그 다음날 처녀는 빚쟁이를 피해서 줄행랑을 놓는 가족과 함께 떠나고 말았다.

그런 이야기 끝에 허 생원은 '동이'가 편모(偏母)만 모시고 살고 있음을 알게 된다. 동이가 자신의 아들일지도 모른다는 생각에 잠기다가 발을 빗디딘 허 생원은 나귀 등에서 떨어져 물에 빠지고 그걸 '동이'가 부축해서 업어 준다. 허 생원은 마음에 짐작되는 데가 있어 '동이'에게 물어 보니 그 어머니의 고향 역시 봉평임을 확인한다. 그리고 어둠 속에서도 '동이'가 자기처럼 '왼손잡이'임을 눈여겨 본다.

<u>뉴스</u>

1. 오늘 정치분야 대정부 질문에서는 고위공직자 비리조사처에 기소권을 부여하는 문제를 놓고 여야간 공방이 벌어졌습니다. 또 장기수 3 명을 민주화운동 희생자로 규정한 의문사진상규명위의 결정을 놓고도 논란이 이어졌습니다.

2. 직장에서 업무 때문에 건강검진이나 질병치료를 못 받기도 하고 또 미루는 경우가 많으실 텐데요, 병원에서 입원 권유를 받았지만 업무때문에 어쩔수 없이 입원을 미루다 질병이 악화돼 사망했다면 '업무상 재해'가 인정된다는 판결이 나왔습니다.

3. 노무현 대통령은 조금 전인 4 시부터 청와대에서 부시 미국 대통령의 특사 자격으로 우리나라를 방문한 콘돌리자 라이스 백악관 국가안보보좌관을 접견하고 있습니다. 노 대통령은 라이스 보좌관과 함께 북한 핵문제와 주한미군 재조정 문제, 그리고 이라크 추가 파병 등 양국 현안에 대해 의견을 나누고 있는 것으로 전해졌습니다.

4. 동탄 신도시 분양을 시작으로 고양과 인천 등 수도권에서 눈길을 끌만한 아파트가 대거 분양됩니다. 가격과 입지여건에서 경쟁력이 높은 이들 아파트 분양이 침체된 부동산 시장의 돌파구가 될 지 주목됩니다.

5. 미국 노동 시장의 고용창출 규모가 예상치에 크게 미치지 못하면서, 미국 노동 시장의 건전성에 의문이 제기 되고 있습니다. 하지만 11 월 대선을 앞두고 있는 조지 부시 미국 대통령은 미국 경제가 꾸준한 성장세를 보이고 있다는 점을 들어 이를 반박하고 나섰습니다.

낱말

6. 사랑; 누구나 쟁취; 만고의 진리; 대부분

7. 남자들은; 너도; 나도; 열 번; 며칠 동안; 니크롬선

8. 늪에서; 비오는 거리; 무조건; 도끼로; 매워서

9. 미워도 다시 한 번; 푸대접; 모진 마음으로; 내외적으로

10. 여자들은; 머리에서; 발끝까지; 목선이; 부족해도

문장

1. 만나기로 한 사람이 나타나지 않아서 전화를 했어요.
2. 오늘 만나기로 한 사람이 내일이나 만나자 전화가 왔어요.
3. 뜨거운 메밀국수보다 찬 메밀국수가 더 맛있어요.
4. 겨울엔 메밀국수보다 좋은 게 많다더라.
5. 누구한테든 말을 하고 가야지.
6. 미안하다는 말은 하지 말아요.

A.2 Recording materials scripts in phonemic transcription

/ijaki

poŋpʰjʌŋtɕaŋɰi pʰatɕaŋ mul[11]jʌp wensontɕapiin tɯtʰimtɕʌnɰi hʌseŋwʌnɯn tɕaŋsaka ɕiwʌntɕʰianasʌ soki saŋhanta. tɕosʌntale ikkɯlljʌ tɕʰuŋtɕuttɕipɯl tɕʰatnɯnta. kʌkisʌ naika ʌlin tɕaŋtolpeŋi toŋilɯl mannanta. hʌseŋwʌnɯn tenatputʰʌ tɕʰuŋtɕutɕipkwa tɕitkʌlilɯl pʌlinɯn toŋika mopɕi mipta. mʌlie pʰito anmalɯn tɕutɕee kjetɕiphako noŋtʰaŋtɕilinjako ttakwilɯl ollinta. toŋinɯn pjʌl panhaŋto hatɕi anko kɯtɕalilɯl mullʌnanta. hʌseŋwʌnɯn maɯmi tɕom keuntɕʰiantʰa.

tɕosʌntalkwa sultɕanɯl tɕuko patko hanɯnte toŋika hwaŋkɯphi talljʌonta. Nakwika pattʑulɯl kkɯnko jatanilanɯn kʌɕita. hʌseŋwʌnɯn tɕakilɯl wemjʌn haltɕullo alattʌn toŋika kɯlʌn kipjʌlkkatɕi hatɕa jʌkan kitʰɯk hatɕika anta. Nakwie tɕimɯl ɕitko tehwatɕaŋɯl hjaŋhe sankilɯl kake twenta. kɯtɯli kanɯn kilkaenɯn talpite memilkkoti hɯtɯlʌtɕike pʰiʌitta.

Talpitale pʰjʌltɕʰʌtɕinɯn memilkkote tɕʌŋkjʌŋe kamtɕʌŋi toŋhetɯintɕi hʌseŋwʌnɯn tɕosʌntaleke mjʌtpʌnina tɯlljʌtɕun ijaki lɯl taɕi kkʌnenta. hantte kjʌŋkika tɕoa hanmitɕʰʌn tutuki tɕapɯn tɕʌki issʌtta. kɯkʌsɯl nolɯmpʰnesʌ ta ilʌ pʌljʌtta. kɯliko kɯnɯn pʰjʌŋseŋ jʌtɕawanɯn injʌni ʌpsʌtta. kɯlʌnte memil kkotɕʰi pʰin jʌlɯmpam kɯnal kɯnɯn tʰopaŋi mutʌwʌ mokjokɯl halʌ keulkalo kata. tali nʌmuto palkɯn kkatalke osɯl pʌsɯlʌ mulpaŋatkanɯlo katta. kɯliko kʌkisʌ sʌŋsʌpaŋne tɕʰʌnjʌlɯl mannatta. sʌŋsʌpaŋnenɯn pʰasanɯl han tʰʌjʌsʌ tɕʰjʌnjʌnɯn sinse hantʰn̠ɯl hamjʌ nunmulɯl pojʌtta. kɯlʌn saŋhwaŋ sokesʌ hʌseŋwʌnɯn tɕʰʌnjʌwa kwankjelɯl metɕʌtko kɯtaɯmnal tɕʰʌnjʌnɯn pittɕeŋilɯl pʰihesʌ tɕulheŋlaŋɯl notnɯn katɕokkwa hamkke ttʌnako malatta.

kɯlʌn ijaki kkɯtʰe hʌseŋwʌnɯn toŋika pʰjʌnmoman moɕiko salko issɯmɯl alke twenta. toŋika tɕaɕinɰi atɯliltɕito molɯntanɯn seŋkake tɕamkitaka palɯl pittitin hʌseŋwʌnɯn nakwi tɯŋesʌ ttʌlʌtɕʌ mule ppatɕiko kɯkʌl toŋika putɕʰukhesʌ ʌpʌtɕunta. hʌseŋwʌnɯn maɯme tɕimtɕaktwenɯn teka issʌ toŋieke mulʌponi kɯ ʌmʌniɰi kohjaŋ jʌkɕi poŋpʰjʌŋimɯl hwakin hanta. kɯliko ʌtum sokesʌto toŋika tɕakitɕʰʌlʌm wensontɕapiimɯl nunjʌkjʌponta.

[11] /l/ in Korean is realised at [ɾ] intervocalically.

njusɯ

il. onɯl tɕʌŋtɕʰipunja tetɕʌŋpu tɕilmunesʌnɯn kowikoŋtɕiktɕa pili tɕosatɕʰʌe kisokwʌnɯl pujʌhanɯn muntɕelɯl notko jʌjakan koŋpaŋi pʌlʌtɕʌtsɯmnita. tto tɕaŋkisu semjʌŋɯl mintɕuhwa untoŋ hiseŋtɕalo kjutɕʌŋhan ɰimunsatɕinsaŋ kjumjʌngwiɰi kjʌltɕʌŋɯl notkoto nonlani iʌtɕʌssɯmnita.

i. tɕiktɕaŋesʌ ʌpmuttemune kʌnkaŋ kʌmtɕinina tɕilpjʌŋtɕʰiljolɯl motpatkito hako tto milunɯn kjʌŋuka manɯɕiltʰentejo, pjʌnwʌnesʌ ipwʌn kwʌnjulɯl patattɕiman ʌpmuttemune ʌttɕʌlsuʌpɕi ipwʌnɯl miluta tɕilpjʌŋi akhwatwe samaŋhettamjʌn ʌpmusaŋ tɕeheka intɕʌŋtwentanɯn pʰankjʌli nawassɯmnita.

sam. nomuhjʌ tetʰoŋljʌŋɯn tɕokɯmtɕʌnin neɕiputʰʌ tɕʰʌŋwateesʌ puɕi mikuk tetʰoŋljʌŋɰi tʰɯksa tɕakjʌkɯlo ulinalalɯl paŋmunhan kʰontollitɕa laisɯ pekakkwan kukkaanpopotɕwakwanɯl tɕʌpkjʌnhako issɯmnita. notetʰoŋljʌŋɯn laisɯ potɕwakwankwa hamkke pukhan hekmuntɕewa tɕuhanmikun tɕetɕotɕʌŋmuntɕe, kɯliko ilakʰɯ tɕʰuka pʰapjʌŋ tɯŋ jaŋkuk hjʌnane tehe ɰikjʌnɯl nanuko issnɯn kʌsɯlo tɕʌnhetɕʌssɯmnita.

sa. toŋtʰan sintosipunjaŋɯl sitɕakɯlo kojaŋkwa intɕʰʌn tɯŋ sutokwʌnesʌ nunkilɯl kkɯlmanhan apʰatʰɯka tekʌ punjaŋtwemnita. kakjʌkkwa iptɕijʌkʌnesʌ kjʌŋtɕeŋljʌki nopʰɯn itɯl apʰatʰɯ punjaŋi tɕʰimtɕʰetwen putoŋsan sitɕaŋɰi tolpʰakuka tweltɕi tɕumok twepnita.

o. mikuk notoŋsitɕaŋɰi kojoŋtɕʰaŋtɕʰul kjumoka jesaŋtɕʰie kʰɯke mitɕʰitɕi mothamjʌnsʌ mikuk notoŋsitɕaŋɰi kʌntɕʌnsʌŋe ɰimuni tɕekitweko itsɯpnita. hatɕiman sipilwʌl tesʌnɯl aptuko itnɯn tɕotɕipusi mikuk tetʰoŋljʌŋɯn mikuk kjʌŋtɕeka kkutɕunhan sʌŋtɕaŋselɯl poiko ittanɯn tɕʌmɯl tɯlʌ ilɯl panpakhako nasʌtsɯpnita.

natmal

yuk. salaŋ; nukuna; tɕeŋtɕʰwi; mankoɰi; tɕinli; tepupun

tɕʰil namtɕatɯlɯn; nʌto; nato; jʌlpʌn; mjʌttɕʰil toŋan; nikʰɯlomsʌn

pʰal. nɯpʰesʌ; pionɯn kʌli; mutɕokʌn; tokkilo; mewʌsʌ

ku. miwʌto taɕi hanpʌn; pʰutetɕʌp; motɕin maɯmɯlo; newetɕʌkɯlo

sip. jʌtɕatɯlɯn; mʌliesʌ; palkkɯtʰkkatɕi; moksʌni; putɕokʰeto

muntɕaŋ

il. mannakilo han salami natʰanatɕi anasʌ tɕʌnhwalɯl hessʌjo.

i. onɯl mannakilo han salami neilina mannatɕa tɕʌnhwaka wassʌjo.

sam. ttɯkʌun memil kuksupota tɕʰan memil kuksuka tʌ masissʌjo.

sa. kjʌulen memil kuksupota tɕoɯnke manhtatʌla.

o. nukuhantʰetɯn malɯl hako kajatɕi.

yuk. mianhatanɯn malɯn hatɕi malajo./

A.3 Recording materials scripts in English translation

<u>Story</u>

The Pongpyeong market is ready to close for the day and Mr. Huh, a left hander, is not so happy about the day's numbers. He reluctantly visits Mrs. Chungju's tavern, dragged by fellow trader Mr. Cho. There, he meets Tongi, a young itinerant vendor. Mr. Huh feels much annoyed by Tongi who is flirting with Mrs. Chungju openly. He throws him a smack, accusing him of being too young to chat up a mature woman. Tongi doesn't say much back to him but dismisses himself from the scene. Mr. Huh feels sorry.

Tongi rushes back while Mr. Huh is having a few drinks with Mr. Cho. He reports that the donkey cut loose and is going crazy. Mr. Huh is a little surprised and thinks highly of Tongi for letting him know about it. He could have not cared, he thought to himself. They are now all back on the road towards another market, Taehwa. The moon is shining on the buckwheat flowers by the road.

Touched by the scenery of the buckwheat flowers in the moonlight, Mr. Huh brings up the story that he has already told Mr. Cho a few times before. Once he made fortune when the economy was good all of which he lost in gambling. And he has never had any luck with women. Then, one summer night when buckwheat flowers were in bloom all around, he went to the brook to take a dip as it was very hot in the hut. Because the moon was shining so brightly, he went into the mill to get undressed. And there, he met Mr. Seong's daughter. Miss Seong started to cry, talking about her family's misfortunes that lead them into bankruptcy. In the middle of that they ended up making love. The next day the girl had to leave the town with her family away from the creditors.

At the end of telling his story, Mr. Huh realizes that Tongi lives alone with a single mother. Deep into the thought that Tongi might be his son, Mr. Huh takes a swing of his leg and falls off the donkey into the water. Tongi helps him up and carries him on his back. Mr. Huh, with this idea in his mind, asks Tongi, who reveals his mother is also from Pongpyeong. And he takes a long stare, despite the dark, at Tongi, who is also a left hander, just like himself.

News

1. Today at the hearing for the government's politics department, there was a battle between the ruling and opposition parties with regards to the issue of granting the indictment rights to the high-ranking government officials' corruption investigation office. The battle continued on the decision made by the Special Act to Find the Truth on Suspicious Deaths that defined 3 long-term inmates as pro-democracy victims.
2. Many miss or postpone their health check-up or treatment because of work. Recent court rulings said that if you die because you have had to put off getting admitted to a hospital because of work even though you have been advised to by your doctor, it is considered a matter of occupational health and safety.
3. President Roh Moo Hyun is meeting with Condoliza Rice, Secretary of National Defence from the White House, who is visiting the Blue House as a special messenger of President Bush of the US. President Roh is reported to be discussing with the Secretary of Defence, Rice, matters such as denuclearisation of North Korea, the US troops in South Korea, and sending additional troops to Iraq, the matters of which currently concern both countries.
4. Starting from the sales in the new city in Tongtan, a large number of eye-catching apartments are going to be open for sale in the capital region such as Koyang and Incheon. Attentions are being paid to the sales of these apartments, which are highly competitive in terms of the price and locations, as to whether they will be a breakthrough in the currently depressed real estate market.
5. Questions are being raised as to the soundness of the American labour market as the job creation rate of the American labour market falls greatly below expectations. However, President Bush, facing the presidential election in November, argued against these concerns, pointing out the fact that the American economy has been making steady progress.

Words

6. love; anyone; achievement; an eternal truth; most
7. men *subj.*; you (also); me (also); ten times; for a few days; Nicrome wire
8. in a swamp; rainy streets; unconditionally; with an axe; (because) it’s spicy
9. bitter but once again; inhospitality; with tough attitudes; domestic and foreign
10. women; from head; to toe; the neck line; insufficient but

Sentences

1. I called because the person I was supposed to meet did not show up.
2. The person I was going to meet today called suggesting meeting tomorrow.
3. Cold buckwheat noodles are tastier than hot buckwheat noodles.
4. I hear that there are many things better than buckwheat noodles in the winter.
5. You should have told someone before you left.
6. Don’t say sorry.

A4. Overview of all experimental subjects

	Regional Accent	Age	Gender	Time spent overseas (mo)	Auditory & Acoustic	Aerodynamic	Accelerometer	Perception
S1	South West	25	M	4	✓			
S2	Central West	25	F	11	✓			
S3	Seoul	29	M	10	✓			
S4	Seoul	22	F	3	✓			
S5	South West	25	M	12	✓			
S6	South West	27	M	3	✓			
S7	South East	23	F	3 wks	✓			
S8	South East	23	F	3 wks	✓			
S9	Seoul	29	M	3		✓		✓
S10	South East	30	M	18		✓		
S11	Seoul	23	M	3		✓		✓
S12	South East	31	M	2		✓		
S13	South	31	F	3		✓		
S14	Seoul	23	F	6		✓		
S15	Seoul	25~30	F	2		✓		
S16	Seoul	20	F	9		✓		
S17	Seoul	26	F	7 weeks			✓	
S18	Seoul	21	F	7 weeks			✓	
S19	Seoul	19	F	9			✓	✓
S20	South West	24	F	3 weeks			✓	
*KS21	Seoul	31	M	12				✓
KS22	Seoul	26	F	4				✓
KS23	Seoul	27	F	6				✓
KS24	South West	33	M	3				✓
KS25	Seoul	27	M	11				✓
KS26	Seoul	30	F	6				✓
KS27	Seoul	35	M	12				✓
ES1	SBE	19	F	Y**				✓
ES2	SBE	18	F	Y				✓
ES3	SBE	38	M	Y				✓
ES4	SBE	38	F	Y				✓
ES5	SBE	44	F	N				✓
ES6	SBE	40	M	N				✓
ES7	SBE	32	F	Y				✓
ES8	SBE	22	F	Y				✓
ES9	SBE	22	F	Y				✓
ES10	SBE	24	F	Y				✓

* Korean subjects are designated KS in the perception test, to distinguish them from English subjects (ES).
** Training in phonetics: Yes or No