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Neural network-based measure of consonant lenition in L2 Spanish

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This study investigates the gradient phonetic variations in the lenition of Spanish voiced and voiceless stops among second language (L2) learners with different levels of proficiency (beginning, intermediate, and advanced). The degree of lenition is measured using posterior probabilities of the continuant and sonorant phonological features, estimated by the deep learning model Phonet. The findings reveal that the degree of lenition, as indicated by the sonorant posterior probability, increases with proficiency. However, no significant effects of proficiency were observed for the continuant posterior probability. Similar to native speakers of Spanish, L2 learners exhibit effects of stress, voicing, and place of articulation on lenition. These results suggest that all learners exhibit lenition of stops as a fricative, but more advanced learners also exhibit lenition as a sonorant. Additionally, lenition in L2 is found to be gradient and influenced by linguistic factors. Moreover, the posterior probabilities of the continuant and sonorant phonological features, estimated by the Phonet model, serve as reliable measures of lenition. Overall, this study reveals the role of proficiency and linguistic factors in shaping the degree of lenition and highlights the effectiveness of the posterior probabilities obtained from the Phonet model in quantifying lenition.

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1. INTRODUCTION

In most, if not all, Spanish dialects, the voiced stops /b, d, ɡ/ typically weaken to voiced fricatives [β, ð, ɣ] in various contexts, including between vowels and after vowels. However, they remain as stops [b, d, ɡ] after pauses, nasals, and for /d/, after /l/. This process, also known as spirantization, is part of a broader phenomenon called lenition, which involves the weakening of consonants. While this weakening was once thought to produce fricatives (e.g., Harris, 1969; Navarro Tomás, 1977; Lozano, 1979; Mascaró, 1984), recent research suggests these sounds are closer to approximants [β̞, ð̞, ɣ̞] (e.g., Martínez Celdrán, 1991; Romero, 1995), indicating a more nuanced and gradient distribution of these sounds influenced by factors such as vowel quality, stress, and speaking rate. Voiceless stops in some Spanish dialects also undergo lenition, becoming voiced.

Lenition presents challenges for second language (L2) learners of Spanish. Research on L2 Spanish learners has shown that their ability to produce and perceive lenited consonants varies significantly. This variability is influenced by factors including the learners' first language phonology, their level of exposure to Spanish, and their overall proficiency in the language. For example, in her 1994 study, Zampini explored how the native language influences English speakers' learning of Spanish voiced stops /b, d, ɡ/, and examined the impact of task formality on their pronunciation. She discovered that the background language affects the second language learning of these phonetic elements in three significant ways. Firstly, the lack of an allophonic lenition rule for voiced stops in English leads English speakers to struggle to lenite /b, d, ɡ/ in Spanish. Secondly, English speakers tend to learn the phone [ð] more slowly than they do [β] and [ɣ], due to the transfer of the phonemic status of English /ð/ to Spanish. Lastly, the presence of the orthographic <v> also interferes with the acquisition of [b] and [β]. This issue is notably more pronounced during tasks that require formal reading than in informal conversational settings, given the different phonemic distinctions between /b/ and /v/ in English but not in Spanish.

Shea and Curtin (2011) examined how language experience affects the pronunciation of the alternation between stops and approximants (b d ɡ ~ β̞ ð̞ ɣ̞) in Spanish, by native English speakers with Low Intermediate and High Intermediate Spanish levels and native Mexican Spanish speakers. The focus was on the use of consonant intensity and release bursts as indicators of this allophonic change, which is largely determined by the consonant's position in the word and the stress of the syllable. The results indicate that the use of these phonetic indicators changes with the level of language experience, with more experienced learners showing patterns more closely aligned with those of native speakers. Furthermore, the findings indicate that learners at the Low Intermediate level initially adopt a simple rule-based approach to phonetic alternation but progress towards more complex patterns as they gain proficiency. This progression implies a gradual development in the ability of more advanced learners to utilize phonetic cues like native speakers and highlights an increase in the awareness of phonetic detail during the learning of allophones.

Drawing on an Optimality Theoretic framework, Cabrelli Amaro (2017) tests the hypothesis that learners with English as their first language (L1) and Spanish as their second language (L2) acquire voiced stop lenition in stages that align with the prosodic hierarchy (Zampini, 1997, 1998). This hypothesis posits that learners initially give priority to prosodic positional faithfulness over a markedness constraint that disfavors postvocalic stops, gradually adjusting this ranking to facilitate the appearance of lenited stops after vowels as their proficiency develops. Contrary to prior assumptions based on Zampini’s findings, the results reveal that learners initially lenite stops to approximants at the syllable onset (word-medial) and then at the prosodic word onset (word-initial), without demonstrating an intermediate stage of acquisition across word boundaries and with its clitics. Additionally, advanced learners were shown to possess the ability to produce lenited stops in postvocalic positions across all prosodic levels, indicating the successful acquisition of the targeted constraint ranking. Furthermore, it was observed that the difference in the degree of lenition between learners and native speakers diminishes as proficiency increases, with some advanced learners achieving production that closely mirrors that of native speakers across various prosodic contexts.

To examine the progression of how individual English-speaking L2 Spanish learners produce the Spanish [β] across various phonetic contexts over time, Nagel (2017) had a group of twenty-six learners record stimuli in two speaking tasks at five intervals over a year, covering their second and third semesters of university-level Spanish instruction. It was found that, although the overall trend did not indicate improvement across the learner group, a significant subset of participants demonstrated marked changes during the study period, showing both advancements and regressions in their pronunciation trajectory.

A study by Salinas (2015) compared the production of Spanish voiced stops /b, d, g/ among English-speaking learners at low-intermediate and advanced levels with that of native Spanish speakers. The study aimed to test several hypotheses: firstly, that advanced learners would exhibit more lenition than the low-intermediate group; secondly, that their results would more closely align with those of native speakers; thirdly, that lenition would be more pronounced in word-internal than in word-initial positions, especially for the low-intermediate group; and lastly, that non-stressed syllables would exhibit more lenition than stressed ones. The study also explored how orthography, specifically the representation of <b> and <v>, affects lenition differently for the low-intermediate group. The findings confirmed that advanced learners indeed exhibited more lenition across all phonemes and conditions compared to their low-intermediate counterparts, supporting the initial hypothesis. Although the patterns of lenition among advanced learners were similar to those of native speakers, notable differences emerged. Specifically, these differences were observed in the production of <b> and <v>, and the effect of position (word-initial vs. word-internal), with both orthography and position exerting a greater influence on advanced learners. Contrary to expectations, increased weakening in word-internal positions was observed for both learner groups, but this was not as pronounced among native speakers. Regarding stress, more lenition was noted in non-stressed syllables for the advanced and native groups, but not for the intermediate group. Orthographically, low-intermediate participants showed a preference for leniting <v> over <b>, a pattern that was also evident among advanced learners. Interestingly, neither group produced <v> as a fricative, suggesting an awareness of its approximant pronunciation in Spanish. Additionally, some learners pronounced the second <d> in <dedo> as a tap, reflecting the influence of their first language, English. Surprisingly, a slight difference in lenition between <v> and <b> was also noted among native speakers, challenging previous claims of no phonological distinction between Spanish <b> and <v>. Overall, the study underscores the need for further research into the effects of formality on lenition and the influence of cognates and calls for larger-scale studies to attain more comprehensive insights, given the limitations posed by the small participant pool.

Lenition affects acoustic properties including intensity, duration, and periodicity, with intensity being a primary measure (e.g., Cole et al., 1999; Ortega-Llebaria 2004; Soler and Romero 1999; Hualde et al. 2011). Specifically, studies have used the intensity difference between consonants and adjacent segments, notably vowels as a lenition indicator, suggesting that smaller differences correlate with more pronounced lenition (e.g., Hualde et al. 2011). Other metrics, such as the maximum rising velocity and the mean intensity of sounds, as well as the relative duration of consonants, have also been employed to assess lenition, indicating that more lenited sounds have shorter durations and different intensity profiles (e.g., Ortega-Llebaria 2004; Soler and Romero 1999; Hualde et al. 2011). The harmonics-to-noise ratio (HNR) is another marker, with more lenited sounds showing a vowel-like quality indicated by a higher HNR (e.g., Bro´s et al. (2021). Unlike previous studies, this study adopted a novel approach to quantify the degree of lenition among three groups of native English speakers with varying levels of L2 Spanish proficiency. It utilized the posterior probability of phonological features relevant to the lenition process, specifically continuant and sonorant. These probabilities were computed by a deep neural network known as Phonet.

A. PHONET

Phonet, introduced by Vásquez-Correa et al. (2019) is a bi-directional recurrent neural network model, trained to recognize input phones as belonging to different phonological classes defined by phonological features (e.g., sonorant, continuant). This semi-automatic tool requires only a segmentally aligned acoustic corpus, utilizing forced alignment. The input for Phonet consists of log energy distributed across triangular Mel filters, computed from 25-ms windowed frames of each 0.5-second chunk of the input signal (for details, see Vásquez-Correa et al., 2019). Once trained, the model can compute posterior probabilities for the phonological features of target segments. It has proven highly accurate in quantifying the degree of lenition in Spanish (Tang et al., 2022; Wayland et al., 2022; Tang et al., 2023) and in modeling the speech impairments of patients diagnosed with Parkinson's disease (Vásquez-Correa et al., 2019). Phonet can be customized with various sets of phonological features and acoustic representations. In this study, we specifically focus on the probability of the phonological features [continuant] and [sonorant] to capture the degree of lenition. The architecture and training process of Phonet is detailed in Vásquez-Correa et al. (2019), with further elaboration on model training for the current study provided by Tang et al. (2023).

2. THIS STUDY

This study extends the Phonet model to investigate the degree of lenition of Spanish stops among three groups of classroom learners of Spanish, all of whom have British English as their first language (L1). The learners are differentiated by their proficiency levels in Spanish.

A. METHODS

I. MATERIALS

The Spanish Learner Language Oral Corpus (SPLLOC) (Michelle et al., 2008) was utilized for this study. It was forced-aligned using the Montreal Force Aligner (version 2.0) (McAuliffe et al., 2017). The corpus comprises oral productions in Spanish by L2 learners engaged in various speaking tasks (interview, narrative, discussion). All learners were native British English speakers receiving formal instruction in L2 Spanish. There were 20 learners at each level, distinguished by age (Beginner = 13-14 years old; Intermediate = 17-18 years old and Advanced = 21-22 years old) and years of instruction rather than by any formal, independent language test. Approximate hours of Spanish instruction were 180 hours, 750 hours, and 895 hours plus a year of study abroad. Additionally, five age-matched native Spanish speakers performed the different sets of tasks at each level. The data for this study were extracted solely from the narrative tasks completed by the learners. Due to technical errors, audio files for two speakers each in the beginner and intermediate groups were excluded from the analysis, leaving 18 participants in both the beginner and intermediate groups, but 20 participants in the advanced group.

Target sounds include both voiced (/b, d, g/) and voiceless (/p, t, k/) stops in word-medial positions. Tables 1 and 2 present the distributions of tokens for each proficiency level in the two word positions, respectively.

Level	**/b/**	**/d/**	**/ g/**	**/p/**	**/t/**	**/k/**
Beginner	69	59	4	45	69	22
Intermediate	127	130	1	119	128	28
Advanced	184	268	3	256	203	64

Table 1: Distribution of voiced and voiceless stops in word-initial position by proficiency level.

Level	**/b/**	**/d/**	**/g/**	**/p/**	**/t/**	**/k/**
Beginner	104	93	52	45	2	93
Intermediate	140	197	72	52	19	102
Advanced	219	308	154	83	22	173

Table 2: Distribution of voiced and voiceless stops in word-medial position by proficiency level.

The target tokens occur in both stressed and unstressed syllables, being preceded by a vowel (open /a/, mid /e, o/, and close /i, u/) or a nasal consonant, and consistently followed by a vowel.

II. STATISTICAL ANALYSES

The sonorant and continuant posterior probabilities generated by the Phonet model served as dependent variables in the linear mixed-effects regression models. The models' fixed variables were stress (stressed or unstressed), voicing (voiced or voiceless), place of articulation (bilabial, dental, and velar), preceding segment (vowel or nasal) preceding vowel height/openness (open, mid, and close), and following vowel height (open, mid, and close). A strong effect of stress on lenition has been reported, with a higher degree of lenition expected in unstressed syllables than in stressed syllables (Ortega-Llebaria 2004, Broś et al. 2021, Eddington 2011). On the contrary, the influence of place of articulation and flanking vowel openness has been inconsistent (Cole, Hualde, and Iskarous 1999, Ortega-Llebaria 2004, Kingston 2008, Lewis 2001, Lavoie 2001]. Overall, velar stops are expected to be weaker than labial and dental/alveolar stops, and the more open the flanking vowels, the greater the degree of lenition is expected (Kircher 2013). Regarding the effect of voicing, voiced stops are expected to be more lenited than voiceless stops (Broś et al. 2021, Colantoni and Marinescu 2010).

Deviation coding was used for the categorical variables stress, voicing, and word status. In contrast, forward difference coding was used for the place of articulation (bilabial > dental > velar), preceding vowel (close > mid > open), and following vowel (close > mid > open) variables. The analyses were conducted using the *lmer* function from the *lme4* package (Bates et al., 2015) in R (R Core Team, 2022). Two models were performed, one for each dependent variable (continuant posterior probability and sonorant posterior probability). After evaluating multiple model structures through maximum likelihood estimation, the best-fit model structure for each dependent variable was determined. The formula for the model is as follows:

DEPENDENT VARIABLES ~ Stress + Voicing + Place of articulation + Preceding vowel

+ Following vowel + Place of articulation: Preceding vowel + Place of articulation: Following vowel + Preceding vowel: Following vowel + (1 | Speaker) + (1 | Word).

Specifically, the model assesses the main effects of Stress, Voicing, Place of articulation, Preceding vowel, and Following vowel, in addition to the interactions between Place of articulation and both Preceding and Following vowels, and the interaction between Preceding and Following vowels. It also accounts for variability across Speakers and Words with random intercepts. Post-hoc comparisons of the interaction terms were conducted using the *emmeans* package, employing Tukey's HSD method for p-value adjustment (Lenth et al., 2021). The results of the best-fit model for each dependent variable will be reported in the following section.

B. RESULTS

I. CONTINUANT POSTERIOR PROBABILITY

Figure 1 visualizes the mean continuant posterior probability across all target tokens (/b, d, g, p, t, k/) in word-initial (left) and word-medial (right) positions for the three groups of learners.

The results of the linear mixed-effects regression model revealed significant effects of Stress, Voicing, and Place of Articulation. These results suggest that the degree of lenition (as fricative-like) is significantly lower in stressed syllables than in unstressed syllables [β = -0.034, t = -3.940; p < 0.001], among voiceless stops compared to voiced stops [β = -0.032, t = -3.158; p < 0.002], and that bilabial stops are significantly less lenited than dental stops [β = -0.028, t = -2.437; p < 0.015]. The effect of Group was not significant, nor were any interactions.

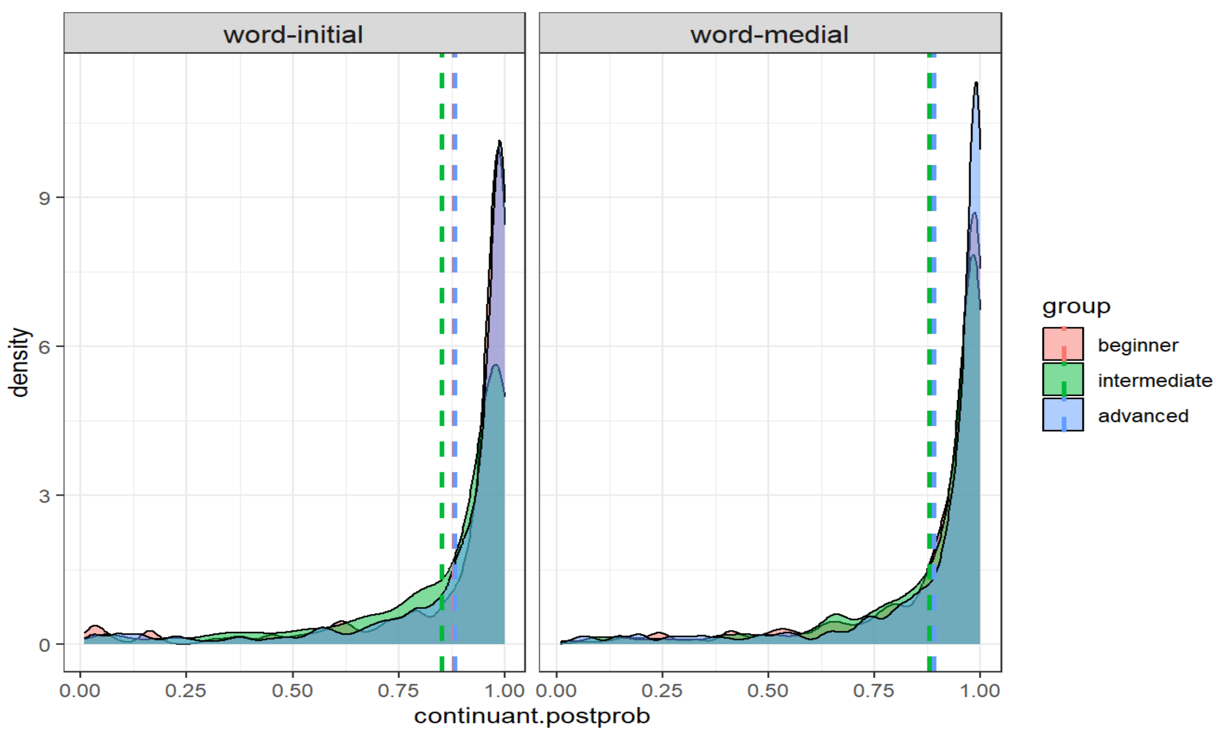

Figure 1: Mean continuant posterior probabilities for the three groups of L2 Spanish learners.

II. SONORANT POSTERIOR PROBABILITY

Figure 2 visualizes the mean sonorant posterior probabilities across the target stop consonants for the three groups of learners in the word-initial position (left) and word-medial position (right). Unlike the continuant posterior probabilities, it is evident that the values are lower for beginners compared to intermediate and advanced learners in both word positions.

The results of the linear mixed-effects model confirmed that the degree of lenition (as approximant-like) is significantly lower for beginners compared to advanced learners [β = -0.051, t = -2.000; p = 0.046]. However, the difference between intermediate and advanced learners was not statistically significant [β = 0.005, t = 0.252; p = 0.801]. Similar to the continuant probability, the degree of lenition is lower in stressed syllables than in unstressed syllables [β = -0.044, t = -2.842; p = 0.005], among voiceless than voiced stops [β = -0.075, t = -4.151; p < 0.001], and bilabial stops are significantly less lenited than dental stops [β = -0.051, t = -2.516; p = 0.012].

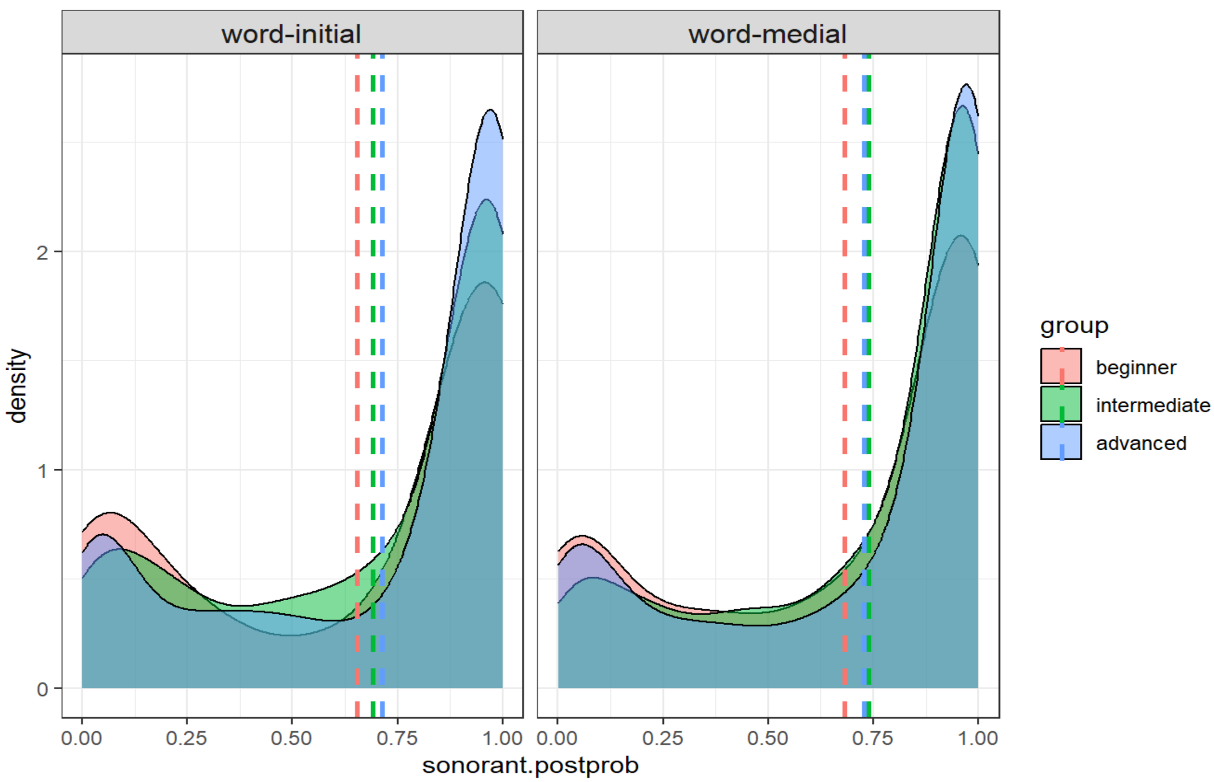

Figure 2: Mean sonorant posterior probability for the three groups of L2 Spanish learners.

3. DISCUSSION AND CONCLUSION

This study introduces a computational method to measure the lenition of stop consonants, employing posterior probabilities of relevant phonological features, namely continuant and sonorant, computed by a deep learning neural network. The continuant feature captures a change from stop to fricative while the sonorant feature captures a change from stop to approximant.

The study explores the gradient phonetic variations in the lenition of Spanish voiced and voiceless stops among second language (L2) learners across various proficiency levels: beginner, intermediate, and advanced. The findings revealed that the degree of lenition, as indicated by the sonorant posterior probabilities, increased with higher learner proficiency. However, no significant effects of proficiency were observed for continuant posterior probabilities. These results suggest that learners at all proficiency levels realized the lenition of stops as fricatives, with those at more advanced levels also showing lenition as sonorants. Additionally, lenition among L2 learners of all proficiency levels was found to be gradient and influenced by linguistic factors including stress, voicing, and place of articulation. Shea and Curtin (2011) hypothesized that learning an allophonic alternation could involve either categorical or gradient knowledge. In line with these researchers' findings, the current findings support the notion of more gradient knowledge in allophonic acquisition. The findings align with Exemplar-based models (e.g., Bybee 2000, 2001, 2003; Pierrehumbert 2001a, 2001b, 2003a, 2003b) of phonological and phonetic knowledge, which assume that detailed information is stored in rich exemplar representations. However, the discovery that learners with a higher degree of L2 proficiency (i.e., intermediate and advanced learners) exhibited significantly higher sonorant posterior probabilities than beginners suggests a lower degree of gradient in phonetic variations among the latter group compared to the former groups.

The relative lack of phonetic gradience among beginners may stem from the instructional methods used in Spanish L2 classrooms, as noted by Shea & Curtin (2011). Specifically, the explicit teaching of the lenition rule—from a stop to a fricative—may lead beginners to initially learn these rules categorically. However, with increased exposure and experience, intermediate and advanced learners develop a more nuanced understanding and application of these rules, demonstrating a gradient approach to phonetic changes.

The finding that dental stops are more lenited than bilabial stops suggests that the phonemic status of /ð/ in English did not prevent the lenition of /d/. Instead, this result is consistent with the hypothesis that the degree of lenition is more pronounced among posterior stops than anterior stops, possibly because their constrictions are less complete (Kingston 2008). This hypothesis contradicts the aerodynamic account, which asserts that intraoral air pressure behind the constriction of a more posterior stop typically increases more than that behind the constrictions of more anterior stops (Ohala 1974, Javkin 1977).

The absence of a significant main effect for word position (word-medial versus word-initial) is surprising, especially when considering the findings of Cabrelli Amaro (2017), which implied that the stages of lenition acquisition might correspond closely with the prosodic hierarchy. Contrary to these expectations, our results suggest that the stages of acquisition do not necessarily align with this hierarchy. Instead, the key variation appears to be in the degree of gradience within the phonetic representation of lenited segments. Specifically, as learners progress, they might not simply acquire a binary distinction of lenition based on word position but rather develop a more nuanced, gradient understanding of how lenition varies across different linguistic contexts. This gradience reflects a deeper phonetic and phonological understanding, suggesting that the process of acquiring lenition is more complex and involves a gradual refinement in the learners' ability to perceive and produce nuanced phonetic variations.

It is important to note that the stimuli used in Cabrelli Amaro's study consisted of read speech, whereas the stimuli in the current study are derived from a narrative speech style. This distinction is crucial as it may account for the observed differences in results. Narrative speech, being more spontaneous and less controlled than read speech, might reveal more naturalistic phonetic variations and lenition patterns. Therefore, the lack of a significant main effect of word position (word-medial versus word-initial) in our findings, contrary to what Cabrelli Amaro (2017) suggests, could be attributed to the differences in speech style. This variation underscores the complexity of lenition acquisition, indicating that the phonetic representation of lenited segments may evolve in a manner that does not strictly adhere to the prosodic hierarchy, but rather, it may also be influenced by the context and style of speech.

Finally, the absence of effects related to the openness of flanking vowels contradicts Kirchner's effort-based view of lenition but instead supports Kingston's (2008) proposal. While Kirchner (2013) suggests that lenition is driven by a grammatical constraint termed LAZY within the Optimality Theoretic framework, which posits that the pronunciation of any given sound should require as little effort as possible, Kingston (2008) presents a different perspective. He argues that the purpose of lenition is to minimize interruptions in the flow of speech, thereby indicating that the affected consonant is part of a prosodic constituent. Kingston hypothesizes that lenition is not governed by the distance articulators must travel, but rather by the difference in intensity that a speaker aims to create between the affected segment and its neighboring sounds. Thus, in Kingston's analysis, lenition serves to complement fortition, being influenced by the position of the affected segment within a prosodic constituent. It signals continuation within a prosodic constituent through greater intensity and less signal disruption, whereas fortition marks the boundaries of prosodic constituents by decreasing signal intensity and increasing signal disruption.

In conclusion, the study underscores the impact of proficiency and linguistic factors on lenition degrees and demonstrates the Phonet model's capacity to quantify fine-grained lenition degrees more reliably than traditional direct acoustic measurements. Thus, Phonet reveals expected gradient lenition patterns governed by established variables, highlighting its effectiveness in accurately quantifying lenition.

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