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Unveiling Denasalization as an Ongoing Sound Change: The Role of Prosody and Gender in Seoul Korean

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Abstract

This study examines variation in coarticulatory vowel nasalization in Seoul Korean as a function of prosodic boundaries and gender, exploring its role in an emerging denasalization sound change. Coarticulatory vowel nasality, measured by A1–P0, was analyzed in the word-initial vowels of /ma.mi/ across three prosodic boundary conditions (IP-initial, AP-initial, and Wd-initial) in 35 speakers in their 20s. Results show that phrase-initial vowels exhibit reduced nasality as part of domain-initial articulatory strengthening, suggesting that denasalization of word-initial nasal consonants extends to the following vowel, reducing its coarticulatory nasalization and thus signaling the progression of a position-driven sound change. Significant gender differences were found: male speakers consistently adhere to this change throughout the vowel, exhibiting greater reductions in coarticulatory vowel nasalization in phrase-initial contexts. In contrast,

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female speakers retain higher nasality levels in both phrase-initial and phrase-medial positions by regulating the coarticulatory process. These gender-related differences may reflect socially grounded perceptions of nasality and/or female speakers' tendency to preserve phonological features, influencing speech production choices. These findings highlight the interplay between prosodically driven phonetic variation and gender: speakers actively control the degree of vowel nasalization, and this phonetic variation, in turn, is further shaped by gender, potentially evolving into a systematic sound change.

Keywords
Vowel nasalization, denasalization, prosodic boundary, gender-related variation, Seoul Korean

1 Introduction

Phonetic forms exhibit inherent variability, influenced by a range of linguistic and non-linguistic factors (e.g., Cho, 2016; Kingston & Diehl, 1994; Lindblom, 1990; Watt, 2006). A significant source of this variability arises from the phonetics–prosody interface, where prosodic elements—such as prosodic boundaries formed by the grouping of words into phrases—play a crucial role in shaping the phonetic realization of phonological forms (e.g., Cho & Keating, 2001; Fougeron, 1999; Garellek, 2022; Keating et al., 2004; see Fletcher, 2010 for a related review). This interface influences not only phonological contrasts but also non-contrastive phonetic details, including low-level phonetic processes. For instance, prosodic factors can shape coarticulatory patterns by influencing the temporal coordination of articulatory gestures. This is particularly evident in vowel nasalization, where an adjacent nasal consonant causes anticipatory nasalization of the vowel due to articulatory overlap (e.g., Kühnert & Nolan, 1999). Given its inevitable mechanistic nature, coarticulatory nasalization is widely attested across languages (e.g., Cohn, 1990; Delvaux et al., 2008; Farnetani, 1990; Scarborough et al., 2015), but its realization varies cross-linguistically and even among speakers of the same language (e.g., Zellou, 2022). This variation suggests that speakers exert some degree of control over this low-level phonetic process, challenging the assumption that it is purely mechanical (see Zellou, 2022 for a comprehensive review). Crucially, a growing body of cross-linguistic research provides further evidence that vowel nasalization is systematically controlled by speakers in relation to prosodic structure. Studies across multiple languages, including English (Cho et al., 2017), French (Fougeron, 2001), Korean (Cho & Keating, 2001; Jang et al., 2018), and Mandarin Chinese (Li et al., 2020), demonstrate that processes at the phonetics–prosody interface operate in a language-specific manner.

For instance, Cho et al. (2017) investigated coarticulatory nasalization in monosyllabic CVN and NVC words in American English across different prosodic environments, including focus-induced prominence and prosodic boundaries. They found that focus-induced prominence, expressed through pitch accent (the primary means of marking prominence in English), lengthened nasal consonants, enhancing their nasality, while neighboring vowels remained oral, resisting nasalization. In contrast, prosodic boundary effects led to the shortening of onset nasal consonants due to domain-initial strengthening, which enhanced oral articulation and, in turn, weakened nasality. This nasal weakening resulted from the reinforcement of the [consonantal] feature through increased oral articulation (Fougeron & Keating, 1997). As a consequence, vowels were less nasalized phrase-initially than phrase-medially. These findings demonstrate that low-level phonetic processes are not purely mechanical but are actively shaped by speakers according to prosodic structure (cf. Cho, 2016).

Seoul Korean presents a distinct language-specific case. While phrase-initial nasality in English is influenced by prosodic structure and remains within the domain of phonetics, the nasal reduction in Seoul Korean appears to have progressed toward phonologization, as proposed by previous literature (e.g., Y. Kim, 2011; Yoshida, 2008; see Yoo & Nolan, 2020 for a related discussion). This ongoing change is reflected in a significant reduction of nasality in phrase-initial positions, resulting in markedly shortened nasal duration (Jang et al., 2018; Yoo & Nolan, 2020). Moreover, empirical findings suggest that this shortened nasal duration is accompanied by an abrupt suppression of vowel nasalization near the onset of the vowel in Seoul Korean (Jang et al., 2018; Yoo & Nolan, 2020). As a consequence, non-native listeners of Korean often misperceive phrase-initial nasal consonants as oral sounds (Y. Kim, 2011; Yoshida, 2008). This extreme nasal reduction suggests that denasalization in Seoul Korean has moved beyond phonetic variation and is instead evolving into a position-dependent phonological process.

In this study, we aim to deepen our understanding of the phonetic underpinnings of Seoul Korean's position-driven denasalization and its status as an ongoing sound change. While many previous studies have provided descriptive analyses of onset nasal consonants as part of this change (Y. Kim, 2011; Yoo & Nolan, 2020; Yoshida, 2008), they have not examined its effect on coarticulatory nasalization in the following vowel—an important phonetic cue to nasality—or how this process may be progressing within the speech community. Thus, this study shifts its focus to how phrase-initial reduction of nasal murmur duration may be reflected in the degree of coarticulatory nasalization in the following vowel, and how this process is conditioned by gender as a sociolinguistic factor. That is, we examine whether this putative phonological process extends beyond the consonant level, as reflected in coarticulatory vowel nasalization, shedding light on its progression toward prosodically conditioned phonologization across genders.

Gender-based differences in speech production may arise from physiological or biological factors, but they also often carry sociophonetic significance—shaping patterns of sound change, reflecting social constructions of gender identity, or indexing communicative goals such as informativeness (e.g., Beddor, 2023; Eckert, 1989; Kendall & Fridland, 2021; Kendall et al., 2023; Labov, 1990; Oh, 2010). In particular, female speakers are frequently observed leading sound changes, as they tend to favor more innovative linguistic expressions (Labov, 1973; Oh, 2010). This pattern is also evident in Seoul Korean, where young female speakers are at the forefront of a boundary-related sound change: the merger of voice onset time (VOT) distinctions between lenis and aspirated stops in phrase-initial positions (Bang et al., 2018; Choi et al., 2020; Kang, 2014). Like denasalization, this change is prosodically conditioned, occurring specifically in phrase-initial contexts. Given this pattern, it is plausible that female speakers also lead denasalization, as both changes involve boundary-related phonetic reduction processes. If this is the case, we would expect female speakers to exhibit greater advancement of prosodically conditioned denasalization, reflected in greater reductions in coarticulatory vowel nasalization in phrase-initial positions compared to phrase-medial positions.

At the same time, an alternative possibility must also be considered. Female speakers are often characterized as producing clearer and more articulate speech, as they tend to be more sensitive to standard and socially prestigious linguistic forms (Byrd, 1994; Labov, 2006; Oh, 2010). Since denasalization results in a reduced and less canonical nasal sound, female speakers may be less inclined to participate in this change, which entails diminished nasalization. Notably, a greater degree of coarticulatory vowel nasalization has been observed in some studies as a characteristic of nasality in clear speech (Beddor, 2009; Scarborough & Zellou, 2013). Furthermore, nasalized speech has been reported as culturally preferred in some Asian communities, including Japan and China (Endo, 2008; Yueh, 2016), which may further discourage female speakers from adopting this sound change. These possibilities indeed align with our preliminary findings based on data from eight female and nine male speakers (Lee et al., 2023), which indicate that while both genders exhibit an extreme reduction in nasal consonant duration in phrase-initial positions to a similar extent, females tend to preserve nasality through vowel nasalization more than males. However, given the limited sample size, these findings remain preliminary.

To build on this, we extend our investigation to 35 Seoul Korean speakers (18 females and 17 males), examining the effects of prosodic position (phrase-initial vs. medial) on coarticulatory vowel nasalization. By analyzing vowel nasalization in the disyllabic word /ma.mi/, we explore how gender interacts with prosodically conditioned denasalization in Seoul Korean. Specifically, we investigate how this low-level coarticulatory process differs between female and male speakers and how gender shapes phonetic variation in relation to prosodic structure. More broadly, this study aims to refine our understanding of the phonetics–prosody interface by examining how sociolinguistic factors, such as gender, influence low-level coarticulatory processes. In doing so, we contribute to a broader discussion on the dynamics of denasalization as an ongoing sound change in Seoul Korean. Together, these findings illuminate how speakers actively control low-level phonetic variation in ways that are phonologically and sociophonetically meaningful.

2 Methods

2.1 Participants and recording

The materials for this study were sourced from an acoustic-articulatory database for Korean, which is currently being constructed at the Hanyang Institute for Phonetics and Cognitive Sciences of Language (HIPCS, 2022). Data from 35 native speakers of Seoul Korean (18 females, 17 males) were analyzed. All participants were born and raised in the Seoul/Gyeonggi region. The mean age of the participants was 23.6 years, with an age range of 19 to 29. The acoustic data were recorded in a soundproof room using a Tascam HC-P2 digital recorder and a SHURE KSN44 condenser microphone at a 44 kHz sampling rate, alongside articulatory data collected with an Electromagnetic Articulograph (Carstens AG501). For the purposes of the present study, only the acoustic data were analyzed.

2.2 Speech materials

The HIPCS database corpus contained several passages, and for this study, we selected one that featured a disyllabic name with nasal consonants /ma.mi/. We analyzed the initial syllable /ma/ of /ma.mi/ to examine the influence of the word-initial nasal consonant on the following vowel /a/. It is worth mentioning that the nasal onset consonant in the second syllable (/ma.<u>mi</u>/) may exert some anticipatory coarticulatory nasalization on the examined vowel (/m<u>a</u>.mi/). However, such effects are generally weaker than those induced by coda nasals within the same syllable (Krakow, 1999). Our analysis focuses on carryover nasalization from the onset consonant in the initial syllable, as we are specifically concerned with the denasalization of word-initial nasals and their effects on the following vowel. Moreover, because the following /m/, as the onset of the second syllable, remains constant across all conditions, and because domain-initial strengthening effects are typically confined to the initial syllable (e.g., Cho, 2016; Cho & Keating, 2001), we expect that any anticipatory nasalization from the second syllable is unlikely to affect the prosodic boundary effects under investigation. Note that we only included /ma/ context to improve measurement accuracy of vowel nasality, as explained in Section 2.3.

The analyzed passage was carefully designed to prompt the production of /ma.mi/ in varying prosodic boundary contexts, and the target /ma.mi/ appeared 11 times across different locations

Table 1. Example Sentences With Target Word /ma.mi/ in Phrase-Initial and Phrase-Medial Contexts (a, b) and With Compound Word /jaŋ.pʰa.mi.ma/ (c). The Entire Passage is Available at https://osf.io/ecm6s/.

a	. . . 왼쪽에 # 마미네라는 빵집이 또 생겼어. . . (# = IP) . . . *wentʃ*oke # mamineɾanɨn p*aŋtʃipi t*o sɛŋkjʌs*ʌ. . .* “. . .on the left also appeared the bakery *Mami*’s . . .”
b	. . . 계피 # 마미빵에 집중하게 되었어 (# = Wd) . . . *kjepʰi # mamip*aŋe tʃiptʃuŋhake tweʌs*ʌ* “(they) began to specialize in *Mami*’s cinnamon bread . . .”
c	. . . 양파를 재료로 넣고 빵을 만들어 양파미마빵, ... *jaŋpʰaɾɨl tʃɛɾjoɾo nʌhko p*aŋɨl mantɨɾʌ, jaŋpʰamimap*aŋ, . . .* . . . “(they) made bread using onions and named it *Mima*’s onion bread . . .”

within this single passage. In some cases, /ma.mi/ was placed after an adverbial phrase, as shown in Table 1-a. In others, /ma.mi/ was incorporated as the second element of a two-word compound noun, as illustrated in Table 1-b. Participants read the passages twice at a normal speech rate and twice at a fast speech rate. However, only the data from the normal speech rate were used for the current analysis, as the fast speech contained numerous tokens where a clear demarcation between the vowel and the surrounding nasal consonants was not possible. In total, 770 tokens were collected (i.e., 35 speakers × 2 repetitions × 11 occurrences of /ma.mi/ in one passage). Forty-five tokens (5% of all tokens collected) were removed due to mispronunciation, hesitation, or noise in the recording.

It is crucial to reiterate that this study is based on a corpus of read speech, rather than a controlled elicitation experiment. Although the passage was constructed to naturally elicit certain prosodic conditions, participants were not given explicit instructions regarding phrasing. As a result, the same sentence within the passage could be produced with different prosodic boundary realizations (e.g., IP-initial, AP-initial, or AP-medial), depending on the speaker’s phrasing choices. As Seoul Korean utilizes at least two primary prosodic levels above the word, according to the intonation model of Jun (2005), namely the Intonational Phrase (IP) and Accentual Phrase (AP), we considered these two prosodic phrase levels in our analysis. The prosodic boundary contexts were manually annotated based on auditory and acoustic cues and categorized as IP-initial, AP-initial, or AP-medial following established K-ToBI conventions (Jun, 2000). Tokens were labeled as IP-initial if there was clear pre-boundary lengthening on the preceding syllable and/or a noticeable pause. Tokens were considered AP-initial if AP-related tonal rises were detected on the preceding syllables, even in the absence of lengthening, as AP-final syllables do not always exhibit pre-boundary lengthening. When there were no such acoustic or auditory cues of AP-final boundaries on the preceding syllable, the token was labeled as AP-medial. Prosodic positions were initially annotated by two authors who were trained K-ToBI transcribers. Any discrepancies were resolved through discussion with two additional authors. The inter-transcriber agreement rate was 89.7%. This resulted in 144 IP-initial tokens, 416 AP-initial tokens, and 165 AP-medial tokens. (Note that for target words of the type shown in Table 1-a, 135 tokens were ultimately categorized as IP-initial, 198 as AP-initial, and 0 as AP-medial. For target words of the type shown in Table 1-b, 9 tokens were categorized as IP-initial, 218 as AP-initial, and 165 as AP-medial.)

It is also important to note that the passage did not include a non-nasal counterpart that could serve as an oral control for the target word /ma.mi/ in phrase-initial position. Ideally, a comparison such as /Ca.mi/ (where C is an oral stop) versus /ma.mi/ would have allowed us to assess vowel nasalization (as reflected in A1–P0) in /ma/ relative to a matched oral context. This would have enabled a direct comparison of how A1–P0 in the nasal context /ma/ varies as a function of prosodic position, relative to its oral counterpart. While this remains a limitation, the existing data still allowed us to examine how vowel nasalization differs between phrase-initial and phrase-medial positions as a function of gender, which is a central focus of this study.

That said, we were able to analyze phrase-medial /p^{h}a/ within the phrase-medial sequence /jaŋ.p^{h}a.mi.ma/ (/jaŋ.p^{h}a/ "onion" + /mi.ma/ "Mima [name]"), as shown in Table 1-c. The sequence /p^{h}a.mi/ thus served as a phrase-medial oral control (/Ca.mi/) for comparison with /ma.mi/. This allowed us to directly compare AP-medial /ma/ and /p^{h}a/—two forms differing in onset nasality but matched in following syllable (/mi/) and prosodic position. This provided a useful window into how a nasal onset consonant preceding the vowel /a/ influences vowel nasalization, relative to an oral onset, while controlling for the upcoming segment. Thus, through this additional analysis in the phrase-medial context, we could not only examine how onset nasality affects vowel nasalization relative to the oral control context in the absence of phrase-initial denasalization, but also how the potential gender effects on the vowel nasalization can still be observable in a more controlled context.

For /p^{h}a/, a total of 140 tokens were collected within the passage (i.e., 35 speakers × 2 repetitions × 2 occurrences). Forty-four tokens were excluded due to an AP boundary following /p^{h}a/, and an additional four tokens were removed due to recording noise. Given that phrase-initial nasal onsets are expected to undergo denasalization, /ma/ in /ma.mi/ is anticipated to retain full nasality phrase-medially. While this comparison does not address the absence of a fully oral control in phrase-initial position, it still offers insight into how variations in onset consonant nasality influence vowel nasality within the phrase.

2.3 Measurement

Building on the method used in Cho et al. (2017), we evaluated the nasality of the vowel by measuring A1–P0 during the vowel's articulation to gauge the extent of nasalization. The A1–P0 value represents the difference in amplitude between the first formant (A1) and the spectral nasal peak (P0), which typically appears around 250–450 Hz. A1–P0 values are inversely proportional to the degree of nasalization, meaning lower A1–P0 values indicate greater nasalization. Since high vowels with an F1 below 500 Hz often have overlapping A1 and P0, we focused only on the non-high vowel /a/ in this study to improve measurement precision. A1–P0 measurements were taken at three relative time points (25%, 50%, and 75%) of the vowel's duration (refer to Cho et al., 2017) using a Praat script developed by Styler (2017). This relative measurement captures the spread of coarticulatory nasalization throughout the vowel, illustrating how the effect extends beyond the proximal point near the nasal consonant. Figure 1 shows the schematized A1–P0 measures at the three relative time points in the vowel. Figure 1(a) shows a smaller value of A1–P0 at the 25% timepoint (which is located closest to the left-edge onset nasal source), indicating a greater degree of vowel nasalization; Figure 1(c) shows a greater A1–P0 value, indicating a lesser degree of vowel nasalization at the 75% timepoint, furthest from the left-edge onset nasal source. Note that while the following /m/ in the second syllable may also influence nasalization, the critical factor—domain-initial strengthening—is expected to affect the first syllable and drive the denasalization process. Thus, any influence from the following /m/ is likely to be consistent—or minimal at most—across experimental conditions.

It should also be noted that this study examines the degree of coarticulatory vowel nasalization in relation to the denasalization process and does not include the direct measurements of onset nasal duration (the nasal murmur before the vowel onset). While examining the degree of nasality and nasal duration in word-initial nasal consonants is important for understanding the patterns of

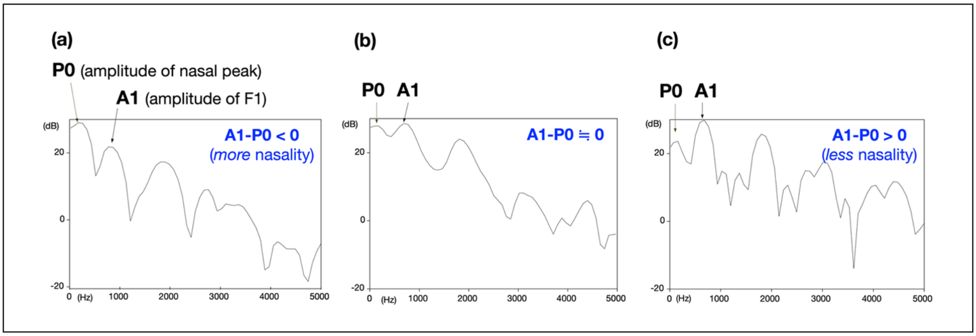

Figure 1. Schematization of vowel nasalization measurements of A1–P0 at three different relative time points in the vowel. The 25% timepoint (located closest to the left-edge onset nasal source) indicates a greater degree of vowel nasalization (with a smaller A1–P0), while the 75% timepoint (furthest from the onset nasal source) shows a lesser degree of vowel nasalization (with a greater A1–P0). (a) 25% point away from N, (b) 50% point away from N, and (c) 75% point away from N.

denasalization, this decision was based on the considerable variability we observed in the realization of these segments across speakers and tokens. Specifically, the dataset—which includes and expands upon the corpus analyzed in Lee et al. (2023)—revealed a wide range of phonetic outcomes: canonical nasal murmurs, weak nasals with low-frequency voicing bars lacking higher-frequency nasal energy, short nasal murmurs followed by non-nasal voicing bars, releases with stop-like bursts, and releases followed by a period of voicing lag, and many other ambiguous cases. (Some of these patterns roughly correspond to various phonetic forms categorized as N, D, N^D, T, and T^H in Yoo & Nolan, 2020.) This phonetic diversity made it difficult to apply consistent and reliable criteria for measuring nasal duration or identifying related acoustic correlates. As a result, we focused our analysis on vowel nasalization, which offered a more stable and quantifiable index of prosodically conditioned nasal effects. While this approach limits our ability to directly assess the relationship between consonantal and vocalic nasality, it allows us to investigate coarticulatory vowel nasalization as a fine-grained phonetic window into position-sensitive denasalization across genders and prosodic contexts. (Note also that Lee et al. (2023) found no gender-related difference in onset nasal duration.)

As a reviewer rightly pointed out, A1–P0 may be influenced by gender- or speaker-specific physiological factors and voice quality, since the nasal peak (P0) can coincide with H1 or H2, which vary across individuals. We acknowledge this potential confound and agree that such factors warrant caution in interpretation. However, our aim is not to make absolute claims about gender-based nasality differences, but to examine how prosodic structure interacts with gender in shaping nasal coarticulation. If gender differences are conditioned by prosodic position rather than uniform across contexts, then potential effects of gender- or speaker-specific baseline voice quality differences on A1–P0, if present, are unlikely, on their own, to account for the observed pattern. Nonetheless, such measurements should be interpreted with caution and remain open to future work incorporating complementary methods to take into account voice quality effects (cf. Garellek, 2022).

2.4 Statistical analysis

The collected data were analyzed using linear mixed-effects models with the *lme4* package (Bates et al., 2015) in R (R Core Team, 2024). For the first model examining the effect of phrase boundaries on vowel nasalization across genders (model 1), the dependent variable was vowel nasality, as measured by A1–P0, and the independent variables were Boundary (IP-initial, AP-initial, and AP-medial), Gender (Female, Male), and their interaction effects. To examine how Boundary and Gender effects might vary across different points within the vowel, an additional independent variable, Timepoint (25%, 50%, 75%), was included. Note that for the purpose of this study, whether Timepoint interacts with the other factors (Boundary and Gender), which could reveal how prosodic effects unfold over the course of the vowel, is of interest, rather than simply the main effect of Timepoint on A1–P0. For coding, Boundary was handled with Reverse Helmert Coding: the first contrast compared IP- versus AP-initial positions, and the second compared phrase-initial (IP-initial, AP-initial) to phrase-medial (AP-medial) positions. Gender was contrast coded (as 0.5 and −0.5). For Timepoint, the first comparison examined 25% versus 50%, while the second compared 50% versus 75%.

In the additional analysis investigating the difference in vowel nasality after nasal versus oral onset consonants in phrase-medial contexts (model 2), the dependent variable remained consistent with the first model, specifically, vowel nasality measured by A1–P0. The independent variables included the Onset consonant (Nasal, Oral), Gender (Female, Male), Timepoint (25%, 50%, 75%), and their interaction effects. Coding for Gender and Timepoint was managed identically to the first model, while Consonant was contrast-coded (as 0.5 and −0.5).

Regarding the random effects structure for both models, we implemented a maximal random effects structure justified by the design (Barr et al., 2013), which included by-speaker and by-repetition intercepts and slopes for the fixed effects, as long as the models converged. If a model failed to converge, we simplified the random slopes by removing those with the least variance. When significant interactions were detected among the factors, pairwise comparisons were conducted with Tukey adjustment using the *emmeans* package (Lenth, 2023).

3 Results

3.1 Model 1: prosodic boundary effects on vowel nasalization across genders

Statistical results on coarticulatory vowel nasality (the smaller A1–P0 values, the more nasalized) are summarized in Figure 2 and Table 2. There was a significant main effect of Boundary ($\beta=-4.237$, $df=1769.5$, $t=-14.987$, $p<.001$) and a Boundary × Timepoint interaction for the comparison between phrase-initial and phrase-medial positions (25%–50%: $\beta=-1.821$, $df=1753.6$, $t=-2.504$, $p<.05$; 50%–75%: $\beta=-1.785$, $df=1753.2$, $t=-2.439$, $p<.05$). As shown in Figure 2(a), vowel nasalization was significantly reduced at phrase boundaries, as indicated by increased A1–P0 values. That is, vowels in phrase-initial positions (both IP-initial and AP-initial) were significantly less nasalized than those in phrase-medial positions. However, comparisons between IP- and AP-initial positions did not reach significance. Note also that while the difference between phrase-initial and phrase-medial conditions remained significant throughout the vowel, the magnitude of this difference decreased toward the vowel offset. This pattern suggests that the boundary effect due to the preceding nasal onset is strongest at the onset of the vowel, aligning with the expectation that denasalization originates near the boundary. There was also a significant main effect of Gender ($\beta=-3.403$, $df=33.2$, $t=-2.224$, $p<.05$) as well as a Gender × Timepoint interaction (25%–50%: $\beta=2.226$, $df=1753.2$, $t=3.407$, $p<.001$). As can be seen in Figure 2(c), female speakers showed lower A1–P0 values than male speakers in general (but see discussion on speaker- and gender-specific A1–P0 in Section 2.3), although the differences became more pronounced at later parts of the vowel.

Most crucially, a significant interaction between Boundary and Gender was found ($\beta=2.532$, $df=1757.7$, $t=4.475$, $p<.001$), as shown in Figure 2(b). The gender difference suggested by the

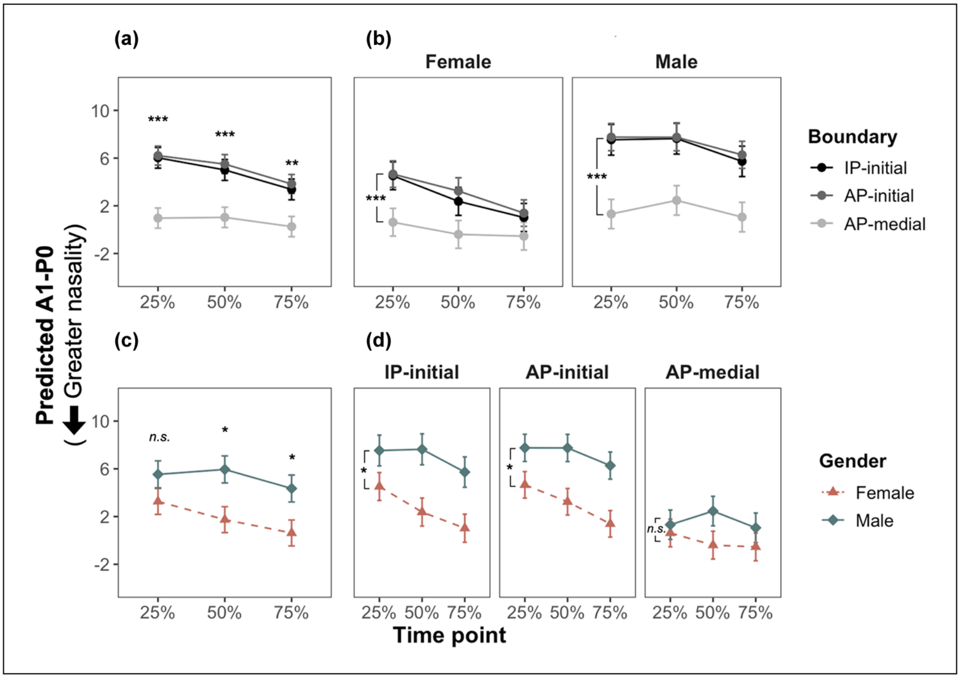

Figure 2. Effects of (a) Boundary × Timepoint, (b) Boundary × Gender × Timepoint, (c) Gender × Timepoint, and (d) Gender × Boundary × Timepoint on vowel nasality across three relative timepoints in Model 1. Error bars refer to *SE*.
***$p < .001$. **$p < .01$. *$p < .05$. *tr.*: $.06 < p < .05$ *n.s.*: $p > .06$.

main effect (i.e., lower A1–P0 for female than for male speakers) was especially pronounced in phrase-initial conditions (both IP-initial and AP-initial), where female speakers retained substantially more nasality. However, no significant three-way interaction involving Timepoint was found, suggesting that the observed patterns were consistent across the vowel's duration. Male speakers consistently exhibited greater reduction in vowel nasalization in phrase-initial positions than female speakers, regardless of Timepoint. Interestingly, visual inspection of the timepoint-specific patterns suggested that, for female speakers, phrase-initial nasal reduction was more evident in the earlier portion of the vowel—around the 25% timepoint—than in the later portion (e.g., the 75% timepoint), as shown in Figure 2(b). This apparent timing difference, however, warrants further investigation, given the absence of a statistically significant three-way interaction. Nonetheless, this contrast between male and female speakers underscores gender-specific prosodic modulation in vowel nasalization. These gender-related differences are further illustrated in Figure 2(d) for both IP-initial and AP-initial positions. However, in AP-medial contexts, the difference disappeared, though female speakers still tended to exhibit slightly greater nasalization, a pattern explored further in the next section.

It is worth noting, however, that the presence of a following /m/ in /ma.mi/ introduces anticipatory coarticulation effects (as mentioned in Section 2.2), raising the question as to whether the observed gender difference in vowel nasality reflects a difference in prosodically conditioned denasalization or anticipatory coarticulation. While we acknowledge that carryover and anticipatory nasalization effects on the vowel /a/ cannot be fully disentangled, we interpret the observed gender effect primarily as gender-specific modulation of prosodically conditioned denasalization.

Table 2. A Summary of Model 1 for Variation in Vowel Nasality (A1–P0) as a Function of Boundary, Gender, and Timepoint.

	Estimate	Std. error	*df*	*t*-value	*p*-value
(Intercept)	3.578	0.768	33.0	4.659	<.001***
Boundary (IPi–APi)	0.376	0.303	1764.0	1.241	.215
Boundary (ini–med)	−4.237	0.283	1769.5	−14.987	<.001***
Gender (F–M)	−3.403	1.530	33.2	−2.224	.033*
Timepoint (25–50)	1.648	0.333	1753.2	4.956	<.001***
Timepoint (50–75)	2.181	0.332	1753.3	6.560	<.001***
Boundary (IPi–APi): Gender (F–M)	0.163	0.606	1764.0	0.270	.787
Boundary (ini–med): Gender (F–M)	2.532	0.566	1757.7	4.475	<.001***
Boundary (IPi–APi): Timepoint (25–50)	−0.388	0.788	1753.3	−0.493	.622
Boundary (ini–med): Timepoint (25–50)	−1.821	0.727	1753.6	−2.504	.012*
Boundary (IPi–APi): Timepoint (50–75)	−0.163	0.782	1753.3	−0.208	.835
Boundary (ini–med): Timepoint (50–75)	−1.785	0.732	1753.2	−2.439	.015*
Gender (F–M): Timepoint (25–50)	2.266	0.665	1753.2	3.407	.001***
Gender (F–M): Timepoint (50–75)	0.653	0.665	1753.3	0.982	.326
Boundary (IPi–APi): Gender (F–M): Timepoint (25–50)	−0.494	1.576	1753.2	−0.313	.754
Boundary (ini–med): Gender (F–M): Timepoint (25–50)	−0.327	1.454	1753.2	−0.225	.822
Boundary (IPi–APi): Gender (F–M): Timepoint (50–75)	0.679	1.564	1753.3	0.434	.664
Boundary (ini–med): Gender (F–M): Timepoint (50–75)	−1.326	1.464	1753.3	−0.906	.365

Note. lmer, a1p0_compensated ~ 1 + boundary * gender * timepoint + (1 − speaker) + (1 − repetition), data.

This interpretation is supported by the finding that the most pronounced gender differences emerge in phrase-initial positions, where denasalization has been extensively documented (Jang et al., 2018; Y. Kim, 2011; Yoo & Nolan, 2020; Yoshida, 2008). Furthermore, gendered variation in sound change processes is well-established in the literature (Labov, 1973, 1990), providing a reasonable interpretation for these findings.

3.2 Model 2: difference in vowel nasality following nasal versus oral onset consonant in phrase-medial context

Statistical results on vowel nasality for vowels following nasal versus oral onset consonants in phrase-medial conditions are summarized in Figure 3 and Table 3. (Recall that this comparison focuses on the phrase-medial /ma/ in /. . .ma.mi. . ./ and the phrase-medial /p^{h}a/ in /. . .p^{h}a.mi. . ./.) There was no main effect of Onset Consonant ($\beta = -0.716$, $df = 25.3$, $t = -0.912$, $p = .370$) or Gender ($\beta = -0.726$, $df = 29.1$, $t = -0.535$, $p = .597$). However, a significant interaction between Onset Consonant and Timepoint was found (25%–50%: $\beta = 4.903$, $df = 611.8$, $t = 5.414$, $p < .001$; 50%–75%: $\beta = 3.280$, $df = 611.9$, $t = 3.631$, $p < .001$). Interestingly, as shown in Figure 3(a), this interaction reflected a somewhat unexpected pattern: the nasal consonant's effect on vowel nasalization became significant only toward the end of the vowel (at 75%: $\beta = -2.36$, $SE = 0.908$, $df = 49.6$, $p < .05$), despite the source of nasality originating from the onset.

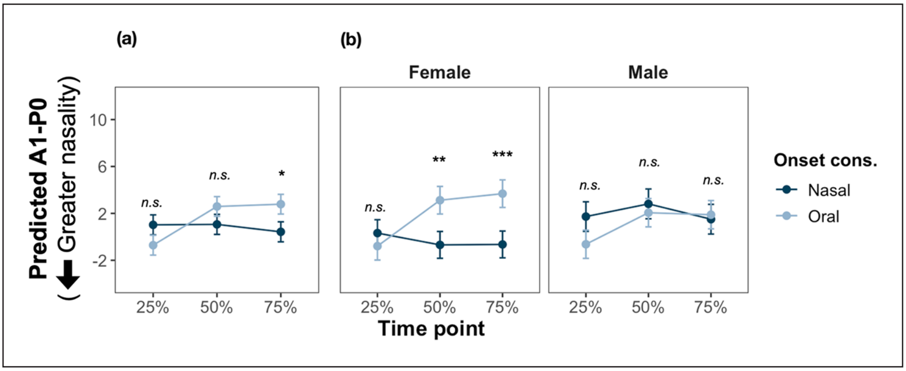

Figure 3. Effects of (a) Onset consonant × Timepoint. (b) Onset consonant × Gender × Timepoint on vowel nasality across three relative timepoints in Model 2. Error bars refer to *SE*.
$^{***}p<.001$, $^{**}p<.01$, $^{*}p<.05$, *n.s.*: $p>.06$.

Table 3. A Summary of Model 2 for Variation in Vowel Nasality (A1–P0) as a Function of Onset Consonant, Gender, and Timepoint.

	Estimate	Std. error	*df*	*t*-value	*p*-value
(Intercept)	1.197	0.679	29.1	1.764	.088
Onset (nasal–oral)	−0.716	0.785	25.3	−0.912	.370
Gender (F–M)	−0.726	1.357	29.1	−0.535	.597
Timepoint (25–50)	−2.079	0.453	611.9	−4.591	<.001***
Timepoint (50–75)	−0.820	0.452	612.0	−1.815	.070
Onset (nasal–oral): Gender (F–M)	−3.253	1.570	25.3	−2.073	.049z*
Onset (nasal–oral): Timepoint (25–50)	4.903	0.906	611.8	5.414	<.001***
Onset (nasal–oral): Timepoint (50–75)	3.280	0.904	611.9	3.631	<.001***
Gender (F–M): Timepoint (25–50)	−0.116	0.906	611.9	−0.128	.898
Gender (F-M): Timepoint (50–75)	−1.094	0.903	612.0	−1.211	.226
Onset (nasal–oral): Gender (F–M): Timepoint (25–50)	4.007	1.811	611.8	2.212	.027*
Onset (nasal–oral): Gender (F–M): Timepoint (50–75)	1.386	1.807	611.9	0.767	.443

Note. lmer, a1p0_compensated ~ 1 + syllable * gender * timepoint + (1 + syllable − speaker), data.

Furthermore, there was a significant interaction of Onset Consonant × Gender ($\beta=-3.253$, $t=-2.073$, $df=25.3$, $p<.05$) as well as a significant three-way interaction between Onset Consonant, Gender, and Timepoint (25%–50%: $\beta=4.007$, $df=611.8$, $t=2.212$, $p<.05$). As shown in Figure 3(b), female and male speakers exhibited distinct patterns in how nasality differed between nasal and oral onset consonants. Notably, male speakers showed no significant difference in vowel nasalization between nasal and oral onset consonants at any timepoint. This lack of distinction may have stemmed from multiple interacting factors that complicate surface patterns and preclude a definitive interpretation. One possibility is anticipatory nasalization from the following nasal consonant (as in /p^ha.mi/ vs. /ma.mi/), which may be sufficiently strong, or saturated, to obscure any effect of the preceding onset consonant (i.e., /p^h/ vs. /m/). Indeed, anticipatory nasalization has often been reported as more prominent than carryover nasalization (e.g., Cohn, 1990; Kawasaki, 1986; Ohala, 1975; but see Delvaux et al., 2008, and Dow, 2020, for evidence of the opposite pattern in French), although this asymmetry is typically more pronounced within the same syllable rather than across syllables (Krakow, 1999). Another possibility, as pointed out by a reviewer, concerns the internal morphological structure of the compound words used in the stimuli. Although /ma/ at the beginning of the second element in the compound /kje.pʰi.ma.mi/ or /jaŋ.pʰa.ma.mi/ is located in the phrase-medial position, there is a possibility that the speakers might also consider it as a word-initial syllable as /ma.mi/ was introduced as an independent word in the prior sentences in the passage. As such, it could remain susceptible to boundary-sensitive denasalization applicable to the word-initial context. In contrast, /pʰa/ in /jaŋ.pʰa.mi.ma/ is clearly word-internal within the compound, and thus less likely to trigger such effects. This structural asymmetry may help explain the absence of a clear nasal/oral onset distinction among male speakers, who generally exhibited more denasalization than female speakers to a level comparable to that of the word-medial /pʰa/, thereby masking any onset-based distinction. In sharp contrast, female speakers maintain a significant distinction between nasal and oral onset conditions, preserving the contrast in onset nasality even in phrase-medial positions. Specifically, they nasalized the vowel more in the nasal onset (/ma.mi/) context than in the oral onset (/pʰa.mi/) context, although the effect was less pronounced than in phrase-initial positions.

4 Discussion

This study investigates how the nasality of the word-initial syllable in the disyllabic word /ma.mi/, assessed through coarticulatory vowel nasalization (quantified by A1–P0), varies as a function of prosodic boundary strength in Seoul Korean and whether this boundary-induced modulation is influenced by gender differences, which may illuminate the dynamics of the putative ongoing sound change in the denasalization process. The results revealed a notable reduction in nasal influence on the following vowel in phrase-initial positions, as evidenced by a significant decrease in coarticulatory vowel nasalization in both female and male speakers. These findings provide new empirical data on the ongoing sound change of denasalization (Y. Kim, 2011; Yoo & Nolan, 2020; Yoshida, 2008), which has been primarily associated with the extreme reduction of consonantal nasal murmur, by showing that position-dependent denasalization also affects coarticulatory vowel nasalization in relation to prosodic structure.

Interestingly, however, no statistical difference was found between IP-initial and AP-initial positions, despite the general expectation that domain-initial strengthening is more robust in IP-initial contexts than in AP-initial ones (e.g., Cho & Keating, 2001). The absence of variation in vowel nasality between these two phrase-initial positions suggests that denasalization may operate—or be in the process of becoming phonologized—at the level of a prosodic phrase, whether an IP or an AP (cf. Y. Kim, 2011; Yoo & Nolan, 2020), rather than being merely a byproduct of domain-initial strengthening as a gradient process, which would predict a stronger effect at higher prosodic boundaries. It is worth mentioning, however, that the absence of a significant prosodic boundary effect between IP and AP in this study contrasts with the findings by Yoo and Nolan (2020), who reported greater denasalization at higher prosodic domains at the phrase level, particularly among older speakers. One possible explanation for this discrepancy lies in the methodological differences between the two studies: while Yoo and Nolan classified nasal segment outcomes categorically based on the resulting consonantal production (e.g., N, N^D, D, T, T^H, corresponding to a full nasal murmur, partially denasalized nasal, voiced stop, voiceless stop, and voiceless aspirated stop, respectively), our study measured vowel nasalization as a continuous acoustic correlate of nasal coarticulation. It is possible that vowel nasalization captures a different, more gradient aspect of the articulatory process, which may not be reflected in the classification of the surface realizations reported by Yoo and Nolan (2020). Furthermore, our study did not allow for a reliable classification of surface nasal realizations, as many productions exhibited ambiguous or uncertain patterns that could not be confidently categorized.

As briefly mentioned in the introduction, the reduction of nasality in initial positions is generally attributed to domain-initial articulatory strengthening, whereby increased effort at the beginning of a phrase enhances *oral* articulation, likely elevating the velum and reducing nasality—an effect observed across languages (e.g., English: Cho & Keating, 2009; Cho et al., 2017; French: Fougeron, 2001; Korean: Cho & Keating, 2001; Jang et al., 2018; Mandarin Chinese: Li et al., 2020). However, in Seoul Korean, as an edge-prominence language where prosodic boundaries such as those of the AP or IP serve as loci for prominence and strengthening (Jun, 2005; J. J. Kim et al., 2024), the impact of domain-initial strengthening that induces nasal reduction appears more extreme than in other languages (Jang et al., 2018; Keating et al., 2004). This parallels findings on oral consonantal effects, where domain-initial strengthening is also more pronounced in Korean than in other languages (Cho, 2022; Keating et al., 2004). The heightened sensitivity to prosodic boundaries in Seoul Korean, particularly at phrase-initial positions, may have progressively exaggerated nasal reduction to the point where the nasal murmur of the consonant becomes difficult for listeners to perceive (cf. Y. Kim, 2011; Yoo & Nolan, 2020; Yoshida, 2008), ultimately driving the ongoing sound change of denasalization toward position-dependent phonologization.

Crucially, our findings suggest that the prosodically driven sound change of denasalization is shaped by gender: while female speakers retained vowel nasalization phrase-initially, male speakers exhibited a greater reduction, aligning more closely with the denasalization process. While we do not examine the direct relationship between consonantal and vocalic nasality, as nasal duration was not included in the current analysis (see Section 2.3 for more details), the gender differences observed in vowel nasalization across prosodic positions remain robust, suggesting that male and female speakers vary in the extent to which prosodically conditioned denasalization extends into the vowel. The gender difference also emerged in phrase-medial contexts, where vowel nasalization was compared between nasal and oral onset conditions. Female speakers showed greater nasality in vowels following a nasal consonant than an oral consonant, whereas male speakers exhibited no such distinction. These findings together suggest that the [nasal] feature, originally linked to the nasal consonant, spreads to the adjacent vowel in female speech. As a result, even in contexts (i.e., phrase-initial) where nasal consonant weakening is expected, female speakers continue to produce nasalized vowels, preserving some degree of nasal articulation within the syllable. By contrast, male speakers appear to have progressed further in the denasalization process. For them, the [nasal] feature seems to have been delinked not only from the consonant but also from the vowel, leading to more complete denasalization. Consequently, in phrase-initial positions, male speakers exhibit a more advanced stage of the sound change, with nasality nearly absent from both the consonant and the following vowel. This more advanced denasalization highlights a significant gender-based divergence in the progression of the sound change in Seoul Korean.

Unlike typical sound changes, which are often led by female speakers (Labov, 1973; e.g., Bang et al., 2018; Choi et al., 2020; Kang, 2014), this shift is instead driven by male speakers. The current data do not offer a definitive explanation, making any interpretation at this stage speculative. Nevertheless, one possible reason for this male-led denasalization may be linked to the tendency of female speakers to produce more articulate speech, exhibiting heightened sensitivity to standard linguistic forms associated with social prestige (Byrd, 1994; Labov, 2006; Oh, 2010). Female speakers have been shown to produce greater realization of sentence-final consonants, less reduction to schwa, fewer elisions, and more complete articulation of consonant clusters (Byrd, 1994; Whiteside, 1996), as well as more distinctive phonemic contrasts (Henton, 1983; Johnson &

Martin, 2001; see Oh, 2010). Since denasalization weakens the distinction between nasal and oral sounds, female speakers—who may prioritize clearer and more articulate speech—might emphasize vowel nasalization, as it is a feature typically associated with clear speech (Beddor, 2009; Scarborough & Zellou, 2013). Our findings indeed align with this possibility, suggesting that female speakers actively maintain and regulate nasality through coarticulatory vowel nasalization in contexts where it would otherwise be reduced or lost.

Beyond articulatory clarity, social perception may also play a role in shaping gendered differences in vowel nasalization. In some East Asian societies, phonetic nasality is not just an articulatory feature but could serve as a socially meaningful cue associated with femininity, softness, and politeness. Speech characteristics linked to these qualities are often considered desirable for women, and nasality seems to be one such quality. For instance, Japanese and Chinese female speakers have been reported to frequently use higher pitch and greater nasality to align with socially preferred phonetic forms in female speech (Endo, 2008; Yueh, 2016). If similar associations exist in Korean, nasality may serve as a gendered sociolinguistic marker, reinforcing femininity in speech.

Considering these possibilities together, along with the fact that linguistic variants often carry different social meanings for different genders (Campbell-Kibler, 2007; Strand, 1999), the weakening of nasality as a phonetic cue for the nasal consonant may conflict with both women's preference for clearer articulation and the sociophonetic value of nasality as a feminine trait. If nasality enhances phonemic contrast and holds social significance in female speech, women may be less inclined to adopt denasalization. The findings of this study, which suggest that female speakers actively preserve nasality by controlling the degree of coarticulatory vowel nasalization in their speech, support this interpretation and underscore the complex interplay between gender, phonetic variation, and sociolinguistic norms in Seoul Korean.

5 Conclusion

This study demonstrates how phonetic variation in coarticulatory vowel nasalization, originally shaped by prosodic structure, may have evolved into a denasalization sound change as a phonological process in Seoul Korean. Specifically, phrase-initial positions exhibit reduced vowel nasality, suggesting that the position-driven denasalization of word-initial nasal consonants extends to the coarticulatory process of the following vowel. Notably, male speakers drive this change, exhibiting more pronounced reductions in vowel nasality in phrase-initial contexts. In contrast, female speakers consistently retain higher nasality levels, even in phrase-medial contexts, possibly indicating that their preference for maintaining phonetic clarity, and/or socially grounded perceptions of nasality, shape their speech production choices.

Taken together, these findings illustrate how socially grounded dynamics refine phonetic variation initially shaped by prosodic structure. The denasalization process in Seoul Korean highlights how position-dependent articulatory processes, such as domain-initial strengthening, can be actively *controlled* by speakers and gradually evolve into a stable sound change, while gender-specific social meanings of nasality either accelerate or inhibit this progression. By highlighting the bifurcation between consistent denasalization in vowel nasalization among male speakers and the preservation of consonantal nasality through vowel nasalization among female speakers—manifested in what are typically considered low-level coarticulatory processes—this study demonstrates how prosodically conditioned phonetic variation can evolve into a more systematic sound change under the influence of gender-related social dynamics. Further research is needed to examine how prosodic structure and other social factors interact to shape low-level phonetic processes, potentially giving rise to sound change across languages.

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Ethical considerations

The study was approved by the Institutional Review Board at Hanyang University (HYUIRB-202405-020). All participants provided written informed consent prior to participating.

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