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The Unstressed Vowel Reduction of Galician

Alba Aguete Cajiao

Departamento de Lengua Española, Universidad de Salamanca, 37008 Salamanca, Spain; alba.aguete@usal.es

Abstract: This study investigates the unstressed reduction process of Galician. In particular, we wondered about: (1) the specific mechanisms involved, (2) whether there are different degrees of reduction, depending on the word-stress position, or whether reduction applies categorically to all unstressed vowels, (3) whether it depends on the duration, and (4) whether it is a mechanical process. In order to answer those questions, an experimental acoustic study with semi-spontaneous speech from six young Galician-native women was conducted. The results were analyzed by applying individual linear mixed-effects models for each vowel. The results show that two different mechanisms are involved in the reduction process, namely raising and centralization, and conclude that, in Galician, this process does not depend on the duration of the segment, and, thus, it is controlled by the grammar of the language.

Keywords: vowel reduction process; vowel duration; Galician vowel system

1. Introduction

The process of reduction of the unstressed vowel system is a common process in many languages (Lindblom, 1963) that consists broadly of the reduction of the acoustic space occupied by unstressed vowels with respect to stressed vowels. A distinction has generally been made between the phonetic and the phonological process (Fourakis, 1991), although some authors consider the phonological process an extension of the phonetic one (van Bergem, 1991, 1993) in which it applies "a systematic substitution of a vowel by any other vowel that is easier to pronounce" (van Bergem, 1991, p. 10-4). Moreover, some authors link this reduction process with vowel deletion phenomena such as apocope and syncopation in some Romance languages (Baird et al., 2021; Romano, 2020). In this regard, the deletion of the vowel in certain word positions can be seen as the last step in the reduction process.

The phonetic process of reduction has been explained as a mechanical phenomenon, which is due to the natural relationship between the degree of stress of a particular syllable and its duration[1] (Lindblom, 1963; Lehiste & Peterson, 1959). In this sense, the duration of a certain segment influences its physical characteristics, since the longer the production of this segment, the easier it is for it to reach its articulatory goal (Lindblom, 1963; Gendrot & Adda-Decker, 2007). According to this view, in the specific case of vowels, a longer duration enables a greater jaw opening, allowing, therefore, for the expansion of the vowel space that manifests itself in a greater opening and in a greater frontness–backness. Conversely, a shorter duration reduces the degree of jaw opening, producing a reduction in the expansion of acoustic space, which manifests itself in higher and more centralized vowels, closer to a schwa [ə] (Clopper et al., 2017). Thus, the unstressed vowel reduction can be understood as a mere mechanical consequence of the shorter duration of unstressed syllables with respect to stressed syllables:

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> Vowels occurring in weakly stressed syllables are articulated with less "effort" and adjustment of the vowel organs that leads to their modification and reduction. [...] [T]iming is the primary variable in determining the reduction of sounds and [...] the articulatory imprecision or laxness that may hypothetically be associated with reduced stress can be neglected in this connection. (Lindblom, 1963, p. 1780)

This would explain why this process is a common phenomenon in languages with stress-timed rhythm (Lindblom, 1963), such as English (Tauberer & Evanini, 2009; Fridland et al., 2014), in which the difference between stressed and unstressed syllables is especially marked. Thus, for example, in French, Audibert et al. (2015) found a correlation between the reduction of the acoustic space of the vowels and the duration of the segment, the speech rate, and the type of speech (formal or informal), where the vowels are shorter and also more reduced.

Although the mechanical explanation has been the basis of much research about the reduction process (see, for example, Meunier & Espesser, 2011; Gendrot & Adda-Decker, 2007), several experimental studies about different languages have shown that this correlation between the duration of the segment and the degree of opening and centering does not always exist (Jacewicz & Fox, 2015; Toivonen et al., 2015; Clopper et al., 2017). Thus, the reduction is not always due to an articulatory undershoot. For instance, the results of Toivonen et al. (2015) for English and Swedish show that, indeed, high vowels are significantly shorter than low vowels, but that, contrary to what was expected, there is no correlation between duration and vowel height according to within-categories results. Instead, it seems that each vowel has an intrinsic distinctive duration and, therefore, duration is a "*controlled* feature of the grammar" (Toivonen et al., 2015, p. 71). Sabev (2023) investigates the same phenomenon in both Western and Eastern Bulgarian and finds a duration and spectral reduction for the low vowels in both varieties (albeit with some differences, since in West Bulgarian the contrast between /i/-/ɛ/ remains), but, instead, he finds no spectral variation for the high vowels. And what is more interesting, he finds differences between vowels in the kind of reduction they undergo, since only the vowel /ɛ/ shows a gradient duration-dependent reduction.

According to a body of research, the prosodic position occupied by a certain segment can modify its articulatory characteristics and, as a consequence, its acoustic result (Fougeron & Keating, 1997). Thus, the segments located at the initial boundary of a prosodic domain tend to be produced with a greater articulatory effort, which also affects the duration of the articulatory gesture, while in the segments produced at the end of the prosodic domain, the articulation is more relaxed (Fougeron & Keating, 1996). In this regard, articulatory strengthening is understood as a greater muscle contraction force in the articulation of a segment (Fougeron & Keating, 1997; Georgeton & Fougeron, 2014), which results in a greater magnitude of its articulatory and acoustic characteristics (Lehnert-LeHouillier et al., 2010). From the linguistic point of view, this strengthening would contribute to reinforcing the syntagmatic differences between elements since it favors the differentiation between a vowel at the beginning and a vowel at the end of a prosodic word, and also to reinforce the paradigmatic differences, since it would help to highlight the differences between segments; for example, between a mid–high and a mid–low vowel (Georgeton & Fougeron, 2014).

This relationship between the initial or final position of prosodic domain and articulatory strengthening has been studied extensively in languages such as English (Lehnert-LeHouillier et al., 2010) and also in Romance languages like French (Georgeton & Fougeron, 2014; Georgeton et al., 2011; Fougeron, 2001). For example, Fougeron and Keating (1996) analyze the effect of the initial limit of prosodic domain on consonant and vowel systems (Fougeron & Keating, 1997) and show that, in the initial position of the prosodic domain, vowels present significantly lower realizations, with less linguo-palatal contact.

Both phonetic and phonological vowel reduction have been attested in many Romance languages, such as Portuguese (Kenstowicz & Sandalo, 2016; Guzzo & Garcia, 2021; Nobre & Ingemann, 1987), Southern Italo-Romance varieties (Baird et al., 2021; Romano, 2020), French (Meunier & Espesser, 2011; Gendrot & Adda-Decker, 2005, 2007), Catalan (Llompart & Simonet, 2018; Nadeu, 2015), some varieties of Spanish (Barajas, 2016) or Galician (Aguete Cajiao, 2020a, 2020b; Aguete Cajiao & Fernández Rei, 2022; Regueira Fernández & Fernández Rei, 2025).

This vowel reduction process can also be affected by different factors aside from word stress, such as the word type—since functional words behave differently from lexical words— the consonantal context (Fourakis, 1991), the speaking style, and, to a lesser degree, the phrase accent (van Bergem, 1993). Moreover, some authors point out that, in many cases, an articulatory undershoot can result, not in a centralized schwa-like vowel, but in a more context-dependent realization of the vowel (Fourakis, 1991). As will be explained later, the aim of the present paper is to analyze the effect of the degree of word stress and duration on the formant structure of vowels in Galician. Therefore, factors such as the consonantal context, the word type, and the phrase accent are outside the scope of this research.

2. The Reduction of the Unstressed Vowel System in Galician

The process of reduction of the unstressed vowel system is a phenomenon that affected the evolution of Latin to the Romance languages (Lausberg, 1971, pp. 252–53) since it led to a reduction in the number of units in an unstressed position with respect to the number of units in a stressed position. As stated above, this phonological phenomenon can be seen as the result of a process of phonetic reduction that would affect the quality of the vowels in an unstressed position, which, ultimately, would lead to the overlap between very close vowels and, essentially, to the loss of oppositions[2] (Lausberg, 1971).

In Galician, one of the first authors to make any reference to the reduction of the unstressed vowel system is Amable Veiga. This author focuses on the phonological value of height oppositions in Galician, specifically on the distinction between mid–high and mid–low vowels, and he indicates that this is a neutralizable opposition of a reductive type (Veiga, 1965, pp. 395–96), that is, a neutralization that results in the reduction of the number of units in unstressed position. The author approaches the process from a phonological standpoint since, for him, the important aspect of this reduction is that the phonological opposition between the mid–high and mid–low front and back vowels only occurs in the stressed position (Veiga, 1965, p. 396).

Prior to Veiga, Lugrís Freire (Lugrís Freire, 2006) had already referenced the process of reduction of the unstressed vowel system, alluding not to the reduction in the number of units but instead to the instability and phonetic characteristics of these sounds in an unstressed position: "no *e* e no *o*, ademais do son aberto e pecho de que xa temos falado, hai outro son máis esmorecido que acerca a primeira á *i* e a segunda á *u*"[3]. We find identical references to the raising of unstressed vowels in other works such as that of Carvalho (1968), who speaks of the existence of the vowel [ə] at a phonetic level, or that of Dámaso Alonso (1972), who makes explicit reference to the fact that the pronunciation of /o/ in final unstressed position is [o̝] and not [u], contrary to what some of his contemporaries claim. On the other hand, Álvarez et al. (1995) consider that there is a gradation of the stress that results in a lower degree of opening of unstressed vowels in the word–final position compared to the vowels in the pre-stressed position, and that its main function would be to act as a word delimitation mechanism in the phonetic chain.

According to the specialized literature, this general process of reduction of the unstressed vowel system has several exceptions: (1) diminutives and other derivatives of a

base word with a mid–low stressed vowel, which would preserve the degree of opening of the vowel (Veiga, 1970, p. 178; Regueira, 2008, 2009); (2) adverbs ending in *-mente* (Veiga, 1970, p. 179); and (3) non-root-stressed forms of the verbal paradigm, which would also preserve the medium–low quality of the radical vowel (Santamarina, 1974). These three exceptions to the application of the reduction process are joined by a relatively recent tendency to open prestressed vowels in the initial syllable, especially in literary words (Regueira, 2010), which would lead to a prestressed system similar to the stressed system. It should be noted that all these exceptions are of variable application, in the sense that not all speakers block the phonological reduction process in these circumstances, but that, according to linguists, the most traditional speakers would still maintain a reduced unstressed vowel system[4].

Explanations for these exceptions are varied. Regarding the maintenance of the base vowel in the derivatives, Veiga (1970, pp. 178–79), for example, considers that it is due to the fact that these derivatives have a double stress and, therefore, they would not be true unstressed vowels. In a similar vein, although from a different theoretical framework, Hualde and Martínez-Gil (1994) analyze the exceptions to the phenomenon from a lexical phonology perspective and propose two morphophonological levels of application of the suffix in such a way that in the derivatives that preserve the vowel of the base word a second stress would be assigned. In contrast, Regueira (2008, 2009) approaches this phenomenon from optimality theory and interprets it as a change in the hierarchy of fidelity constraints, which would force fidelity to the root of the base word over the application of the reduction process.

With respect to the phonological adaptation of loanwords with prestressed vowels in absolute initial syllables that are pronounced as mid–low vowels (/ɛ/ and /ɔ/), Aguete Cajiao (2020a) studies experimentally, from a reading corpus, whether this phenomenon can be due to the effect of strengthening at the initial prosodic domain. Her data show that there is a strengthening in such a way that the higher the domain in which the vowel is embedded the more open and less centralized it is, and she concludes, in the same line as Álvarez et al. (1995), that the prosodic strengthening functions as a marker of the initial and final boundaries of the word.

Although this phenomenon has not been the subject of special interest in Galician linguistics, the acoustic characteristics derived from the application of the process of reducing the unstressed vowel system have been studied by Molinos Castro (2002) and Regueira (2007). Both authors focus on unstressed vowel systems in the absolute word–final position and note the raising and centralization, as well as the shorter duration in relation to the stressed vowel systems, depending on the position within the phonological utterance. In addition, in both works, they show that an important part of the vowels in the sample is "off", devoiced, or presenting a creaky voice, a phenomenon that would be strongly linked to the weakening of unstressed positions. Similar data were found by Tomé Lourido (2018) and Aguete Cajiao (2020a, 2020b). Vidal Figueiroa (1997), although without providing experimental data, concludes that, for the traditional vowel system of Vigo, the reduction consists of a double process of raising and centralization.

Aguete Cajiao (2020a, 2020b) presents probably the most comprehensive description with empirical data available so far for the whole Galician vowel system. The results of her work show a strong raising of the low central vowel /a/ in word-initial unstressed position, which is even more pronounced in word-final unstressed position. She also notes a strong centralization of the vowel /e/ in word-initial unstressed position and a raising of the vowel /o/ in unstressed position, leading to an overlap with /u/. In addition, her results on duration show that prestressed vowels have durations similar to stressed vowels, in opposition to the word-final unstressed vowels, which are significantly shorter[5]. On the

other hand, the results of this work show that the prestressed vowel system with seven units is residual in the analyzed sample, contrary to what most linguists assume in the previously cited works.

Hence, the various approaches that have been made in recent times to the Galician vowel system from different theoretical and methodological perspectives show the existence of more variation and variability (see above all Aguete Cajiao, 2020a, 2020b) than had been assumed in both theoretical and descriptive works, such as those of Porto Dapena (1977); Taboada (1979)[6], and Álvarez et al. (1995). The main drawback of the theoretical proposals that lack experimental data, considering that the Galician vowel system has not yet been sufficiently studied from an acoustic perspective, is that we do not know to what extent these theoretical proposals and solutions conform to the reality of the data. And, on the other hand, the current situation is that, even in the most complete works of an experimental nature, only data from read speech have been incorporated so far. Therefore, we still lack descriptive works of the Galician vowel system that use data from recordings of natural speech. All this highlights the need to address the question of the reduction of the unstressed vowel system of Galician from a theoretical perspective based on empirical data that allows us to better understand the nature and characteristics of this process.

The aim of this research is to provide new empirical data from samples of semi-spontaneous speech, which will allow us to better understand the phonetic characteristics of the process of vowel reduction in Galician, and that will also allow us to understand the nature of the phenomenon—if we are dealing with a purely mechanical phenomenon or if it is controlled by speakers— as well as its relationship with other parameters, such as duration and its position within the word. Taken as a whole, this approach will contribute to a deeper understanding of the mechanisms underlying vowel reduction in natural speech contexts.

3. Research Questions and Hypotheses

Due to this background about the vowel reduction process in general, and in Galician in particular, in this paper, we pose the following research questions and hypotheses:

1. How is this process manifesting acoustically in Galician? Is it a process consisting of a single mechanism of vowel space reduction, or can we distinguish two different mechanisms—raising and centralization?
2. Is it a stepped process in which a hierarchy of stress operates leading to different degrees of reduction as some works point out, or does it affect all unstressed vowels to the same degree?
3. To what extent, as indicated by numerous researchers, is this process of reduction correlated with the duration of the vowel in unstressed positions?
4. And, therefore, can we consider that it is merely a mechanical phenomenon in Galician, or should we interpret it as language-specific process that speakers can control?

In relation to the first of the research questions formulated, our hypothesis is that the process consists of two mechanisms, one of centralization and one of raising, as suggested by the most recent findings with experimental data (Aguete Cajiao, 2020b).

On the other hand, since, as indicated by various previously seen experimental investigations (i.e., Georgeton & Fougeron, 2014; Georgeton et al., 2011), unstressed word-final positions are phonetically and phonologically weaker than word-initial positions, our hypothesis is that the reduction process is more pronounced in the word-final unstressed position than in the word-initial unstressed position. However, since in the evolutionary history of Latin to the Romance languages, the word-internal unstressed positions were the most prone to syncope and, therefore, to extreme weakening, we expect internal unstressed vowels to present an even more pronounced process of reduction (then, following the

hierarchy: stressed > initial unstressed > final unstressed > intermediate unstressed). We believe that this would be the expected behavior, especially if the motivation for this process is purely mechanical.

With respect to the third research question, we expect the duration of the vowels and the degree of spectral reduction to be correlated and, therefore, the longer the vowel, the greater the opening. With respect to the degree of centralization, a longer duration of the articulatory gesture should enable more extreme realizations of each vowel.

Therefore, the last hypothesis formulated is that the process of reduction of the unstressed vowel system is actually a highly controlled language-specific process in Galician, that is to say, it is part of the grammar of the language.

4. Materials and Methods

4.1. Participants

For this study, the vowels of a total of six women, all native speakers of Galician, aged between 20 and 27 were analyzed. At the time of the recording, all of them were studying language and literature at one of the Galician universities. In the six cases, their initial and usual language is Galician, and all of them declared that they used other languages only in exceptional cases. Table 1 shows a summary of the main characteristics of the subjects in the sample.

Table 1. Participant's background.

Participant	Age	Language	Origin	Environment
M06	20	Galician	Arzúa	Rural
M23	27	Galician	Lalín	Urban
M24	21	Galician	Melide	Urban
M26	20	Galician	Mazaricos	Rural
M27	24	Galician	O Rosal	Rural
M28	24	Galician	A Coruña	Urban

4.2. Recordings

Data samples were obtained through 10-to-15-minute-long semi-guided interviews in which the interviewer posed different questions about their biography (family relations, linguistic background, work and personal situation, etc.). These interviews were also used to obtain the sociodemographic background of the speakers.

All six interviews were made by the author of this research in a non-soundproof but quiet room at the Instituto da Lingua Galega. The recordings were made in Audacity (Audacity Team, 1999–2024) using a condenser microphone model AKG C520 (Harman, Aarhus, Denmark) connected by XLR to a sound card, model M-Track Plus from M-Audio (inMusic Brands Inc., Cumberland, RI, USA) with a MacBook Pro computer (Apple, Cupertino, CA, USA) and a sample rate of 48,000 Hz.

4.3. Procedure

Since the data were obtained from semi-spontaneous interviews and, therefore, the contexts of occurrence of each vowel or the number of examples of each of them were not controlled. The selection of study vowels was made manually from listening to the audio. The criterion used was to maximize the number of tokens for each vowel, that is, as many vowels of each type as possible were selected for each informant since it was considered preferable to have a larger volume of data that allows to eliminate part of the variability expected to be found in spontaneous speech despite having an unbalanced sample of the number of vowels of each type and for each speaker.

However, there were three exceptions: (1) both initial and final vowels affected by a process of sandhi (coarticulation with another vowel or coalescence) were not considered since it was impossible to segment the individual vowel; (2) those cases affected by a creaky voice were removed because they could distort the formant values of the vowels (Keating & Garellek, 2015); and (3) those cases in which the audio was interfered by background noise or in which the speaker laughed were also removed.

Thus, the same vowel could be used to obtain the four stress configurations studied, but the same word repeated on several occasions in the interview did not always allow for the analysis of the same number of vowels. For example, from a word like "Malpica", we could extract the word-initial unstressed /a/, the stressed /i/, and the word-final unstressed /a/. However, in some of the repetitions of this form, it was only possible to analyze one or two of the vowels, either because one of the vowels was affected by a creaky voice because it coalesced with the vowel of the following word or because some background noise was heard that made the formant measurement difficult.

In addition to the cases mentioned above, those vowel segments that were devoiced or elided, a total of 117 (48 elisions and 69 devoicings) were discarded from the formant analysis (and were not included in the count below referred of the number of vowels analyzed) in the sample analyzed as a whole[7].

Finally, diphthongs were not analyzed in this work, as only Galician monophthongs were considered. Non-final posttonic unstressed vowels were also excluded from this work because we could not find a sufficient number of cases. Also, the position of the selected vowels within the sentences (in the edges or in the middle) was not controlled.

4.4. Data Extraction

Vowel segmentation was also done manually in Praat (Boersma & Weenink, 1992–2022) through visual inspection of the oscillogram and spectrogram, following the criteria used by Aguete Cajiao (2020b, pp. 65–66) and Clopper et al. (2005, p. 1663). This process was completed with the help of a script (Aguete Cajiao, 2022) that automatically opened and saved the sound file together with the segmentation in a TextGrid file[8]. Formant data of F1, F2, and F3[9] were extracted from the midpoint of the vowel together with the duration in Praat, also with the aid of a script (Aguete Cajiao, 2022) that extracted and saved the acoustic values in a csv file. The formant data were taken from the midpoint of the vowel because this is the most stable position and the least influenced by co-articulation with consonants in contact. In all cases, the Burg algorithm of formant detection was used, with a low-pass filter below 5500 Hz. The data were manually reviewed and plotted to find formant detection errors, which were corrected when appropriate by adjusting the formant ceiling.

The final sample of vowels analyzed in this research consists of a total of 1470 vowels. Table 2 shows the total number of tokens analyzed for each vowel according to stress position. As it can be seen, the less common vowels are /ɛ/ and /ɔ/, since in our sample, we only find them in a stressed position, while the most represented vowels are /a/, /e/, and /o/ because these are vowels that occur in all the analyzed positions (stressed, initial unstressed, intermediate pretonic unstressed[10], and final unstressed).

The formant data obtained were normalized following the Lobanov procedure (Lobanov, 1971) (cfr. Adank et al., 2004; Clopper et al., 2005) using the *phonR* package (McCloy, 2016) in R[11]. The duration values, which were measured in milliseconds, were also normalized following Fridland et al. (2014). According to this method, the average duration of each speaker's vowels is set to 1, so all normalized values above 1 will indicate above-average durations, and all values below 1 will indicate below-average durations.

Table 2. Number of tokens for each vowel analyzed in this study.

Vowel	Stressed	Initial Unstressed	Intermediate Pretonic Unstressed	Final Unstressed	Total
/i/	104	50	30	-	184
/e/	109	70	66	63	308
/ɛ/	96	-	-	-	96
/a/	122	132	53	111	418
/ɔ/	62	-	-	-	62
/o/	49	83	36	106	274
/u/	70	26	32	-	128

4.5. Statistical Analysis

In order to analyze the behavior of the reduction of the unstressed vowel system and check whether there are significant differences in the degree of raising and centralization between the different stress positions, mixed-effect models were made for F1, F2, and the duration of each vowel[12] with the packages *lme4* (Bates et al., 2015) and *lmerTest* (Kuznetsova et al., 2017) in R (R Core Team, 2021) with RStudio (Posit Team, 2024). Therefore, for each vowel, we fitted a single LMM, including the stress as a fixed factor and a random intercept structure for subjects and items. In addition, a pairwise comparison was conducted between the stress conditions for each vowel by applying a Tukey adjustment. All plots were made using the package *ggplot* (Wickham, 2009).[13]

5. Results

Figure 1 shows the mean values of each vowel according to the stress position they occupy in the word. Altogether, the chart shows a stressed system of seven units opposed to the unstressed, smaller both in the number of units (/i/, /e/, /a/, /o/, and /u/ in non-final unstressed position and /e/, /a/, and /o/ in the word-final unstressed position) and in the phonetic realization.

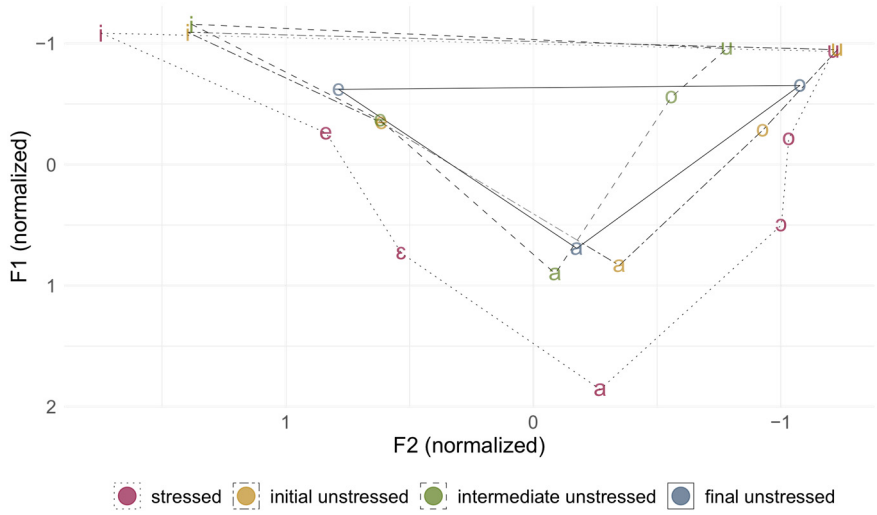

Figure 1. Formant chart of the mean values for each vowel according to stress for the sample data set. The average F1 is shown on the ordinate axis and F2 on the abscissa axis.

The visual inspection of Figure 1 shows that, in a generalized way, vowels undergo a process of reduction characterized by the movement towards the center of the vowel space. The vowel /a/ is fundamentally characterized by a movement in the plane of the F1. In fact, it is the vowel that presents a greater movement of raising. Front vowels seem to undergo mainly a process of centralization and slight raising, with quite similar results

in the three unstressed positions, except for the unstressed final /e/, which undergoes a greater raising but a lower centralization. Instead, it seems that back vowels undergo an even more pronounced centralization process than front vowels, which occurs in the initial or intermediate prestressed position but not in the final unstressed position, where the most relevant characteristic seems to be the raising of the vowel /o/.

With respect to duration, in Figure 2, a clearly longer average duration of vowels in the stressed position than in the initial and mid-prestressed position can be observed, whereas vowels in the final unstressed position have mean values similar to stressed ones. It is also worth noting that the lowest stressed vowels, i.e., /ɛ/ and /ɔ/, as well as /a/, have much longer durations than the mid–high and high vowels, which may be reflecting the universal tendency for low vowels to be longer than the high vowels (see, for example, Rosner & Pickering, 1994, p. 192).

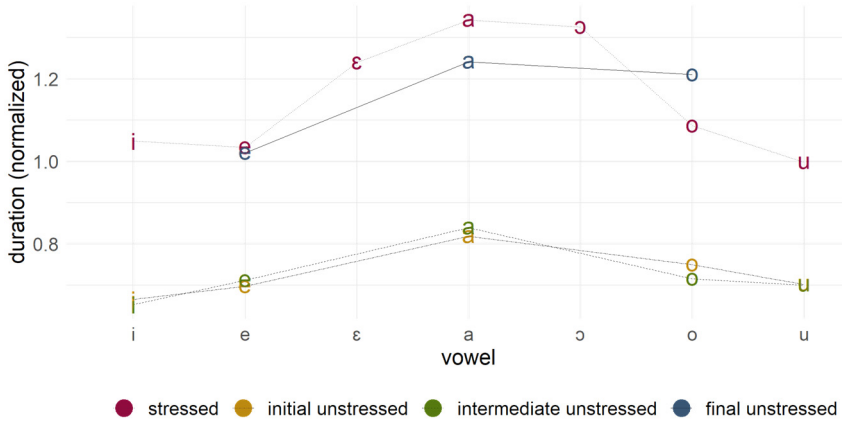

Figure 2. Average durations of each vowel according to stress position for the entire data sample.

This preliminary visual inspection seems to indicate that the reduction of an unstressed vowel system is characterized by two mechanisms: one of raising and one of centralization. The fact that, in the final unstressed position, a reduction of the vowel space is observed, but with average durations similar to those of stressed vowels, indicates that the reduction of the unstressed vowel system is independent of duration.

5.1. Differences in the F1 Due to the Degree of Stress

The results of the mixed-effects model for /a/ show that there are indeed significant differences in F1 depending on the stress (F (3, 396.1) = 79.797, $p < 0.001$). Specifically, the F1 has significantly higher values in the stressed position (M = 1.837) than in the initial (M = 0.830), intermediate (M = 0.878), and final (M = 0.687) unstressed positions. Thus, it is confirmed that /a/ is significantly higher in any of the unstressed positions than in the stressed position. In addition, there are significant differences between the degree of height of /a/ in the initial and final unstressed position (see Table 3), which suggests that this raising may be stepped.

The results for the vowel /e/ indicate that there are also significant differences in F1 depending on the stress (F (3, 242.59) = 10.13, $p < 0.001$). This vowel presents significantly lower F1 values, that is, it is more closed, in the final unstressed position (M = −0.635) than in the rest of the stress positions ($M_{stressed}$ = −0.236; $M_{initial}$ = −0.342; and $M_{intermediate}$ = −0.359).

Also, in the vowel /o/, there are significant differences in F1 according to word stress (F (3, 213.76) = 11.135, p <0.001). The vowel /o/ presents a behavior similar to that of /a/ since it has significantly higher values of F1 in the stressed position (M = −0.238) than in the intermediate unstressed position (M = −0.519) and final unstressed position (M = −0.652), where, therefore, the vowel is significantly higher, while the initial unstressed position

presents intermediate values (M = −0.302) that are only significantly different from those of the final position.

Table 3. Summary of the pairwise comparisons for the F1 of each vowel, using the Tukey adjustment.

F1 (Lobanov)	*β*	SE	df	t	*p*
/a/					
Stressed—initial	0.97084271	0.08364496	394.446166	11.6067091	<0.001
Stressed—intermediate	0.95422473	0.10517232	392.780142	9.07296451	<0.001
Stressed—final	1.18863642	0.08289592	400.190448	14.3389016	<0.001
Initial—intermediate	−0.016618	0.10338809	405.134609	−0.160734	0.998
Initial—final	0.21779371	0.08421713	395.518226	2.58609746	0.049
Intermediate—final	0.23441169	0.10596603	389.692156	2.21213991	0.121
/e/					
Stressed—initial	0.10595171	0.07162676	241.248934	1.47921953	0.451
Stressed—intermediate	0.12301867	0.07603227	193.56637	1.61797964	0.370
Stressed—final	0.39896224	0.07423126	230.630861	5.37458519	<0.001
Initial—intermediate	0.01706697	0.07749367	266.890986	0.22023691	0.996
Initial—final	0.29301054	0.07729834	273.329358	3.79064456	0.001
Intermediate—final	0.27594357	0.07755866	277.017893	3.55786944	0.002
/o/					
Stressed—initial	0.09836822	0.08208717	220.127681	1.19833852	0.628
Stressed—intermediate	0.28891807	0.10266332	197.397473	2.81422887	0.027
Stressed—final	0.37929983	0.07622292	239.458939	4.97619099	<0.001
Initial—intermediate	0.19054985	0.09338645	200.635403	2.04044423	0.176
Initial—final	0.28093161	0.06550989	207.671783	4.28838502	0.001
Intermediate—final	0.09038176	0.09023817	210.677571	1.00159123	0.748
/i/					
Stressed—initial	0.02498729	0.06411728	165.213344	0.38971219	0.919
Stressed—intermediate	0.02251541	0.07458353	157.114662	0.30188184	0.951
Initial—intermediate	−0.0024719	0.08249184	163.029615	−0.029965	0.999
/u/					
Stressed—initial	0.00802831	0.08087295	91.5271378	0.09927062	0.994
Stressed—intermediate	0.07059976	0.07449501	74.8471684	0.94771131	0.612
Initial—intermediate	0.06257145	0.09156458	96.5001031	0.68335871	0.773

For the high vowels /i/ and /u/, there is no evidence of significant differences in F1 depending on the stress (/i/: F (2, 161.75) = 0.0947, p = 0.907; /u/: F (2, 85.126) = 0.4694, and p = 0.627).

5.2. Differences in the F2 Due to the Degree of Stress

The results of the mixed-effects model for the vowel /a/ show that there are significant differences (see Table 4) in F2 depending on the stress (F (3, 409.74) = 11.299, $p < 0.001$). The results of the pairwise comparisons indicate that, in the initial unstressed position, the vowel has significantly lower F2 values (M = −0.399) and, therefore, is significantly further back than in the stressed position (M = −0.236), intermediate unstressed (M = −0.0781) position, and final unstressed position (M = −0.174).

For the vowel /e/, significant differences are also observed in F2 due to the word stress (F (3, 272.88) = 4.0401, p = 0.007). The results show that the F2 is significantly lower and, therefore, the vowel is more centralized in the initial unstressed position (M = 0.543) than in the stressed position (M = 0.802) or the final unstressed position (M = 0.784), while the intermediate unstressed position has intermediate values (M = 0.663).

Table 4. Summary of the pairwise comparisons for the F2 of each vowel using the Tukey adjustment.

F2 (Lobanov)	*β*	SE	df	t	*p*
/a/					
Stressed—initial	0.16338972	0.05081726	411.319116	3.21524055	0.007
Stressed—intermediate	−0.1581563	0.06419153	411.771252	−2.463819	0.067
Stressed—final	−0.0615578	0.05041244	411.868995	−1.2210828	0.613
Initial—intermediate	−0.321546	0.06247794	407.217728	−5.1465532	<0.001
Initial—final	−0.2249475	0.05120372	409.813803	−4.3931866	<0.001
Intermediate—final	0.09659854	0.06484934	408.750485	1.48958404	0.444
/e/					
Stressed—initial	0.25944909	0.08253822	275.223978	3.14338116	0.009
Stressed—intermediate	0.13921258	0.08900478	231.718481	1.56410225	0.401
Stressed—final	0.01812337	0.08577826	259.882957	0.21128164	0.996
Initial—intermediate	−0.1202365	0.08787316	291.286037	−1.3682962	0.520
Initial—final	−0.2413257	0.08782104	291.328702	−2.7479259	0.032
Intermediate—final	−0.1210892	0.08796306	297.615867	−1.3765916	0.515
/o/					
Stressed—initial	0.016446515	0.09499703	256.529693	−0.1731266	0.998
Stressed—intermediate	−0.3203374	0.12120387	239.908311	−2.6429638	0.043
Stressed—final	0.0601904	0.08741902	266.093264	0.68852754	0.901
Initial—intermediate	−0.3038909	0.1100152	240.840099	−2.7622632	0.031
Initial—final	0.07663692	0.07567918	246.060804	1.01265529	0.742
Intermediate—final	0.38052785	0.10548851	248.13349	3.60729174	0.002
/i/					
Stressed—initial	0.28930978	0.08724211	122.996084	3.3161714	0.003
Stressed—intermediate	0.35931166	0.09927737	141.144984	3.61927064	0.001
Initial—intermediate	0.07000187	0.11235697	140.09886	0.62303099	0.807
/u/					
Stressed—initial	−0.0271998	0.13664231	97.6671361	−0.1990585	0.978
Stressed—intermediate	−0.4244659	0.13005488	81.7408986	−3.2637444	0.004
Initial—intermediate	−0.3972661	0.15301303	98.4059925	−2.5962892	0.029

There are also significant differences in F2 depending on the stress for the vowel /o/ (F (3, 250.76) = 4.3416, p = 0.005). The LMM results show that F2 is significantly higher in the intermediate unstressed position (M = −0.666) than in the rest of the word-stress positions ($M_{stressed}$ = −0,986; $M_{initial}$ = −0,970; M_{final} = −1,046), that is to say, in the intermediate position, it is significantly more centralized, as seemingly indicated in the visual inspection of the data.

The LMM results show significant differences in the F2 of /i/ as a function of stress (F (2, 133.01) = 9.4291, p = 0.001). The vowel /i/ has significantly lower F2 values in the initial unstressed position (M = 1.46) and in the intermediate (M = 1.39) position than in the stressed position (M = 1.75), which indicates that it is centralized when it is unstressed.

And finally, there are also significant differences in the F2 of /u/ depending on the stress (F (2, 91.146) = 5.8033, p = 0.004). This vowel has significantly higher F2 values in the intermediate unstressed position (M = −0.832), that is, it presents greater centralization than in the stressed position (M = −1.256) or than in the initial unstressed position (M = −1.229).

5.3. Differences in the Duration Due to the Degree of Stress

With respect to duration, the results of the model indicate that there are significant differences between duration and stress (F (3, 397.81) = 28.771, p < 0.001). Specifically, the pairwise comparisons (see Table 5) for the duration of /a/ indicate that there are two opposing groups: the stressed and the final unstressed positions have significantly longer

durations ($M_{stressed}$ = 1.365; M_{final} = 1.239) than the initial and intermediate unstressed ones ($M_{initial}$ = 0.818; M intermediate = 0.814).

Table 5. Summary of the pairwise comparisons for the duration of each vowel using the Tukey adjustment.

Duration	*β*	SE	df	t	*p*
/a/					
Stressed—initial	0.54692537	0.06811513	395.994153	8.02942534	<0.001
Stressed—intermediate	0.55038813	0.08568603	395.421432	6.42331243	<0.001
Stressed—final	0.12547421	0.06768236	402.912217	1.85386866	0.249
Initial—intermediate	0.00346276	0.08430592	406.908748	0.04107373	0.999
Initial—final	−0.4214512	0.06866057	396.290914	−6.1381833	<0.001
Intermediate—final	−0.4249139	0.08636471	390.438439	−4.9199948	<0.001
/e/					
Stressed—initial	0.3375022	0.07172629	182.705124	4.70541804	<0.001
Stressed—intermediate	0.32146919	0.07390373	141.848722	4.34983713	<0.001
Stressed—final	0.0176023	0.07363192	184.044066	0.23905802	0.995
Initial—intermediate	−0.016033	0.07781051	231.665906	−0.206052	0.996
Initial—final	−0.3198999	0.07831227	247.783015	−4.084927	<0.001
Intermediate—final	−0.3038669	0.07880117	259.012299	−3.8561214	<0.001
/o/					
Stressed—initial	0.30719946	0.09840843	180.655558	3.12167835	0.01
Stressed—intermediate	0.34051039	0.12486106	153.329091	2.72711449	0.03
Stressed—final	−0.1617061	0.092225	204.48512	−1.7533869	0.299
Initial—intermediate	0.03331093	0.11324943	156.404962	0.29413773	0.991
Initial—final	−0.4689056	0.07841847	186.737665	−5.9795293	<0.001
Intermediate—final	−0.5022165	0.10908331	162.719161	−4.603972	<0.001
/i/					
Stressed—initial	0.35388014	0.07021152	100.472553	5.04020068	<0.001
Stressed—intermediate	0.38918174	0.08157104	136.553235	4.77107727	<0.001
Initial—intermediate	0.0353016	0.09141148	128.888435	0.38618343	0.921
/u/					
Stressed—initial	0.23742433	0.07660337	119.423429	3.09939819	0.006
Stressed—intermediate	0.24071315	0.06902378	116.450454	3.48739432	0.001
Initial—intermediate	0.00328882	0.08734394	119.355708	0.03765365	0.999

The results for the vowel /e/ also show significant differences in duration as a function of word stress (F (3, 195.8) = 12.263, $p < 0.001$). The results of the pairwise comparisons show that, again, there are two groups differentiated from each other: the stressed position and the final unstressed position have significantly longer durations ($M_{stressed}$ = 1.031; M final = 1.013) than the initial and intermediate unstressed ones ($M_{initial}$ = 0.693; $M_{intermediate}$ = 0.709).

Also, for the vowel /o/, there are significant differences in duration according to word stress (F (3, 176.24) = 14.951, $p < 0.001$). The vowel /o/ again shows two groups: the stressed and the final unstressed ($M_{stressed}$ = 1.046; M_{final} = 1.208) with significantly longer durations than the initial and intermediate unstressed ($M_{initial}$ = 0.739; $M_{intermediate}$ = 0.706).

For the vowel /i/, the LMM results are also significant for duration (F (2, 118.15) = 18.796, $p < 0.001$). Here, there are also differences between the vowel in the stressed position, where the duration is significantly longer (M = 1.044), and the unstressed positions (M initial = 0.691; M intermediate = 0.655) where the duration is shorter.

And, finally, the vowel /u/ also presents significant differences in duration depending on the word stress (F (2, 123.96) = 8.7582, $p < 0.001$). According to pairwise comparisons,

the stressed position (M = 0.941) has significantly higher duration values than the initial unstressed position (M = 0.704) and the intermediate unstressed position (M = 0.700).

These results suggest that there is no correlation between the degree of reduction of the vowel and its duration since the position in which the degree of raising is greater is the final unstressed one, which is also the one with the highest duration values.

6. Discussion

The overall results of this research are of interest for the study of the reduction of unstressed vowels in Galician. In general, the results show that, in our data sample, there is indeed a reduction in the vowel space of unstressed vowels with respect to the stressed ones, as indicated by previous studies (Vidal Figueiroa, 1997; Aguete Cajiao, 2020a, 2020b; Regueira Fernández & Fernández Rei, 2025). Although this general trend can be traced, each vowel seems to present a different behavior as a consequence of this process.

Thus, the central vowel /a/ is the vowel that presents a greater reduction in the degree of raising when unstressed; a similar behavior for the vowel /a/ has been reported for French (Meunier & Espesser, 2011, p. 276), Southern Italo-Romance (Baird et al., 2021), and Catalan (Nadeu, 2015). It is fundamentally characterized by undergoing a strong stepped raising in which a hierarchy of different degrees of raising applies so that the /a/ is more closed in the initial unstressed position than in the stressed position, and even closer in the intermediate and final unstressed positions. These results are coherent with Aguete Cajiao (2020b) and Aguete Cajiao and Fernández Rei (2022), who find three degrees of opening of the central vowel /a/ depending on whether the vowel is in a stressed, initial unstressed, or final unstressed syllable. Although there are also significant differences in the degree of frontness–backness when this vowel is in an initial unstressed syllable, we believe that this variation may be dependent on the consonantal context, similar to what Aguete Cajiao (2020b) detects, and not on the fact that there is actually a movement in the horizontal plane depending on stress. This possibility is consistent with the behavior of other languages, in which the F2 of reduced vowels are highly dependent on the immediate context (van Bergem, 1993; Fourakis, 1991). Another possibility is that the backness undergone by /a/ when in the initial unstressed position (which, along with the intermediate position, is the one in which this vowel is shortest) is due to an effect of a positive correlation between the duration and F2. However, in this case, it would be expected that the effect of this correlation would affect both the initial and the intermediate syllable.

In the front vowels, on the other hand, it seems that the most pronounced phenomenon is the centralization in unstressed positions. The mid–high front vowel /e/ presents, in this case, a stepped, non-continuous centralization in such a way that the vowel is more centralized in the initial position than in the intermediate one and more centralized in the intermediate position than in the final stressed or unstressed position. In addition, the raising mechanism affects the vowel /e/ only when final, but not in the rest of the unstressed positions.

In contrast, the vowel /i/ is more centralized in any of the unstressed positions, but, similarly to what has been found in previous experimental research on Galician (Aguete Cajiao, 2020b), as well as in other languages such as French (Meunier & Espesser, 2011) and Bulgarian (Sabev, 2023), no lowering has been found in the unstressed positions. The lowering of high vowels resulting from a reduction process is possible, as it was attested for example in languages like Brazilian Portuguese (Nobre & Ingemann, 1987; Kenstowicz & Sandalo, 2016), but there is no evidence that this happens in Galician. This behavior suggests that the reduction applies in a specific direction and consists not of one single movement towards the center of the vowel acoustic space but of two different movements: raising and centralization (in this regard, see Veloso, 2016 for a phonological interpretation

of European Portuguese reduction). Moreover, this result proves that the reduction process is not mechanical.

Similar to /a/, the mid–high back vowel /o/ also has a non-continuous raising in unstressed syllables. Thus, this vowel is higher in the initial unstressed position than in the stressed one and is even higher in the final unstressed position than in the intermediate position. In addition, it undergoes a marked centralization in the intermediate unstressed position. This same phenomenon of centralization also affects /u/ when in the intermediate unstressed position, but as for /i/, no lowering has been attested for the high back vowel.

With respect to duration, the results showed, for all vowels, a clear difference between the stressed position and the initial and mid-unstressed positions, which, in all cases, had shorter durations. For their part, the durations of the vowels /e/, /a/, and /o/ in the final unstressed syllable were similar to the stressed ones. These results contrast with those obtained by Aguete Cajiao (2020b), who found longer durations in the initial unstressed position and significantly shorter in the final stressed position. These differences between both investigations are probably due to methodological differences between both experiments, specifically the difference in the type of speech analyzed. While Aguete Cajiao's (2020b) results were based on read speech where the final unstressed vowel was never in the absolute final position of the sentence, and in which the initial unstressed vowel was in the initial absolute position without consonantal onset, in the present research, samples of semi-spontaneous speech were used, where phrase-final and word-final lengthening are more frequent (White et al., 2020; Paschen et al., 2022). And, in addition, where absolute initial vowels in the words were discarded because they were sandhi positions.

In short, all vowels presented centralization (except /a/), but not all presented raising/lowering[14], and in all cases, the unstressed positions, except the final one, have shorter durations than the stressed ones. Table 6 shows a summary of the extent to which each of the vowels is affected by the mechanisms involved in the aforementioned process.

Table 6. Summary of the mechanisms involved in the reduction process, and the amount in which they affect each vowel with respect to the stress counterpart (= means equal to the stressed counterpart; − means that the given parameter is reduced; + means that the given parameter is slightly increased; ++ means that the given parameter is moderately increased; and +++ means that the given parameter is strongly increased).

Vowel	Initial Unstressed	Intermediate Unstressed	Final Unstressed
/i/	= raising + centralization − duration	= raising + centralization − duration	-
/e/	= raising ++ centralization − duration	= raising + centralization − duration	+ raising = centralization = duration
/a/	+ raising = centralization − duration	++ raising = centralization − duration	+++ raising = centralization = duration
/o/	+ raising = centralization − duration	++ raising + centralization − duration	++ raising = centralization = duration
/u/	= raising = centralization − duration	= raising + centralization − duration	-

The results obtained shed some light on the nature of the reduction phenomenon in the Galician vowel system. The first hypothesis we formulated in this regard was that the process of reduction of the unstressed vowel system in Galician would be manifested acoustically through a double mechanism of raising and centralization. Along the lines of previous works, the data of this investigation confirm that this process consists of two complementary mechanisms: one of raising and one of centralization, which, moreover, affect each vowel in a different way.

Our second research question was whether this process produces different degrees of reduction, that is, whether there is a hierarchy of stress or whether it affects all vowels in unstressed position to the same extent. The hypothesis we formulated, considering the existing bibliography, was that the reduction process would be more pronounced in the intermediate position, followed by the final unstressed position, and that the position with less reduction would be in the initial unstressed one because it usually receives the most articulatory effort. The results of this research do not allow us to answer this question and only partially confirm our hypothesis.

On the one hand, a stepwise reduction following a hierarchy stressed > pretonic > posttonic is observed in /a/ and in /o/, since the unstressed position of the maximum opening is the initial one, but, in contrast, the intermediate position aligns with the final unstressed position, with both presenting similar degrees of F1 raising. However, the fact that the positions of maximum centralization of the vowels are, at least for /o/ and for /u/, the intermediate ones also seems to support our hypothesis that the intermediate positions are the most affected by the reduction (since they would suffer not only raising but also centralization). On the contrary, the vowel /e/ only presents raising in the final unstressed position, which would go against our hypothesis that the intermediate position is the most susceptible to the reduction.

With respect to the third of our research questions, we wondered if there was a correlation between the duration and the degree of reduction that could contribute to understanding the nature of the phenomenon in Galician. This research question was linked to the last of the questions we tried to answer, that is, if this process can be considered phonological in Galician or if it is a purely phonetic process.

Our initial hypothesis was that there would be a correlation between the duration and the degree of opening, and, on the other hand, that there would be no relationship between the duration and the degree of centralization. However, the results of this research do not fully support our hypotheses.

Taking into account all the results together, and especially the fact that final unstressed vowels with durations similar to the stressed ones also present reduction, we believe that the phenomenon of reduction of the unstressed vowel system in Galician is a highly controlled process, suggesting that the different spectral characteristics of stressed versus unstressed vowels are controlled by the grammar of the language (Tauberer & Evanini, 2009; Fridland et al., 2014; Jacewicz & Fox, 2015; Toivonen et al., 2015), thus being part of the phonological specification of the Galician vowels, in line with authors such as Solé and Ohala (2010, p. 608), who suggest that it is "deliberately controlled by the speaker". A possible explanation for this behavior (following, again, Solé & Ohala, 2010) is that speakers use spectral reduction to enhance the distinction between the stressed and unstressed syllables, as well as to mark word boundaries. Future research should delve deeper into this hypothesis. Moreover, in line with previous works, we consider that the phonological process of reduction in Galician (according to which there is a neutralization between mid–low and mid–high vowels in unstressed word positions) can be interpreted as an extension of the phonetic one.

7. Conclusions

The aim of this research was the study of the unstressed vowel reduction process in Galician. In particular, we wondered about: (1) the specific mechanisms involved, (2) whether the reduction applies to various degrees or not, (3) whether it depends on the duration, and (4) whether it is a mechanical or a controlled language-specific process. In order to do so, an experimental (acoustic) study with semi-spontaneous speech from six young Galician-native women was conducted.

Broadly, this research showed that this process affects every unstressed vowel. Although there is no clear evidence on whether this is a stepwise process or not, the results confirmed that two different mechanisms, raising and centralization, characterize the phonetic process. Also, as we explained in the previous section, regarding the overall results of the study, our position is that this is a phonetic process that is language-specific (i.e., controlled by the speaker), which interacts in speech with the phonologic process, i.e., with the neutralization process that leads to a reduction in the number of vowels in the unstressed position compared to stressed positions (vid. Section 2).

Furthermore, as far as we are aware, this work is the first to provide empirical acoustic data on unstressed intermediate vowels of Galician, and it is one of few to provide a sample of data from semi-spontaneous speech. However, possibly due to the fact that this method does not allow for controlling the items or for balancing their presence in the sample, we did not find examples of mid–low unstressed vowels that have been seen in previous studies. The fact that there are no mid–low unstressed vowels in our sample does not mean, obviously, that they do not exist in Galician, but it is certainly an indication of their unusualness.

In future research, it is necessary to substantially increase the sample of data and consider different age ranges and social and educational strata, which will allow us to account for the process in its entirety, as well as for other linguistic variables such as the speech rate and the prosodic structure in which vowels are embedded.

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Institutional Review Board Statement: This study was conducted in accordance with the Declaration of Helsinki, and approved by the Ethics Committee of the University of Santiago de Compostela (USC 06/2022).

Informed Consent Statement: Informed consent was obtained from all subjects involved in this study.

Data Availability Statement: The recordings are not publicly available due to ethics protocol reasons.

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Notes

[1] The degree of stress of a given syllable is marked by acoustic parameters such as a increase in the fundamental frequency, a greater duration and a stronger expiratory effort (Lehiste & Peterson, 1959).

[2] Lausberg (1971) also relates it to the degree of intensity with which the syllables would be produced, and differentiates prestressed, which he considers secondary stressed vowels and therefore more intense, from poststressed, which are less intense.

[3] "in *e* and in *o*, in addition to the open and closed sounds that we have already talked about, there is another more subdued sound that brings the first *i* and the second *u* closer together".

[4] However, Regueira (2009) considers that this phenomenon would have been completed and that there are no longer speakers with the conservative system of five pretonic vowels.

[5] Note that this work used laboratory speech and that word-final unstressed vowels were never at the absolute end of a sentence.

[6] Both the work of Porto Dapena (1977) and that of Taboada (1979) are based, albeit anecdotally, on experimental data.

[7] Of the total elisions in our sample, 41.7% occur before a pause, that is, when the vowel is in absolute final position, or immediately before the fricative /s/ (29.2% of cases), which functions as plural mark in Galician. With respect to devoicing, 69.6% occur before a pause and 21.7% before the fricative /s/. These results suggest that these two relaxation processes are favored by absolute final position preceding the pause (58% of the total cases) or preceding /s/ (25% of the total).

[8] This is the file format for transcription and tagging in Praat.

[9] F3 was analyzed, but is not included in the data analysis because it is not a particularly relevant parameter in the characterization of Galician vowels.

[10] Henceforth "intermediate unstressed".

[11] All analyses were performed in the RStudio graphical environment.

[12] Although, according to the bibliography, we can find the vowels /ɛ/ and /ɔ/ in unstressed pretonic position, in our sample there were no such cases. Thus, the vowels /ɛ/ and /ɔ/ were excluded from the analysis because they are presented only in stressed position.

[13] All the scripts used in the vowel analysis, as well as the data, are available in the online repository: https://osf.io/ka28n/ (accessed on 19 December 2024).

[14] While raising would be the expected movement for the reduction of the low and mid vowels, the reduction process would be expected to affect the lowering of the high vowels /i/ and /u/.

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