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Exploring variables affecting vowel sequences across word boundaries in Peninsular Spanish

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Abstract

This article presents an analysis of variables that can influence the behavior of vowel sequences across word boundaries in Peninsular Spanish. The analyses have been conducted using the following variables: vowel type, syllable type, word type, articulation rate, stress, and the position of the sequence in the utterance. Results show that combinations with stress favor maintenance when considering the main accent of the utterance and the sequence's position at the utterance boundary. On the other hand, vowel type, syllable type, and word type have presented fewer effects than stress on the preference to maintain the hiatus or contract it in any way, as there was a tendency for sandhi in almost all types of combinations. Lastly, articulation rate has shown higher rates correlating with increased likelihoods of sequence contraction.

Keywords

vowel sequences; word boundaries; sandhi; hiatus; Peninsular Spanish

Variables que afecten les seqüències vocàliques en límits de mot en espanyol peninsular

RESUM

Aquest article analitza les variables que influeixen en les seqüències vocàliques als límits de paraula en l'espanyol peninsular. S'han considerat sis variables: tipus de vocal, síl·laba i paraula, velocitat d'articulació, accentuació i posició en l'enunciat. Els resultats indiquen que les combinacions amb accent afavoreixen el manteniment, especialment quan coincideixen amb l'accent principal i es troben al final de l'enunciat. En canvi, el tipus de vocal, síl·laba i paraula tenen menys impacte, ja que gairebé totes les combinacions tendeixen al sandhi. Finalment, una major velocitat d'articulació s'associa a una probabilitat més alta de contracció de la seqüència.

MOTS CLAU

seqüències vocàliques; límits de mot; sandhi; hiat; espanyol peninsular

1. Introduction

1.1. The behavior of vowel sequences across word boundaries in Spanish

In spoken discourse, Spanish allows for the contraction of hiatuses that occur when vowels meet across word boundaries. The contraction of the vowels in Spanish can result in the formation of a diphthong or a monophthong (Jenkins, 1999; Aguilar, 2003, 2005, 2017; Hualde, 1994, 2013; Alba, 2006; Bakovic, 2007; Garrido, 2007; Hualde et al., 2008; Smith et al., 2008; Barberia, 2006, 2012; Herrero De Haro & Alcoholado Feltstrom, 2024). In this context, when two adjacent vowels meet at a word boundary, certain phonetic and prosodic factors come into play, influencing the likelihood of contraction or maintenance of hiatus. According to various studies (Kaisse, 1977; Casali, 1997, 2021; Myers, 2020, among others), such types of sandhi are effects of the tendency to avoid hiatuses in vowel encounters. The anti-hiatus tendency is also a characteristic trait found since Latin times (Allen, 1978) and persists in Romance languages (Quilis, 1999; Hualde, 2013; Alba, 2006; Chitoran & Hualde, 2007; Adams, 2007; Aguilar, 2017; Alcoholado Feltstrom, 2020a, 2020b).

Stress patterns, for example, play a crucial role in determining the behavior of adjacent vowels. Jenkins (1999) presents insightful observations regarding the behavior of stressed elements within phonological resolution. According to him, stressed vowels remain unchanged during resolution, except when they're adjacent to another stressed vowel. He also highlights that hiatus tends to be preserved when a stressed vowel is followed by a vowel other than /e/. Similarly, Hualde (1994) and Hualde et al. (2008), in studies on the contraction of mid vowels in Spanish, argue that the contraction of mid vowels is influenced by stress, that is, combinations of unstressed vowels contract more easily than those with stressed vowels.

Aguilar (2003), in a study on vowel combinations in /Va/ contexts, found a higher occurrence of hiatuses in a general overview of the corpus. However, when analyzing only VV sequences, she observed a greater number of monophthongs, and in VˈV combination contexts, diphthongs were more prevalent. The author concludes that hiatuses occurring in stressed syllables may exhibit a tendency to resist contraction, favoring the preservation of their individual phonetic identity. Conversely, unstressed syllables may be more prone to undergo contraction, resulting in a fusion of adjacent vowel sounds.

In other studies by Aguilar on segmental weakening in vowel links (2005, 2006, 2010, 2017), the author emphasizes that processes weakening the vowel within a boundary sequence are common in Spanish. Nevertheless, Aguilar highlights four conditions of morphological and prosodic nature that prevent vowel coalescence into a single syllable: 1. phrases with two prosodic nuclei (e.g., "*la altura*", which has only one prosodic nucleus, has a higher probability of vowel coalescence compared to "*tela adhesiva*", which has two prosodic nuclei); 2. primary lexical stress; 3. ambiguity with another word sequence (e.g., the vowels in "*para acabar*" tend to maintain both vowels to avoid confusion with "*para cavar*"); and 4. the presence of monosyllabic words like <*y*, *e*, *o*, *u*, *ni*, *no*>, where vowel elision can lead to the loss of grammatical information.

Alba (2006) analyses the relationship between vowel quality and stress concerning hiatus versus sandhi processes in the spoken Spanish data of New Mexico. Her findings reveal that when the second vowel is /a/ and /e/ tend to favor the occurrence of sandhi processes – considering that his data were always /a/ as the first vowel, followed by some of the five vowels in Spanish. Regarding stress, the research suggests that contraction is more likely to occur in contexts with unstressed vowels.

Moreover, Alba expands his analysis to include the influence of other factors on the distribution of hiatus and sandhi contexts, such as syllable type and word type. However, it is remarkable that these factors do not exert as considerable influence as factors like stress and vowel quality in his analysis. Nevertheless, the author observes that open syllables can be more susceptible to undergo contraction, resulting in a reduction in the number of observed hiatuses. Furthermore, the role of word type in the frequency of sandhi occurrences is considered, yet its significance in Alba's analysis is relatively limited. Functional words display a propensity for contraction over hiatus maintenance, but their impact is not deemed as crucial in the overall assessment.

Regarding string frequency, Alba (2006) demonstrates that contraction occurred more frequently in items with higher string frequency, significantly surpassing the rate observed in items with lower string frequency. The findings related to string frequency are particularly intriguing because they indicate that usage patterns hold a significant role in the process of contraction.

Barberia (2006; 2012) investigates the occurrence of potential hiatus contraction situations in Peninsular Spanish. Through her analysis, Barberia identifies contexts where hiatuses are likely to undergo contraction, resulting in the formation of diphthongs or monophthongs. Her observations highlight a tendency toward sandhi when sequences present the mid-front vowel /e/ in any position (as the first or second vowel), more so than combinations with other vowels in the sequence. The findings also indicate that the type of words is not statistically significant, as all possible combinations consistently involve a reduction in the duration of the vowel sequence, which is a result of any sandhi process. Finally, the syllable type variable shows a greater propensity for sandhi in contexts of closed syllables.

Smith et al. (2008), on the other hand, conducted an analysis on data from Mexican Spanish spoken in Veracruz, Mexico. Their results demonstrate a preference for not maintaining hiatus in 94% of the data. The authors also observe that the duration of hiatuses is longer in comparison to cases of sandhi. In their analysis, stress appears not to influence vowel combinations.

The reduction of vowels may also be linked to the speaker's articulation rate. In this context, Nadeu (2014) explores the effects of stress and articulation rate on vowel reduction and quality in two closely related languages: Catalan and Spanish. The study is based on the acoustic analysis of vowels produced by native speakers of both languages under different conditions of stress and speech articulation. The results of the study suggest that stress and articulation rate have significant effects on vowel reduction in both languages, although these effects vary depending on the specific vowel. Additionally, it was found that articulation rate has a more notable effect on vowel duration than on its acoustic quality.

Moreover, Souza (2010) points out that faster articulation may reduce hiatus sequences to sandhi. This suggests that increased speech rate could influence the phonetic realization of vowel sequences, potentially favoring the simplification of hiatuses into monophthongs.

Finally, Voigt and Schüppert (2014) investigate the effect of articulation rate on syllable reduction in Spanish and European Portuguese. The results show that there were no significant differences between the articulation rates of both languages. It was also found that syllable reduction in Spanish mainly occurs in final vowels and the consonants that follow them, while in Portuguese, reduction mainly occurs in final consonants.

1.2. The present study

In this study, our goal is to investigate some variables and their impacts on sandhi contraction and hiatus maintenance across word boundaries in Spanish, utilizing semi-spontaneous data from Peninsular Spanish speakers. By examining vowel type, syllable structure, word type, articulation rate, stress patterns, and the position of the sequences in speech, we aim to elucidate the underlying mechanisms governing the interaction among these factors.

1.3. Hypothesis

For this study, some hypotheses have been formulated. These hypotheses are based on previous studies, considering the factors vowel type, syllable type, word type, articulation rate, stress, and sequence position within the utterance between pauses:

Hypothesis 1 (Vowel Type): There are higher probabilities of sandhi when the sequence is from a mid-vowel to a high vowel (or vice versa). The combination of a low vowel to a high vowel may be more challenging for sandhi to occur, as it involves a more sustained tongue movement to produce both vowels.

Hypothesis 2 (Syllable Type): Closed syllables can be more susceptible to sandhi than open syllables, as posited by Barberia (2006, 2012).

Hypothesis 3 (Word type): A sequence of functional words tends to contract vowels at the boundary more than the context of lexical words. In the contexts of a monosyllabic functional word and another lexical word, sandhi may depend on whether the functional word is going to lose grammatical information or not (Aguilar, 2006).

Hypothesis 4 (Articulation Rate): The values of articulation rate can affect the vowel sequence across word boundaries. This means that the lower the articulation rate of utterance between pauses, the greater the tendency toward contraction of sequences through some type of sandhi.

Hypothesis 5 (Stress and sequence position): Sandhi tends to occur more frequently when both vowels are unstressed, as postulated by Jenkins (1999), Aguilar (2003, 2017), among others. In sequences where at least one of the vowels is stressed, contraction will depend on the correlation between word stress and two additional factors: if the sequence receives the main stress of the entire utterance and whether the sequence occurs within or at the boundary of the utterance between pauses.

2. Method

2.1. Participants

The phonetic experiment conducted for this study is based on data collected from 10 native speakers of Salamanca, Spain, all of whom are university students aged between 20 and 34 years old. All participants signed an informed consent form to voluntarily participate in the study. Table 1 contains labeling information, gender, and the number of vowel sequence productions considered in this study:

Participant	**Sex**	***n***
Sal1	F	178
Sal2	F	176
Sal3	F	160
Sal4	M	152
Sal5	F	135
Sal6	F	152
Sal7	F	138
Sal8	M	108
Sal9	F	176
Sal10	M	130
Total		1,505

Table 1. Information about the research participants.

2.2. Recordings

Data were collected through interviews with the informants, focusing on specific topics: a) talking about travels; b) talking about their city; c) studies. The purpose of these topics was to create a relaxed environment that would allow the informants to respond spontaneously to the questions. Each topic included a set of 5 to 10 questions, and overall, the interviews lasted for 20 to 25 minutes.

For the recordings, a computer, a unidirectional microphone, and a Scarlett 2.0 audio interface were used. The data was recorded using the Audacity software, with a sampling frequency of 44,100Hz. All interviews took place in rooms with good acoustics at the Faculty of Philology or the Brazilian Studies Center at the University of Salamanca.

The audio files from the interviews were segmented into utterances between pauses containing vowel sequences across word boundaries. In the end, a total of 1,505 vowel sequences were obtained. A total of 454 data points were discarded due to difficulties in extracting formants caused by external noises during speech and other disturbances occurring during the recordings.

2.3. Acoustic analysis

The acoustic analysis was performed using the free software Praat, version 6.0.53 (Boersma & Weenink, 1992–2019). In Praat, the values of F1 and F2, as well as the duration of the sequences, were extracted. Formant points were obtained based on the scripts by Fernanda Barrientos,[1] adapted for this study.

In the formant analysis, possibilities of sandhi production have been identified, emerging from monophthongs or diphthongs, as well as the possibility of maintaining hiatus sequences. Monophthongs were characterized by the acoustic energy of F1 and F2 that remain at a steady level, indicating the presence of a single vowel in the spectrogram (Kent & Read, 1992). For diphthongs, a gradual descent or ascent has been verified, mainly in F2, which can occur from the beginning of the portion corresponding to the gliding segment and continue throughout the formant transition for rising diphthongs, or vice versa for falling diphthongs. Hiatus, on the other hand, can present two stationary levels of formant energy, each representing the production of each vowel (Barbosa & Madureira, 2015).

The extraction of formant values for monophthongs was performed using points relative to the 20%, 50%, and 80% of the spectral space of the vowel. For diphthongs and hiatuses, 11 points of F1 and F2 were extracted, aiming to observe in more detail the degree of stability/instability of the vowels that can become glides. Subsequently, transcriptions have been labeled using the TextGrid function, in three different tiers: the first with the phonetic segmentation of vowels within the sequences; the second with the segmentation into phonetic syllables of the utterances between pauses; the third with the orthographic transcription of the statement produced by the speaker. Figures 1, 2, and 3 exemplify the cases of monophthongs, diphthongs, and hiatuses in the data, respectively.

Furthermore, the total duration of the sound articulation produced between pauses was measured, considering the syllable count per second of the interpausal speech (cf. Santiago & Mairano, 2022). Observations of the acoustic waveform and spectrogram were made for syllable segmentation and labeling.

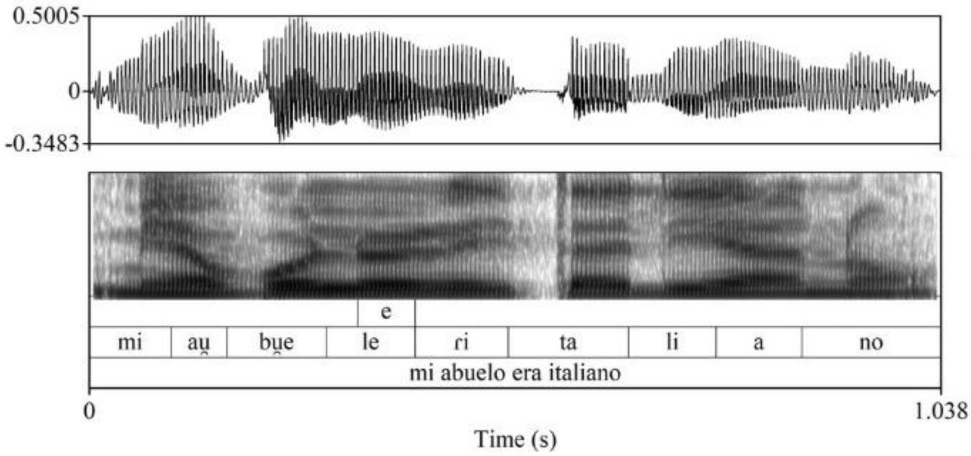

Figure 1. Sound wave, spectrogram, and TextGrid of a monophthong [e] (participant Sal1).

[1] Tutorials available online: Praat scripting I: Basic Operations (https://www.fernandabarrientos.cl/praat1.pdf), Praat scripting II: Perceptual experiments (https://www.fernandabarrientos.cl/praat2.pdf).

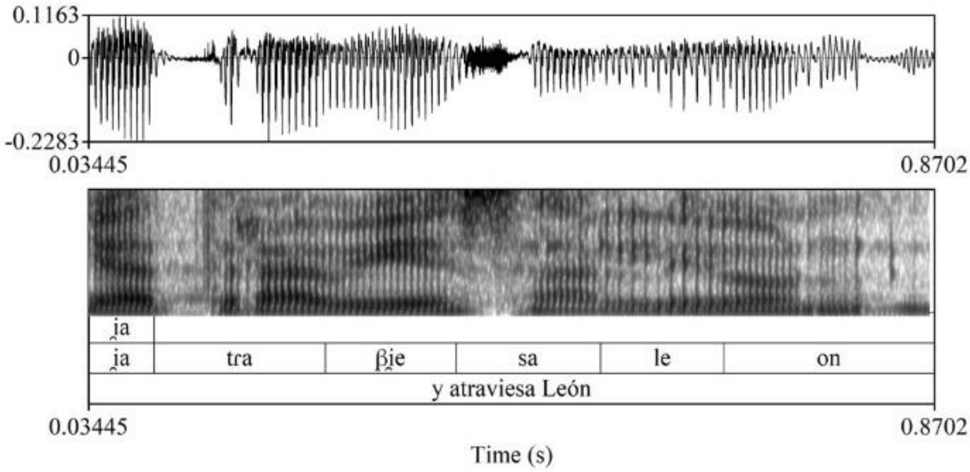

Figure 2. Sound wave, spectrogram, and TextGrid of a diphthong [i̯a] (participant Sal6).

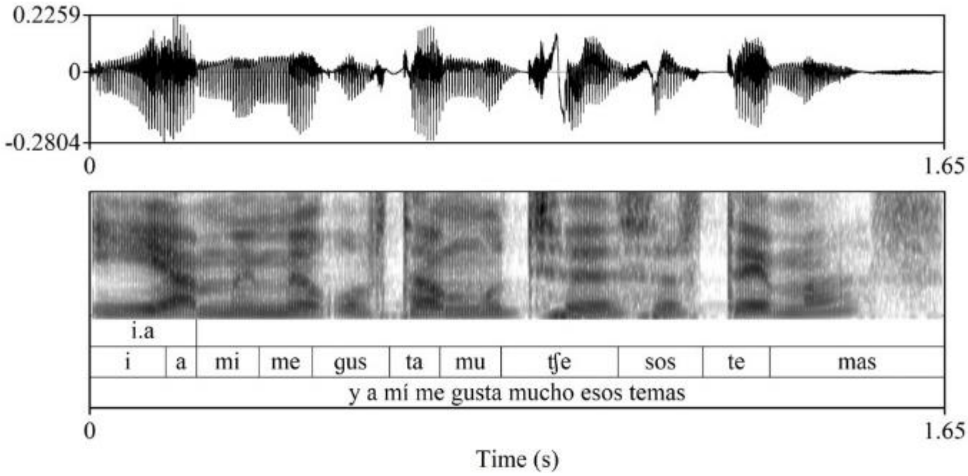

Figure 3. Sound wave, spectrogram, and TextGrid of a hiatus [i.a] (participant Sal3).

2.4. Statistical analysis

The RStudio environment, the interface for R (R Core Team, 2021), was used for testing the statistical analysis, as well as for constructing the graphs (except for the figures of waveforms, spectrograms, and TextGrids, which were produced in Praat). For the inferential analysis, a mixed effects logistic regression model was constructed for each fixed variable. This model combines elements of logistic regression, which is used to model relationships between binary or categorical variables, with the inclusion of random effects that consider the repeated structure of the data (Sonderegger et al., 2018). The response variable was defined as "sandhi" (with a value of 1 in the binary sandhi/hiatus relationship) and "no sandhi" (with a value of 0). Each model included the participant as a random effect.

The glmer function was used to construct the regression models and the model fitting was performed using an analysis of variance projected with the anova function from the lme4 package (Bates et al., 2015). Also, the results in log-odds were also converted to probabilities using the invlogit function from the scales package (Wickham & Seidel, 2022) and tab_model function from the sjPlot package (Lüdecke, 2018).

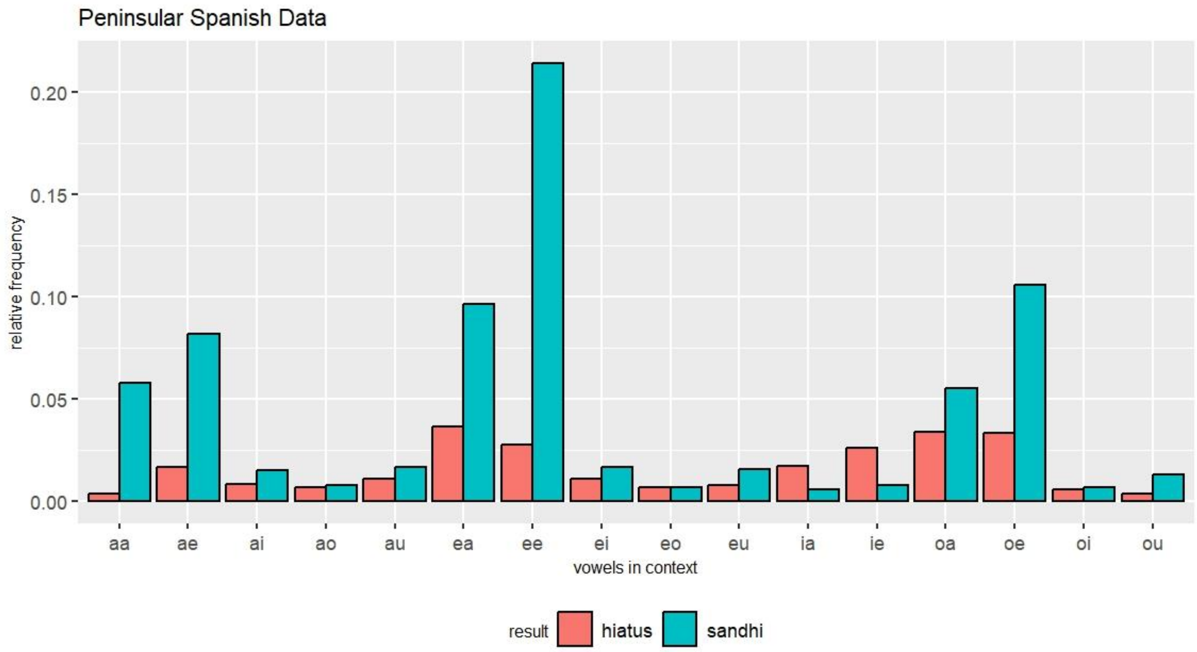

Figure 4. Distribution of data by vowel combination.

3. Results

3.1. Vowel type

The chart in Figure 4 illustrates the distribution of data based on vowel combinations within the sequences. Among all possible combinations, the sequences /aa/, /ae/, /ai/, /ao/, /au/, /ea/, /ee/, /ei/, /eo/, /eu/, /ia/, /ie/, /oa/, /oe/, /oi/, and /ou/ were selected for statistical analysis due to their substantial number of productions. Other sequences were omitted from the analyses either because no data was available or due to an insufficient number of productions.

In general, it can be observed that most of the data exhibits a tendency towards contraction through some sandhi process. On the other hand, a higher number of hiatus instances have been identified in the sequences /eo/, /ia/, and /ie/.

For the statistical analysis of sandhi/hiatus based on the vowel type in the sequences, the best-fitted mixed logistic regression model has considered the sequence type (/aa/, /ae/, /ai/, /ao/...) as a predictor variable, and the binary variable sandhi/hiatus as the response variable. The informant has continued as a random effect.

The results of our best-fitted model suggest a higher probability of maintaining hiatus only in the sequences /ia/ and /ie/. On the other hand, sequences /aa/, /ae/, /ea/, /ee/, /oa/, /oe/, and /ou/ have presented percentage values above 50%, indicating a higher probability of contraction through some type of sandhi. Contexts /ai/, /ao/, /au/, /ei/, /eo/, /eu/, and /oi/ have higher probabilities of contraction, but the confidence intervals fluctuate below and above 50%, indicating that the model cannot infer the preference to maintain hiatus or contract those sequences. The estimates can be observed from the values (in log-odds) of the intercept and slopes (Figure 5) and the predicted probabilities in the model (Figure 6).

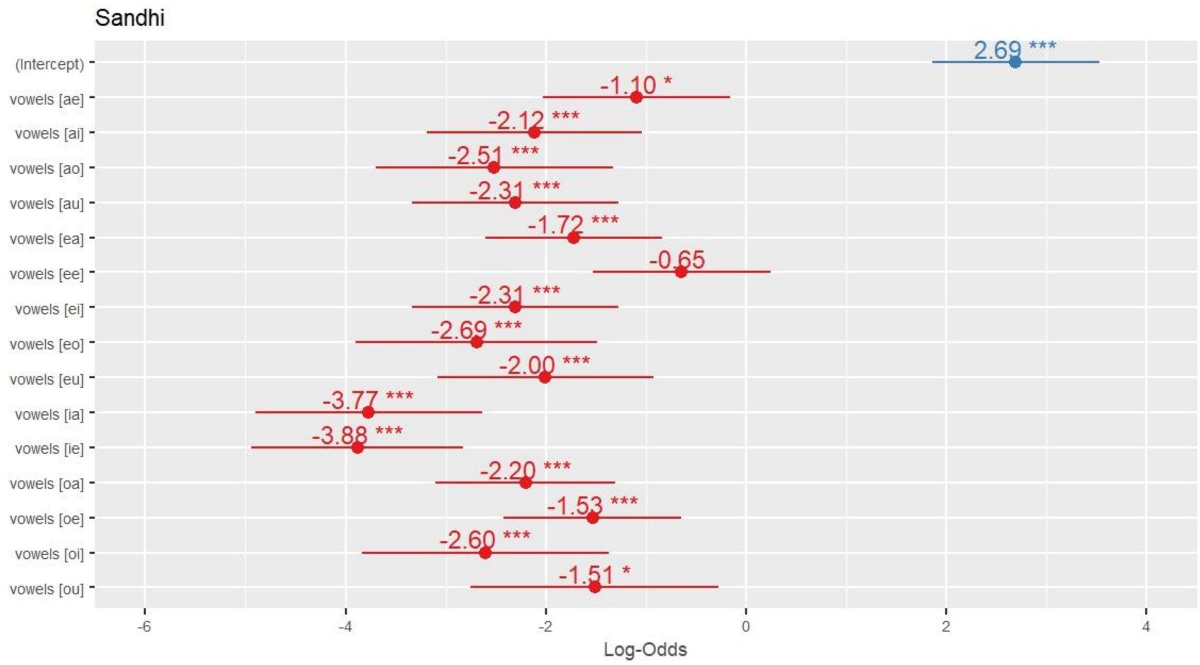

Figure 5. Estimated values (in log-odds) of the binomial logistic regression for the intercept (reference sequence is /aa/) and slopes for each sequence in Model 1. Confidence interval is also indicated (α = 0.05)**.**

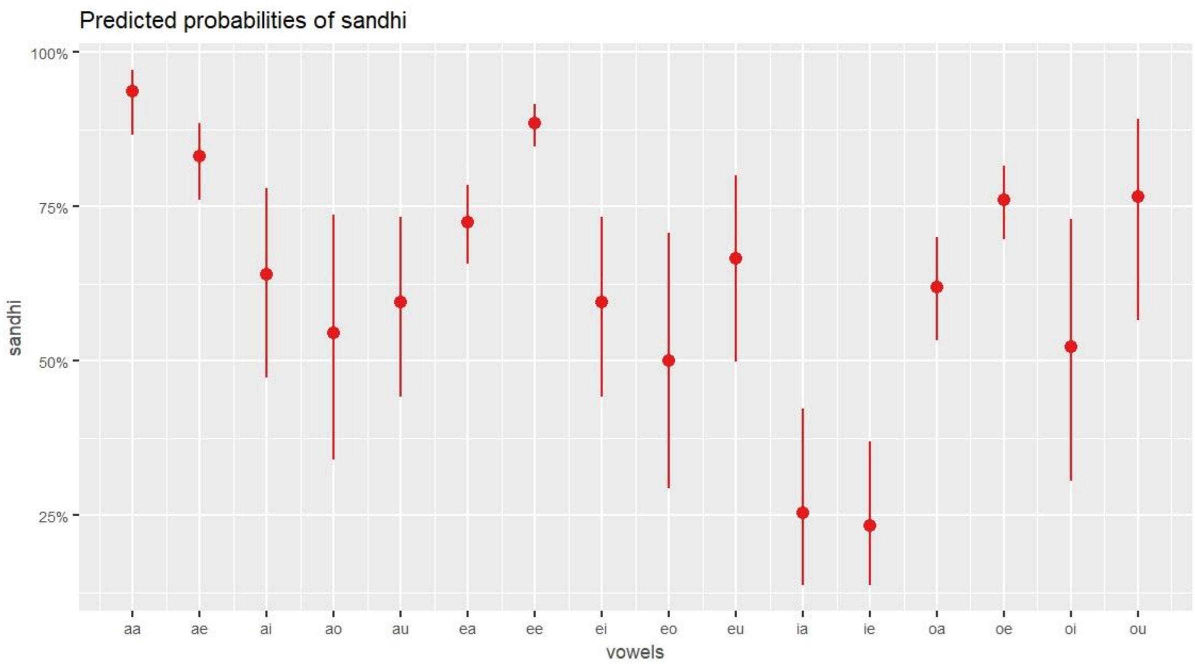

Figure 6. Predicted probabilities of sandhi. Confidence intervals are also indicated (α = 0.05).

3.2. Syllable type

Regarding the type of syllable of the second vowel, a significant amount of data was available for statistical analysis: i) closed syllables, with the presence of alveolar sounds in the coda position, or ii) open syllables, without elements in this position. For the logistic regression model, the binary relationship 1-sandhi and 0-hiatus was considered as the response variable, the consonant (or absence) in the coda position, and the second vowel of the sequence as fixed variables, with the participant as a random effect.

The results of the model show that the contexts of closed syllables with alveolar consonants or open syllables due to the absence of segments in the coda position do not seem to exert a significant influence on the second vowel of the sequence. The only contexts that showed slightly higher probabilities of sandhi were those with the vowels /e/ and /u/ followed by an alveolar segment in the coda position, while in the context without coda, there were higher probabilities of hiatus. However, since the confidence intervals overlap with 50%, clear trends cannot be inferred from this data. Figure 7 presents the estimates, and Figure 8 the predicted probabilities of the model.

3.3. Word type

Regarding the variable of word type, grammatical words primarily fulfill grammatical functions in the structure of a sentence. Examples of grammatical words include prepositions, conjunctions, personal pronouns, possessive pronouns, relative pronouns, and articles. Lexical words, on the other hand, are those that have a specific lexical or semantic meaning, and they are the main words that contribute content and meaning in a sentence. Examples of lexical words include nouns, verbs, adjectives, and adverbs (RAE & ASALE, 2009).

In our analysis, data indicate a tendency towards contraction in any combination (content-function, function-content, content-content, and function-function), as the frequency of sandhi is significantly higher than that of hiatus in all contexts. This finding, supported by the exploratory data analysis, is confirmed through the application of a fitted mixed effects logistic regression model. The model, which considers a binary response variable (1 for sandhi and 0 for hiatus) based on the type of words, incorporates the random effect of the informant. Like the analysis of other variables conducted earlier, the estimates of this model are presented through the log-odds values of the intercept and slopes (Figure 9), as well as the predicted probabilities in the model (Figure 10):

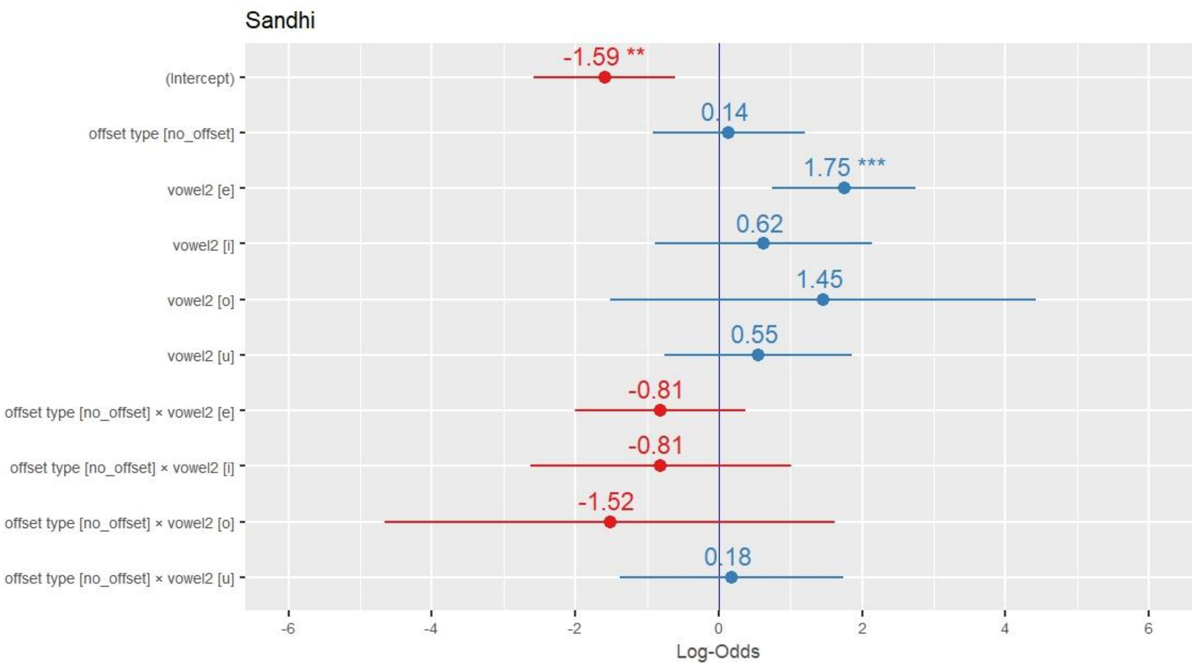

Figure 7. Estimated values (in log-odds) of the binomial regression regarding the intercept (the reference is offset_type[alveolar] when the vowel is /a/) and the slopes of each sequence in the model. Confidence interval is also indicated ($\alpha = 0.05$).

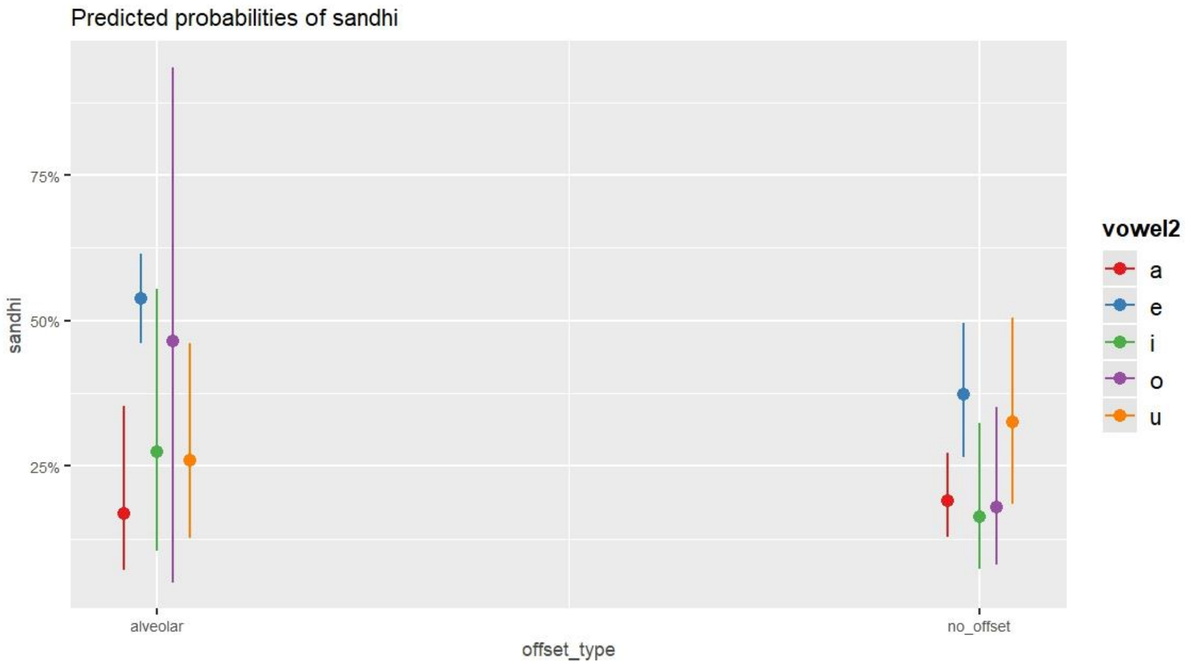

Figure 8. Predicted probabilities of sandhi in Peninsular Spanish (through elision or conversion of the second vowel into a glide), considering potential influences of the type of adjacent consonant in coda position on the second vowel of the sequence. Confidence interval is also indicated (α = 0.05).

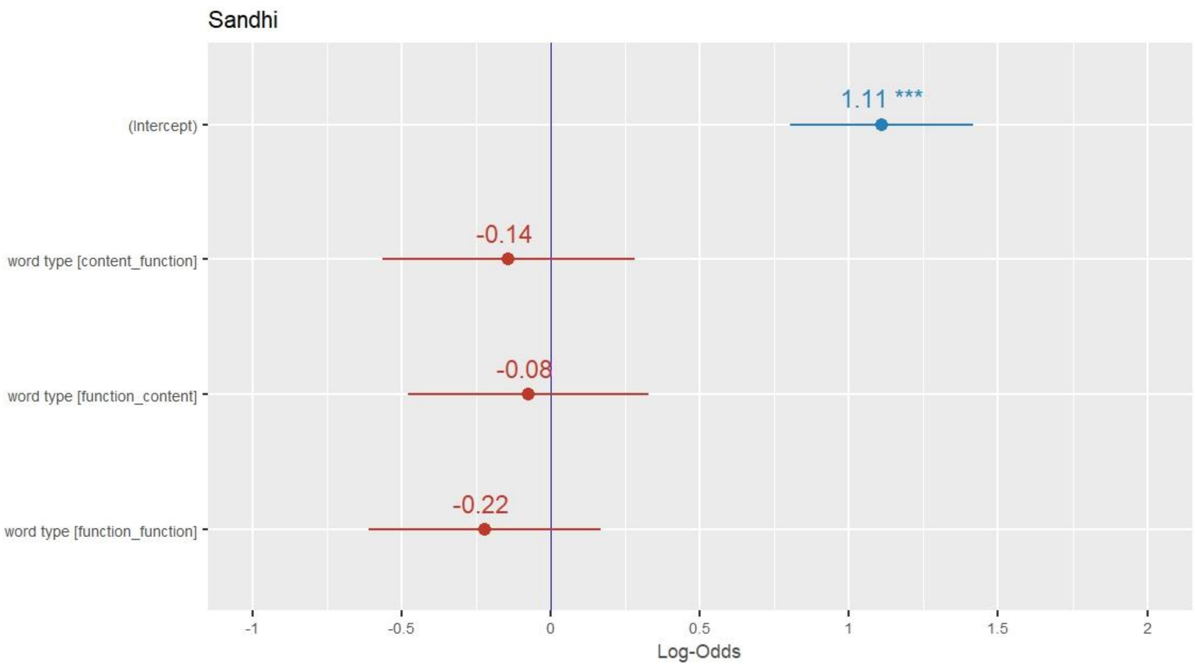

Figure 9. Estimated values (in log-odds) of the binomial regression for the intercept (functional-functional word combination) and slopes for each combination. Confidence interval is also indicated (α = 0.05).

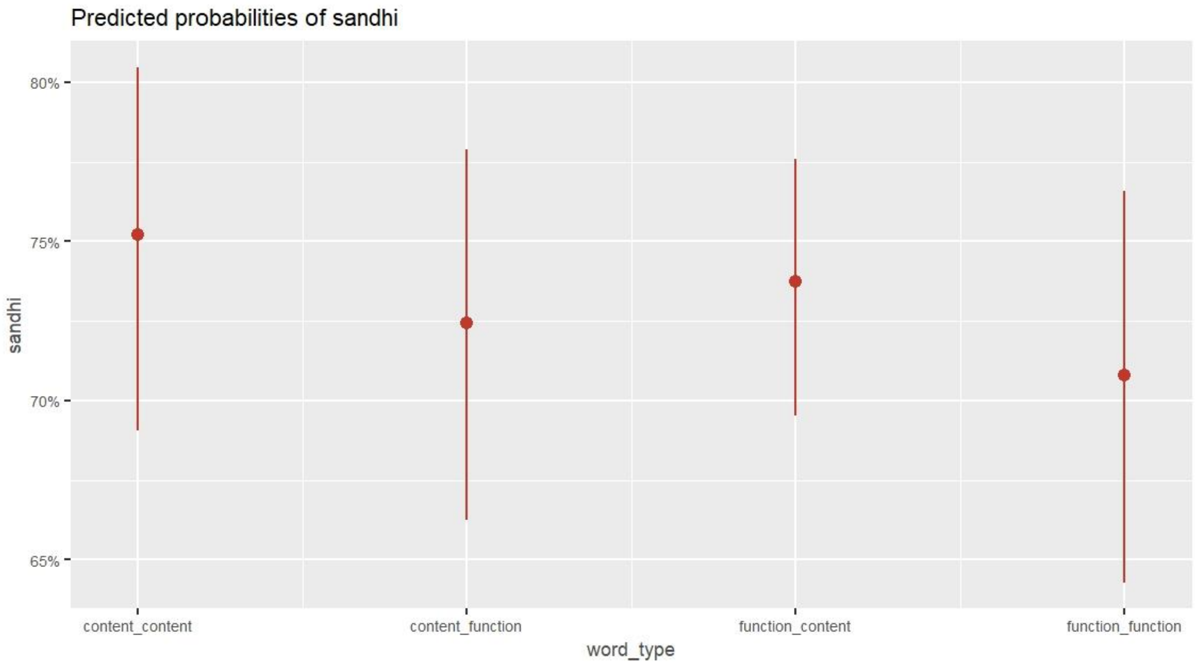

Figure 10. Predicted probabilities of maintaining hiatus by word type combination. Confidence interval is also indicated (α = 0.05).

3.4. Articulation rate

The analyses of the articulation rate verify if there are differences between inter-pausal utterance rates that contain a reduced vowel sequence (due to some type of sandhi) or a hiatus sequence across word boundaries. This effect is related to the idea that a faster articulation rate – measured by a higher number of syllables per second – may favor vowel contraction (Santiago & Mairano, 2022).

For the articulation rate analysis, the count of the number of syllables per second was used (Crystal & House, 1990; Voigt & Schüppert, 2014; Santiago & Mairano, 2022). First, a binary contrast code was created, with 1 for sandhi and 0 for hiatus. Then, for exploratory data analysis, a boxplot was constructed to show the differences between the articulation rate values of speech with sandhi sequences and speech with maintained hiatus at word boundaries.

The results can be observed in Figure 11. It appears that there are not many differences between sandhi and hiatus values. On the other hand, the means for sandhi and hiatus were x=7.30 and x=6.92, respectively, indicating that speeches with sandhi may have faster articulation rates (higher values) than speeches with hiatus.

Considering the variability among informants in the analyses, a mixed effects logistic regression model has been applied. The best-fitted model has the binary relationship 1-sandhi and 0-hiatus as the response variable, syllabic rate values (in syllables per second) as the predictor variable, and the informant as a random effect. Figure 12 shows that when the articulation rate increases by 1 syllable per second, there is an increase of 0.21 (values in log-odds). This suggests that with each increase in the articulation rate, there is a higher probability of vowel sequence sandhi occurring across word boundaries. Figure 13 converts log-odds values to probabilities, presenting a logistic regression line and a smoothing curve with confidence intervals.

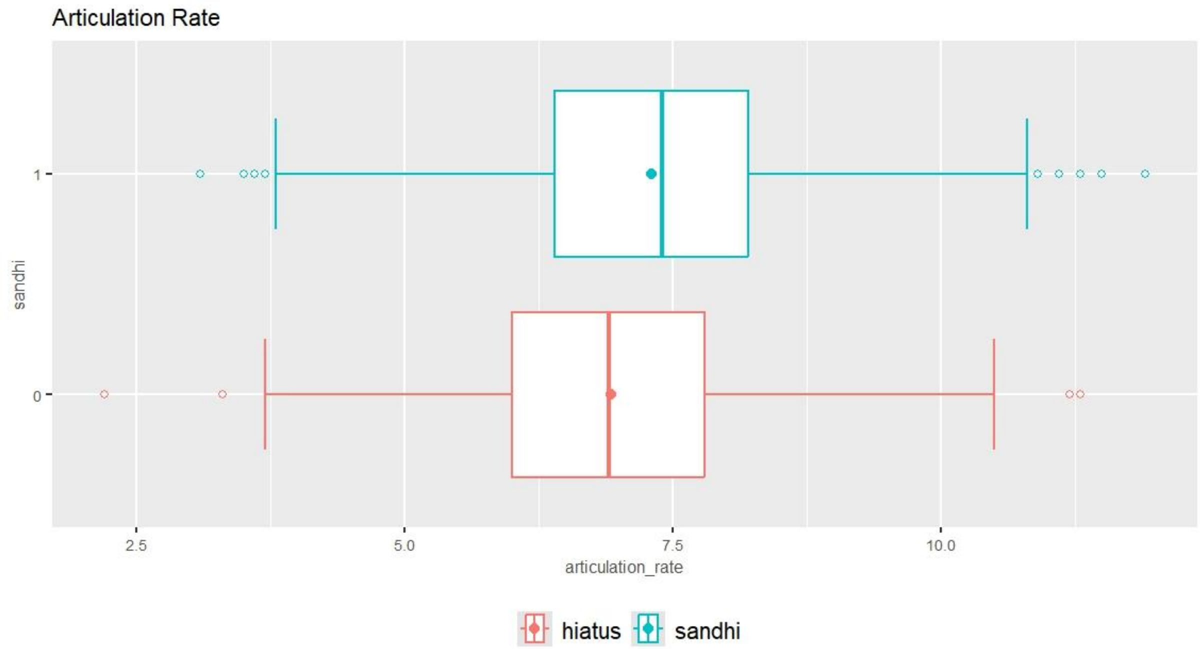

Figure 11. Boxplot with articulation rate values for speeches with vocalic sandhi and hiatus.

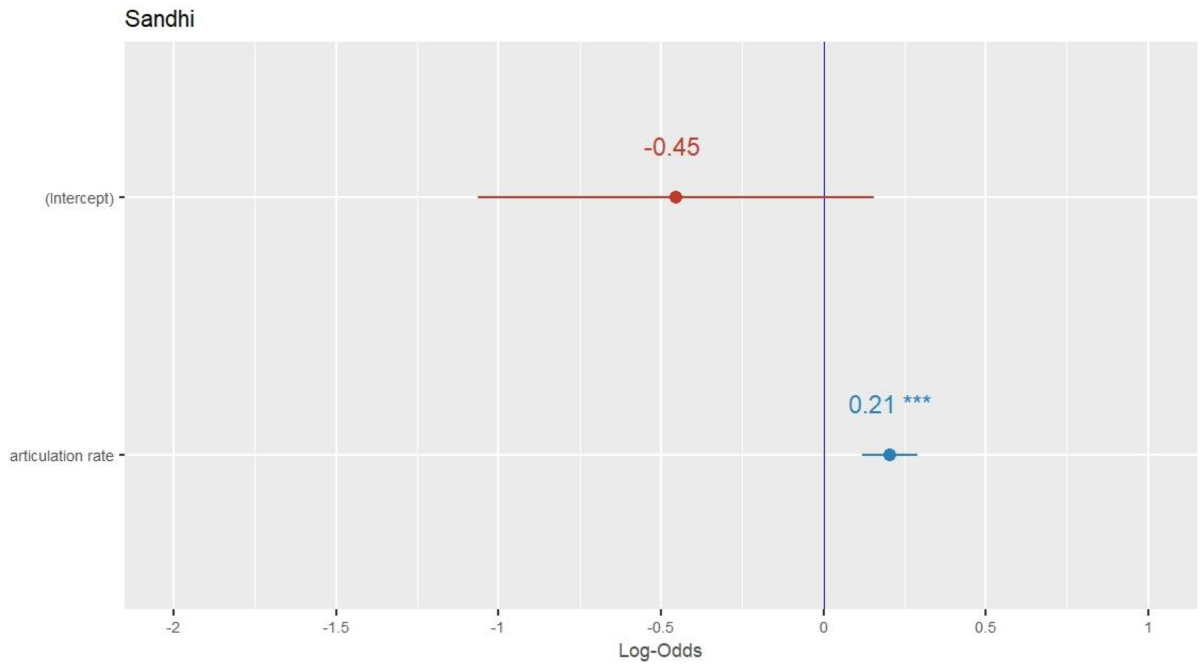

Figure 12. Estimated values (in log-odds) of the logistic regression for the intercept (when the articulation rate is =0) and the slopes of the model (an increase of 0.21 for each unit change in the articulation rate). Confidence interval is also indicated ($\alpha = 0.05$).

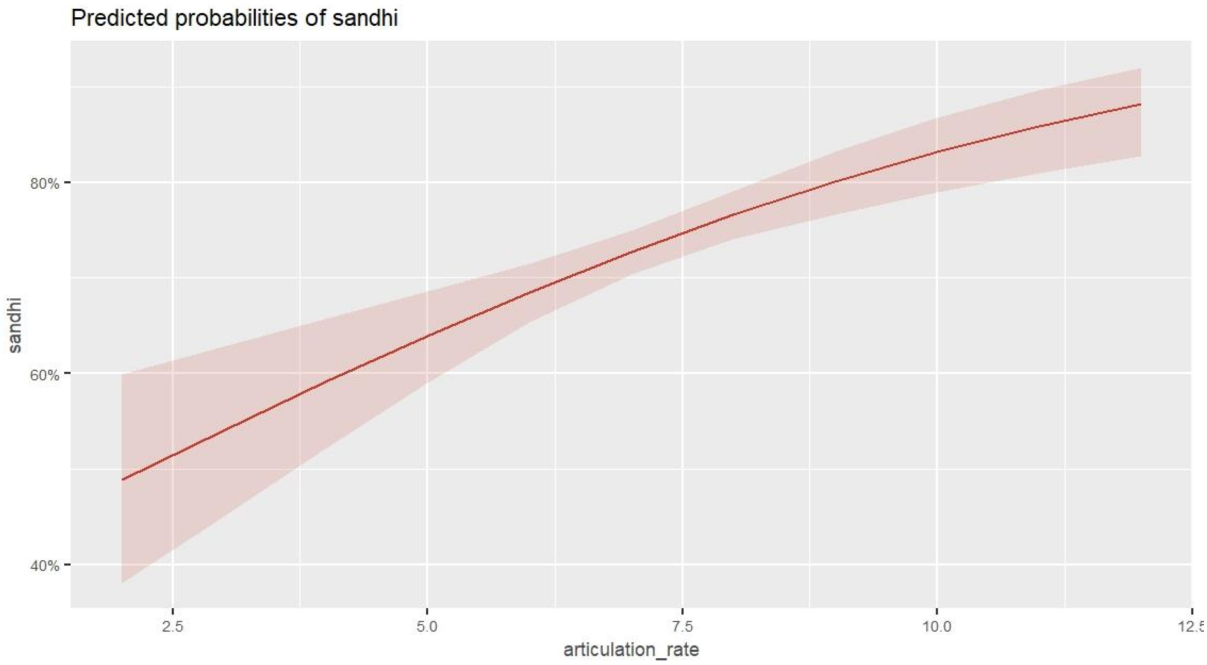

Figure 13. Predicted probabilities of vowel sandhi (through the deletion or conversion of the second vowel into a glide), considering potential influences of the adjacent consonant type in the coda position of the sequence. Confidence interval is also indicated (α = 0.05).

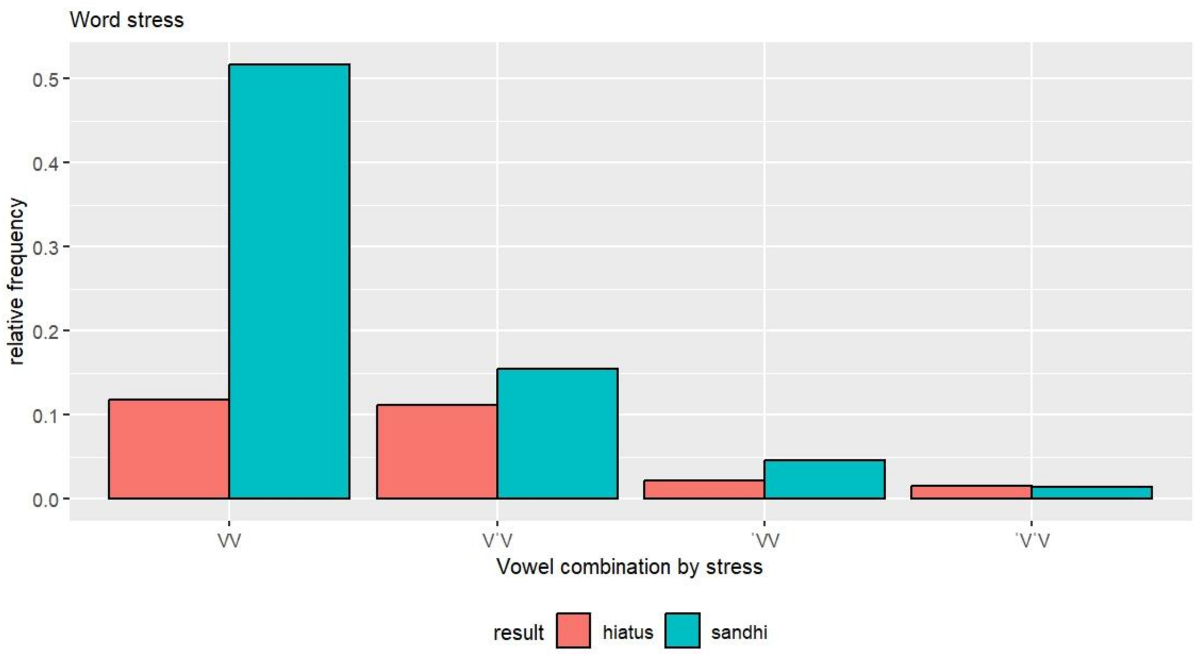

Figure 14. Relative frequency of data grouped by stress pattern.

3.5. Stress and sequence position

The analyses of stress patterns indicate that most productions involve the contraction of the sequence through some type of sandhi, in any combination of stress (VV, VˈV, ˈVV, ˈVˈV). Figure 14 illustrates the data distribution based on combinations of stressed and/or unstressed vowel sequences and the production type. The graph shows that unstressed vowel sequences have a greater number of sandhi occurrences than hiatus. The same trend is observed for ˈVV and VˈV vowels sequences, although the differences are not as pronounced as in the unstressed vowels context. On the other hand, in the context of stressed vowels, the data frequency was nearly the same for both sandhi and hiatus cases.

When considering whether the sequence carries the primary accent of the entire utterance, the data indicates a higher number of hiatus instances when the sequence bears the primary accent, while there is a higher number of sandhi occurrences if the sequence does not bear the primary accent. The position of the sequence in the utterance can also be associated with stress, which may influence the application of sandhi. This implies that unstressed vowels may be more susceptible to sandhi, but it depends on where the sequence is in the utterance between pauses.

Examining the probabilities of whether stress influences sandhi or hiatus maintenance, a mixed effects logistic regression model was executed. The best-fitting model considered sandhi (with a value of 1 in the binary sandhi/hiatus relationship) as the response variable and the informant as a random effect. As a predictor variable, in addition to the stress factor of vowels in the sequences, the two variables mentioned were considered significant for the analysis: the effect when the vowel receives the primary stress of the entire utterance between pauses and the effects when the sequence is at the pause boundary.

The results of the best-fitting regression model indicate that the unstressed context and when the sequence is not at the boundary seem to avoid hiatus more than the stressed context (Table 2). Figure 15 presents the probabilities of whether sandhi or hiatus occurs based on the predictor variables of the model.

The positive value of the intercept in log-odds suggests a probability greater than 50% (the conversion of log-odds to percentages yields a result of 83%) for the occurrence of sandhi when both vowels are unstressed and when the context is not at a pause boundary. The confidence interval and *p*-value reveal that this probability is above 50%. The same occurs in the ˈVV and VˈV contexts, without the primary utterance stress and outside a pause boundary. However, for the context of stressed vowels without the primary utterance stress and when the context is not at a pause boundary, the model could not estimate confidence intervals for more or less than 50%. Therefore, it couldn't ascertain whether there are more probabilities of hiatus or sandhi.

Observing the contexts of vowels when it does not carry the primary utterance stress but is at the pause boundary, lower probabilities of sandhi are observed in all contexts with at least one stressed vowel. For unstressed vowels sequences, the confidence intervals cross 50%, so the model cannot infer a tendency to maintain hiatus in this context.

Sandhi Predictors	**Log-odds**	**CI**	***p***
(Intercept)	1.52	1.36 – 1.69	**<0.001**
word_stress [VˈV]	-0.74	-1.04 – -0.43	**<0.001**
word_stress [ˈVV]	-0.81	-1.25 – -0.36	**<0.001**
word_stress [ˈVˈV]	-1.38	-2.01 – -0.76	**<0.001**
utterance_stress [yes]	-0.99	-1.46 – -0.52	**<0.001**
pause_boundary [yes]	-1.73	-2.40 – -1.06	**<0.001**

Table 2. Results of the mixed-effects binomial logistic regression model.

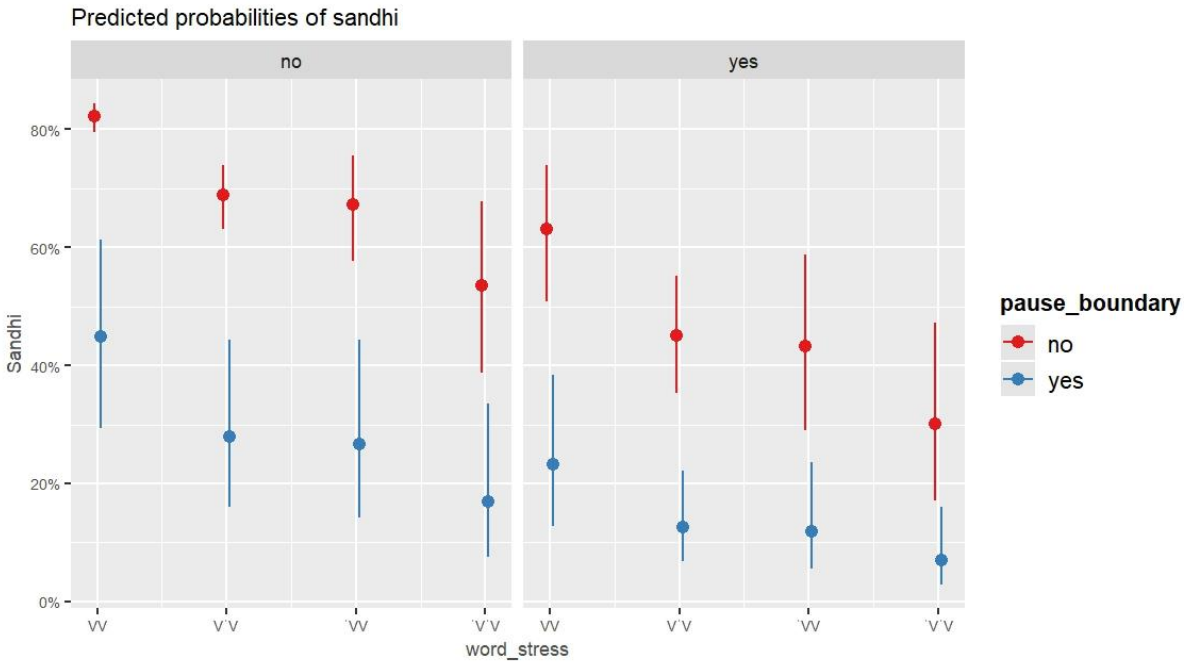

Figure 15. Predicted probabilities of sandhi, based on word stress, utterance stress (represented by the blocks no/yes), and pause boundary. Confidence interval is also indicated (α = 0.05).

In contrast, positive values for when one of the vowels in the sequence has the primary utterance stress (utterance_stress[yes]) and if the sequence is at a pause boundary (pause_boundary[yes]) indicate higher probabilities of maintaining hiatus in these circumstances. However, it is important to note that the VV context cannot receive the primary utterance stress, and ˈVV context had no data with the primary utterance stress or at a pause boundary. This implies that the model has considered for the percentages in those contexts the calculation of the intercept plus the estimates of each variable and then converted the result (given in log-odds) to probabilities.

4. Discussion and conclusion

This study analyzed the probabilities of sandhi in vowel sequences across word boundaries in semi-spontaneous data of Peninsular Spanish. The analysis drawn from this study reveal significant contributions to understanding what occurs in this context. It is clear that sandhi emerges as a natural phenomenon, and this process becomes increasingly prominent in spontaneous discourse. The results indicate that sandhi considerably surpasses hiatus, emphasizing the relevance of this post-lexical phenomenon within the phonology framework of the Spanish language.

What happens is that some factors exert a more significant influence than others in sandhi blocking, thus maintaining the hiatus. In this sense, evidence has been sought to address the proposed hypotheses, considering whether some variables can have effects on the sandhi processes. Regarding to vowel type, previous study by Alba (2006) examines the variety of Spanish spoken in New Mexico and identifies a tendency toward sandhi, primarily in combinations of mid vowels /e, o/ followed by high vowels /i, u/ as the second vowel in the sequence at the boundary. In our data, the only sequence with sandhi probabilities exceeding 50%, where the high vowel is the second, has been /ou/. The other combinations with the second high vowel have had values that cross the 50% threshold, meaning a greater tendency to perform some sandhi process could not be inferred.

It was also observed that the highest probabilities of maintaining hiatus were in the combinations /ia/ and /ie/, i.e., in combinations where the high vowels are the first vowel of the sequence. These results are interesting because, for example, in the case of /ie/, a sequence where the proximity of tongue movements could facilitate articulatory junction, and thus, could have a tendency toward sandhi. However, this is not the case, as other variables could be more relevant to sandhi processes.

Word type has very similar probability values for sandhi in all combinations. This observation raises intriguing questions about the role of word type in sandhi phenomena. While it is well-established that functional words are typically more susceptible to phonetic reduction than lexical words (Alba, 2006), our findings suggest that additional factors may be more salient in determining whether contraction occurs.

On the other hand, faster articulation rates – the fewer syllables per second, the faster the speech production – lead to a greater likelihood of contraction through sandhi. These findings align with the results of Nadeu (2014), who explored the effects of articulation rate on vowel reduction. As described in the introduction, his study suggested that higher articulation rates contribute to faster speech, potentially favoring vowel contraction.

Finally, stress is a variable that can have a significant influence on sandhi application, as described by Jenkins (1999), Aguilar (2003), Alba (2006), among others. Our study has found evidence supporting the hypothesis that unstressed vowel contexts tend to undergo sandhi. However, sequences with at least one stressed vowel may resist some type of contraction when considering the sequence's position in the sentence and the main stress of the entire utterance. This proposition implies that if one of the syllables in the sequence is the stressed syllable of the word but does not receive the main stress of the utterance, some contraction process is applied at the vowel boundary.

To summarize, our findings indicate that among the analyzed variables, stress, sequence position, and articulation rates are identified as the most influential factors shaping the behavior of vowels in boundary sequences. It was observed that the context of stress in sequences emerges as a fundamental factor, where initially, stressed vowels favor hiatus preservation. However, this phenomenon appears to be intrinsically linked to its correlation with the primary accent of the interpausal utterance and the position of the vowel sequence. Furthermore, the results indicate that articulation rates also influence sequences at word boundaries. As the number of syllables produced per second increases, the likelihood of sandhi occurrence rises. Consequently, this pattern suggests that articulation speed not only affects the duration of the entire utterance between pauses but also influences sandhi manifestation.

It's important to note that the research has been based on semi-spontaneous data, allowing for a more natural approach to the linguistic phenomenon under study. Greater spontaneity in recordings more faithfully reflects the dynamics of everyday speech, providing a more realistic insight into how vowel sequences manifest in diverse contexts. The authenticity of semi-spontaneous data strengthens the applicability of the results to real communication contexts, enhancing the external validity of the research. However, it is acknowledged that the lack of control over certain contexts in linguistic production can lead to significant variability in the data. In this regard, the absence of controlled experimental conditions may hinder the management of certain variables, such as the limitation in analyzing adjacent segments, highlighting the importance of considering other types of consonants to fully understand their influence on the sandhi phenomenon.

Supplemental material

The data structure, as well as the scripts used for the analyses, are available at the following link: https://osf.io/hpwvy/?view_only=6361dd298f554cf7a1e6497be6703fa0.

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