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Alfredo Herrero de Haro

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Covariants of Gemination in Eastern Andalusian Spanish: /t/ following Underlying /s/, /k/, /p/ and /ks/

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Abstract: In Eastern Andalusian Spanish, consonants are deleted in syllable-final position, triggering regular gemination of a following consonant, even across word boundaries. This paper investigates five underlying phonemic contexts involving /t/, including singleton /t/ and four different underlying /C+t/ sequences that typically surface as [tː], by analyzing how durational and formant differences vary depending on the presence and identity of the preceding underlying consonant. Following the acoustic and statistical analyses of 444 instances of /ˈeta/, /ˈesta/, /ˈekta/, /ˈepta/ and /ˈeksta/, a Discriminant Function Analysis shows that differences in the total duration of /t/ and in the duration of the closure of /t/ are the strongest cues to distinguishing singletons from geminated consonants, with 91.9% and 90.6% accurate classifications, respectively. Cues indicating which specific consonants have been deleted before /t/ are much less robust and more varied in nature. It is unclear, however, whether this outcome is due to different compensation strategies in each case or whether they are affected by some kind of underlying coarticulatory effect. Given that gemination in this language variety is the result of regular $/C_1C_2/$ to [Cː] assimilation, and that its underlying phonemic status has not been demonstrated, Eastern Andalusian Spanish is unusual amongst languages studied with respect to gemination, making this study typologically interesting.

Keywords: Eastern Andalusian Spanish; gemination; consonant deletion; durational differences; vowel formants

1. Introduction

The present study aims to investigate whether the deletion of different word-medial codas (/s/, /k/, /p/ or /ks/) triggers the regular gemination of a following /t/ in Eastern Andalusian Spanish (henceforth *EAS*). It also aims to identify potential covariants of gemination in EAS. Another objective of the present paper is to determine the relative predictive weight of each covariant in identifying not only singletons and geminates, but also the underlying consonant in each case.

EAS is a variety of Spanish spoken in the southeast of Spain, mainly in the provinces of Almería, Granada and Jaén (Herrero de Haro and Hajek 2022). Although EAS shares many characteristics with neighboring Western Andalusian Spanish (henceforth *WAS*), one important difference is that, in EAS, vowels are regularly opened or lowered before a deleted syllable-final /s/, e.g., *dos* /dos/[dɔ̞], 'two' (e.g., Villena Ponsoda 2000); vowel opening, to the extent described for EAS, has not been noted in other varieties of Spanish (Henriksen 2017). In this paper, the term *deletion* is used as a cover term for when a phoneme does not surface directly in the phonetic output, even though it may leave some other assimilatory trace, e.g., *esta* /ˈesta/[ˈe̞tːa] 'this one'. The term *Andalusian Spanish* is used to refer to both EAS and WAS. More information regarding the differences between these two varieties of Spanish can be found in Jiménez Fernández (1999), Villena Ponsoda (2000), Moya Corral (2010) and Valeš (2014).

With respect to conditioned vowel lowering, which has been a major focus of research on EAS to this point, some scholars have argued that only /e/, /a/ and /o/ lower before

an underlying /s/ (e.g., Navarro Tomás 1938, 1939; Henriksen 2017), whereas others have claimed that all five Spanish vowels do (/i/, /e/, /a/, /o/, and /u/) (e.g., Peñalver Castillo 2006). Other studies have found evidence that EAS vowels lower before other underlying consonants (e.g., Herrero de Haro 2016, 2017a). As a consequence, different scholars have proposed surface vowel systems for EAS that vary from eight vowels (e.g., Navarro Tomás 1938, 1939) to fourteen vowels (Herrero de Haro 2019c). More information on EAS vowel opening can be found in Herrero de Haro (2017b, 2023) and Herrero de Haro and Hajek (2022).

For the purposes of the present discussion, a consonant is considered geminated in EAS if it appears immediately after an underlying consonant that does not surface, even across a word boundary. Therefore, /t/ is considered a geminate in *esta* [ˈe̞tːa], 'this one', and in *es tuyo* '[e̞ ˈtːuɟo], 'it is yours', and is considered a singleton in *cometa* [koˈmeta], 'kite', and in *alto* [ˈalto], 'tall', in which the underlying /l/ is not deleted.

Previous studies on gemination in EAS have focused on relatively few features, most typically durational differences and in no more than three underlyingly phonemic /V(C$_1$)C$_2$V/ contexts (e.g., in /st/, /pt/ and /kt/ by Gerfen and Hall 2001 or Bishop 2007). However, this paper aims to develop a more detailed analysis of gemination that takes into account the discrete classification of gemination and of covariants of gemination in a series of five different contrasts (listed below) to see whether the identity of the underlying consonant can also be detected, or at least to see to what extent this can be established using different measurements.

Conservative varieties of Spanish, which do not reduce or delete codas, only have singleton consonants; innovative varieties of Spanish, which delete codas, typically have a singleton–geminate surface contrast, e.g., /VCV/ > [VCV] v /VC$_1$C$_2$V/ > [VC$_{:2}$V]. We consider this surface contrast to be phonetic and not underlying, because, for example, in highly normative production, influenced by the written standard, the underlying cluster can potentially surface. This approach is consistent with descriptions of EAS and other geminating varieties of Spanish by other scholars, e.g., Monroy and Hernández-Campoy (2015) on Murcian Spanish or Torreira (2012) on WAS. Furthermore, we still do not have a detailed picture of what other covariants exist in the singleton–geminate contrast. It should be noted that, while consonant duration is considered the main cue to gemination, vowel duration is a covariant. Although this study does not explore perception, a greater understanding of phonetic features could help clarify which cues are the most likely ones to act or not at a perceptual level, thus also providing clues to the potential phonologization of the singleton–geminate contrast in EAS and other innovative varieties of Spanish. Evidence from Spanish would in turn also contribute to the increasing body of research on gemination across languages (e.g., Hamzah et al. 2016; Hedia and Plag 2017; Kubozono 2017; Ridouane and Turco 2019).

In other languages, such as Japanese and Italian, research has shown that gemination (i.e., increased consonant duration) is usually accompanied by other acoustic cues or predictable covariants, such as shortening the vowel preceding the geminated consonant in Italian (e.g., Esposito and Di Benedetto 1999). Idemaru and Guion (2008) identified the following covariants of consonant gemination in Japanese: (a) vowels preceding a geminated consonant are longer in duration, whereas vowels following a geminate are shorter; (b) F0 and intensity changes between these vowels are greater in geminates; and (c) there is more creaky voicing in vowels following geminates. Idemaru and Guion (2008, p. 183) also concluded that vowel duration, F0 and intensity changes have "fairly strong categorization power" for Japanese. In Pattani Malay, amplitude is greater in syllables after geminates, and this helps the perception of the contrast (Abramson 1992). Languages also differ in the function and directionality of covariance. Bengali shows greater levels of intensity in words that contain a geminate, whereas Turkish does not (Idemaru and Guion 2008). The reasons for cross-linguistic variation, such as different vowel duration effects before geminates in Italian, Japanese and other languages, remain unknown (see also Maddieson 1984; Khattab and Al-Tamimi 2014). However, it should also be noted

that, although studies investigating gemination usually focus on well-established lexical or phonemic contrasts, as is the case of gemination in Japanese and Italian, the current paper analyzes phonetic gemination occurring as a result of /C₁C₂/ to [C:] assimilation. EAS is particularly unusual when compared to other languages studied with respect to gemination, as EAS does not have an established underlying or lexical consonant length contrast, but a phonetic one resulting from synchronic consonant cluster reduction. The status of EAS gemination makes this particular study therefore typologically interesting because it also seeks to cast light on the process of the phonologization of gemination on the path to underlying contrastivity, e.g., /ˈpakto/ > [ˈpakto] > [ˈpa̰t:o] *pacto*, 'pact', in EAS is in contrast, for instance, to Italian, in which all trace of the original non-homorganic consonant (seen in Latin PACTU) is lost at all levels of representation, hence having only /ˈpat:o/ > [ˈpat:o] *patto*, 'pact'.

1.1. Background

EAS gemination was first identified by Schuchardt (1881) as a result of the assimilation of the historical /s/ through an intermediate phase of articulatory reduction, referred to traditionally as 'aspiration', i.e., /sC/ > /hC/ > /C:/ giving, for example, *pasta*, 'pasta', [ˈpasta] >[ˈpa̰ht:a] > [ˈpa̰t:a]. However, all EAS consonants assimilate to the following consonant in word-medial clusters except /l/, /n/ and /r/, which only do so under more limited conditions (Herrero de Haro and Hajek 2022). As a result, the surface geminate inventory is large in EAS.

The realization of the lenited /s/ is itself highly variable synchronically. The underlying phonological sequences /sp/, /st/ and /sk/ are of particular interest because, in addition to a lengthened stop closure at the surface, they have also been found to be produced with pre-aspiration preceding the stop closure, for example, *casta*, 'caste', [ˈkaht:a] ~ [ˈkaʰt:a] in some studies (Gerfen 2002; O'Neill 2010) and with post-aspiration after the stop closure in other studies, for example, *casta*, 'caste' [ˈkat:ʰa] (Torreira 2007a, 2012; Parrell 2012).

EAS gemination has also been identified as the primary cue to distinguishing minimal pairs. Bishop (2007, p. 1765) concluded that, when /s/ is produced as [h] word-medially in EAS, the lengthening of the stop consonant, rather than [h], acts as a "a strong, disambiguating cue to listeners in making phonemic decisions as to an underlying coda".

Going even further, EAS gemination can mark other contrasts apart from an underlying coda versus zero. According to Gerfen and Hall (2001, p. 2), there is a "subtle yet consistent production pattern distinguishing forms derived from an underlying /s/ and those derived from an underlying voiceless stop (/p/ or /k/)", such as in *casta* /ˈkasta/ 'caste' and *capta* /ˈkapta/ 'he/she captures'. Gerfen (2002) found that consonant lengthening increases in the context of an underlying /s/, whereas the duration of the preceding vowel decreases. It has also been posited that, in EAS, consonant gemination is a more reliable indicator than vowel lengthening to mark an underlying /s/ (Gerfen and Hall 2001; Gerfen 2002; Bishop 2007; O'Neill 2010), although Carlson (2012) proposed the opposite. Additionally, Bishop (2007) found that an increase in the closure duration of the stop following a deleted /s/ made his listeners perceive *hasta*, 'until', as *apta*, 'capable'.

Gemination has also been widely studied in the closely related variety of Western Andalusian Spanish (WAS) (e.g., Torreira 2012). Consonant deletion or assimilation triggers pre- and/or post-aspiration of the following consonant, but this is much more common in WAS than it is in EAS. In addition, the former also presents higher duration values for pre- and post-aspiration than those in the latter variety (e.g., Herrero de Haro 2017b). Lenited tokens also present longer VOT values in WAS than those in the Spanish spoken in central Spain (Henriksen and Harper 2016). In WAS, underlying /sp/, /st/ and /sk/ are produced with longer VOT at the surface than that of simple intervocalic voiceless stops (Torreira 2007a, 2012; Parrell 2012; Ruch and Harrington 2014; Henriksen and Harper 2016). The sequence /st/ can surface as [st] (when reverting to a normative pronunciation based on more formal Standard Spanish), [ʰt] or [tʰ] in WAS, but it is most common with

post-aspiration. Torreira (2012), Parrell (2012) and Ruch and Harrington (2014) believed that WAS post-aspiration is of a coarticulatory nature, arising when glottal spreading is produced at the same time as the closure of the voiceless stop, rather than before. Torreira (2012) hypothesized that any articulatory causes of lengthening in the articulation of /t/ or of a vowel are dialect-specific, as "extensive overlap and consonantal lengthening do not occur in the [hC] clusters of other [non-Andalusian] Spanish varieties" (Torreira 2012, p. 49). In WAS, segmental sequences formed of a vowel, an underlying /s/ and a voiceless stop are longer when pre-aspiration is present than when there is no pre-aspiration but there is a lengthened VOT (O'Neill 2010). Younger WAS speakers produce words such as *lista*, 'list', with aspiration following a long stop closure (i.e., [ˈlitːʰa]). In WAS, there is a trading relationship between pre-aspiration on the one hand and VOT, and closure duration on the other, which seems to indicate that any variation found in pre- and post-aspiration is due to the timing of glottal and supraglottal gestures (O'Neill 2010). Similar links between gemination, pre-aspiration and post-aspiration have also been found in other languages, such as in Italian (e.g., Stevens and Hajek 2007). As posited above, overlapping can account for a wide variety of alternations depending on gestural overlap. It should also be noted that the type of pre- and post-aspiration noted in Andalusian Spanish is different from that which appears in languages such as Icelandic or Scottish Gaelic, in which these phenomena occur segmentally and are not related to reductions in an adjacent segment (Ruch and Peters 2016). Moreover, in Andalusian Spanish, (pre-)aspiration is not limited to /s/ preceding voiceless stops but can occur in all contexts (including before sonorants) in which a syllable-final /s/ is debuccalized (e.g., *isla*, 'island', [ˈiʰlːa]; *mismo*, 'the same', [ˈmiʰmːo]; etc.).

Although previous studies on EAS gemination have studied occlusion, the pre- and post-aspiration of the consonant and the duration of the first vowel (V1), no study to date has considered other possible covariants, such as the duration of the second vowel (V2), or F1 and F2 values for V1 and V2. Examining cues other than duration could help us better understand the precise nature of EAS gemination in a word context. Even if consonant length is the primary cue to distinguishing between singleton and geminated consonants in EAS, such as in, e.g., Italian, Japanese and Hindi (Esposito and Di Benedetto 1999; Pickett et al. 1999; Payne 2005; Turco and Braun 2016), additional secondary cues might also be at play.

1.2. Aims and Research Questions

The aim of the present paper is to analyze the complex relationship between consonant deletion and the gemination of the following /t/ in EAS. In the first instance, this study examines whether the deletion of a word-medial coda (/s/, /k/, /p/ or /ks/) triggers the regular gemination of a following /t/ in EAS. It also aims to identify the potential covariants (durational and non-durational) of gemination in EAS through a series of acoustic and statistical analyses before proceeding to determine by means of a Discriminant Function Analysis (DFA) the relative predictive weight of individual covariants, both overall and also according to the identity of the underlying deleted consonant. Finally, it explores the reasons that might explain any different phonetic realizations that arise due to consonant deletion.

This study is motivated by previous findings for other languages (e.g., Idemaru and Guion 2008 for Japanese) as well as for EAS (e.g., Gerfen 2002). For this, we investigate the durational and non-durational differences of gemination of /t/ in a series of related structures, i.e., the underlying sequences of the segments /ˈeta/, /ˈesta/, /ˈekta/, /ˈepta/ and /ˈeksta/ embedded in actual lexical contexts, to see if the singleton–geminate distinction in these words in EAS is solely dependent on: (a) whether or not /t/ in these forms is preceded by any deleted consonant, regardless of its underlying identity, or (b) whether, in turn, some features present different values depending on what the preceding underlying consonant is. It was decided to focus on /t/, given how rich and frequent the context of /ˈe(C)ta/ is in EAS, which allows us to investigate real words rather than

pseudowords and to control for the place and manner of articulation. Likewise, studies on EAS and WAS gemination usually focus on voiceless stops, and this allows for a better comparison between the present study and past ones. Further research on other geminated EAS consonants is, of course, still needed.

Based on the /ˈe(C)ta/ frame of words, such as /ˈeta/ and /ˈesta/, the acoustic features studied in the present study are the (a) F1 (in Hz) of /e/, (b) F2 of /e/, (c) duration of /e/ (in ms), (d) closure duration of /t/, (e) VOT of /t/, (f) F1 of /a/, (g) F2 of /a/ and (h) duration of /a/. The variables *Closure duration* and *VOT* are added to obtain the variable *Total duration of /t/* (as in Idemaru and Guion 2008). *Duration of /e/*, *Closure duration*, *VOT*, and *Duration of /a/* were added to obtain the variable *Total duration of the sequence*. It was decided to investigate consonantal occlusion, VOT and the duration of the vowels, as they have been investigated in gemination studies in other languages (e.g., Esposito and Di Benedetto 1999 on Italian); vowel formants are included in the analysis, as research has shown that specific F1 and F2 values can be used to identify underlying consonants in EAS (e.g., Herrero de Haro 2017c).

The present study investigates the following research questions:

1. Does the deletion of /s/, /k/, /p/ or /ks/ in the word-medial coda position trigger the gemination of a following /t/ in EAS? We expect so, because coda deletion has been shown to trigger gemination in EAS, although no experimental study has investigated this in all of these phonetic contexts.
2. Does the closure duration or VOT of /t/ vary consistently depending on whether it follows an underlying /s/, /k/, /p/ or /ks/? We expect so, because some studies have found durational differences in closure and VOT in EAS depending on the underlying consonant, although this has been studied in sequences that are different from the ones investigated here.
3. Are there other covariants of gemination? If so, do these vary depending on the underlying preceding consonant, and what is their relative predictive weight? We expect other covariants of gemination to be present because this is the case cross-linguistically, and phonetic changes usually do not occur in isolation. We are unsure regarding their predictive power, as durational differences and vowel formants have both shown to be very reliable cues for identifying underlying consonants in EAS.
4. What explains any different phonetic realizations that may arise due to consonant deletion? We believe that some coarticulatory processes might still be at play because some studies have shown evidence that supports underlying consonant-specific coarticulation in EAS. A trading relationship might also explain the patterns of variation of certain features, such as an increase in the duration of a feature being accompanied by a reduction in the duration in another one, because this has been reported for EAS and cross-linguistically.
5. What pattern of variation do gemination and covariants of gemination display in a language variety in which gemination is the result of consonant assimilation and the phonemic status of gemination has not been demonstrated? Because surface gemination is the norm in EAS, we anticipate patterns of EAS gemination and covariants of gemination to be similar to those of languages with fully phonemic gemination.
6. What cross-linguistic implications derive from the research in this paper? We are interested in knowing to what extent the findings we report follow similar patterns in other languages, perhaps showing a higher degree of similarity with typologically similar languages, such as Italian.

2. Materials and Methods

2.1. Protocol and Speakers

The first author visited his native town of El Ejido (Almería) in Eastern Andalusia and neighboring towns to gather audio data. The participants were asked to name a series of objects presented in photographs on a printed PowerPoint presentation. Carrier phrases were not used to avoid coarticulatory effects and to reduce fatigue in the participants.

The elicitation task only started after a few minutes of informal conversation in order to make the participants as relaxed as possible and to encourage speaking in their normal EAS accent. This methodology was motivated by the fact that Andalusian speakers can present more normative pronunciation when their speech is being analyzed, and various studies have identified the need to elicit data that are as authentic as possible for the study of regional variation by local interviewers (e.g., Martínez Melgar 1986; Henriksen and Willis 2010). As explained by Herrero de Haro and Hajek (2022), coda consonants are more likely to be produced by EAS speakers when they adopt or move toward a more normative pronunciation. More formal conversations or settings can trigger the pronunciation of codas in EAS and fewer instances of regional variation in general (e.g., Ruch and Peters 2016; Tucker and Ernestus 2016; Hedia and Plag 2017). Picture identification in an informal setting was chosen as a mid-point between laboratory pronunciation and spontaneous speech because free speech would not produce the necessary number of tokens for each context of /t/, and controlled settings such as reading usually result in hypercorrection. The first author, the interviewer, is a local, and his accent and trivial topics of conversation made the participants feel at ease when using their vernacular accent. Using photographs to elicit words with the desired phonemic contexts also aimed to help control speech rate, which has been found to have an effect on aspiration (e.g., Parrell 2012; Ruch and Peters 2016). The samples analyzed for the present paper were provided by ten speakers from Western Almería (five males and five females) between the ages of 25 and 45. We have no reason to believe that the results from this paper cannot be generalized to Eastern Andalusia as a whole, but this could be investigated in a future paper.

2.2. Data Collection

The phonemic contexts analyzed in this paper are /ˈeta/, /ˈesta/, /ˈekta/, /ˈepta/ and /ˈeksta/, which, as seen below, are embedded in native lexical items. Coda reduction or the assimilation of consonants other than /s/ has received little attention in EAS (cf. Gerfen 2002). As explained in several earlier studies (e.g., Gerfen 2002; Herrero de Haro 2018), the sequence /ˈeta/ is pronounced [ˈeta] in EAS, whereas the other four sequences are generally pronounced [ˈẹtːa]. All the items used in this study have the structure /ˈe(C)ta/ to control for stress position and vowel category.

Photographs were used to elicit as many words as possible; however, on some occasions, it was necessary to include a definition to elicit a particular word, such as *cuarta, quinta y . . .*, 'fourth, fifth and . . . ', to prompt *sexta* [ˈsẹtːa], 'sixth'. To avoid any bias, the researcher never modelled the word but defined it so that each speaker drew the pronunciation from their linguistic memory. Tokens were discarded if a participant did not know a particular word and if the researcher said it before the participant. Each speaker was asked to say each word five times, but to minimize any possible listing effect, as identified in Khattab and Al-Tamimi (2014), only the first four repetitions were analyzed. The recordings were made in local schools, at the participant's house or in the local library, but the process was always the same.

Tokens were discarded for any one of the following reasons: (1) if the typical features of EAS were not apparent, such as a speaker producing the sequence /st/ as the normative Standard Spanish [st], which is not normal or expected in vernacular EAS; (2) if there was no visible pause between repetitions; and (3) if one of its features (e.g., F2 of /e/) could not be reliably measured.

The words that the participants were asked to produce are included in Table 1; limited lexical options in particular contexts explain the imbalance in the dataset. We are not aware of research on the effect of word frequency on the production of geminates, and we are unable to account for any effects of the word frequency of target tokens.

Table 1. List of words that the participants were asked to produce.

Phonemic Context	Word	Expected Phonetic Realization in EAS	Meaning
/ˈeta/	*cometa*	[koˈmeta]	'kite'
	zeta	[ˈθeta]	'zed'
	chaqueta	[tʃaˈketa]	'jacket'
	maleta	[maˈleta]	'suitcase'
/ˈesta/	*honesta*	[oˈnẹt̪:a]	'honest, feminine'
	resta	[ˈrẹt̪:a]	'subtraction'
	cesta	[ˈθẹt̪:a]	'basket'
/ˈekta/	*secta*	[ˈsẹt̪:a]	'cult'
	recta	[ˈrẹt̪:a]	'straight line'
	arquitecta	[aɾkiˈtẹt̪:a]	'female architect'
/ˈepta/	*inepta*	[iˈnẹt̪:a]	'inept, feminine'
	acepta	[aˈθẹt̪:a]	'she accepts'
	adepta	[aˈθẹt̪:a]	'affiliated, feminine'
/ˈeksta/	*sexta*	[ˈsẹt̪:a]	'sixth'
	decimosexta	[deθimoˈsẹt̪:a]	'sixteenth'

With a total of 15 words, 10 participants and 5 repetitions for each word, a total of 750 words were recorded. As previously explained, the fifth repetition of each word was discarded to avoid issues created by the listing effect (150 words). Out of the remaining 600 words, 156 were discarded for the reasons outlined above. A total of 444 tokens were analyzed for the present study. We understand that a bigger data set would have been preferred; however, it is worth noting that other recent studies of gemination have analyzed similar data sets (e.g., Hedia and Plag 2017 had 314 tokens, and Strycharczuk and Koen 2018 had 500 tokens). Our corpus includes nouns, adjectives and verbs, but it is important to state that previous studies focusing on gemination have not found links between phonetic features and lexical status (Idemaru and Guion 2008). It is believed that lexical status acts mainly at the perceptual level rather than at the production level (Walley and Flege 1999). A breakdown of the number of tokens is included in Table 2.

Table 2. Number of analyzed tokens (speaker *n* = 10).

	Male	Female	Total
/ˈeta/	74	75	**149**
/ˈesta/	29	44	**73**
/ˈekta/	44	45	**89**
/ˈepta/	45	28	**73**
/ˈeksta/	30	30	**60**
Total	**222**	**222**	**444**

2.3. Acoustic Analysis

There is some disparity among methodologies used to classify vowel duration in different varieties of Spanish. For example, Gerfen (2002) and Torreira (2007b) reported that, when an underlying /s/ is produced as [h], vowels are longer than vowels in open

syllables only if the period of aspiration is considered as part of the vowel. Alternatively, if the period of aspiration is not considered part of the vowel preceding [h], vowels are shorter in this context than those in open syllables. Different methodologies can yield different results, and this outcome must be considered when comparing our results to previous studies.

The examination of pre- and post-aspiration was an initial aim of the present study, but pre-aspiration was only found in 56 out of 444 tokens (12.6%), and post-aspiration was found only in 14 of them (3.2%). This contrasts with the findings of Gerfen (2002), who found that /sC/ and /C/ differ in the presence of aspiration preceding the stop closure, but this difference could be due to the fact that both studies focus on different geographical areas where EAS is spoken. Therefore, although the acoustic cues to identify pre- and post-aspiration were used in segmentation in the present study, given their respective low frequencies, pre-aspiration was combined into *closure duration*, and post-aspiration was combined into *VOT*, in a similar fashion to Stevens and Hajek (2010) and Henriksen and Harper (2016). It should be noted that the co-occurrence of pre- and post-aspiration with the same consonant is rare cross-linguistically (Helgason and Ringen 2008; Torreira 2012).

As in Herrero de Haro (2017c, 2019b), the first and second vowel formant frequencies were measured from the stable section closest to the peak of intensity. Vowel stability is characterized by minimal movement in F1 and the F2. This coincides to a high degree with the center of the vowel and reduces the impact of possible coarticulation caused by neighboring segments. Praat's LPC algorithm (Boersma and Weenink 2016) was used to measure formant values. Taking the average formant value from a section of the vowel rather than measuring a specific point also reduces the impact created by formant fluctuation and transitions (Warren 2018). A comparison of different methods to measure vowel formants (e.g., values at a single point or averaged over the entire vowel) concluded that the different results obtained from the various methods are marginal and that all methods give essentially the same outcomes (Van Son and Pols 1990, p. 1962). Following Torreira and Ernestus (2011), vowel formants were not normalized, and the present analysis was based on raw formant values in Hz. Speaker differences were accounted for by coding speakers as random factors in the statistical analysis.

All Praat settings were set to default (Boersma and Weenink 2016) except for the *maximum formant* (Hz), which was set at 5000 Hz for male speakers and 5500 Hz for female speakers, as recommended by Wikström (2013).

The onset and offset of different features were identified using cues from both the spectrogram and the waveform, although waveforms were used to mark specific points because they have been reported to allow for a better resolution than that of spectrograms (Torreira 2007a). Figure 1 illustrates how the audio was segmented; *F* indicates where F1 and F2 were measured, *P* means pre-aspiration, *O* stands for occlusion, and *V* stands for VOT. The criteria used for segmentation are explained below.
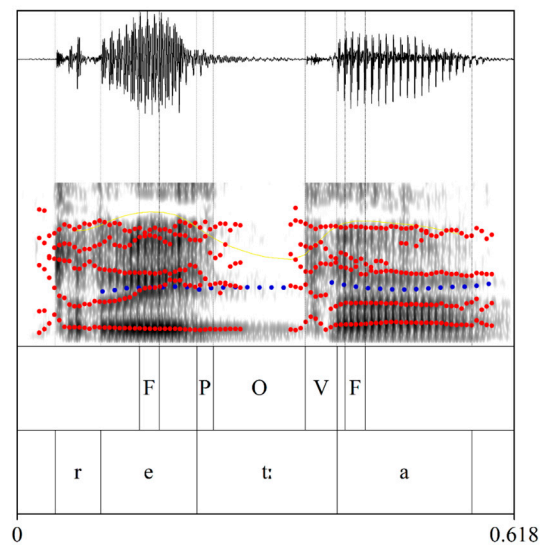
Figure 1. Segmentation of the word *recta* [ˈrẹtːa], 'straight', pronounced by a 38-year-old male speaker.

(a)   The onset of /e/ was determined at the last zero-crossing before an intense increase in energy in the F2 and F3 of the vowel; using the F2 and F3 of vowels to identify cut points for segmentation as has also been done in other studies (e.g., Torreira 2012). The offset of /e/ was marked at the zero-crossing of the last harmonic cycle before the occlusion of /t/ or, if there was aspiration present, before the period of a breathy voice.

(b)   Aspiration before the occlusion of /t/ (if present) was marked at the offset of /e/, as in Stevens and Hajek (2010). Following Torreira (2007a, p. 115), the offset of /e/ was defined as "the point where F2 showed a clear decrease in energy, regardless of whether the following aspiration period displayed some sort of breathy voicing or plain aspiration". Using a clear decrease in F2 energy to mark the offset of a vowel is common in the literature (e.g., Henriksen and Harper 2016). The offset of pre-aspiration (if present) was marked at the first zero-crossing after the abrupt decrease in energy following the breathy voice period. Following Torreira (2007a) and Henriksen and Harper (2016), the offset of aspiration was identified based on the presence of frication noise in high frequencies (4000–5000 Hz).

(c)   Following Henriksen and Willis (2010, p. 118), "the acoustic cues leading to the determination of an 'occlusion' were a reduction or cessation of formant structure and reduced waveform amplitude". The onset of the occlusion of /t/ was marked at the offset of /e/, at the first zero-crossing after an abrupt decrease in amplitude on the waveform, which (typically) manifested on the spectrogram as a decrease in energy in the F2 and F3 regions of the previous vowel (Torreira 2012), as a decrease in its formant intensity (Henriksen and Harper 2016); and as lack of (Gerfen and Hall 2001) or an abrupt decrease in energy in the waveform (Gerfen and Hall 2001; Hedia and Plag 2017). The offset of occlusion was identified at the beginning of the release of /t/, as in Henriksen and Harper (2016). This release can be easily identified in the waveform as a small increase in amplitude and in the spectrogram as a sudden burst of energy (Gerfen and Hall 2001).

(d)   The onset of the VOT of /t/ was marked at the offset of occlusion. The offset of the VOT of /t/ was identified according to the appearance of the clearly defined F1 and F2 of /a/ (if no post-aspiration present), and it was marked at the last zero-crossing before an abrupt increase in energy was first detected after the onset of the VOT. If there was post-aspiration of /t/, the offset of the VOT was marked at the ending point of the VOT at the downward zero-crossing before a whole first cycle could be perceived in the signal (Torreira 2007a); the criteria to identify post-aspiration were

the same as those used for pre-aspiration. Using waveforms to identify the VOT has also been done in other studies analyzing varieties of Andalusian Spanish (e.g., Torreira 2007a). As Torreira (2007a, p. 115) stated, "even though this method cannot be considered entirely faithful to the events in the speaker's glottis, the signal being the result of overlapping supraglottal and glottal gestures, it appeared to be a consistent way of measuring VOT in the absence of articulatory data". Citing Stevens (1998, p. 456), Torreira (2007a) explained how the stop release, a period of supraglottal frication, and post-aspiration overlap in the signal.

(e) The onset of /a/ was marked at the offset of the VOT. The onset of the vowel was defined as the first zero-crossing of the first oscillation of the waveform following the burst (Turk et al. 2006; Nadeu 2016). If there was post-aspiration, the offset of post-aspiration was identified according to the appearance of the clearly defined F1 and F2 of /a/. Although F2 is more reliable when identifying the onset of a vowel after a stop (e.g., Idemaru and Guion 2008), both F1 and F2 were used to minimize any potential errors. Although voicing has been used in other studies of WAS to mark the onset of a vowel (e.g., Torreira 2012), using voicing in that way was avoided in the present paper, as breathy voice can be voiced in Spanish (e.g., Torreira and Ernestus 2011), and some of our samples showed that aspiration can be voiced in EAS. This phenomenon has been reported before (e.g., Navarro Tomás 1939; Alarcos Llorach 1958). Moreover, some of our samples presented voicing of the stop closure. This phenomenon has been documented in other varieties of Spanish spoken in Spain and Latin America (O'Neill 2010; Torreira and Ernestus 2011 and references therein; Ruch and Peters 2016), but the voicing of voiceless stops is more frequent in Almería than it is in other Andalusian provinces, such as Granada, Seville and Cádiz (O'Neill 2010). Therefore, all measurements were taken manually, as automatic procedures could not be relied upon (e.g., segmenting using pitch trackers based on ESPS/Waves as in Scheffers 1983). Furthermore, lenition is linked to a higher percentage of voicing as a coarticulatory effect of the glottis having to adapt to conflicting configurations (Hoole 1999).

(f) The offset of /a/ was marked at the first zero-crossing in the waveform after an abrupt decrease in energy in the F2 of the vowel, as per Torreira (2007a). Using changes in energy levels in the F2 has also been used to delimit the offset of vowels by other researchers (e.g., Turk et al. 2006; Nadeu 2016).

(g) As with /e/, the F1 and F2 of /a/ were measured from the stable section closest to the peak of intensity.

2.4. Statistical Analysis

The statistical analyses were performed using SPSS version 27. It was divided into two parts: standard inferential testing in the first instance (Sections 3.2–3.11), followed by a DFA in which this was relevant (see Section 3.12). The bar graphs of means with 95% confidence intervals were inspected first to compare the effects of phonemic contexts, gender and order on the dependent variables (the acoustic features measured). Due to lexical limitations, the phonemic contexts of /ˈeta/, /ˈesta/, /ˈekta/, /ˈepta/ and /ˈeksta/ could not be investigated entirely just in disyllabic words; longer words had to be used in some cases. However, some studies on gemination have controlled for word duration and have found it to be non-significant (Hedia and Plag 2017). It could be argued that the relative rather than absolute duration of durational features should be used in a statistical analysis to account for differences in word length, so a series of linear mixed-effects models were built to explore this. The durational features of our study (Duration of /e/, Closure duration, VOT, Total duration of /t/ and Duration of /a/) and the durational features divided by the duration of each syllable were used as the dependent variable. The phonemic context was coded as the independent variable, and the speaker was entered as a random variable, with random intercepts and slopes. Following Field (2018, p. 966), the covariance structure *Unstructured* was used. The duration of /e/, closure duration, VOT, total duration of /t/

and duration of /a/ were identified as significant or non-significant by the linear mixed-effects models in the same cases regardless of whether the dependent variable was an absolute measure or a relative measure (durational measure divided by syllable length); in other words, using absolute or relative measures yielded the same results. With this in mind, we focused on absolute duration rather than on relative duration in EAS geminated /t/ because studies on geminates have shown that the absolute duration yields more powerful models (Oh and Redford 2012; Hedia and Plag 2017). A mixed ANCOVA with each acoustic measure as its own dependent variable and phonemic context as the independent variable was run; this test was chosen because it can compare one variable between groups while controlling for covariates (Field 2018, pp. 745–46). All assumptions of the ANCOVA were tested as per Field (2018, pp. 574–603), and these were met. In order to control for speaker variability, the order (first, second, third or fourth repetition of a word), gender and speaker were entered as random variables; as per Eddington (2015, p. 110), these are factors that we wanted to account for but whose differences in results were not of interest to the study. If the ANCOVA was significant, a complex contrast based on the maximized contrast for phonemic context (specific to each ANCOVA) was run. If this was significant, a complex contrast was carried out. Scheffé rather than a Tukey post hoc test was used to determine significance because the Scheffé test does not assume an equal number of scores for each group (Eddington 2015, p. 66). It should be noted that simplifying statistical analyses by excluding non-significant predictors is standard practice (Baayen 2008; Turco and Braun 2016; Hedia and Plag 2017). If a complex contrast has an *F* score above 11.69, then it is considered significant ($p < 0.05$) (Wallenstein et al. 1980). An effect size measure (η_p^2) is also given because this is more reliable than a *p* value when measuring significance (Eddington 2015, pp. 19–20). Finally, a DFA was performed as per Field (2018, pp. 974–83) to identify which dependent variables discriminate phonemic contexts better; all assumptions for the DFA were tested for and met, as per Burns and Burns (2008, pp. 589–606). Covariants' effects can overlap, but a DFA "provides categorisation power of a specific factor regardless of whether that effect/contribution overlaps with other factors" (Idemaru and Guion 2008).

2.5. Inter-Rater Reliability Test

To ensure that appropriate coding was followed and to avoid rater bias, the audio was segmented by two different raters. An inter-rater reliability test was conducted to identify any possible variation with respect to the segmentation of the data.

Rater 1, a native speaker of English, analyzed 301 out of the 444 tokens in this study, and Rater 2 (the first author), a native speaker of Spanish, analyzed the remaining 143 tokens. An inter-rater reliability (henceforth *IRR*) test was carried out to see whether these data could be merged.

Rater 2 analyzed 41 tokens of the 301 analyzed by Rater 1 (13.6%); this percentage is similar to that used in similar studies (e.g., 12.4% in Henriksen and Harper 2016; 13.4% in Regan 2017). A minimum of 12.5% of samples were analyzed for each of the five independent variables (i.e., 15/113 for /ˈeta/, 7/49 for /ˈesta/, 9/66 for /ˈekta/, 7/51 for /ˈepta/ and 3/22 for /ˈeksta/). Tokens were also spread as equally as possible amongst all the speakers. IRR was undertaken via a series of intra-class correlation (ICC) tests on SPSS. This type of test can be used to estimate IRR quantitative data and has been identified as the most appropriate for the type of data analyzed in our study.

Following methodologies outlined in Hallgren (2012), Landers (2015) and Koo and Li (2016), the necessary restrictions and assumptions were examined and met for our data (e.g., an equal number of ratings per rater). Following Landers (2015), the ICC coefficient model was set as "two-way mixed" on SPSS, because both raters rated all participants that were compared in the inter-rater reliability test. Following Hallgren (2012) and Landers (2015), "Type" was set as "absolute agreement", as it was important for the measurements of both raters to be similar in absolute value.

Table 3 includes the results of the ICC. In each of the five data columns, the results on the left are single measures (index for the reliability of one rater), and the ones on the

right are average measures (index for the averaged reliability of different raters). An ICC estimate of 1 indicates perfect agreement, and 0 only indicates random agreement (Hallgren 2012). There is, however, no agreement regarding how to interpret ICC coefficients. For example, Hallgren (2012) (citing Cicchetti 1994), provided the following classification for qualitative ratings of agreement: IRR is poor if under 0.40, fair if between 0.40 and 0.59, good if between 0.60 and 0.74 and excellent if between 0.75 and 1.0.

Table 3. Two-way mixed, absolute agreement ICC (95% confidence interval) calculated on SPSS. Single measures are on the left, and average measures are on the right of each column.

Variable	/ˈeta/	/ˈesta/	/ˈekta/	/ˈepta/	/ˈeksta/
F1 /e/	0.689/0.816	0.802/0.890	0.922/0.959	0.959/0.979	0.986/0.993
F2 /e/	0.954/0.976	0.944/0.971	0.986/0.993	0.953/0.976	0.994/0.997
Dur /e/	0.799/0.889	0.441/0.612	0.812/0.896	0.800/0.889	0.987/0.993
Closure duration	0.821/0.902	0.825/0.904	0.796/0.887	0.896/0.945	0.884/0.938
VOT /t/	0.619/0.765	0.957/0.978	0.821/0.902	0.844/0.916	0.928/0.963
Dur /t/	0.831/0.908	0.789/0.882	0.776/0.974	0.848/0.918	0.510/0.676
F1 /a/	0.828/0.906	0.975/0.988	0.755/0.860	0.728/0.842	0.996/0.998
F2 /a/	0.939/0.968	0.910/0.953	0.959/0.979	0.986/0.993	0.989/0.994
Dur /a/	0.842/0.914	0.796/0.887	0.763/0.866	0.694/0.819	0.921/0.959
Duration sequence	0.870/0.930	0.924/0.960	0.875/0.933	0.755/0.860	0.978/0.989

Following Koo and Li (2016) and Hallgren (2012), the IRR was analyzed via SPSS using a two-way mixed, 95% confidence interval, absolute agreement ICC (McGraw and Wong 1996) to examine the consistency of the acoustic analysis between both raters.

According to the criteria outlined in Cicchetti (1994), the ICC average measures present excellent agreement in all cases except in the case of the *duration of /e/* for /ˈesta/, which has good agreement. The agreement in single measures is excellent for all variables, except in the *F1 of /a/* and *duration of /a/* for /ˈepta/ and the *VOT* of /t/ for /ˈeta/, which have good agreement, and in the *duration of /e/* for /ˈesta/, which shows fair agreement. Overall, there is a high degree of agreement between the raters, and merging the data from Rater 1 and Rater 2 is justified.

3. Results

3.1. Acoustic Analysis

Average values for the results from the acoustic analyses are presented in Table 4. Values in brackets are the ratios of the duration of /e/, /t/ and /a/ in geminates compared to singletons. Although analyzing differences between genders is not a focus of this study, we include some information for readers' interest.

Table 4. Average value of measurements (with ratio values in brackets for the same factor in relevant long and short contexts).

		F1/e/ (Hz)	F2/e/ (Hz)	Dur /e/ (ms)	Closure (ms)	VOT (ms)	Dur /t/ (ms)	F1 /a/ (Hz)	F2 /a/ (Hz)	Dur/a/ (ms)	Total dur (ms)
/ˈeta/	Male	450	1945	99.01	101.98	17.1	119.08	663	1407	159.96	378.06
	Female	489	2268	101.73	85.01	15.87	100.88	728	1640	106.71	309.33
	Both	470	2108	100.38	93.44	16.48	109.92	695	1524	133.16	343.46
/ˈesta/	Male	474	1870	84.16 (0.85)	160.52 (1.57)	25.10 (1.47)	185.62 (1.56)	679	1307	162.37 (1.02)	432.14 (1.14)
	Female	509	2240	98.77 (0.97)	145.51 (1.71)	27.15 (1.71)	172.66 (1.71)	794	1631	124.39 (1.17)	395.82 (1.28)
	Both	495	2093	92.97 (0.93)	151.47 (1.62)	26.34 (1.6)	177.81 (1.62)	748	1502	139.48 (1.05)	410.25 (1.19)
/ˈekta/	Male	465	1851	82.28 (0.83)	177.03 (1.74)	20.97 (1.23)	198.00 (1.66)	672	1344	155.01 (0.97)	435.29 (1.15)
	Female	507	2143	91.14 (0.89)	158.27 (1.86)	24.29 (1.53)	182.56 (1.81)	741	1639	119.95 (1.12)	393.65 (1.27)
	Both	486	1999	86.76 (0.86)	167.54 (1.79)	22.65 (1.37)	190.19 (1.73)	707	1493	137.28 (1.03)	414.24 (1.21)
/ˈepta/	Male	467	1938	89.44 (0.90)	175.46 (1.72)	18.51 (1.08)	193.97 (1.63)	693	1350	156.36 (0.98)	435.07 (1.15)
	Female	533	2293	100.26 (0.99)	162.95 (1.92)	23.29 (1.47)	186.24 (1.85)	783	1599	122.56 (1.15)	409.06 (1.32)
	Both	492	2074	93.59 (0.93)	170.66 (1.83)	20.34 (1.23)	191 (1.74)	727	1446	143.39 (1.08)	425.09 (1.24)
/ˈeksta/	Male	471	1816	85.85 (0.87)	163.25 (1.6)	18.90 (1.11)	182.15 (1.53)	651	1372	131.57 (0.82)	399.57 (1.06)
	Female	524	2055	85.65 (0.84)	159.43 (1.88)	23.88 (1.5)	183.31 (1.82)	755	1646	109.98 (1.03)	377.95 (1.22)
	Both	498	1936	85.25 (0.85)	161.34 (1.73)	21.39 (1.3)	182.73 (1.66)	703	1509	120.77 (0.91)	388.75 (1.13)

The data from Table 4 are easier to appreciate in Figures 2–5. Formants and durational variables are grouped to allow for better interpretation (e.g., F1 and F2 values are not grouped together, as the variation in F1 is difficult to appreciate when the Y-axis extends to over 2000 Hz).
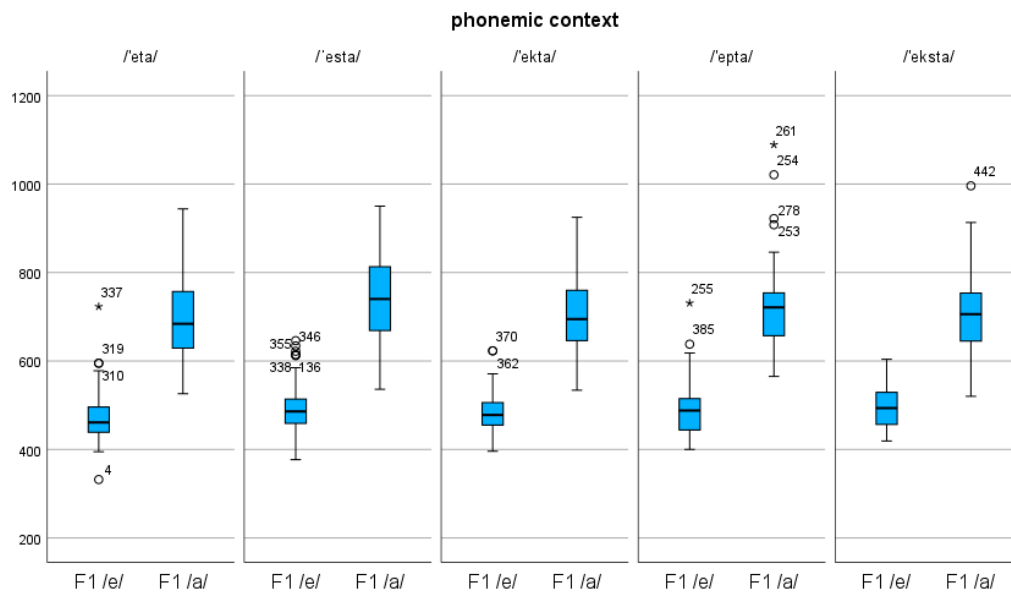
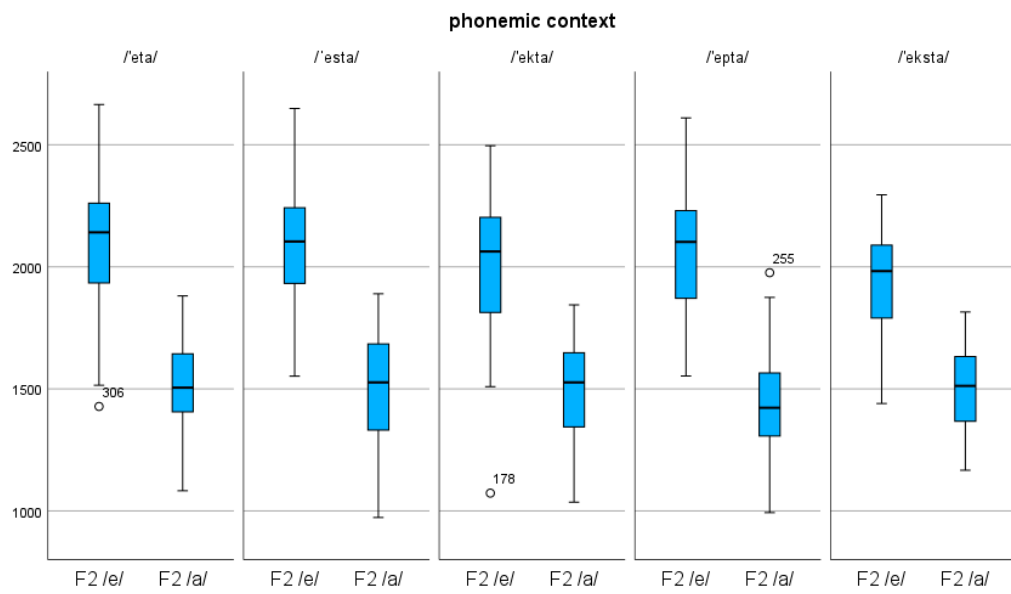**Figure 2.** Mean F1 of /e/ and mean F1 of /a/ for each phonemic context.

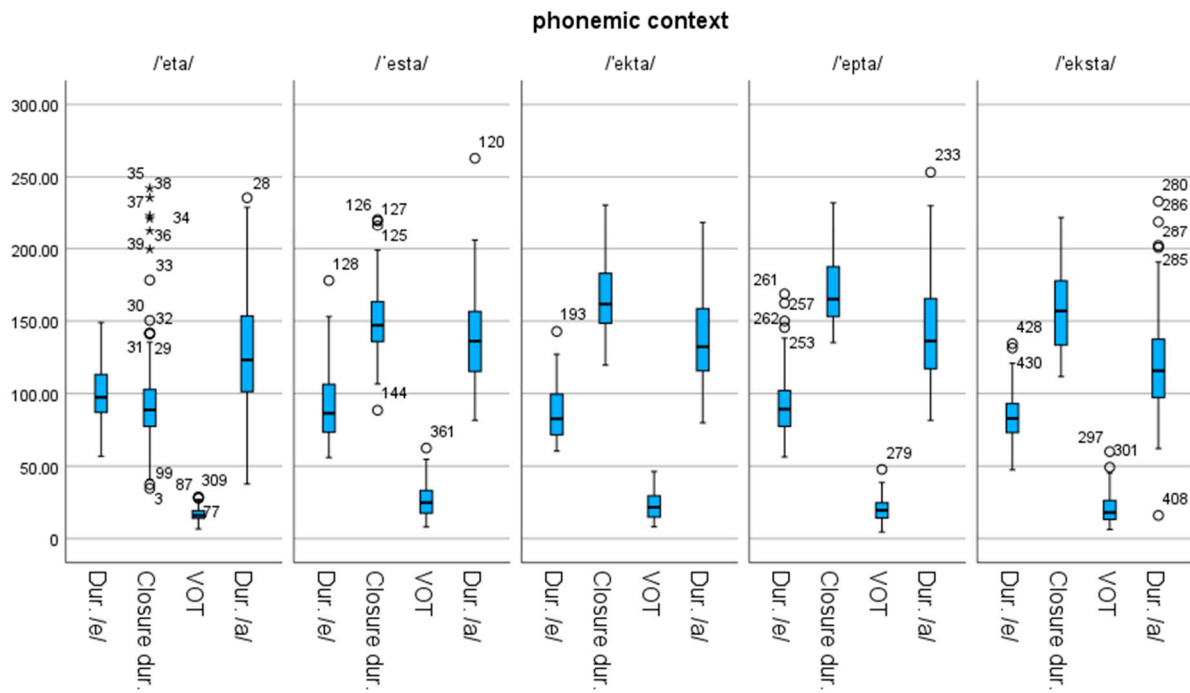**Figure 3.** Mean F2 of /e/ and mean F2 of /a/ for each phonemic context.

Figure 4. Mean duration of /e/, closure duration, VOT and duration of /a/ for each phonemic context.
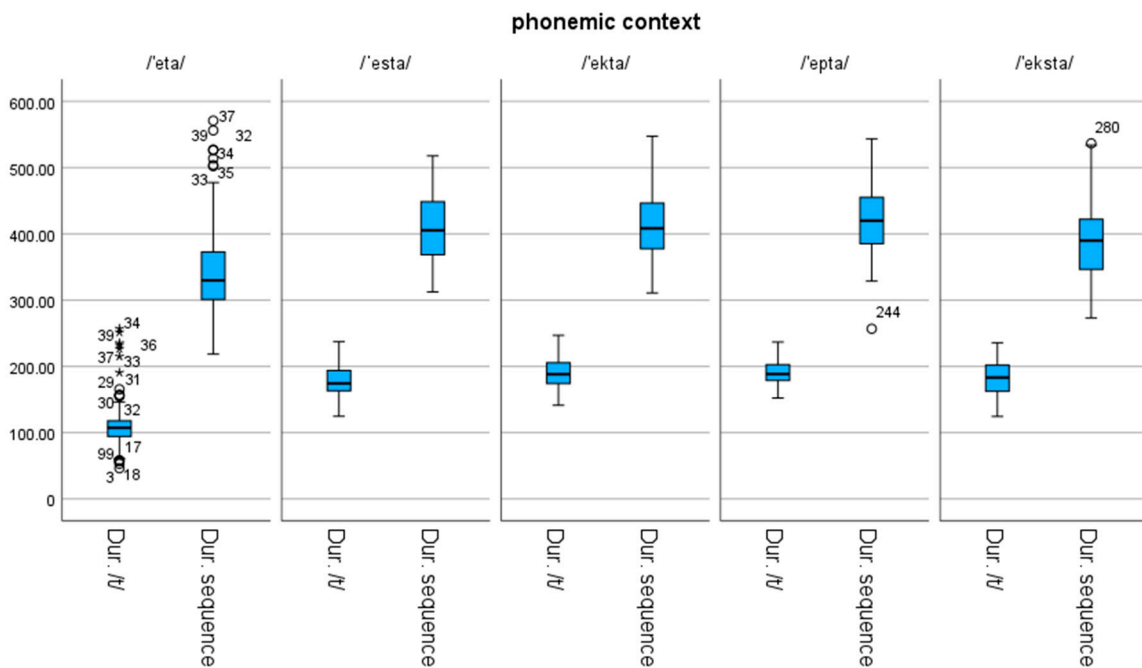

Figure 5. Mean duration of /t/ and duration of the whole sequence for each phonemic context.

3.2. F1 of /e/

The mixed ANCOVA reveals a significant effect for phonemic context ($F_{(4, 29)} = 3.28$, $p = 0.025$, $\eta_p^2 = 0.310$). A post hoc strategy was undertaken in which, first, the maximized contrast was constructed, and then a complex contrast that was most likely to reach significance was constructed. The maximized contrast is simply a contrast in which the coefficient for each group in the contrast is the deviation between its mean and the mean of all groups combined (grand mean). The sequences /ˈeta/ and /ˈekta/ present a lower F1 of /e/ compared to the grand mean, and /ˈesta/, /ˈepta/ and /ˈeksta/ are above average. A complex contrast comparing the phonemic contexts /ˈeta/ and /ˈekta/ to /ˈesta/, /ˈepta/

and /ˈeksta/ was run, which resulted in non-significance (F (1, 270) = 9.30, $p > 0.05$, $\eta_p^2 = 0.033$). This means that, when /ˈeta/ and /ˈekta/ are compared to /ˈesta/, /ˈepta/ and /ˈeksta/, there is no appreciable difference in F1. Phonemic context has a significant effect on F1 only when considering all phonemic contexts together, but comparisons across phonemic contexts are not significant.

3.3. F2 of /e/

The mixed ANCOVA reveals a significant effect for phonemic context (F (4, 27) = 10.4, $p < 0.001$, $\eta_p^2 = 0.607$). A maximized contrast was performed to understand where the differences in F2 lie among the five contexts. The results suggest that /ˈeta/ and /ˈepta/ have a much higher F2 than the grand mean, whereas /ˈesta/ and /ˈeksta/ have one that is much lower. The complex contrast is significant (F (1, 270) = 91.18, $p < 0.05$, $\eta_p^2 = 0.252$), with the F2 of /ˈeta/ and /ˈepta/ found to be 158 Hz higher than those of /ˈekta/ and /ˈeksta/ (/ˈesta/ is not included in the comparisons of the means because it has a negligible difference compared to the grand mean).

3.4. Duration of /e/

The mixed ANCOVA reveals a significant effect for phonemic context (F (4, 27) = 6.44, $p = 0.001$, $\eta_p^2 = 0.484$). The maximized contrast shows that /e/ is longer in /ˈeta/ and /ˈepta/ than it is in /ˈesta/, /ˈepta/ and /ˈeksta/. The complex contrast is significant (F (1, 270) = 32.56, $p < 0.05$, $\eta_p^2 = 0.108$), with the duration of /e/ in /ˈeta/ and /ˈepta/ being 9.72 ms longer than it is in /ˈesta/, /ˈekta/ and /ˈeksta/.

3.5. Closure Duration

The mixed ANCOVA is significant for phonemic context (F (4, 27) = 133.3, $p < 0.001$, $\eta_p^2 = 0.950$) and has a very large effect size. The maximized contrast confirms that the closure duration in /ˈeta/ is much shorter than those of the rest. The complex contrast is significant (F (1, 270) = 716.67, $p < 0.001$, $\eta_p^2 = 0.726$). The results indicate that the closure duration is 72.2 ms shorter in /ˈeta/ than it is across the other four phonemic contexts.

3.6. VOT of /t/

The mixed ANCOVA reveals a significant effect for phonemic context (F (4, 26) = 3.43, $p = 0.022$, $\eta_p^2 = 0.350$). The maximized contrast shows that /ˈeta/ and /ˈeksta/ should be compared to the other three phonemic contexts (/ˈesta/, /ˈekta/, and /ˈepta/). The complex contrast is significant after applying the Scheffé method (F (1, 270) = 54.46, $p < 0.05$, $\eta_p^2 = 0.168$). The complex contrast indicates that the VOT of /t/ is 3.8 ms shorter in /ˈeta/ and /ˈeksta/ than it is in /ˈesta/, /ˈekta/ and /ˈepta/.

3.7. Total Duration of /t/

Closure duration and *VOT* are combined to obtain the variable *Total duration of /t/* (as in Idemaru and Guion 2008). The mixed ANCOVA is significant for phonemic context (F (4, 28) = 138, $p < 0.001$, $\eta_p^2 = 0.952$). The maximized contrast shows that the total duration for /t/ is shorter than the average duration of /t/ across the five contexts in the case of /ˈeta/, and it is greater for the other four phonemic contexts. The total duration for /t/ in /ˈeta/ is 77.4 ms shorter compared to the average duration of /ˈesta/, /ˈekta/, /ˈepta/ and /ˈeksta/, which is shown to be significant in the complex contrasts (F (1, 270) = 812.2, $p < 0.001$, $\eta_p^2 = 0.751$).

3.8. F1 of /a/

The mixed ANCOVA is not significant for phonemic context (F (4, 27) = 1.72, $p = 0.175$, $\eta_p^2 = 0.204$), so no further post hoc tests are carried out.

3.9. F2 of /a/

The mixed ANCOVA is non-significant for phonemic context (F (4, 27) = 2.72, p = 0.05, η_p^2 = 0.288). No further post hoc analyses are carried out.

3.10. Duration of /a/

As the mixed ANCOVA is non-significant for phonemic context (F (4, 27) = 1.39, p = 0.265, η_p^2 = 0.168), no follow-up post hoc analysis is performed.

3.11. Overall Duration of Sequence

The mixed ANCOVA is significant for phonemic context (F (4, 28) = 41.5, p < 0.001, η_p^2 = 0.854). The maximized contrast shows that the total duration of the sequence for /ˈeta/ is much shorter compared to the other four phonemic contexts. The complex contrast for this is significant (F (1, 270) = 228.8, p < 0.001, η_p^2 = 0.459), suggesting that the total duration of the entire sequence is 67.8 ms shorter for /ˈeta/ compared to those of /ˈesta/, /ˈekta/, /ˈepta/ and /ˈeksta/.

3.12. Identification of Phonemic Contexts from Acoustic Measures

A separate Discriminant Function Analysis (DFA) is performed for features with significant differences (F1 of /e/, duration of /e/, closure duration of /t/, VOT of /t/, total duration of /t/ and total duration of the sequence). As in Idemaru and Guion (2008), this is performed to investigate exactly how well phonemic contexts can be predicted from differences in acoustic measures.

Table 5 shows the percentage of correct classification for each phonemic contrast. As the percentage becomes higher, it becomes easier for the model to accurately identify a phonemic context from a measured feature.

Table 5. Percentage of correct classification by the Discriminant Function Analysis for each factor. Highest values for each cue and context are in gray.

Factor	/ˈeta/	/ˈesta/	/ˈekta/	/ˈepta/	/ˈeksta/	Average
F1 of /e/	64.4%	2.7%	10.1%	2.7%	48.3%	25.6%
Duration of /e/	52.3%	1.4%	5.6%	11%	60%	26.1%
Closure duration	90.6%	54.8%	6.7%	45.2%	15.1%	42.5%
VOT of /t/	65.1%	52.1%	6.7%	5.5%	3.3%	26.54%
Total duration of /t/	91.9%	56.2%	9.0%	43.8%	8.3%	41.84%
Total duration of sequence	72.5%	15.1%	5.6%	4.1%	26.7%	24.8%
Average	72.80%	30.38%	7.28%	18.72%	26.95%	31.23%

As Table 5 shows, the features are ordered in the following way regarding the level of accuracy of identifying /ˈeta/ and, hence, for distinguishing between singletons and geminates: total duration of /t/ (91.9%) > closure duration (90.6%) > total duration of the sequence (72.5%) > VOT of /t/ (65.1%) > F1 of /e/ (64.4%) > duration of /e/ (52.3%). It is important to remember that, although the percentage of identification for /ˈeta/ is the percentage of the classification of singletons vs. geminates, the percentage of identification for each of the other four sequences is the percentage of identification of a specific context (i.e., the underlying consonant); the value of 6.7% for the closure duration of /ˈekta/ means that the closure duration identifies the sequence /ˈekta/ correctly amongst the five phonemic contexts in 6.7% of cases. It should be noted that, although other studies in gemination have studied the contrast between singletons and geminates (e.g., Hedia and Plag 2017) or even different clusters causing gemination in EAS (e.g., Gerfen 2002), the present study includes five different phonemic contexts.

4. Discussion

The results of the acoustic and statistical analyses show that a singleton–geminate category is reliably present in EAS, at least at the surface level.

4.1. Formant Values

Overall, the F1/F2 measures for /e/ and /a/ vary very slightly according to phonemic context or gender. Although our analysis shows that /e/ opens before an underlying consonant in EAS, as has been widely reported for EAS (Herrero de Haro and Hajek 2022), there is no appreciable difference between the F1 of /ˈeta/ and /ˈekta/ compared to those of /ˈesta/, /ˈepta/ and /ˈeksta/. However, contextual differences for F2 are more evident. The statistical analysis shows that the F2 of /e/ in /ˈeta/ and /ˈepta/ is 158 Hz higher than that of /ˈekta/ and /ˈeksta/. This could indicate that, even though there is no indication of any gestures remaining from the underlying /k/ or /ks/, the vowel backs as though it is still affected by coarticulatory forces of a velar consonant; this phenomenon is described as *underlying coarticulation* by Herrero de Haro (2019a). This is a complex issue, as "underlying representations cannot be the sole base for articulation" (Hedia and Plag 2017). On the other hand, a higher F2 of /e/ in /ˈeta/ and /ˈepta/ could be explained as contact by /e/ with front consonants. No statistical difference is found for the F1 or F2 of post-consonantal final /a/, and it seems that the phonemic context has no effect on the acoustic measures of the vowel in question.

4.2. Durational Features

The closure duration, VOT, total duration of /t/ as well as overall duration of the sequence show that /ˈeta/ has the shortest duration out of the five phonemic contexts. Gender and order seem to have a very small effect on these four dependent variables.

Duration measures related to /t/ are found to be the most reliable cues. Constriction is known to be the most reliable cue for gemination across languages (Hamzah et al. 2016), and it predicts gemination with an accuracy of 90.6% in our study. Closure duration is, on average, 72.2 ms shorter in /ˈeta/ than it is in the other four contexts, and it follows this scale in the contexts with the following underlying consonants: /ˈepta/ > /ˈekta/ > /ˈeksta/ > /ˈesta/. This does not replicate the pattern assumed by Ruch and Peters (2016) for pre-aspiration in /s/ + voiceless stop sequences in EAS and WAS, who predicted that it would be longer in velar than it is in dental stops and shorter before a bilabial stop.

The complex contrast shows that the VOT of /t/ is 3.8 ms shorter in /ˈeta/ and /ˈeksta/ than it is in /ˈesta/, /ˈekta/ and /ˈepta/. The appearance of /ˈeksta/ in the first group shows that gemination is not always accompanied by a longer VOT. The percentage of identification is 65.1% for VOT of /t/, which has previously been identified as a strong cue for a preceding underlying consonant in clusters in EAS gemination (e.g., O'Neill 2010). It follows the following declining scale: /ˈepta/ > /ˈeksta/ > /ˈekta/ > /ˈesta/. Henriksen and Harper (2016), however, in their study of lenition in south-central Peninsular Spanish, found that dorsal consonants produce the highest VOT, followed by coronal and labial consonants. It should be noted, however, that the present paper studies EAS and that differences in results with Henriksen and Harper (2016) could be due to analyzing different varieties of Spanish. Furthermore, any difference in the results between studies could be due to geographical differences. One should be cautious believing that any findings in a specific EAS location apply to all EAS territory, as stated by Herrero de Haro and Hajek (2022). As explained by Ruch and Peters (2016), results on Andalusian gemination vary considerably between studies, and, as already noted, some researchers have found that different sociolinguistic features such as age cause differences in VOT in Andalusian Spanish. For example, Henriksen and Harper (2016) found fricatives to be longer before /k/ than those before /p/ or /t/, contra Méndez Dosuna (1985). The present study, however, identifies a trading relationship between closure duration and VOT, similar to what Henriksen and Harper (2016) suggested, with /s/ deletion causing the shortest occlusion and longest VOT in /t/ and /p/ deletion causing the longest occlusion and shortest VOT of /t/.

It should be noted that, for Torreira (2007a), even though post-aspiration in voiceless stops following aspirated /s/ in related WAS is regarded as the "acoustic consequence of a gestural reorganization at the onset of the syllable", with some evidence also of post-

aspiration previously reported for EAS (Ruch and Peters 2016), only 56 out of 444 (12.6%) tokens in the present corpus presented evidence of post-aspiration. Although Torreira (2007a) and Ruch and Peters (2016) concluded that there is a sound change in progress from pre- to post-aspiration in WAS and in EAS, there is not strong evidence of this for EAS in the present study.

The total duration of /t/ is the most reliable variable regarding identifying /ˈeta/ correctly and, as a result, for distinguishing short /t/ ([t]) in /ˈeta/ from geminated /t/ ([tː]) in all other contexts. This finding supports a similar claim by Gerfen (2002) and Bishop (2007), and it confirms that the deletion of /s/, /k/, /p/ and /ks/ in word-medial codas triggers the gemination of a following /t/ in EAS. Although studies such as Idemaru and Guion (2008) concluded that consonant duration can categorize singletons in 100% of cases and geminates in over 95% of cases in Japanese, the categorization power for the identification of singletons vs geminates in EAS is slightly lower at 91.9%. This could be due to the fact that EAS gemination is the result of an active process of regular /C1C2/ to [Cː] assimilation, as well as to the fact that five phonemic contexts are investigated in the present paper, instead of just singletons vs. geminates. Although the closure duration and total duration of /t/ can reliably identify /ˈeta/ with an accuracy of over 90%, the correct identification of a specific phonemic context is much lower when there is an underlying consonant before /t/. In sharp contrast to /ˈeta/ (72.80%), the overall values for correct identification show that the phonemic context with the highest percentage is /ˈesta/ (30.38%), followed by /ˈeksta/ (26.95%), /ˈepta/ (18.72%) and /ˈekta/ (7.28%). Interestingly, /s/ is the most frequent coda consonant in Spanish and the one with the highest functional load (Gerfen 2002); it is possible, subject to further investigation, that these two factors explain the higher rates of identification for /s/.

Regarding vowel duration, both /e/ and /a/ show some variability depending on the phonemic context, and males produce shorter vowels. Order, however, is usually very similar across phonemic contexts. The vowel /e/ is 9.72 ms longer in /ˈeta/ and /ˈepta/ than it is in /ˈesta/, /ˈepta/ and /ˈeksta/, but further research is required to understand whether this leads to any differentiation at a perceptual level. Although this difference is statistically significant, it is much smaller than the suggested just noticeable difference threshold of 25 ms identified by Klatt and Cooper (1975) and may not therefore provide a reliable perceptual cue. Furthermore, it has been shown that languages that do not have elastic vowels tend to have vowel length as a contrastive feature, such as Japanese (Takeyasu and Giriko 2017), and other research has also shown that vowel duration can vary significantly between Spanish varieties (Morrison and Escudero 2007). Therefore, a possible phonologization of the duration of /e/ is not very likely.

The total duration of the sequence is shortest in /ˈeta/ contexts by 67.8 ms when compared to those of /ˈesta/, /ˈekta/, /ˈepta/ and /ˈeksta/. The sequence /ˈeksta/ has the lowest overall duration of all the /Ct/ contexts, and the total duration of /t/ is shorter for /ˈeksta/ than it is for /ˈekta/. This indicates that having two underlying consonants in /ˈeksta/ does not per se trigger greater lengthening, as may have arguably been expected.

In the case of EAS, we believe that gemination can be seen as a very efficient way of maintaining the /t/ versus /Ct/ contrast once /C/ is deleted. Gemination is a feature that is very simple in terms of articulatory effort and is perceptually salient (Vihman and Majorano 2017). Furthermore, the presence of various covariants with seemingly redundant information enhances perception (Esposito and Di Benedetto 1999; Idemaru and Guion 2008).

4.3. Relevance of Covariants in Gemination Cross-Linguistically

The nature and relevance of covariants in gemination are known to be to a large extent language-specific, although cross-linguistic tendencies often emerge. In EAS, the vowel preceding /t/ (i.e., /e/) is shorter before a geminate; this tends to be the case across languages, for example, in Italian (Esposito and Di Benedetto 1999; Turco and Braun 2016), in Hindi (Shrotriya et al. 1995) and in Kannada and Tamil (Maddieson 1985). However,

there have been reports of languages in which there is no durational difference of vowels depending on whether they precede a singleton or a geminate, as is the case for Tarifit Berber and Taqbaylit Berber (Bouarourou et al. 2018). Idemaru and Guion (2008), on the other hand, found that vowels are longer before geminates in Japanese. Likewise, although Idemaru and Guion (2008) concluded that a vowel after a consonant is longer in singletons, the data from the present study suggest that /a/ is longer after geminated /t/, with the exception of /ˈeksta/, which is the only geminated context with a duration of /a/ shorter than that for /ˈeta/. According to Esposito and Di Benedetto (1999), the only significant differences between singleton and geminate consonants are related to the duration of a previous vowel and closure duration, as is also the case in Hindi geminates (Shrotriya et al. 1995). Sadakata and McQueen (2013) reached similar conclusions for Japanese geminates versus singleton consonant contrasts, although vowel duration is greater before geminates. On the other hand, Esposito and Di Benedetto (1999) believed that the perception of timing is based on rhythm, not on sound segments, which then accounts for compensation processes between vowel and consonant durations. Similar compensation processes may be in operation in EAS.

Furthermore, our paper contributes to developing a more nuanced understanding of cross-linguistic patterns related to gemination. /e/ does not shorten as much in EAS when it precedes a geminated /t/ triggered by a deleted /p/. Although /e/ before geminates shows a shortening pattern that is statistically significant, /a/ after geminates does not reach statistical significance. As in other studies, such as Idemaru and Guion (2008) or Local and Simpson (1999), in contrast to Abramson (1992), V2 has not acted as a major cue for distinguishing singletons from geminates.

Whereas the Japanese singleton to geminate ratio is 1:3 (Idemaru and Guion 2008), the EAS ratio seems to be between 1:1.56 and 1:1.85, depending on the underlying consonant that triggers gemination. These values are similar to those reported for Italian (1:1.85 cited in Idemaru and Guion 2008). Our results fit with Ham's (2001) observation that mora-timed languages such as Japanese display singleton–geminate durational ratios that are more robust than those of syllable-timed languages, such as Italian and, in our case, Spanish. Furthermore, as Idemaru and Guion (2008) explained, languages with a robust difference in consonant duration tend to have longer vowels before geminates, and this is the opposite for languages with a less robust durational distinction; our results also fit with this typological observation. This pattern, however, does not seem to apply equally across the four geminated contexts in our study, because /ks/ is the phonemic context with the shortest gemination of /t/, and it is also the context with the shortest duration of /e/ before a geminated consonant.

Fernández Sevilla (1980, pp. 456–505) argued that, in the case of Spanish, regarding coda final deletion in words such as *más*, 'more'; *mar*, 'sea', *mal*, 'bad', *hasta*, 'until', *acta*, proceedings', or *apta*, 'capable', speakers have lost conscience of the underlying consonant. Instead, they maintain a contrast in their minds based on the consonant versus zero, i.e., they decode a message by identifying (or not) that a coda consonant is deleted. This seems to assume that, once speakers identify that a consonant is deleted, they use contextual information or other cues to identify what the deleted consonant is and, based on that, identify the uttered word. Therefore, the main contrast in EAS speakers' minds is /ˈeta/ versus /ˈeCta/, without focusing on additional contrasts based on different underlying consonants. Whether EAS speakers can identify specific underlying consonants based on durational and other differences linked to surface geminate segments and the cognitive mechanisms behind such identifications falls outside the remit of the present paper (however, see also below). It is interesting to note, however, how EAS gemination and covariants of gemination show similar patterns in a number of respects to those reported in some languages with fully phonemic or lexical gemination, e.g., Italian. This is noteworthy, because EAS gemination is triggered by the assimilation of a consonant in the phonetic output, and the omitted consonant is still present in the underlying structure. By the same token, it may be pertinent that, although Italian has inherited the geminate contrast from

Latin, it has also greatly expanded the lexical frequency of underlying gemination through a historical process of cluster assimilation, e.g., Latin PACTU > Italian /ˈpatto/, 'pact'.

4.4. Review of the Research Questions

Regarding research question 1 and the effect of medial coda consonant deletion on the duration of the following /t/, the statistical tests show that, as expected, the deletion of /s/, /k/, /p/ and /ks/ triggers the gemination of a following /t/ in EAS. The ANCOVA test suggests that occlusion is 72.2 ms shorter in /ˈeta/ when compared to that in environments in which a consonant is deleted. This feature can distinguish /ˈeta/ from /ˈeCta/ in 90.6% of cases, according to the DFA test. Likewise, the VOT of /t/ is also consistently longer if /t/ is preceded by an underlying consonant, and this can accurately identify singletons or geminates in 65.1% of cases. The DFA test suggests that the duration of /t/ can classify a consonant as a singleton accurately in 91.9% of cases. This is consistent with research in other languages that also point to the durational properties of consonants as the main cues to differentiating singletons from geminates, (e.g., Al-Tamimi and Khattab (2015) for Arabic; Hamzah et al. (2016) for Kelantan Malay).

Regarding question 2 and the effect of different coda consonants on closure duration and VOT, even though, as expected, there are differences between the means of occlusion or VOT of /t/ depending on what consonant is deleted (Table 4), these are not always statistically significant. According to the ANCOVA test, the occlusion of /t/ is significantly shorter for /ˈesta/ than it is for /ˈekta/, /ˈepta/ and /ˈeksta/. These last three phonemic contexts present very similar closure durations, although it is the shortest for /ˈeksta/, followed by /ˈekta/ and then /ˈepta/. With regard to the VOT of /t/, it is the longest in /ˈesta/, followed by /ˈekta/, /ˈeksta/ and, finally, /ˈepta/. Furthermore, although according to the DFA test, the occlusion and VOT of /t/ can identify an underlying /s/ in 54.8% and 52.1% of cases, respectively, these percentages are 45.2% and 5.5% for an underlying /p/ and only between 3.3% and 15.1% for /k/ and /ks/. Although closure duration and the VOT of /t/ can more reliably distinguish some underlying consonants, particularly /s/, from others, it does not allow discrimination between the four contexts analyzed with underlying consonants. This indicates that /ˈesta/, /ˈekta/, /ˈepta/ and /ˈeksta/ are well on the path to merging fully into [ˈ e̞tːa]. However, the precise stage of evolution of these potential mergers and their implications for EAS and language evolution in general also need further consideration.

In response to question 3 and the identification of covariants, according to the ANCOVA test, the only covariants whose differentiation is statistically significant (other than the closure duration, VOT and total duration of /t/) are the F1 of /e/, duration of /e/ and total duration of the sequence. This is in line with what was expected. The F1 of /e/ is higher when /e/ is followed by an underlying consonant, which indicates the lowering of the vowel. The lowering of the vowel, however, is very mild when /k/ is deleted, and there is no difference in lowering when the deleted consonant is /s/, /ks/ or /p/. The vowel /e/ shortens when it precedes a geminated consonant, and it does so less when /p/ is deleted. The DFA results suggest that the duration of /e/ can reliably identify underlying /ks/ in 60% of cases, but this is only 11% or below for underlying /s/, /k/ or /p/. According to the ANCOVA test, the overall duration of the sequence (duration of /e/ + total duration of /t/ + duration of /a/) is 67.8 ms shorter when there is no underlying consonant. When there is an underlying consonant, /ˈepta/ presents the longest overall duration, followed by /ˈekta/, /ˈesta/ and, finally, /ˈeksta/. The total duration of the sequence can be used to classify singleton /t/ accurately in 72.5% of cases according to the DFA results, but the percentage of identifying the specific underlying consonant falls below 26.7%. The relative weight of covariants varies according to the point of articulation but is not consistent nor equally weighted. These results provide further evidence that durational differences might be the main cues to distinguish singletons from geminates cross-linguistically and that covariants of gemination are language specific, as explained in Sections 4.2 and 4.3, respectively.

Regarding question 4, the reasons that may explain different phonetic realizations depending on the underlying phonemic context are varied. As expected, a trading relationship is at play because the consonant that causes the longest occlusion of /t/ is the one that causes the shortest VOT, and vice versa; this kind of relationship has been reported before in the literature (e.g., Henriksen and Harper 2016). The closure duration increases depending on the preceding underlying consonant in the following ascending order: /s/ < /ks/ < /k/ < /p/, and the VOT of /t/ increases in the following order: /p/ < /ks/ < /k/ < /s/. A shorter closure duration in the sequence with an underlying /s/ can be explained by the similar place of articulation of /s/ and /t/; any coarticulatory movement that might lengthen the occlusion of /t/ in the phonetic realization of /kst/, /kt/ or /pt/ seems to be still somewhat present when the consonant is deleted before /t/. This is what Herrero de Haro (2019a) refers to as underlying coarticulation. A longer VOT of /t/ following an underlying /s/ can be explained by the fact that a longer VOT compensates for a shorter occlusion period while still maintaining a consonant /t/ which is distinguishably longer than a singleton /t/. The lowering of /e/ before a deleted consonant has been consistently reported in EAS before (e.g., Herrero de Haro 2017b), and although some research has found different levels of lowering depending on the underlying consonant (e.g., Herrero de Haro 2016), there is no acoustic analysis of vowels before a deleted /k/ or /ks/ to date. The statistical analysis shows that /e/ backs when it precedes an underlying /k/ or /ks/, and it seems that the backing of /e/ prevents it from lowering more. Finally, in terms of the duration of preceding /e/, the gemination of /t/ triggers /e/ shortening. The shortening of /e/ appears to be a compensatory phenomenon allowing /t/ to become longer without increasing the overall length of the word. The fact that /e/ shortens less when /p/ is deleted than it does when /s/, /k/, or /ks/ are deleted could be because less of the time fraction of /e/ is used when the tongue backs toward the place of articulation of consonants pronounced further back, perhaps as part of a possible underlying coarticulation. There are other possible explanations for the shortening of /e/ before a geminate in EAS. This shortening could be due to differences in phonological representations, such as syllabic affiliations; vowels in closed syllables are shorter (Maddieson 1985). Vowel shortening may also be produced in order to enhance the length contrast on a geminate segment (Kluender et al. 1998). There could also be perceptual issues at play: (1) the closure duration, VOT of /t/ and total duration of /t/ are the strongest cues to identify an underlying /s/ before /t/ in EAS; (2) the F1 of /e/ is the most reliable feature to identify an underlying /k/; (3) the closure duration and total duration of /t/ are the best features to identify an underlying /p/; and (4) the duration of /e/ is the strongest cue to identifying an underlying cluster /ks/ before /t/ in EAS. It is also possible that frequency and functional load, as well as the fact that /s/ is the only consonant with morphological value at the word boundary, explain differences in identification rates. /s/ yields higher identification rates than the other underlying consonants do, and it is also the more common consonant and the one with the highest functional load out of all the consonants analyzed in this study.

With respect to question 5, although research on gemination has been based on languages in which gemination is a phonemic feature, the present study analyzes gemination and covariants of gemination in a language variety in which gemination is the result of consonant assimilation and the phonemic status of gemination has not been demonstrated. As expected, patterns of gemination and covariance in EAS seem to be similar to some languages with a fully phonemic gemination, such as Italian. EAS only displays gemination when a consonant is deleted, and although gemination is the most frequent pattern, it is not present in EAS when speakers revert to more formal pronunciation and syllable-final consonants are pronounced. However, we have not found evidence of reliable differences in gemination or in covariants of gemination between fully phonemic gemination, e.g., in Italian, and deletion-triggered EAS gemination.

Finally, regarding question 6 and the cross-linguistic implications from this study, there are various points to mention. Vowels are shorter in EAS before geminated consonants,

as in languages such as Italian, Hindi, Kannada and Tamil. V1 seems to be a stronger cue of gemination than V2 in EAS; this also seems to be the case cross-linguistically. The five contexts investigated in the present study show that gemination might be a gradual category, rather than a binary one consisting only of singleton and geminate consonants. As Esposito and Di Benedetto (1999) proposed for Italian, timing perception in EAS might be based on rhythm; this can explain compensation processes between vowel and consonant length. Last, the singleton to geminate ratio in EAS is similar to the one reported for Italian but is much shorter than the one reported for Japanese; this seems to fit, as we have already noted, Ham's (2001) belief that mora-timed languages, such as Japanese, have more robust singleton–geminate duration ratios than those of syllable-timed languages, such as Italian.

5. Conclusions

Two of the aims of the present paper were to investigate whether the deletion of a word-medial coda (/s/, /k/, /p/ or /ks/) triggers the regular gemination of a following /t/ in EAS and to identify potential covariants of gemination in EAS. Another aim was to investigate the relative predictive weight of each covariant in identifying not only singletons and geminates, but also the underlying consonant in each case.

The present article identifies patterns specific to EAS patterns of variation in the singleton–geminate contrast. The data do not indicate that there are different degrees of consonant lengthening linked to a specific deleted consonant. However, it is clear that EAS now incorporates a new category of geminated consonants, at least at a phonetic level. Thus, /t/ vs. /Ct/ is now distinguished on the surface as /t/ vs. /tː/ when the first consonant in the cluster is deleted. Although the /t/ vs. /Ct/ contrast is still present once a coda is deleted, more specific contrasts seem to have merged (e.g., /kt/ vs. /pt/). Covariants differ across languages; however, the covariants of gemination in EAS that are analyzed in this paper allow for the identification of underlying codas. However, they do not consistently distinguish between different underlying consonants. Furthermore, our analysis shows strong similarities between the patterns of variation of deletion-triggered EAS gemination and those in some languages with fully phonemic gemination, such as Italian. These findings help to answer the question of how contrasts may be retained or neutralized cross-linguistically. However, further research, especially across languages, is needed to answer this more comprehensively. This study also raises relevant questions regarding what differences there are, if any, in geminated consonants depending on the path along which gemination has developed.

References

Abramson, Arthur S. 1992. Amplitude as a cue to word-initial consonant length: Pattani Malay. *Haskins Laboratories Status Report on Speech Research* SR-109/110: 251–54.

Alarcos Llorach, Emilio. 1958. Fonología y fonética (a propósito de las vocales andaluzas). *Archivum: Revista de la Facultad de Filología* 8: 193–205.

Al-Tamimi, Jalal, and Ghada Khattab. 2015. Acoustic cue weighting in the singleton vs geminate contrast in Lebanese Arabic: The case of fricative consonants. *The Journal of the Acoustical Society of America* 138: 344–60. [CrossRef] [PubMed]

Baayen, R. H. 2008. *Analyzing Linguistic Data. A Practical Introduction to Statistics Using R*. Cambridge: Cambridge University Press.

Bishop, Jason B. 2007. Incomplete neutralization in Eastern Andalusian Spanish: Perceptual consequences of durational differences involved in s-aspiration. In *Proceedings of the International Congress of Phonetic Sciences*. Edited by Jürgen Trouvain and William J. Barry. Dudweiler: Pirrot, pp. 1765–68.

Boersma, Paul, and David Weenink. 2016. Praat: Doing Phonetics by Computer (Version Version 6.0.19). Available online: http://www.praat.org (accessed on 26 August 2016).

Bouarourou, Fayssal, Tomoki Koya, Saïd Bouzidi, Béatrice Vaxelaire, and Rudolph Sock. 2018. Cross-language and language-specific acoustic correlates of gemination in Berber and Japanese. In *2nd International Conference on Natural Language Speech Processing*. Algiers: IEEE, pp. 160–165.

Burns, Robert, and Richard Burns. 2008. *Business Research Methods and Statistics Using SPSS*. London: Sage.

Carlson, Kristin M. 2012. An acoustic and perceptual analysis of compensatory processes in vowels preceding deleted post-nuclear /s/ in Andalusian Spanish. *Concentric: Literary and Cultural Studies* 38: 39–67.

Cicchetti, Domenic V. 1994. Guidelines, criteria, and rules of thumb for evaluating normed and standardized assessment instruments in psychology. *Psychological Assessment* 6: 284–90. [CrossRef]

Eddington, David. 2015. *Statistics for Linguists: A Step-by-Step Guide for Novices*. Newcastle upon Tyne: Cambridge Scholars Publishing.

Esposito, Anna, and Maria Gabriella Di Benedetto. 1999. Acoustical and perceptual study of gemination in Italian stops. *The Journal of the Acoustical Society of America* 106: 2051–62. [CrossRef]

Fernández Sevilla, Julio. 1980. Los fonemas implosivos en español. *Thesaurus* 35: 456–505.

Field, Andy. 2018. *Discovering Statistics using IBM SPSS Statistics: North American Edition*, 5th ed. Thousand Oaks: Sage.

Gerfen, Chip. 2002. Andalusian codas. *Probus* 14: 247–77. [CrossRef]

Gerfen, Chip, and Kathleen Hall. 2001. *Coda Aspiration and Incomplete Neutralization in Eastern Andalusian Spanish*. Manuscript, Chapel Hill: University of North Carolina at Chapel Hill.

Hallgren, Kevin A. 2012. Computing inter-rater reliability for observational data: An overview and tutorial. *Tutorials in Quantitative Methods for Psychology* 8: 23–34. [CrossRef]

Ham, William. 2001. *Phonetic and Phonological Aspects of Geminate Timing*. New York: Routledge.

Hamzah, Mohd Hilmi, Janet Fletcher, and John Hajek. 2016. Closure duration as an acoustic correlate of the word-initial singleton/geminate consonant contrast in Kelantan Malay. *Journal of Phonetics* 58: 135–51. [CrossRef]

Hedia, Sonia Ben, and Ingo Plag. 2017. Gemination and degemination in English prefixation: Phonetic evidence for morphological organization. *Journal of Phonetics* 62: 34–49. [CrossRef]

Helgason, Pétur, and Catherine Ringen. 2008. Voicing and aspiration in Swedish stops. *Journal of Phonetics* 36: 607–28. [CrossRef]

Henriksen, Nicholas. 2017. Patterns of vowel laxing and harmony in Iberian Spanish: Data from production and perception. *Journal of Phonetics* 63: 106–26. [CrossRef]

Henriksen, Nicholas, and Sarah K. Harper. 2016. Investigating lenition patterns in south-central Peninsular Spanish /sp st sk/ clusters. *Journal of the International Phonetic Association* 46: 1–24. [CrossRef]

Henriksen, Nicholas C., and Erik W Willis. 2010. Acoustic characterization of phonemic trill production in Jerezano Andalusian Spanish. In *4th Conference on Laboratory Approaches to Spanish Phonology*. Edited by Marta Ortega-Llebaria. Somerville: Cascadilla Proceedings Project, pp. 115–27.

Herrero de Haro, Alfredo. 2016. Four mid front vowels in Western Almería: The effect of /s/, /r/, and /θ/ deletion in Eastern Andalusian Spanish. *Zeitschrift für Romanische Philologie* 132: 118–48. [CrossRef]

Herrero de Haro, Alfredo. 2017a. Four mid back vowels in Eastern Andalusian Spanish: The effect of /s/, /r/, and /θ/ deletion on preceding /o/ in the town of El Ejido. *Zeitschrift für Romanische Philologie* 133: 82–114. [CrossRef]

Herrero de Haro, Alfredo. 2017b. The phonetics and phonology of Eastern Andalusian Spanish: A review of literature from 1881 to 2016. *Íkala, Revista de Lenguaje y Cultura* 22: 313–57. [CrossRef]

Herrero de Haro, Alfredo. 2017c. Four low central vowels in Eastern Andalusian Spanish: /a/ before underlying /-s/, /-r/, and /-θ/ in El Ejido. *Dialectologia et Geolinguistica* 25: 23–50. [CrossRef]

Herrero de Haro, Alfredo. 2018. Context and vowel harmony: Are they essential to identify underlying word-final /s/ in Eastern Andalusian Spanish? *Dialectologia* 20: 107–45.

Herrero de Haro, Alfredo. 2019a. Consonant deletion and Eastern Andalusian Spanish vowels: The effect of word-final /s/, /r/, and /θ/ deletion on /i/. *Australian Journal of Linguistics* 39: 107–31. [CrossRef]

Herrero de Haro, Alfredo. 2019b. The vowel /u/ before deleted word-final /s/, /r/, and /θ/ in Eastern Andalusian Spanish. *Lengua y Habla* 23: 56–75.

Herrero de Haro, Alfredo. 2019c. Catorce vocales del andaluz oriental: Producción y percepción de /i/, /e/, /a/, /o/ y /u/ en posición final y ante /-s/, /-r/ y /-θ/ subyacentes en Almería. *Nueva Revista de Filología Hispánica* 67: 411–46. [CrossRef]

Herrero de Haro, Alfredo, and John Hajek. 2022. Illustrations of the IPA: Eastern Andalusian Spanish. *Journal of the International Phonetic Association* 52: 135–56. [CrossRef]

Herrero de Haro, Alfredo. 2023. Descripción acústica del andaluz oriental: Estado de la cuestión. In *Sistematicidad y Variación en la Fonología del Español*. Edited by Á. Arias. A Coruña: Editorial Axac., pp. 213–50.

Hoole, Phil. 1999. Laryngeal coarticulation. Section A: Coarticulatory investigations of the devoicing gesture. In *Coarticulation: Theory, Data and Techniques*. Edited by William J. Hardcastle and Nigel Hewlett. Cambridge: Cambridge University Press, pp. 260–69.

Idemaru, Kaori, and Susan G. Guion. 2008. Acoustic covariants of length contrast in Japanese stops. *Journal of the International Phonetic Association* 38: 167–86. [CrossRef]

Jiménez Fernández, Rafael. 1999. *El andaluz*. Madrid: Arco/Libros.

Khattab, Ghada, and Jalal Al-Tamimi. 2014. Geminate timing in Lebanese Arabic: The relationship between phonetic timing and phonological structure. *Laboratory Phonology* 5: 231–69. [CrossRef]

Klatt, Dennis H., and William E. Cooper. 1975. Perception of segment duration in sentence contexts. In *Structure and Process in Speech Perception*. Edited by Antonie Cohen and Sibout G. Nooteboom. Heidelberg: Springer, pp. 69–89.

Kluender, R. Keith, Randy L. Diehl, and Richard A. Wright. 1998. Vowel-length differences between voiced and voiceless consonants: An auditory explanation. *Journal of Phonetics* 16: 153–69. [CrossRef]

Koo, Terry K., and Mae Y. Li. 2016. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *Journal of Chiropractic Medicine* 15: 155–63. [CrossRef]

Kubozono, Haruo, ed. 2017. *The Phonetics and Phonology of Geminate Consonants*. Oxford: Oxford University Press.

Landers, Richard N. 2015. Computing intraclass correlations (ICC) as estimates of interrater reliability in SPSS. *The Winnower* 2: 1–4.

Local, John, and Adrian Simpson. 1999. Phonetic implementation of geminates in Malayalam nouns. In *Proceedings of the 14th International Congress of Phonetic Sciences (ICPhS 14)*. Edited by John J. Ohala, Yoko Hasegawa, Manjari Ohala, Daniel Granville and Ashlee C. Bailey. San Francisco: University of California, pp. 595–98.

Maddieson, Ian. 1984. *Patterns of Sounds*. Cambridge: Cambridge University Press.

Maddieson, Ian. 1985. Phonetic cues to syllabification. In *Phonetic Linguistics*. Edited by Victoria Fromkin. London: Academic Press, pp. 203–21.

Martínez Melgar, Antonia. 1986. Estudio experimental sobre un muestreo de vocalismo andaluz. *Estudios de Fonética Experimental* 2: 198–248.

McGraw, Kenneth O., and Seok P. Wong. 1996. Forming inferences about some intraclass correlation coefficients. *Psychological Methods* 1: 30–46. [CrossRef]

Méndez Dosuna, Julián. 1985. La duración de -s en los grupos sp, st, sk: A propósito del orden regular de difusión en algunos cambios fonéticos. In *Symbolae Ludovico Mitxelena Septuagenario Oblatae*. Edited by Luis Michelena and José Melena. Vitoria: Universidad del País Vasco, pp. 647–55.

Monroy, Rafael, and Juan Manuel Hernández-Campoy. 2015. Illustrations of the IPA: Murcian Spanish. *Journal of the International Phonetic Association* 45: 229–40. [CrossRef]

Morrison, Geoffrey Stewart, and Paola Escudero. 2007. A cross-dialect comparison of Peninsular- and Peruvian-Spanish vowels. In *Proceedings of the 16th Congress of Phonetic Sciences*. Edited by Jürgen Trouvain and William J. Barry. Saarbrücken: Universität des Saarlandes, pp. 1505–08.

Moya Corral, Juan A. 2010. El oriente andaluz y el español común. In *XVI Jornadas sobre la Lengua Española y su Enseñanza*. Edited by Juan A. Moya Corral and Marcin Sosinski. Granada: Universidad de Granada, pp. 101–15.

Nadeu, Marianna. 2016. Phonetic and phonological vowel reduction in Central Catalan. *Journal of the International Phonetic Association* 46: 33–60. [CrossRef]

Navarro Tomás, Tomás. 1938. Dédoublement de phonèmes dans le dialecte andalou. *Travaux du Cercle Linguistique de Prague* 8: 184–86.

Navarro Tomás, Tomás. 1939. Desdoblamiento de fonemas vocálicos. *Revista de Filología hispÁnica* 1: 165–67.

O'Neill, Paul. 2010. Variación y cambio en las consonantes oclusivas del español de Andalucía. *Estudios de Fonética Experimental* 19: 11–41.

Oh, Grace E., and Melissa A. Redford. 2012. The production and phonetic representation of fake geminates in English. *Journal of Phonetics* 40: 82–91. [CrossRef]

Parrell, Benjamin. 2012. The role of gestural phasing in Western Andalusian Spanish aspiration. *Journal of Phonetics* 40: 37–45. [CrossRef]

Payne, E. M. 2005. Phonetic variation in Italian consonant gemination. *Journal of the International Phonetic Association* 35: 153–81. [CrossRef]

Peñalver Castillo, Manuel. 2006. El habla de Cabra: Situación actual. *Anuario de Estudios Filológicos* 29: 247–53.

Pickett, Emily, Sheila Blumstein, and Martha Burton. 1999. Effects of speaking rate on the singleton/geminate contrast in Italian. *Phonetica* 56: 135–57. [CrossRef]

Regan, Brendan. 2017. A study of ceceo variation in Western Andalusia (Huelva). *Studies in Hispanic and Lusophone Linguistics* 10: 119–60. [CrossRef]

Ridouane, Rachid, and Giuseppina Turco. 2019. Why is gemination contrast prevalently binary? Insights from Moroccan Arabic. *Radical: A Journal of Phonology* 1: 62–91.

Ruch, Hanna, and Jonathan Harrington. 2014. Synchronic and diachronic factors in the change from pre-aspiration to post-aspiration in Andalusian Spanish. *Journal of Phonetics* 45: 12–25. [CrossRef]

Ruch, Hanna, and Sandra Peters. 2016. On the origin of post-aspirated stops: Production and perception of /s/ + voiceless stop sequences in Andalusian Spanish. *Laboratory Phonology: Journal of the Association for Laboratory Phonology* 7: 1–36.

Sadakata, Makiko, and James M. McQueen. 2013. High stimulus variability in nonnative speech learning supports formation of abstract categories: Evidence from Japanese geminates. *The Journal of the Acoustical Society of America* 134: 1324–35. [CrossRef]

Scheffers, Michael. 1983. Simulation of auditory analysis of pitch: An elaboration of the DWS Pitch Meter. *Journal of the Acoustical Society of America* 74: 1716–25. [CrossRef]

Schuchardt, Hugo. 1881. Die Cantes Flamencos. *Zeitschrift für Romanische Philologie* 5: 249–322. [CrossRef]

Shrotriya, Nisheeth, Sada Siva Sarma, Rajesh Verma, and Shyam Sunder Agrawal. 1995. Acoustic and perceptual characteristics of geminate Hindi stop consonants. In *International Conference of Phonetic Sciences*. Edited by Kjell Elenius and Peter Branderud. Stockholm: Arne Strömbergs Grafiska, vol. 4, pp. 132–35.

Stevens, Kenneth N. 1998. *Acoustic Phonetics*. Cambridge and London: The MIT Press.

Stevens, Mary, and John Hajek. 2007. Towards a phonetic conspectus of preaspiration: Acoustic evidence from Sienese Italian. In *Proceedings of the 16th International Congress of Phonetic Science*. Edited by Jürgen Trouvain and William J. Barry. Saarbrücken: Universität des Saarlandes, pp. 429–34.

Stevens, Mary, and John Hajek. 2010. Pre-aspirated /pp tt kk/ in standard Italian: A sociophonetic v. phonetic analysis. In *13th Australasian Annual Conference on Speech Science and Technology*. Edited by Marija Tabain, Janet Fletcher, David Grayden, John Hajek and Andew Butcher. Melbourne: Australasian Speech Science and Technology Association, pp. 14–16.

Strycharczuk, Patrycja, and Sebregts Koen. 2018. Articulatory dynamics of (de) gemination in Dutch. *Journal of Phonetics* 68: 138–49. [CrossRef]

Takeyasu, Hahime, and Mikio Giriko. 2017. Effects of duration and phonological length of the preceding/following segments on perception of the length contract in Japanese. In *The Phonetics and Phonology of Geminate Consonants*. Edited by Haruo Kubozono. Oxford: Oxford University Press, pp. 85–117.

Torreira, Francisco. 2007a. Coarticulation between aspirated-s and voiceless stops in Spanish. An interdialectal comparison. In *Selected proceedings of the 9th Hispanic Linguistics Symposium*. Edited by Nuria Sagarra and Almeida Jacqueline Toribio. Somerville: Cascadilla Press, pp. 113–20.

Torreira, Francisco. 2007b. Pre-and postaspirated stops in Andalusian Spanish. In *Segmental and Prosodic Issues in Romance Phonology*. Edited by Pilar Prieto, Joan Mascaró and María Josep Solé. Amsterdam: Benjamins, pp. 67–82.

Torreira, Francisco. 2012. Investigating the nature of aspirated stops in Western Andalusian Spanish. *Journal of the International Phonetic Association* 42: 49–63. [CrossRef]

Torreira, Francisco, and Mirjam Ernestus. 2011. Realization of voiceless stops and vowels in conversational French and Spanish. *Laboratory Phonology* 2: 331–53. [CrossRef]

Tucker, Benjamin V., and Mirjam Ernestus. 2016. Why we need to investigate casual speech to truly understand language production, processing and the mental lexicon. *The Mental Lexicon* 11: 375–400. [CrossRef]

Turco, Giuseppina, and Bettina Braun. 2016. An acoustic study on non-local anticipatory effects of Italian length contrast. *The Journal of the Acoustical Society of America* 140: 2247–56.

Turk, Alice, Satsuki Nakai, and Mariko Sugahara. 2006. Acoustic segment durations in prosodic research: A practical guide. In *Methods in Empirical Prosody Research*. Edited by Stefan Sudhoff, Denisa Lenertová, Roland Meyer, Sandra Pappert, Petra Augurzky, Ina Mleinek, Nicole Richter and Johannes Schließer. Berlin: Walter de Gruyter, pp. 1–27.

Valeš, Miroslav. 2014. Panorama de la sociolingüística andaluza. *Linguistica Pragensia* 24: 45–54.

Van Son, Rob J. J. H., and Louis C. W. Pols. 1990. Formant frequencies of Dutch vowels in a text, read at normal and fast rate. *The Journal of the Acoustical Society of America* 88: 1683–93. [CrossRef]

Vihman, Marilyn, and Marinella Majorano. 2017. The role of geminates in infants' early word production and word-form recognition. *Journal of Child Language* 44: 158–84. [CrossRef]

Villena Ponsoda, Juan Andrés. 2000. Identidad y variación lingüística: Prestigio nacional y lealtad vernacular en el español hablado en Andalucía. In *Identidades lingüísticas en la España autonómica*. Edited by Georg Bossong and Francisco Báez de Aguilar González. Madrid: Iberoamericana Vervuert, pp. 107–50.

Wallenstein, Sylvan, Christine L. Zucker, and Joseph L. Fleiss. 1980. Some statistical methods useful in circulation research. *Circulation Research* 47: 1–9. [CrossRef]

Walley, Amanda C., and James E. Flege. 1999. Effect of lexical status on children's and adults' perception of native and non-native vowels. Journal of Phonetics. *Journal of Phonetics* 27: 307–32.

Warren, Paul. 2018. Quality and quantity in New Zealand English vowel contrasts. *Journal of the International Phonetic Association* 48: 305–30. [CrossRef]

Wikström, Jussi. 2013. An acoustic study of the RP English LOT and THOUGHT vowels. *Journal of the International Phonetic Association* 43: 37–47. [CrossRef]