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Vowel nasalization does not cue ambisyllabicity in American English nasals: Evidence from nasometry[a)]

Sarah Rose Bellavance,[1,b)] Amanda Eads,[1] Aidan Katson,[2] José Álvarez Retamales,[3] Alden McCollum,[3] Auromita Mitra,[3] and Lisa Davidson[3]

[1]*Department of Communicative Sciences & Disorders, New York University, 665 Broadway, New York, New York 10012, USA*

[2]*Department of Linguistics, University of California, Santa Cruz, 1156 High Street, Santa Cruz, California 95064, USA*

[3]*Department of Linguistics, New York University, 10 Washington Place, New York, New York 10003, USA*

srb664@nyu.edu, are326@nyu.edu, akatson@ucsc.edu, jj.alvarezretamales@nyu.edu, amccollum@nyu.edu, auromita.mitra@nyu.edu, lisa.davidson@nyu.edu

Abstract: Using visual spectrographic examination of vowel nasalization to diagnose the syllabic affiliation of phonologically ambisyllabic nasal consonants (e.g., *gamma*), Durvasula and Huang [(2017). Lang. Sci. **62**, 17–36] argued that anticipatory vowel nasalization in these words patterns with word-medial codas. Using nasometry, the current study finds that anticipatory nasalization before monomorphemic and multimorphemic (*scammer*) ambisyllabic nasals differ from word-medial coda (*gamble*) and word-final nasals (*scam*), but not from other intervocalic nasals. Additionally, vowel nasalization is sensitive to the manner of the preceding phoneme. These findings demonstrate that quantifying anticipatory nasalization using nasometry differs from visual spectrographic criteria. © *2024 Author(s). All article content, except where otherwise noted, is licensed under a Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).*

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1. Introduction

In some phonological analyses of English, consonants between a stressed and unstressed vowel are considered ambisyllabic; that is, such consonants are syllabified as the coda of the preceding syllable and as the onset of the following syllable (Giegerich, 1992; Hammond, 1999; Hayes, 2009). Phonological processes, such as alveolar flapping in American English (Kahn, 1968; Rubach, 1996), have long been argued to occur in ambisyllabic environments (Anderson and Jones, 1974; Trager and Bloch, 1941). However, these accounts have not gone unchallenged. Alternative explanations for apparently ambisyllabic phenomena include, for example, a rule of resyllabification (Borowsky, 1986; Selkirk, 1982), syllabification systems that maximize onsets (Jensen, 2000), foot-based metrical analyses (Harris, 2004; Kiparsky, 1979), or the Weight-Stress Principle (i.e., stressed syllables should be heavy, while unstressed syllables should be light) (Duanmu, 2009).

Given the contentious theoretical status of ambisyllabicity, various efforts have been made to probe speaker intuitions concerning syllabification, with the aim of establishing some psycholinguistic evidence for or against ambisyllabicity. Syllable doubling tasks, in which participants are made to repeat syllables (e.g., *ap-ap-ple-ple*/*a-a-ple-ple*) (Giegerich, 1992) of a disyllabic word containing a potentially ambisyllabic consonant have found variable evidence in support of speakers' awareness and implementation of ambisyllabicity. Likewise, pause-break tasks (identifying the "most natural sounding" placement of a period of silence within a word) (Derwing, 1992; Ishikawa, 2002), syllable reversal tasks (reversing the order of syllables) (Treiman and Danis, 1988), and simply asking participants to "identify the first part" of a word (Elzinga and Eddington, 2014) have all revealed that English speakers do not categorically identify "ambisyllabic" consonants. Instead, judgments and performance are highly variable and somewhat unstable, only sometimes patterning as though the potentially ambisyllabic consonant belongs to both relevant syllables.

Attempts to discover robust acoustic or articulatory correlates of ambisyllabicity in English have also been largely inconclusive. Various factors, beyond mere syllabification, have been shown to affect the articulation of intervocalic consonants. Stress placement and surrounding vowel quality have been shown to affect the magnitude of velum movement during intervocalic consonants (Krakow, 1989), as well as degree of tongue backness (darkness) for intervocalic /l/ (Gick, 2003; Sproat and Fujimura, 1993), which has also been shown to be sensitive to morphological boundaries (Lee-Kim *et al.*, 2013). In response, recent work, like that of Durvasula and Huang (2017), has sought to control as much as possible for

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[b)]Author to whom correspondence should be addressed.

these confounds, in search of a true acoustic correlate of ambisyllabicity. As the current study is largely based on this work, we will turn now to more detailed discussion of Durvasula and Huang (2017).

1.1 Durvasula and Huang (2017)

Durvasula and Huang (2017) used a speech production experiment to investigate acoustic evidence for ambisyllabicity in the degree of anticipatory nasalization in English VN(V) sequences. They compared the degree of anticipatory nasalization in vowels across four conditions: words containing a potentially ambisyllabic nasal consonant (*gamma*), words with a word-medial nasal coda (*gamble*), words with a word-medial nasal onset (*gamete*), and words with a word-final nasal coda (*gam*). The distinction Durvasula and Huang (2017) draw between the ambisyllabic condition (ˈgam.ma) and the word-medial onset condition (ˈga.ˌmete) is based on the absence or presence of secondary stress on the second syllable. In the word-medial onset condition, secondary stress induces the preceding consonant into onset position.

Durvasula and Huang (2017) identified vowel nasalization visually, according to three acoustic criteria observable in Praat spectrograms (Boersma and Weenink, 2022): abrupt decrease in F1 intensity, appearance of anti-formants, and appearance of a nasal pole. They marked the point at which the spectrogram was deemed to have met these criteria as the point of onset of nasalization in the vowel. Using these criteria, they found that the proportion of anticipatory nasalization during the vowel in the ambisyllabic condition in a fast speech-rate condition was different from vowels in the word-medial onset environment and from onset and word-final coda environments in slow and normal speech-rate conditions, but not different from word-medial codas in any speech-rate condition. Across all speech-rates, pre-nasal vowels in the word-medial onset condition had the lowest amount of nasalization, followed by pre-nasal vowels in the ambisyllabic condition and word-medial coda positions, followed by pre-nasal vowels in the word-final coda condition. Durvasula and Huang (2017) seem to provide acoustic evidence that anticipatory nasalization is sensitive to the syllabification of the following nasal.

However, it is unclear that the acoustic criteria used by Durvasula and Huang (2017) will always be present and identifiable in a signal, or that it is necessarily accurate to represent vowel nasalization as having an abrupt onset. To address these concerns, the present study sought to replicate and extend Durvasula and Huang (2017) by using nasometry. Nasometry allows for the separate recording of the nasal and oral channels, meaning that the amplitude of the signal produced out of the nasal cavity can be directly measured, independent of the signal produced out of the oral cavity. This method has been recently used to investigate, for example, positional differences with respect to nasalization in French nasal vowels (Dow, 2020), anticipatory nasalization in Caribbean and non-Caribbean dialects of Spanish (Bongiovanni, 2021a), and formant frequencies in nasalized vowels (Carignan, 2018).

An example of our nasometry data is shown in Fig. 1. We observe, minimally, two shortcomings with the acoustic criteria of Durvasula and Huang (2017) (abrupt decrease in F1 intensity, appearance of anti-formants, and appearance of a nasal pole). First, the visual criteria do not always align with the onset of increased amplitude in the nasal channel, as demonstrated in the top left and bottom right panels of Fig. 1. The red dashed lines correspond to the onset of nasalization according to Durvasula and Huang (2017) visual criteria, but the nasometry data show increased amplitude in the nasal channel starting well before this point, with a gradual increase in nasal amplitude over the course of the vowel. Indeed, regardless of where in the vowel the visual criteria would place the onset of nasalization, such an abrupt boundary would obscure invaluable time course information which is straightforwardly available in the nasometry data. Our second concern is that many tokens in the present study included vowels with robust nasalization starting at the onset of the vowel according to the nasometry data, but none of the three criteria outlined was clearly visible in the spectrograms (Fig. 1, top right panel, where the [ɪ] in *sinner* has a consistent amplitude in the nasal channel throughout the vowel).

1.2 Current study

Using nasometry, the current study sought to verify whether Durvasula and Huang's (2017) acoustic methodology adequately captures the onset and degree of nasalization in English VN(V) sequences. First, we investigate whether the degree and time course of anticipatory nasalization in a vowel preceding a potentially ambisyllabic nasal consonant are different from alternatively syllabified nasals. Second, we investigate whether the degree of nasalization in the preceding vowel is sensitive to the manner of the onset consonant.

For the first research question concerning potential differences between syllable types, we hypothesized that we would find more nasalization before codas than before onsets (Byrd *et al.*, 2009; Krakow, 1989). Following the normal speech-rate results from Durvasula and Huang (2017), we hypothesized that the monomorphemic ambisyllabic syllable type would have an amount of nasalization that is indistinguishable from the word-medial coda, but perhaps different from both onsets and word-final codas. Additionally, we hypothesized that multimorphemic ambisyllabic syllable types could be even closer to word-final codas than the monomorphemic condition since the nasal is linked to the coda in the base (e.g., *scam* – *scammer*) (Lee-Kim *et al.*, 2013).

A secondary research question regarding the effect of the onset consonant arose after observing in pilot testing that the onset of nasalization seemed delayed after stops as compared to fricatives in onset position (e.g., *bonnet* vs

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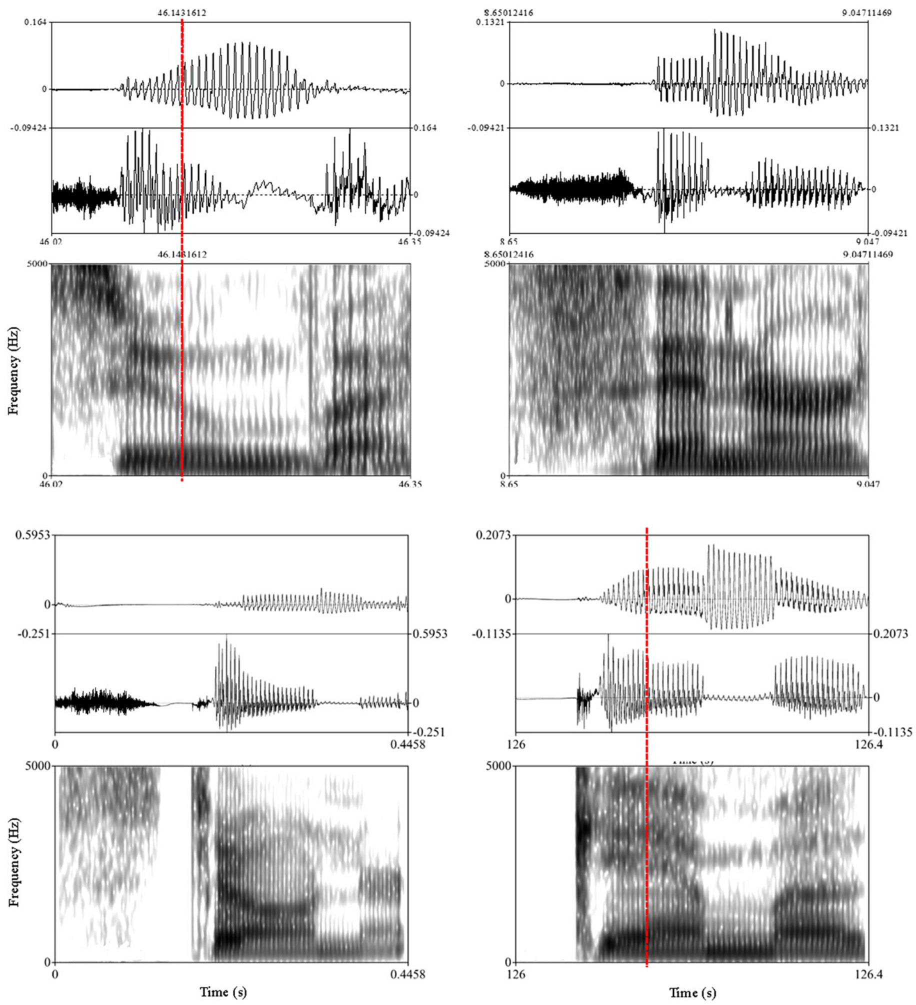

Fig. 1. Top left panel: An example of the word *Zumba* showing the nasal channel (top), oral channel (middle), and spectrogram (bottom). The visual criteria set by DH, marked with a red dashed line, do not align with the onset of nasalization in the nasal channel. Top right panel: An example of the word *sinner.* The visual criteria set by DH are not clearly present, but the vowel is nasalized throughout. Bottom left panel: An example of the word *stoner*. The visual criteria set by DH align with the onset of nasalization in the nasal channel. Bottom right panel: An example of the word *gamma.* The visual criteria set by DH, marked with a red dashed line, do not align with the onset of nasalization in the nasal channel.

sonnet). Consequently, we included both stop-initial and fricative-initial stimuli in order to investigate whether the pilot findings would generalize.

2. Methods

The data collection for this study was approved by the New York University Institutional Review Board. We used nasometry to extract oral and nasal acoustic data, and then used these data to build a Bayesian generalized additive model (Wood, 2017) to investigate predictors of nasalance (Carignan, 2018) in vowels preceding nasal consonants.

2.1 Participants

Our data came from 11 speakers of American English who lived in the New York City area at the time of data collection. Participants' ages ranged from 21 to 37 years old at the time of recording. Ten participants are women and one is a man. No participants reported a history of speech, language, or hearing disorders. Several participants were raised in New York or New Jersey. However, five participants were from other areas (California, Colorado, Hawaii, Oregon, Puerto Rico). One participant was born in Singapore and spent their adolescent years in California. Another participant was born in Beijing and moved to the U.S. for high school. These two participants have significant exposure to and interaction with American dialects of English and do not pattern differently than the others. Therefore, they have not been excluded from the dataset. Two participants heard languages other than English in the home but do not speak those languages. Five participants are

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bilingual (1 English-Japanese, 1 English-Mandarin, 1 English-Serbo-Croatian, 3 English-Spanish). All participants provided informed consent and were compensated $10 for their time. The experiment lasted approximately 20 min in total.

2.2 Data collection

The data for this study were collected in a soundproof booth at New York University. All participants were recorded using the same handheld Glottal Enterprises nasometer (NAS-1 SEP Clinic). The nasometer consists of a sound-blocking plate with USB microphones above and below the plate. There were three different sized plates that were changed as necessary to create the most comfortable seal for each participant. The participants held the nasometer perpendicular to their face with the plate pressed against their cheeks and upper lip to create a tight seal in order to ensure that the nasal and oral acoustic channels were separated. The two channels were captured on a laptop computer using Praat (Boersma and Weenink, 2022) as the recording software. The experimenter observed the participant during recording to ensure that the plate did not shift.

During the experiment, participants were asked to read 200 sentences at a normal speech-rate. The stimuli consisted of five repetitions of carrier sentences (e.g., "Repeat ___ for me.", "Say ___ to her.") for each of the 30 target words (five word types with six words per type). The five word types were: monomorphemic ambisyllabic (e.g., *gamma*, *finish*); multimorphemic ambisyllabic (e.g., *scammer, sinner*); word-medial coda (e.g., *gamble, cinder*); word-medial onset where the second syllable has secondary stress (e.g., *gamete, synapse*); and word-final coda C(C)VN (e.g., *scam, sin*). There were an additional ten filler words that were also repeated five times each within the carrier sentences. The full set of target and filler words can be found in the supplementary material. Importantly, the word types used in this study were those used in Durvasula and Huang (2017), with the addition of the multimorphemic ambisyllabic condition. The onset consonants in the target words were balanced for fricative vs stop, and vowels were balanced across word type. It should be noted that neither word frequency, nor the quality of the pre-nasal vowel was controlled across stop and fricative onsets. This will be discussed in Sec. 5.

2.3 Analyses

Praat scripts were used to extract information for both target and filler words. The intensity (root mean square pressure) was measured at 50 equidistant time intervals across the pre-nasal vowel intervals for both the nasal and oral channels (see also Bongiovanni, 2021a; Dow, 2020). Data processing and analyses were conducted using R (R Core Team, 2021), whereby nasalance was calculated as the amplitude of the nasal channel divided by the sum of the amplitude of the nasal channel and the amplitude of the oral channel, for each of the 50 time intervals in the preceding vowel (Carignan, 2018).

We used a one-way ANOVA to verify a difference of nasalance in vowels followed by a nasal consonant compared to a filler consonant. To investigate nasalance in the preceding vowel for our five syllable types, we built a generalized additive mixed model (GAMM) using the bam() function from the mgcv package (Wood, 2017). GAMMs are useful for capturing non-parametric relationships between two or more variables (see Baayen and Linke, 2020 for a review). In their computation, these non-parametric relationships are functions that encompass more than one coefficient to fit the data (often referred to as "smooth terms"). Because we do not expect time to have a linear relationship to the amount of nasalance, GAMMs provide an appropriate solution for modeling our data. Our model included predictor variables of syllable type, preceding phoneme (the manner of the phoneme before the vowel), one smooth term for time interval by syllable type, one smooth term for time interval by preceding phoneme, and random effects for word, vowel, and speaker. The outcome variable was nasalance in the vowel preceding the nasal consonant. To ensure model robustness, we compared the number of knots and estimated degrees of freedom for each smooth term (Sóskuthy, 2017). The number of knots was deemed appropriate given this comparison. Concurvity and model residuals were also examined and deemed appropriate to proceed with interpretation (Tomaschek *et al.*, 2018; Wood, 2017).

3. Results

To validate the quality of our data, we first conducted a one-way ANOVA to verify a difference of nasalance in vowels followed by a nasal consonant rather than a filler consonant. A significant difference was confirmed in the expected direction ($F = 41\,398$ $p < 0.001$), where there was a greater degree of nasalance for vowels followed by a nasal consonant ($\text{mean} = 0.343$, $SD = 0.194$) than for those followed by a filler consonant ($\text{mean} = 0.091$, $SD = 0.091$).

To answer our first research question, we used Bayesian GAMMs to analyze the trajectory of nasalance throughout the time course of the pre-nasal vowel. To examine the nature of nasalance in the pre-nasal vowel for the monomorphemic ambisyllabic case, we set this syllable type as the reference level (partial effects plots with 95% confidence intervals are available in the supplementary material). Results from the model revealed that the degree of nasalance throughout the vowel was significantly less for the monomorphemic ambisyllabic syllable type than for the word-final ($p < 0.001$) and word-medial coda types ($p < 0.001$), but not significantly different from the medial onset ($p = 0.08$) or multimorphemic ambisyllabic ($p = 0.258$) syllable types. The full model output and partial effects plots are available in the supplementary material. Descriptive plots for nasalance trajectories are also available in the supplementary material.

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Smooth difference plots are used to visually examine the statistical differences between the smooth functions of two levels of a predictor (in this case, syllable type). The difference between the smooth functions is considered significant when the 95% confidence intervals do not include zero. The left and middle panels of Fig. 2 visualize the statistically significant differences between the monomorphemic ambisyllabic type and word-final and word-medial coda types for each time interval. In the left panel, nasalance values for monomorphemic ambisyllabic and word-final types are not significantly different at the earliest time intervals in the pre-nasal vowel but become significantly different near time interval 8 and throughout the remainder of the vowel. The middle panel shows that nasalance in the monomorphemic ambisyllabic and word-medial coda types is significantly different across all time intervals in the pre-nasal vowel.

Using the same Bayesian GAMM, we investigated the impact of the preceding phoneme's manner upon the degree of nasalization in the pre-nasal vowel. We found that the degree of nasalance was significantly higher when the onset consonant preceding the vowel was a fricative rather than a stop ($p = 0.01$). Raw trajectories of nasalance in the pre-nasal vowel plotted by onset consonant is provided in the supplementary material. While the fricative context seems to start with a higher degree of anticipatory nasalization that steadily increases across the vowel, the stop context reveals a slightly less linear pattern, particularly between the 4th and 16th time intervals and after the 32nd time interval. This is supported by the difference plot in the right panel of Fig. 2.

Although we have already provided results for both of our research questions, the previous results have only been reported in relation to the monomorphemic ambisyllabic type. The current study extends Durvasula and Huang (2017) by adding a multimorphemic ambisyllabic type. We ran a second model with the syllable types re-leveled to include the multimorphemic ambisyllabic type as the baseline. The degree of nasalance throughout the vowel was also significantly less for the multimorphemic ambisyllabic syllable type than for the word-final ($p = 0.031$) and word-medial coda types ($p = 0.036$), but not significantly different from the medial onset ($p = 0.638$) or monomorphemic ambisyllabic ($p = 0.258$) syllable types. Results for the preceding phoneme were replicated for the first model, with the preceding fricative predicting more nasalance than a preceding stop ($p = 0.01$). The full model output and partial effects plots are available in the supplementary material.

4. Discussion

The current study sought to verify the outcome of previous research using visual criteria to determine whether there are reliable phonetic correlates of ambisyllabicity (Durvasula and Huang, 2017). Using nasometry, we were able to separate the amplitude of the signal into oral and nasal channels. Our first objective was to determine whether the implementation of nasalization in the vowel preceding a nasal in an ambisyllabic syllable type differs from other syllable types. Our second objective was to determine if the degree of nasalization in the vowel was sensitive to the manner of the preceding phoneme. We found that the monomorphemic ambisyllabic type significantly differed from word-medial and word-final coda

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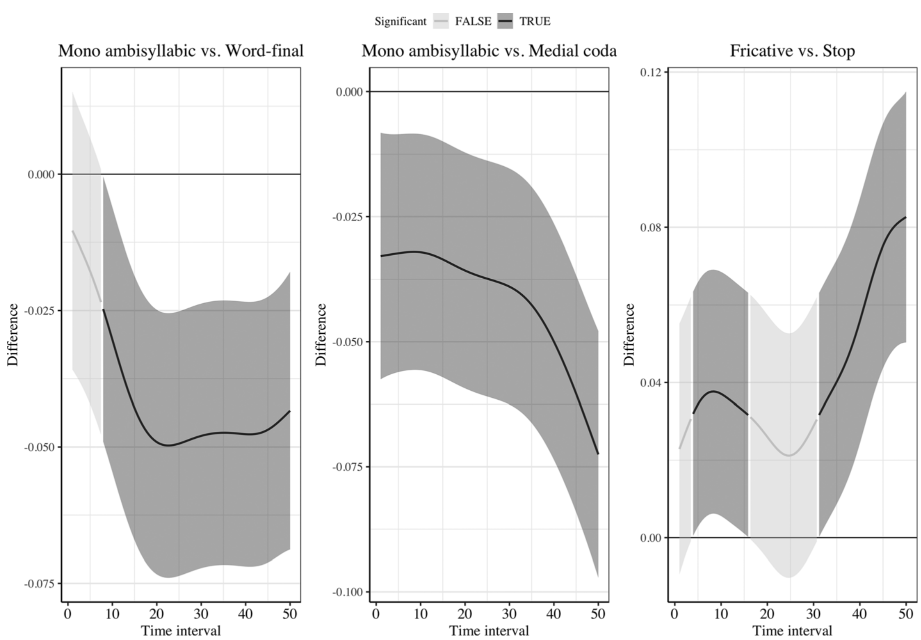

Fig. 2. Left panel: Smooth function differences between ambisyllabic and word-final syllable types. Middle panel: Smooth function differences between ambisyllabic and word-medial coda syllable types. Right panel: Smooth differences of the nasalization of the vowel when the preceding phoneme is a fricative or a stop.

syllables and did not significantly differ from the multimorphemic ambisyllabic type or word-medial onset syllables. Contrary to our expectations that the multimorphemic ambisyllabic type would pattern similarly to the word-final coda type due to morphological effects (e.g., Lee-Kim *et al.*, 2013), we found that the multimorphemic ambisyllabic type also significantly differed from word-medial and word-final coda syllables and did not significantly differ from the monomorphemic ambisyllabic type or word-medial onset syllables. For both ambisyllabic types, the degree of nasality in the vowel was greater after a preceding fricative than after a stop.

The results presented here do not fully corroborate previous findings. Our results are in line with our hypothesis that there would be greater nasalance for vowels preceding a coda nasal than those preceding an onset nasal (Byrd *et al.*, 2009; Krakow, 1989). However, our results contrast with our hypothesis concerning anticipatory nasalization in ambisyllabic words. Through visual spectrographic inspection, Durvasula and Huang (2017) reported that the monomorphemic ambisyllabic type had more nasalance than word-medial onset syllables, the same amount as word-medial coda syllables, and less than word-final coda syllables (for normal and slow speech rates). In contrast, we found that the monomorphemic and multimorphemic ambisyllabic types had significantly less nasalance than word-medial and word-final coda syllables, and not a significantly different amount than word-medial onset syllables. Furthermore, the multimorphemic ambisyllabic type had an amount of nasalance that patterned the same as the monomorphemic ambisyllabic type. Our results suggest that the monomorphemic and multimorphemic ambisyllabic cases pattern similarly to the other intervocalic types, rather than patterning with the word-medial coda.

In line with our second hypothesis, the current study found that a fricative preceding the pre-nasal vowel predicted a significantly greater amount of nasalance than a stop. As we detail in Sec. 5, however, vowels in our stimuli were not controlled for across onset consonant types. Therefore, the findings regarding our second hypothesis raise further questions. Previous research has argued that both oral stops and frication similarly disfavor a lowered velum because they both require high intraoral pressure (Ohala and Ohala, 1993; Shosted, 2006), although evidence has also been found that nasalization during a voiced stop closure can be used to enhance voicing in some languages (Solé, 2009, 2011). Additionally, nasalization from a preceding nasalized vowel can impact the quality of a following fricative in some languages (Shosted, 2006), and even to such an extent that a nasalized approximant is produced instead (Warner *et al.*, 2015). Considering these previous findings, it is not clear why the rate of nasalization following fricatives in our findings is earlier and greater as compared to stops. To more fully answer this question, it would be advantageous to examine factors, such as whether the voiced stops are produced with nasalization, whether the velum begins lowering during the end of the fricative (e.g., with the use of MRI data), and whether delaying velum lowering ensures a stronger stop burst; but given the short length of this paper and the limitations of our stimuli, these are all questions for future research.

Taken together, these results demonstrate that ambisyllabicity may not be reflected in the timing or degree of anticipatory nasalization. There is a lack of convincing phonetic and psycholinguistic evidence for ambisyllabicity in the literature (Duanmu, 2009; Giegerich, 1992; Hammond, 1999; Treiman and Danis, 1988), including the current study; however, this does not preclude phonological arguments for ambisyllabicity. Nonetheless, these results call into question whether visual spectrographic criteria are best suited to determine the onset or degree of nasalization. Acoustic information available from nasometry provides a more accurate and detailed measure. Separate oral and nasal channels highlight that nasalization frequently begins at the onset of the vowel and increases over time for all types, which would be difficult to ascertain from visual criteria alone. Other acoustic measures such as A1-P0 may provide complementary information (Styler, 2017). Future studies should further explore the relationship between nasal and oral acoustic information.

5. Limitations

The primary limitations in this study relate to the nature of our stimuli. As previously mentioned, we were attempting to replicate and extend Durvasula and Huang (2017). In order to prioritize creating stimuli for each syllable type that had the appropriate onset consonant manner, vowel, and nasal consonant without being too infrequent, unfamiliar, or a nonce word, we did not control for word frequency or use the same vowels in the stop-onset and fricative-onset conditions. Additionally, it is unclear that the word-medial onset condition is truly representative of an onset condition, due to primary stress occurring on the first syllable. However, in order to replicate Durvasula and Huang (2017), we followed their criteria and did not introduce an additional variable of differing primary stress patterns (e.g., ˈ*gamete* vs *com*ˈ*mit*).

Further, there are some considerations when evaluating the use of hand-held nasometer for recording nasalance. Bongiovanni (2021b) notes the "bulky presence" of the instrument as well as the potential for split attention between holding the instrument and focusing on the task at hand. We also note the possibility for a loose seal of the plate to the face during data collection; however, an experimenter was present for all recordings and routinely checked that the seal was tight to the participant's face.

6. Conclusion

The current study sought to verify previous claims regarding the patterning of ambisyllabic words compared to other word types (Durvasula and Huang, 2017). Using nasometry, we did not find that ambisyllabic words were the same as word-medial codas, but rather that monomorphemic and multimorphemic ambisyllabic words (e.g., *gamma, scammer*)

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significantly differed from medial-coda (e.g., *gamble*) and word final words (e.g., *scam*). For both ambisyllabic types, the degree of nasality in the vowel was sensitive to the manner of the preceding phoneme. While phonological or psycholinguistic arguments for ambisyllabicity cannot be ruled out, neither Durvasula and Huang (2017) nor the current study provides support for acoustic criteria for ambisyllabicity. However, this study raises a question about appropriate methodologies for quantifying anticipatory nasalization.

Supplementary Material

See the supplementary material for a table of the stimuli used in the experiment, model outputs, partial effects plots, and raw trajectories of nasalance.

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Author Declarations

Conflict of Interest

The authors have no conflicts to disclose.

Ethics approval

Data collection for this study was approved by the New York University IRB.

Data Availability

Data and R scripts are available at the following OSF link: https://osf.io/dbckf/.

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