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Article *in* Studies in Hispanic and Lusophone Linguistics · May 2017

DOI: 10.1515/shll-2017-0001

Whitney Chappell
University of Texas at San Antonio

DE GRUYTER Studies in Hispanic and Lusophone Linguistics 2017; 10(1): 1–37

Whitney Chappell* and Christina García

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Abstract: In several dialects of Spanish, men tend to exhibit more intervocalic /s/ voicing than women, e. g., *oso* 'bear' as [ozo], and this difference may have a physiological basis. File-Muriel et al. (2015, Disentangling the physiological from the socially-learned in gradient, sociophonetic processes: Evidence from s-realization in Barranquilla, Colombia. Unpublished manuscript) found that vocal tract size conditions /s/ aspiration in Barranquilla, and Nadeu and Hualde (2013, Reinterpretation of biomechanics as gender-conditioned variation in the origin of diachronic intervocalic voicing. Available at http://washo.uchicago.edu/pub/workshop/nadeu.pdf) contend that speakers with larger vocal tracts may have greater difficulty controlling vocal fold cessation. The present work serves as a continuation of these studies, utilizing 18 sociolinguistic interviews to determine (i) what factors are most predictive of intervocalic [z] in Costa Rica and (ii) whether physiology can potentially explain its origin. The results of a statistical analysis using 1,647 tokens of /s/ show that both gender and physiological factors significantly condition voicing ($p < 0.001$), with more voicing in men's speech, as F2 decreases, and as f0 decreases. However, one would expect more gradient voicing in men's speech if physiological factors caused the gender-based voicing difference, but women voice more gradiently while men produce higher rates of 0 % and 100 % voicing. We conclude that while physiological factors may have been its original source, non-physiological factors currently condition /s/-voicing in Costa Rica, with male speakers aiming for categorical targets for social motivations.

Keywords: Costa Rican Spanish, /s/ voicing, gender, physiology

***Corresponding author: Whitney Chappell,** University of Texas at San Antonio, San Antonio, TX, USA, E-mail: Whitney.Chappell@utsa.edu
Christina García, Saint Louis University, St. Louis, MO, USA, E-mail: garciacm@slu.edu

1 Introduction

The voicing of /s/ before a voiced consonant occurs in almost all varieties of Spanish, e. g., *los muslos* 'the thighs' as [loz.ˈmuz.los]. On the other hand, phonetically gradient intervocalic /s/ voicing, e. g., *los usos* 'the uses' as [lo.ˈzu.zos][1] takes place in a more limited set of dialects, including Argentine, Ecuadorian, Mexican, Costa Rican, and Peninsular Spanish. Other than dialectal surveys (Canfield 1981; Lipski 1994; Quesada Pacheco and Vargas Vargas 2010) and a few works on the more phonological /s/-voicing process in Quito and Cuenca (Robinson 1979; Toscano Mateus 1953), relatively scarce work has been conducted on intervocalic /s/ voicing until the past decade, when interest in the phenomenon prompted a flurry of investigations throughout the Spanish-speaking world. To date, however, no studies have explored the production of intervocalic [z] in Costa Rican Spanish, and the present work seeks to determine the social and linguistic factors most predictive of this variant.

In addition to providing the first quantitative analysis of Costa Rican [z] production, this study contributes to the ongoing conversation about the origin of intervocalic consonant voicing. Recent studies have claimed that the voicing of intervocalic consonants may be due to physiological rather than social factors, as men's larger vocal tracts and thicker vocal folds make the cessation of vocal fold vibration between vowels more difficult (File-Muriel et al. 2015; Nadeu and Hualde 2013).[2] Should this assertion be true, men would be expected to exhibit more gradient voicing at the beginning of intervocalic /s/, while women would be more likely to produce a fully voiceless [s]. An analysis of percent intervocalic /s/ voicing based on 18 sociolinguistic interviews with Costa Rican Spanish speakers calls this notion into question, finding more categorical behavior in male speech and more gradient behavior in female speech. In line with a recent perception study that finds an association between intervocalic [z] and high evaluations of masculinity (Chappell 2016), we conclude that intervocalic /s/ voicing in Costa Rican Spanish is in the incipient stages of conventionalization. In other words, the more categorical behavior of [z] in Costa Rican men's speech can be explained not by physiological differences between men and women but by the indexical meaning attributed to [z].

1 The transcription of word-final /s/ before a vowel as second-word initial reflects the post-lexical resyllabification typical of word-final, prevocalic consonants in Spanish (Morgan 2010).
2 It should be noted that vocal tract size and vocal fold thickness are not the only factors that contribute to voicing; lung volume and laryngeal-oral timing also play a role.

2 Literature review

2.1 Costa Rican Spanish

The Costa Rican Central Valley is well known for phonetic tendencies that differ considerably from neighboring Central American countries. For example, unlike Panamanian and Nicaraguan dialects, syllable- and word-final /s/ is strongly retained in Central Valley Spanish, /tɾ/ clusters are often affricated, e. g., *tres* 'three' as [[t̠ɹ̊es], and /r/ is produced as a retroflex or assibilated rhotic, e. g., [kaɻo] for *carro* 'car' (Lipski 1994: 223). Until recently, dialectal surveys represented the extent of linguistic research in Costa Rica (Agüero 1962; Canfield 1981; Lipski 1994; Navarro Tomás 2004; Quilis 1993), but increased interest in the region and the variety has yielded more nuanced work over the course of the past two decades.

Linguistic foci have included pronominal forms of address (Agüero 1962; Michnowicz et al. 2016; Moser 2003, 2010a, 2010b; Quesada Pachecho 1996, 2010; Rojas Blanco 2003; Vargas 1974; Vega González 1995; Villegas 1963), the retroflex or assibilated production of intervocalic /r/ along with the retroflex production of syllable-final /r/ (Adams 2002; Calvo Shadid and Portilla Chaves 1998; Sánchez Corrales 1986; Umaña Aguilar 1981; Vásquez Carranza 2006), syllable-final /s/ (Quesada Pacheco 1984; 1988), and the conservative behavior of /b, d, g/ in the variety (Carrasco 2008; Carrasco et al. 2012). The production of intervocalic [z], e. g., *las olas* 'the waves' as [la.ˈzo.las], has been mentioned only briefly in the literature. Lipski (1994) writes, "At times word-final prevocalic /s/ is voiced to [z]" (223), and while Lipski does not mention other environments, the first author has also observed voiced /s/ word initially and word medially, e. g., *la sala* 'the hall' as [la.ˈza.la] and *piso* 'floor' as [ˈpi.zo]. In order to more fully understand this intervocalic voicing phenomenon, the following section details the findings of previous investigations that have explored intervocalic /s/ voicing in other dialects of Spanish.

2.2 /s/ voicing in Spanish

2.2.1 Introduction to preconsonantal and prevocalic /s/ voicing in Spanish

In more traditional works on Standard Spanish, /s/ voicing is said to take place before a voiced consonant, e. g., *desde* 'from' as [ˈdez.ðe], as the result of a categorical phonological process of regressive voicing assimilation. However, more recent studies have found gradience in the degree of /s/ voicing before a voiced consonant (Campos-Astorkiza 2014; A. García 2013; Romero 1999; Schmidt and Willis 2011), with the degree of voicing constrained by speech rate, position within the phrase, and place and manner of articulation of the following consonant. In other words, the traditional analysis of preconsonantal /s/ voicing oversimplifies the complex and gradient nature of the process, and the degree of gestural overlap (Browman and Goldstein 1989) between /s/ and the following consonant depends on numerous factors.

Intervocalic /s/ voicing, on the other hand, is less frequent across varieties of Spanish. It is typical of Ecuadorian Spanish (Chappell 2011; Robinson 1979; Strycharczuk et al. 2013), with nearly categorical voicing taking place word finally between vowels in Quito Spanish, e. g., *misa mores* 'my loves' as [mi.za.ˈmo.ɾes], as well as at morphemic boundaries in Cuenca Spanish, e. g., *desayuno* 'breakfast' as [de.za.ˈɟju.no] (Robinson 1979: 138). Farther south in Loja, the intervocalic /s/ voicing appears to be more variable, occurring most frequently word initially and word finally, but also in word-medial positions (C. García 2015: 184–186).

The distribution of intervocalic /s/ voicing is similar in several other dialects as well. Gradient intervocalic voicing has been described in non-contact varieties of Peninsular Spanish, including Madrid (Hualde and Prieto 2014; Torreira and Ernestus 2012) and other parts of Central Spain (Torreblanca 1986). In Catalonian Spanish, where Spanish is in contact with Catalan, both McKinnon (2012) and Davidson (2014) find that variable voicing is more likely word finally than word medially, where voicing is rare, and this generalization holds for non-contact Madrid Spanish as well (Hualde and Prieto 2014; Torreira and Ernestus 2012). Intervocalic voicing has also been casually observed in Asturian Spanish (Bárkányi 2014).

In Latin America, variable intervocalic /s/ voicing has been noted in Buenos Aires Spanish (Rohena-Madrazo 2011), and Schmidt and Willis (2011) describe one Mexican male who systematically voiced intervocalic /s/, illustrating the interspeaker variability of the phenomenon. Finally, A. García (2013) explores intervocalic /s/ voicing among speakers from Bogotá, but due to the low rates of voicing overall, she concludes that intervocalic /s/ voicing is not typical of Highland Colombian Spanish.[3]

3 The intervocalic voicing of /p, t, k/ has also been observed in a number of Spanish dialects, predominantly in Spain (Hualde et al. 2011; Machuca 1997; Nadeu and Hualde 2013; Torreira and Ernestus 2011 among others). This voicing process seems to be more common in spontaneous speech than reading tasks and led by men, which parallels the intervocalic /s/ voicing process, but a detailed comparative analysis is needed to determine whether /s/ voicing and /p, t, k/ voicing are independent of one another.

Based on the aforementioned studies, there appear to be two disparate processes at play across the Spanish-speaking world. First, the intervocalic /s/ voicing in Quito and Cuenca, while some gradient behavior is observable, behaves as a phonological reduction. The voicing is nearly categorical word finally (or both word finally and at morpheme boundaries), and it rarely occurs elsewhere. On the other hand, the voicing phenomenon in Loja, Spain, Mexico, and Buenos Aires does not behave like a phonologically conditioned weakening, but rather exhibits a great deal of variation based on word position, speaker, gender,[4] speech rate, and other factors. This phonetically variable voicing may occur word initially, word medially, and word finally, illustrated alongside the voiceless realizations expected in Standard Spanish in (1).

(1)	**Standard Spanish**	**Dialect with phonetically gradient voicing**
la sopa 'the soup'	[la.ˈso.pa]	[la.ˈzo.pa]
casa 'house'	[ˈka.sa]	[ˈka.za]
los otros 'the others'	[lo.ˈso.tros]	[lo.ˈzo.tros] (from C. García 2015: 22).

It is this type of voicing that primarily concerns us in this work, as it parallels the process found in Costa Rican Spanish. For this reason, the following paragraphs discuss the results of studies conducted outside of Quito and Cuenca, focusing on dialects in which the voicing is variable and gradient rather than phonological in nature.

2.2.2 Linguistic and social factors conditioning intervocalic /s/ voicing

Several linguistic and extralinguistic factors have been found to constrain intervocalic /s/ voicing across dialects of Spanish. The linguistic factor most predictive of intervocalic /s/ voicing is word position, with voicing most likely word finally (Chappell 2011; Davidson 2014; C. García 2015; Hualde and Prieto 2014; Strycharczuk et al. 2013). Speech rate and stress have also been found to predict /s/ voicing, with more voicing in faster speech (Torreira and Ernestus 2012; A. García 2013; Strycharczuk et al. 2013; C. García 2015) and between unstressed vowels (Davidson 2014; C. García 2015; Torreira and Ernestus 2012).[5] The fact

4 Following the variationist literature on /s/ voicing, the word "gender" is used throughout the text. However, the word is not used to designate socially constructed gender identities but rather the speaker's biological sex.

5 C. García also discovers that voicing is more likely in Lojano Spanish before non-high vowels.

that voicing is most likely in faster speech, in unstressed environments, and word finally suggests that /s/ voicing constitutes a reduction process in Spanish.

In support of the notion that intervocalic /s/ voicing represents a lenition process, greater gestural blending occurs as speech rate increases (cf. Hardcastle and Hewlett 1999), meaning the voiced glottal gesture of the surrounding vowels overlaps with the voiceless glottal gesture of the intervening /s/.[6] In other words, there may not be enough time to produce glottal aperture for voiceless /s/ in faster speech. Additionally, gestural magnitude and length tend to decrease in unstressed positions (Cooper 1991), which means that intervocalic /s/ has less time to reach its full voiceless target, resulting in more voiced productions. In unstressed environments in Spanish stops are also weakened (Cole et al. 1999), bolstering the argument that lenition processes occur in less prosodically prominent positions.

Findings on the importance of other linguistic factors vary across dialects, across studies, and are overall less conclusive. Chappell (2011) finds more voicing in high frequency words in Ecuadorian Spanish, but Torreira and Ernestus (2012) do not find frequency to be a significant predictor of voicing in Madrid Spanish. If intervocalic /s/ voicing constitutes a change in progress, high-frequency words should exhibit more voicing, as they "have more opportunity to be affected by phonetic processes" (Bybee 2001: 11) in line with usage-based theories. In terms of the effect of the morphological status of /s/, Davidson (2014) and Torreira and Ernestus (2012) do not find it to be a significant predictor of voicing. However, Davidson (2014: 6) finds that prosodic boundaries condition voicing, with stronger prosodic boundaries, i. e., noun/verb + adjective/adverb pairings, resulting in more voicing than weaker prosodic boundaries, i. e., determiner/preposition + noun phrase. These inconclusive results may be due to dialectal differences, methodological differences, or a combination of the two.

In terms of nonlinguistic factors of note, McKinnon (2012) concludes that task constrains voicing in Catalonian Spanish, with intervocalic [z] more likely in casual, oral tasks than in reading tasks (McKinnon 2012). Age has only been reliably tested by C. García (2015), who finds that younger speakers in Loja are more likely to voice than older speakers. Finally, language contact seems to play a role in Spanish in contact with Catalan, a language in which /s/ and /z/ are neutralized to [z] word-finally. Based on language dominance and area of residence, McKinnon (2012) and Davidson (2014) note that contact does play a role,

6 The use of "glottal gesture" follows Browman and Goldstein (1989), who contend that gestures represent phonological primitives and these oral and glottal gestures are specified for certain parameters, e. g., closed constriction degree or open glottis (voicelessness), respectively.

but the directionality of their results is unexpected. First, McKinnon (2012) finds that the relatively balanced bilingual group voices more frequently than even the Catalan-dominant group, and speakers living outside the city center where Catalan is more readily employed voice less than city dwellers. Davidson (2014) finds that the most Catalan-dominant group and the most Spanish-dominant group voice more than the intermediate groups, which is again a rather confounding result. Regardless, language contact should not be a factor in Costa Rican Spanish, as no other languages are in contact with Spanish in the Central Valley.

The authors' impressionistic observations of Costa Rican Spanish suggest that male speakers tend to voice more than females, which makes gender a potentially important factor in the present study. In other works on /s/ voicing, McKinnon (2012) notes a slight gender effect in Catalonian Spanish, with female participants slightly favoring voicing while males slightly disfavor (with factor weights of .53 and .48, respectively), but Torreira and Ernestus (2012) find the opposite: male speakers tend to fully voice /s/ almost twice as much as female speakers in Madrid Spanish. C. García (2015) also confirms a predominance of voiced intervocalic /s/ in men's speech in Loja, Ecuador.

In spite of the lack of research on the production of intervocalic [z] in Costa Rican Spanish, recent work has explored the perception of the variant and the social attributes it indexes through a matched-guise task (Chappell 2016). In this task, 12 utterances were taken from six Central Valley Spanish speakers and were manipulated to include (i) only intervocalic [s] or (ii) only intervocalic [z]. 106 Costa Rican participants listened to these 24 audio files and evaluated each speaker on perceived social features like level of education, masculinity, friendliness, etc. Chappell (2016) finds that when listeners hear intervocalic [z], both male and female speakers receive lower evaluations of class and level of education, and only men receive higher evaluations of niceness, confidence, masculinity, and a local identity when intervocalic /s/ is voiced. In other words, intervocalic [z] appears to carry covert prestige for male speakers but not female speakers, providing men with more social incentive to use the nonstandard variant than women. This finding is relevant to the present study because men may have a social reason to produce intervocalic /s/ voicing. That is, intervocalic [z] may be a social target rather than the involuntary result of physiology.

2.3 Voicing and the body

Sociolinguistic studies generally evaluate the effect of speaker gender on linguistic production without much regard for physiological factors that could also play a role in the variation. Men tend to have larger oral cavities and thicker vocal folds than women, which makes it difficult to distinguish between socially learned linguistic behaviors and physiologically motivated differences (File-Muriel et al. 2015). Particularly relevant to the present paper is the fact that a larger larynx makes vocal fold cessation in intervocalic contexts more difficult (Lucero and Koenig 2005).

Exploring this issue with intervocalic /p t k/ voicing in Iberian Spanish and Basque, Nadeu and Hualde (2013) find a great deal of interspeaker variation with male speakers producing more voiced tokens than female speakers. While these gender differences may have a physiological basis, Nadeu and Hualde (2013) cannot exclude the possibility that voicing is also a socially constructed phenomenon. According to the authors, the difficulties controlling vocal fold cessation between vowels caused by a larger larynx would explain more voice leakage (or gestural overlap) from the surrounding vowels but cannot entirely explain the tendency for men to fully voice these supposedly voiceless obstruents. While it is possible that physiology plays a role, Nadeu and Hualde (2013) merely speculate that the male speakers included in the analysis have larger larynxes based on their biological sex and do not employ laryngeal measurements to substantiate their claims.

Studies exploring physiological factors like oral tract length and vocal fold thickness generally rely on technology that directly enables their measurement, such as x-rays, MRIs, or CT scans (Takemoto et al. 2006). However, this technology is costly and inaccessible for many scholars, which is why proxies for physiological measurements are often employed. Acoustic measurements of vowel formants and spectral properties commonly serve as these proxies, indirectly pointing to physiological differences. For instance, because a vowel's second formant is associated with the distance from the vocal folds to the site of the constriction, File-Muriel et al. (2015) measure the second formant (F2) of Spanish /i/, the front-most vowel in the language, to indirectly establish vocal tract length. These authors also utilize fundamental frequency (f0) to indirectly assess vocal fold thickness, as thinner vocal folds tend to correlate with higher f0.

It should be noted that the relationship between acoustic and articulatory factors is not perfectly linear (Stevens 1989), meaning the indirect inferences made based on articulation may not be as accurate as direct measurement techniques. While only a weak connection exists between f0 and body size (González 2004), the connection between f0 and vocal fold thickness is clearer. The levels of testosterone circulating through the male body during puberty permanently change the larynx, lengthening and thickening the vocal folds, which lowers fundamental frequency (Jenkins 1998). Similarly, the F2 of the [i] vowel serves as an indirect measurement of vocal tract length. According to Fant (1960), only with the [i] vowel is "… the mouth cavity with associated orifices found to be the essential determinant of F2. F2 of [i] is clearly a half-wavelength resonance of the back cavity" (Fant 1960: 121). In other words, when physiology is compared with acoustic properties, there is a "specially good agreement" (Fant 1966: 27) between the F2 of the [i] vowel and vocal tract area. For these reasons, f0 and F2 are taken to be reasonable proxies for the concrete physiological measurements via x-rays, MRIs, or CT scans of vocal fold thickness and vocal tract length, respectively.[7]

To explore the relationship between gender and physiology in intervocalic fricative voicing in Spanish, File-Muriel et al. (2015) conducted 16 sociolinguistic interviews with speakers of Barranquilla Spanish, including eight females and eight males. Using Praat, they measured each fricative's average Center of Gravity (COG) and percent voicelessness. As COG measures the spectrum's central tendency or mean, a lower COG is indicative of a weakening tendency,[8] and an analysis of percent voicelessness enables a discussion of the gradient nature of /s/ voicing by male and female speakers of Barranquilla Spanish. File-Muriel et al. (2015) then conduct two stepwise linear regression models, the first fitted to COG and the second fitted to percent voicelessness. In the first model fitted to COG, the authors find both gender ($p < 0.01$) and mean F2 ($p < 0.001$), which is indicative of vocal tract size, to be significant predictors of /s/ weakening. In the second model fitted to percent voicelessness, mean f0 emerges as highly significant ($p < 0.001$), but gender does not reach significance.

The authors conclude that individual physiology does, in fact, play a role in intervocalic /s/ voicing, but the extent to which socially learned behaviors contribute to /s/ realization remains unclear. Gender, f0, and F2 tend to overlap; that is, men tend to have lower f0 and lower F2, making it rather difficult to distinguish between physiological and social distinctions. Additionally, any

7 As an anonymous reviewer points out, the greater lung volume typical of the male body may also contribute to gestural overlap. Small and moderate airflows involve a subglottal pressure that is equivalent to the alveolar pressure; that is, there is a small drop in pressure from the lungs to the trachea (Stevens 1971: 1182). Larger airflows, on the other hand, involve a larger pressure drop from the lungs to the trachea, with subglottal pressure that is greater than the alveolar pressure. These pressure differences based on lung volume may result in laryngeal-oral timing differences that could alter intervocalic obstruent voicing. Future studies should measure lung volume via spirometry and investigate its effect on voicing processes.

8 According to Bjorndahl (2015), "… voicing introduces energy in the low-frequency range, and thus voiced sounds will have lower centroid values than their voiceless counterparts" (245).

statistical model constructed to investigate the effect of gender and physiology must carefully consider these overlapping measurements. To resolve this issue in a statistically sound way, one joint factor could be created combining the different, overlapping parameters or separate models could be constructed using only gender, f0, or F2 as an independent variable in each model. However, the collinearity of these three measurements calls into question the conclusion that physiology is responsible for greater rates of voicing among men.

If intervocalic voicing is, in fact, the result of physiological differences between men and women, the intervocalic vocal fold cessation difficulty experienced by men with larger vocal tracts and thicker vocal folds should emerge clearly in other languages as well. In Appalachian English, Hazen et al. (2015) investigate intervocalic /z/ devoicing and word-final /z/ devoicing, e. g., [lusɪŋ] for *losing* and [bis] for *bees*. The authors note that in word-internal position, regardless of gender, "The historical internal /s/ forms have kept distinct their acoustic qualities from those of internal /z/, despite the pressures of surrounding voiced sounds" (1). In other words, intervocalic /s/ is not voiced more by men than by women, which indicates an ability to control vocal fold cessation in the presence of phonemic differences. Word finally, "wide variability exists between individual speakers for these acoustic qualities, but no socially-grouped directionality arises for all voicing qualities" (1), again posing a problem for the physiological perspective.

The physiological versus social argument is complicated further by Fuchs and Toda (2009), who investigate the acoustic differences between men and women's /s/ realizations in English and German. In their analysis, the authors find support for both the physiological argument and the social argument. On the one hand, they note a correlation among palatal length, length of the front cavity, and the acoustics of /s/ realization, which indicates that physiology does condition /s/ production. On the other hand, the researchers find that gender-based differences in the articulation of /s/ persist even when physiological differences were taken into account, which suggests the physiological account does not completely account for the gender differences.

The aforementioned studies do not entirely explain the role of physiology and learned social behavior in the gendered treatment of variation, and, more specifically, in the treatment of intervocalic /s/ voicing in Spanish. In order to address this unanswered question, we pose the following research questions:

1. What social and linguistic factors condition intervocalic /s/ voicing in Costa Rican Spanish?
2. What is the role of (i) gender and (ii) physiological factors in the emergence and spread of intervocalic /s/ voicing?

3 Methodology

3.1 Data collection

To explore the research questions raised in Section 2.3, the first author collected data in the San José province of Costa Rica in the summer of 2014.[9] A total of 22 sociolinguistic interviews were conducted with Costa Rican Spanish speakers who were born and raised in and around the capital city of San José. Each interview lasted between 40 and 90 minutes, resulting in a total of more than 17.5 hours of recorded data.

18 of the 22 sociolinguistic interviews were selected for analysis, allowing for an even distribution of participants' age and gender. Four interviews were excluded, as technical difficulties or background noise rendered an acoustic analysis of intervocalic /s/ voicing impossible. The 18 interviews include an even distribution of gender (9 male speakers, 9 female speakers) and three age ranges (6 speakers under the age of 30, 6 speakers between 30 and 50, and 6 speakers above the age of 54), allowing for a discussion of voicing differences based on these two social predictors.[10]

Each Costa Rican Spanish speaker participated in two tasks. First, the interviewee engaged in a casual conversation with the first author, discussing a range of topics including personal interests, family, hobbies, movies, travels, and areas of interest within Costa Rica. Following this informal interview, the participant read a list of 64 sentences designed to elicit intervocalic /s/ in a range of linguistic positions. In this reading task, preceding and following vowels, the stress of the preceding and following vowels, and the position of the /s/ within the word were manipulated to provoke /s/ in different environments. Example sentences showing the different positions of intervocalic /s/ in the stimuli are provided in (2) below, with the target /s/ bolded and underlined.

(2) Word-initial /s/: *Cuando ella* ***<u>s</u>****alió, yo estaba trabajando.*
'When she left, I was working'

9 The researcher who conducted these interviews is an educated female L1-English, L2-Spanish speaker, and her nonnative speech makes convergence among the Costa Rican Spanish speakers unlikely.

10 All participants were fairly homogeneous in terms of education, having graduated from high school and attended some amount of college. The authors have observed both highly educated and less educated Costa Rican men exhibit high rates of intervocalic voicing, but future studies should consider the effect of education more exhaustively.

Word-medial /s/: *No queremos que pa**s̲**e otra vez.*
'We don't want it to happen again.'
Word-final /s/: *Cuando compre una de estas casa**s̲** inolvidables, estaré feliz.*
'When I buy one of these unforgettable houses, I will be happy.'[11]

To avoid fluency issues and limit the number of production errors, participants were instructed to read each sentence two times. All readers were able to produce the sentences fluently on the first or second attempt, and the production with the fewest discontinuities or errors was selected for coding, as outlined below in Section 3.2.

3.2 Coding of the data

In the data analysis phase, the investigators followed File-Muriel and Brown (2011) and began coding the interviews at exactly the ten-minute mark, allowing participants to familiarize themselves with the nature of the task and speak in a more informal manner. Sixty tokens of intervocalic /s/ were coded in the spontaneous speech task, including 20 tokens each from word-initial, word-medial, and word-final positions. All 64 tokens of /s/ from the reading task were coded for each participant. The word-medial tokens were originally divided into three separate categories, including word-medial tokens at a non-morphemic boundary, word-medial tokens at a morphemic boundary, and word-medial tokens at a verbal morphemic boundary, e. g., *eso* 'this', *desorden* 'disorder', and *empezó* 'it began', respectively. These categories were conflated into a single medial category due to a lack of significance among the different types of word-medial tokens.

In total, 1,647 tokens of intervocalic /s/ were included, including 732 in the reading task and 915 in the spontaneous speech task, and these tokens were coded for a range of social and linguistic independent variables. These factors included the speaker (as a random effect), the speaker's age, the speaker's gender, the mode (interview or reading), the position within the word (initial, medial, final), the stress of the preceding vowel, the stress of the following vowel, the preceding vowel, and the following vowel. Additionally, the duration

11 Although the target /s/ is bolded and underlined here for the reader's convenience, all target words were presented in broad focus domains. That is, no sounds or words were underlined, bolded, or emphasized.

of the surrounding three words was measured along with the number of syllables in those surrounding words, allowing the authors to account for speech rate. For example, if the three-word, nine-syllable sequence *estas casas inolvidables* 'these unforgettable houses' took 1.5 seconds for the speaker to produce, the nine syllables would be divided by the three-word duration (1.5 seconds) for a speech rate of six syllables per second. Finally, f0 and F2 were coded for each speaker and converted to the Bark scale in order to normalize, as is common practice in the study of variation in vowels (Watt et al. 2011). The f0 of the vowels preceding and following each target /s/ were measured at the midpoint of the vowels. Preceding f0, following f0, difference between preceding and following f0,[12] and average preceding/following f0 were all included in the model construction in order to determine the effect of f0 changes on /s/ voicing. Average preceding f0 was ultimately selected for use in the models presented in Section 4.2. Following File-Muriel et al. (2013), F2 was measured in ten tokens of /i/ for each speaker and averaged, which provides an estimate of oral cavity length. Interactions between independent variables were included where relevant in all analyses; however, no significant interactions were found.

In terms of the dependent variable, the acoustic analysis of percent voicing followed the procedure outlined by C. García (2015: 66–68). First, the duration of the entire intervocalic fricative was measured by hand. To identify the onset of the fricative, the researchers relied on a series of parameters, namely the disappearance of the preceding vowel's formant structure, a decrease in amplitude in the waveform, and the appearance of high-frequency noise in the spectrogram. Similarly, the offset was identified by the emergence of the following vowel's formant structure, the increased amplitude in the waveform associated with the following vowel, and the disappearance of high-frequency noise in the spectrogram. Once the fricative's total duration was measured, the percent voicing was calculated based on the periodicity of the waveform and the voicing bar visible in the spectrogram. The intervocalic /s/ could be completely voiceless (0 % voiced), completely voiced (100 % voiced), or partially voiced. Partially voiced tokens often involved some voicing at the beginning of the /s/ as well as at the end. For this reason, the duration of voicing at the beginning of the fricative was added to the

12 It should be noted that variation in intonation could influence f0 measurements and, consequently, the effect of f0 in our models. For this reason, abnormally high f0 measurements were excluded from analysis, and the averaging of measurements was intended to decrease the potential impact of pitch accents. Additionally, preceding and following f0 were both measured and no significant difference was found between these measurements in the model construction, suggesting that f0 measurements near /s/ realizations were relatively stable. As a result, it is unlikely that variation in intonation could compromise the results presented in this paper.

duration of voicing at the end of the fricative to arrive at the total voicing. To calculate the percent voicing, the total duration of voicing was divided by the total duration of the fricative. The percent voicing was measured by hand (instead of using the Praat voicing report, for instance), given that several previous studies have found measurement by hand to be the most reliable method of acoustic analysis of fricative voicing (cf. Gradoville 2011), especially in the case of naturalistic data in which an automated report could be fooled by "phantom" glottal pulses that are the result of background noise.

3.3 Statistical analysis

A wide variety of statistical treatments have been employed to analyze intervocalic /s/ voicing in the literature, including both categorical and continuous measures. In the categorical analyses, Davidson (2014) and Bárkányi (2014) compare majority voiced tokens to majority voiceless tokens. On the other hand, Campos-Astorkiza (2014) and McKinnon (2012) employ a tripartite distinction: voiceless (0–20 %), partially voiced (20–90 %), and fully voiced (100 %). Other scholars have chosen to leave percent voicing as a continuous measure (A. García 2013; Hualde and Prieto 2014; Rohena-Madrazo 2011; Schmidt and Willis 2011; Strycharczuk et al. 2013). The issue with this type of continuous analysis is that measuring percent voicing of /s/ often yields a distribution that is not normal (Rohena-Madrazo 2011; C. García 2015), which precludes the use of ordinary linear regression tests. Rohena-Madrazo (2011) gets around this issue by performing an arcsine transformation of his data.

We opted to employ a continuous analysis of voicing, but we recognize that a linear regression without data transformation is inappropriate due to the non-normal distribution of the data. Figure 1 shows a histogram of the overall distribution of percent voicing in our data from Costa Rican Spanish. It is evident that these data are not normally distributed and furthermore that there are inflated values at 0 % voiced and 100 % voiced, which motivates the use of a statistical test more complex than simple linear regression.

As a result, we follow C. García (2015) in utilizing a statistical test that is more suited to this type of data: inflated beta regression using the package *gamlss* in R (Stasinopoulos et al. 2015). Inflated beta regression was specifically designed to work with percentages and is therefore ideal for the present analysis. It takes into account the inflated values at the two ends of the scale (in this case 0 % and 100 % voiced) by fitting four parameters to the data. The first parameter, *mu*, shows the main effects of the model and thus will be the focus of our attention in the results sections. The second, *sigma*, represents standard

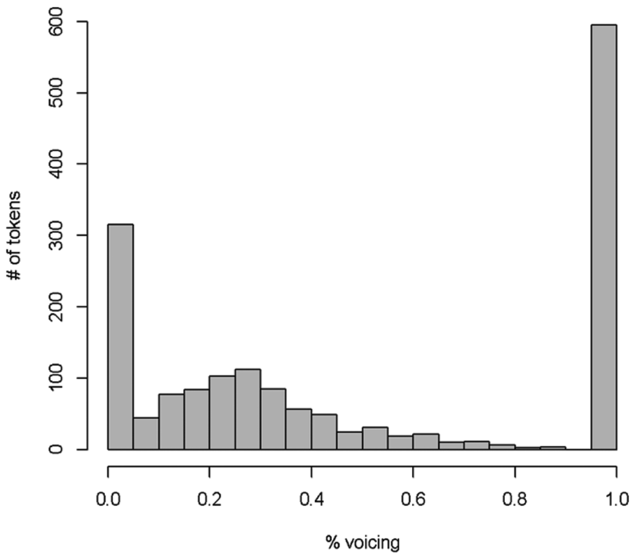

Figure 1: Overall percent voicing across speakers and modes.

deviation, showing which independent variables exhibit higher variance. The third parameter, *nu*, is fitted to the inflated values at the lower end of the scale, demonstrating under which conditions a token is more likely to be 0 % voiced than partially or fully voiced. Finally, *tau* is fitted to the inflated values at the high end of the scale, showing when a token is more likely to be 100 % voiced than elsewhere in the range of voicing. Given these four parameters, inflated beta regression allows for a statistically sound continuous analysis of voicing without violating the assumptions of linear regression while also providing additional information about the independent variables that condition the 0 % and 100 % tokens. The fitting of inflated beta models followed an iterative process and models were compared by looking at AIC scores and residual plots to determine the best model in each case.

Before further analysis was completed, a model with both read and interview data was run to confirm that mode is a significant predictor of percent voicing. Upon further examination of the data, it was determined that it would be most appropriate to separate the data by mode and perform separate analyses for read and interview data. The boxplot in Figure 2 shows that the mean percent voicing, as well as the range of voicing, is quite different in the two modes, and the differential variance makes it statistically unsound to combine the two datasets. This decision is confirmed by the fact that, as will be seen in the results, different predictors are shown to be significant in the read versus interview analyses.

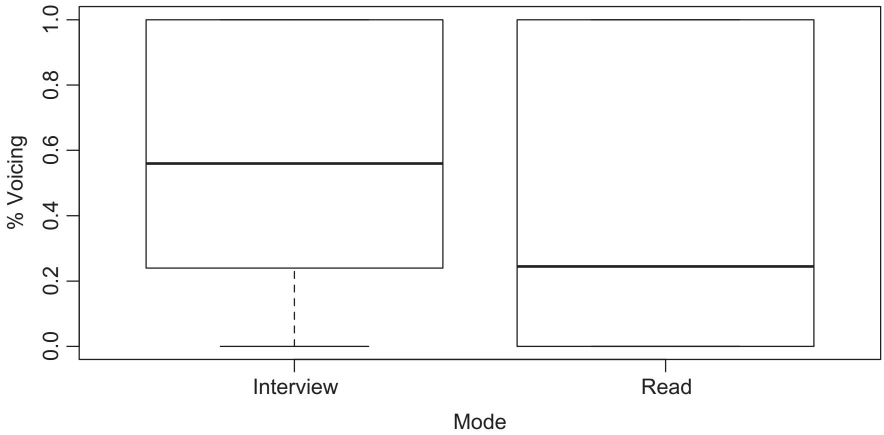

Figure 2: Percent voicing by mode (interview vs. read).

Additionally, collinearity issues were tested with the function vif in R (R Core Team 2014). As expected, gender, F2, and f0 were found to be collinear and thus it was necessary to build separate models for each of these independent factors. Figure 3 shows a plot of the correlation among F2, f0, and gender, clearly demonstrating that knowledge of one factor enables a linear prediction of the others. That is, a lower f0 will correspond to a lower F2, which, in turn, will correspond to male speakers. As the results for individual predictors may not be valid when collinearity is present in a model, separating these collinear factors into three models is the most statistically sound treatment of the data,

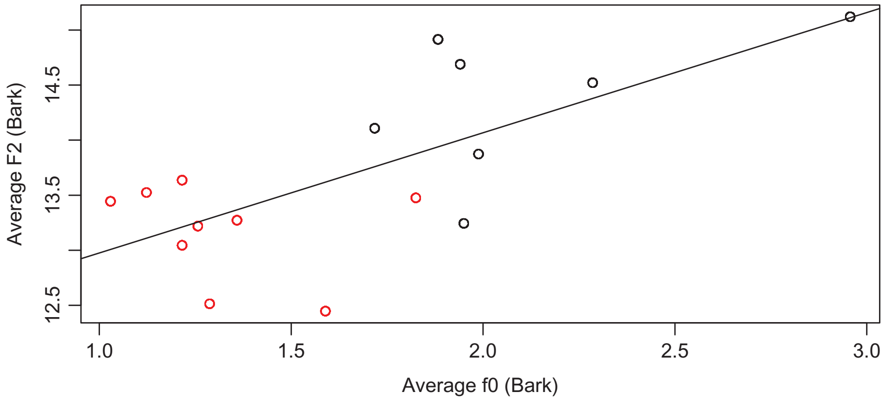

Figure 3: AB line showing speakers' collinear f0, F2, and gender. Red dots represent male speakers; black dots represent female speakers.

preventing potential effects from being blurred by collinearity. All other independent predictors were included in every model since no other collinearity issues were found.

4 Results

4.1 Descriptive statistics

Before turning to the results of the statistical models, it is helpful to look at the trends in the dataset. Overall, in both read and interview datasets, the mean percent voicing is 50 % ($N = 1{,}647$). While this may not seem remarkable at first, it is important to remember that according to the standard phonological rules of Spanish (Morgan 2010: 249; Navarro Tomás 2004) there should be no voicing (or only sporadic voicing) in this environment. Table 1 demonstrates the means for percent voicing by mode and position. Table 2 shows what percentage of the tokens in each mode and position are fully (100 %) voiced.

Table 1: Means for percent voicing ($N = 732$ for read data, 915 for interview data).

	Word initial	Word medial	Word final	Overall
Read data	30.5	39.7	47.6	38.8
Interview data	52.8	55.9	68.2	59.0

Table 2: % of fully voiced tokens ($N = 732$ for read data, 915 for interview data).

	Word initial	Word medial	Word final	Overall
Read data	17.6	25.4	37.1	25.5
Interview data	37.5	44.1	55.1	44.6

As expected from the literature review, there is more voicing in the interview than the read data, and in both modes, the most voicing takes place in word-final position. The pattern of voicing found here for Costa Rican Spanish mirrors that of C. García (2015) for Lojano Spanish in that voicing is found in all three positions and is variable in each position. In Loja, however, the average percent voicing of intervocalic /s/ across positions is 36.2 % in read speech and 45.7 % in spontaneous speech, making the mean percent voicing in the interview data in

Costa Rica notably higher. The percentages of fully voiced tokens in Table 2 show that overall one-fourth of the read tokens and almost half of the interview tokens are fully voiced. The directionality of voicing based on word position in Tables 1 and 2 is the same, with the least average or full voicing word initially and the most word finally.

Furthermore, unlike what has been found for Peninsular varieties, there is considerable voicing of word-medial intervocalic /s/ in Costa Rican Spanish, and the voicing exhibited is quite clearly not the categorical pattern described for Quito and Cuenca Spanish. Figure 1 and Table 1 considered together prove that voicing in Costa Rican Spanish is both gradient and variable, more akin to voicing in Lojano Spanish (C. García 2015).

4.2 Statistical models

We now turn to the statistical analysis of the data. In each case, percent voicing serves as the dependent variable, and only one of the three collinear independent variables (gender, f0, or F2, respectively) is included. As noted in Section 3.3, the reading and interview modes had to be separated given the different variance in each task. In total, six models were fitted to the data: 1) interview data with gender, 2) interview data with F2 (Bark), 3) interview data with f0 (Bark), 4) read data with gender, 5) read data with F2 (Bark), and 6) read data with f0 (Bark). In the results section that follows, we will discuss first the model with gender included and then explain how the models with F2 and f0 differ in both modes. While the focus will be on the main effects seen in the first parameter, *mu*, we will discuss the results of the other parameters where relevant to the analysis.

Tables 3–5 present the results of the best models for the interview subset of the data ($N = 915$ tokens). In these tables, positive estimates in *mu* indicate higher percent voicing, while negative estimates indicate lower percent voicing. In the columns following the estimates, the standard error (*SE*), t-values, and relative *p*-values are listed. In the case of categorical predictors, the reference level is specified in parentheses after the name of the independent variable. The first model, in Table 3, shows the results when gender is included among the independent factors. First looking at the main effects in *mu*, we see that as predicted, in the interview data there is significantly higher percent voicing in men's speech, as speech rate increases, and in final position as compared to initial and medial. Additionally, there is a correlation between voicing and age whereby percent voicing increases as participant age increases; however, caution should be taken when interpreting that result, as will be discussed in

Table 3: Model fitted to percent voicing in the interview task using gender as an independent variable ($N = 915$).

	Estimate	*SE*	t value	*p*-value
mu – main effects				
(Intercept)	−1.18	0.18	−6.40	<0.001
Gender (reference level is Female)				
Male	0.24	0.07	3.67	<0.001
Speech Rate	0.05	0.02	2.67	<0.01
Position (reference level is Final)				
Initial	−0.23	0.09	−2.50	<0.05
Medial	−0.20	0.09	−2.29	<0.05
Age	0.005	0.002	2.12	<0.05
sigma – variance				
(Intercept)	−0.25	0.15	−1.67	0.09
Position (reference level is Final)				
Initial	−0.08	0.11	−0.67	0.50
Medial	−0.29	0.11	−2.55	<0.05
Age	−0.01	0.003	−3.21	<0.01
nu – when % voicing is more likely to be 0				
(Intercept)	1.59	0.38	4.21	<0.001
Gender (reference level is Female)				
Male	1.15	0.25	4.55	<0.001
Age	−0.11	0.01	−8.36	<0.001
tau – when % voicing is more likely to be 100				
(Intercept)	−2.69	0.34	−8.01	<0.001
Gender (reference level is Female)				
Male	0.98	0.16	6.24	<0.001
Speech Rate	0.29	0.04	7.49	<0.001
Position (reference level is Final)				
Initial	−0.67	0.19	−3.60	<0.001
Medial	−0.55	0.18	−3.06	<0.01
Following Stress (reference level is Stressed)				
Unstressed	0.64	0.15	4.13	<0.001
AIC: 1132.42				

Section 5. The results for the second parameter, *sigma*, demonstrate that there is more variability in percent voicing in final and initial positions and in younger participants' speech. The results for *nu* show that a token is more likely to be 0 % voiced when spoken by a male participant, and also a younger participant. Finally, according to the results for *tau*, a token is more likely to be 100 % voiced

Table 4: Model fitted to percent voicing in the interview task using F2 (Bark) as an independent variable ($N = 915$).

	Estimate	*SE*	t value	*p*-value
mu – main effects				
(Intercept)	2.19	0.61	3.58	<0.001
F2	−0.22	0.04	−5.16	<0.001
Speech Rate	0.05	0.02	2.69	<0.01
Position (reference level is Final)				
Initial	−0.23	0.09	−2.50	<0.05
Medial	−0.19	0.09	−2.28	<0.05
sigma – variance				
(Intercept)	−0.24	0.15	−1.67	0.10
Position (reference level is Final)				
Initial	−0.08	0.11	−0.70	0.48
Medial	−0.29	0.11	−2.55	<0.05
Age	−0.01	0.003	−3.26	<0.01
nu – when % voicing is more likely to be 0				
(Intercept)	14.38	2.63	5.46	<0.001
F2	−0.78	0.17	−4.64	<0.001
Speech Rate	−0.13	0.06	−2.09	<0.05
Age	−0.13	0.02	−8.42	<0.001
tau – when % voicing is more likely to be 100				
(Intercept)	7.22	1.47	4.91	<0.001
F2	−0.68	0.11	−6.45	<0.001
Speech Rate	0.28	0.04	6.75	<0.001
Position (reference level is Final)				
Initial	−0.68	0.19	−3.63	<0.001
Medial	−0.57	0.18	−3.14	<0.01
Following Stress (reference level is Stressed)				
Unstressed	0.67	0.16	4.28	<0.001
AIC: 1124.725				

in men's speech, as speech rate increases, in final position, and before an unstressed vowel. While these last three results concord with general reduction patterns, it seems at first paradoxical that it could simultaneously be more likely for a token to be 0 % and 100 % voiced in men's speech. We will return to this issue in Section 5.2. Regardless, it is clear that gender plays an important role in the interview data given that it is the only predictor to be found significant in *mu*, *nu*, and *tau*.

Table 5: Model fitted to percent voicing in the interview task using f0 (Bark) as an independent variable ($N = 915$).

	Estimate	*SE*	t value	*p*-value
mu – main effects				
(Intercept)	−0.44	0.18	−2.46	<0.05
f0	−0.25	0.07	−3.39	<0.001
Speech Rate	0.05	0.02	2.75	<0.01
Position (reference level is Final)				
Initial	−0.23	0.09	−2.51	<0.05
Medial	−0.19	0.09	−2.30	<0.05
sigma – variance				
(Intercept)	−0.24	0.15	−1.67	0.10
Position (reference level is Final)				
Initial	−0.07	0.11	−0.65	0.52
Medial	−0.29	0.11	−2.55	<0.05
Age	−0.01	0.003	−3.28	<0.01
nu – when % voicing is more likely to be 0				
(Intercept)	3.33	0.59	5.56	<0.001
f0	−0.58	0.20	−2.85	<0.01
Age	−0.12	0.01	−8.30	<0.001
tau – when % voicing is more likely to be 100				
(Intercept)	−0.92	0.42	−2.16	<0.05
f0	−0.82	0.17	−4.78	<0.001
Speech Rate	0.31	0.04	8.00	<0.001
Position (reference level is Final)				
Initial	−0.92	0.42	−2.16	<0.05
Medial	−0.56	0.18	−3.16	<0.01
Following Stress (reference level is Stressed)				
Unstressed	0.61	0.15	3.94	<0.001
AIC: 1153.963				

Tables 4 and 5 present similar models to that seen in Table 3, but with F2 considered in Table 4 and f0 in Table 5 (in place of gender). Overall, the results for these two models mirror what was already discussed for the model with gender. For the F2 model in Table 4, F2 (measured in Bark) is found to be significant in all of the same parameters as gender and trends in the expected direction. In *mu*, F2 and percent voicing have an inverse relationship, corroborating that men voice more since average F2 is lower for the male speakers in this participant pool (see Figure 3). For *nu* and *tau*, we once again see a paradoxical account whereby participants with lower F2 produce more 0 % and 100 % voiced tokens. The results for all other predictors in this model are the same as the gender model except that speech rate is significant in the *nu* parameter: as expected, as speech rate increases, it is less likely that a token will be 0 % voiced.

In the case of the f0 model presented in Table 5, f0 (measured in Bark) is found to be significant in the same three parameters where gender and F2 were found to be significant. For *mu*, percent voicing increases as f0 decreases, indicative of men voicing more than women given their lower average f0 (see Figure 3). Additionally, as seen in *nu* and *tau*, a token is more likely to be 0 % or 100 % voiced as the participant's average f0 decreases. All other predictors selected as significant in this model are the same as those of the gender model, with the same directionality of effects.

Tables 6–8 present the results of the best models for the read subset of the data ($N = 732$ tokens). As before, positive estimates in *mu* represent higher percent voicing, while negative estimates represent lower percent voicing. In these models, fewer independent variables are found significant as compared to the interviews models, likely due to the lower amount of variance in the read data. The first model for the read data, which considers gender as an independent variable, can be seen in Table 6. For the main effects, gender is the only significant predictor, once again with male participants exhibiting significantly higher percent voicing. According to *sigma*, younger participants show higher variation in percent voicing, as was seen previously in the interview data. The results for *nu* indicate that younger participants are also less likely to produce 0 % voiced tokens. Finally, for *tau*, the likelihood of a token being 100 % voiced is greater in males' speech, as speech rate increases, in final and medial positions, and before unstressed vowels. These results mirror the interview results except that in the read data there is no difference between medial and final positions. As in the interview data, the importance of gender is evident given that it is the only significant main effect.

The models for the read data presented in Tables 7 and 8, which consider F2 and f0, respectively, mirror the model just discussed for gender. In Table 7, F2 is a significant predictor in *mu* and *tau*, as was the case for gender in Table 6, but here F2 also appears in *nu*: percent voicing increases as F2 decreases, and lower F2 values increase the likelihood of a token being 0 % or 100 % voiced. The other results for the F2 model are the same as those of the gender model. In the read data model considering f0 (Table 8), f0 is a significant predictor only in *tau*, suggesting it is not as strong of a predictor in the read data as gender or F2.

Table 6: Model fitted to percent voicing in the reading task using gender as an independent variable ($N = 732$).

	Estimate	*SE*	t value	*p*-value
mu – main effects				
(Intercept)	−1.03	0.05	−21.21	<0.001
Gender (reference level is Female)				
Male	0.26	0.06	3.79	<0.001
sigma – variance				
(Intercept)	−0.39	0.13	−3.02	<0.01
Age	−0.01	0.003	−3.75	<0.001
nu – when % voicing is more likely to be 0				
(Intercept)	2.72	0.32	8.49	<0.001
Age	−0.11	0.01	−9.71	<0.001
tau – when % voicing is more likely to be 100				
(Intercept)	−5.16	0.73	−7.08	<0.001
Gender (reference level is Female)				
Male	1.57	0.23	6.75	<0.001
Speech Rate	0.37	0.07	5.17	<0.001
Position (reference level is Final)				
Initial	−0.82	0.31	−2.67	<0.01
Medial	−0.22	0.26	−0.83	0.40
Following Stress (reference level is Stressed)				
Unstressed	0.97	0.22	4.43	<0.001
AIC: 814.98				

Table 7: Model fitted to percent voicing in the reading task using F2 (Bark) as an independent variable ($N = 732$).

	Estimate	*SE*	t value	*p*-value
mu – main effects				
(Intercept)	1.64	0.64	2.56	<0.05
F2	−0.19	0.05	−3.95	<0.001
sigma – variance				
(Intercept)	−0.40	0.13	−3.05	<0.01
Age	−0.01	0.003	−3.69	<0.001
nu – when % voicing is more likely to be 0				
(Intercept)	8.31	2.02	4.12	<0.001
Age	−0.12	0.01	−9.81	<0.001
F2	−0.39	0.14	−2.87	<0.01
tau – when % voicing is more likely to be 100				

(*continued*)

Table 7: (*continued*)

	Estimate	*SE*	t value	*p*-value
(Intercept)	11.85	2.19	5.39	<0.001
F2	−1.10	0.16	−7.12	<0.001
Speech Rate	0.32	0.07	4.77	<0.001
Position (reference level is Final)				
Initial	−0.71	0.31	−2.31	<0.05
Medial	−0.14	0.26	−0.57	0.57
Following Stress (reference level is Stressed)				
Unstressed	1.01	0.22	4.57	<0.001
AIC: 815.39				

Table 8: Model fitted to percent voicing in the reading task using f0 (Bark) as an independent variable ($N = 732$).

	Estimate	*SE*	t value	*p*-value
mu – main effects				
(Intercept)	−0.89	0.04	−25.52	<0.001
sigma – variance				
(Intercept)	−0.40	0.13	−3.05	<0.01
Age	−0.01	0.003	−3.73	<0.001
nu – when % voicing is more likely to be 0				
(Intercept)	2.69	0.32	8.46	<0.001
Age	−0.12	0.01	−9.68	<0.001
tau – when % voicing is more likely to be 100				
(Intercept)	−3.28	0.83	−3.93	<0.001
f0	−0.73	0.23	−3.17	<0.01
Speech Rate	0.44	0.07	6.53	<0.001
Position (reference level is Final)				
Initial	−0.67	0.29	−2.27	<0.05
Medial	−0.16	0.25	−0.65	0.52
Following Stress (reference level is Stressed)				
Unstressed	0.87	0.21	4.12	<0.001
Age	0.02	0.007	2.04	<0.05
AIC: 855.53				

Nevertheless, the direction of the effect is as expected: lower f0 values (typical of males' speech) are correlated with 100 % voiced tokens. The other results mirror those already discussed for the read models with the exception of age being significant in *tau* for the f0 model.

5 Discussion

In the discussion that follows, we will look at the overall patterns seen in both the read and interview data, as set forth in the models presented in Section 4.2. First, we will focus on the significant predictors of percent voicing that are not related to gender or physiology. The importance of gender and its physiological correlates (F2 and f0) will be addressed in Section 5.2.

5.1 Predictors of voicing other than gender, F2, and f0

According to the inflated beta models with the best fit, speech rate, following stress, position, and age are significant predictors in one or more parameters. Speech rate appears in both *mu* and *tau* for the interview data, and in *tau* for the read data. The overall trend is that as speech rate increases, percent voicing and the likelihood of a 100 % voiced token increases. Figure 4 further exemplifies this pattern with a scatterplot of percent voicing and speech rate (measured in syllables per second) for each of the datasets. In both graphs in this figure, we see a positive correlation between percent voicing and speech rate, as was also found by File-Muriel et al. (2015); C. García (2015).[13]

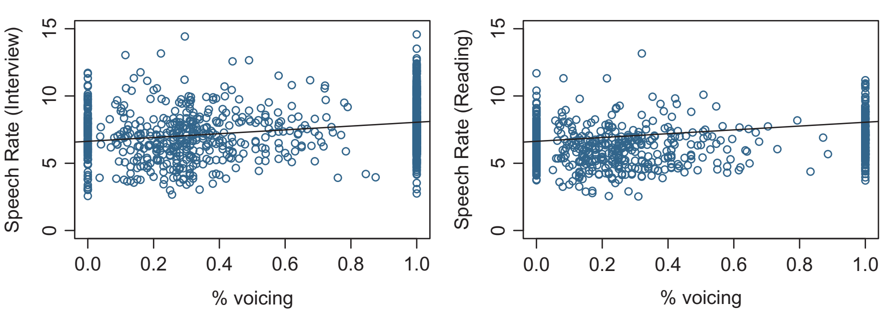

Figure 4: Effect of speech rate on percent voicing in the interview and reading task.

For following stress, a significant effect is found in *tau* for both interview and read data, exhibiting that the likelihood of a 100 % voiced token increases when the following vowel is unstressed. Figure 5 shows this effect with a boxplot of percent voicing by the stress of following vowel, in which we can see that the

13 The same directionality based on speech rate was also observed in Nadeu and Hualde (2013) with the voicing of voiceless stops.

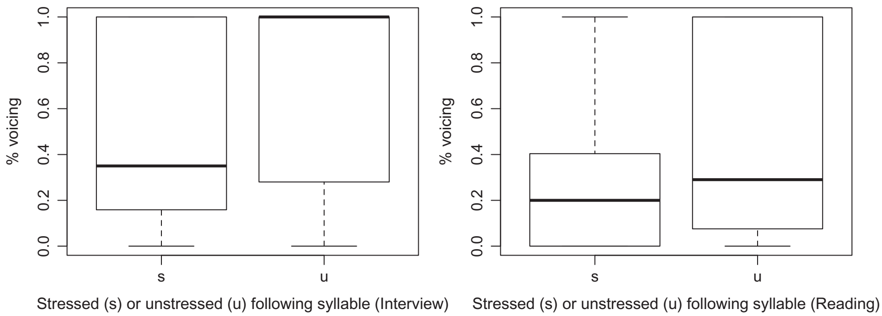

Figure 5: Effect of following stress on percent voicing in the interview and reading task.

effect of following stress is greater in the interview data. The results of speech rate and following stress taken together are consistent with the idea that intervocalic /s/ voicing is a reduction process (cf.; Hualde and Prieto 2014; Torreira and Ernestus 2012). According to a gestural account of speech (Browman and Goldstein 1989), as speech rate increases, gestures between sounds will overlap more, which could cause the voiced gesture of the surrounding vowels to blend or overtake the voiceless gesture of the intervocalic /s/. This increased blending will also occur in environments that favor phonetic reduction, such as before an unstressed vowel.

Position within the word also exhibits an important effect on voicing as it is significant in *mu, sigma*, and *tau* in the interview data and in *tau* in the read data. The overall results for position show higher percent voicing and increased likelihood of 100 % voiced tokens in final position, as compared to initial and medial position, although the difference between final and medial position in the read data is not significant.[14] Figure 6 presents these results with a boxplot of percent voicing for the three word positions. In the interview data, the median percent voicing for initial and medial positions is similar, while for final position the median reaches 100 % voiced. In the reading task, the word-final effect is reduced and a clear stair-step pattern appears with increasing median percent voicing from initial, to medial, to final position.

More voicing in word-final position is not unexpected given that many previous studies have also found more voicing in this position (Chappell 2011; Davidson 2014; C. García 2015; Hualde and Prieto 2014; Strycharczuk et al. 2013). This word-final lenition has been explained in two ways. First, individual units

14 Additionally, the results for sigma demonstrate that there is more variation in final and initial positions as compared to medial position.

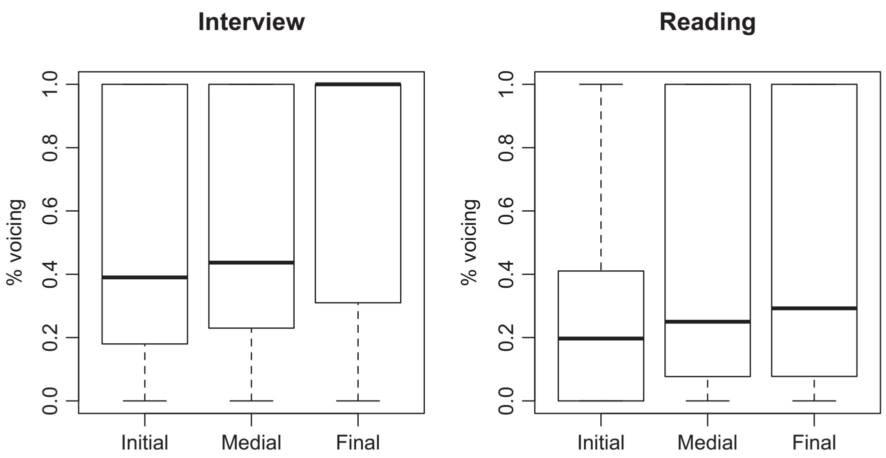

Figure 6: Effect of position on percent voicing in the interview and reading task.

become shorter in longer words, often undergoing massive reduction (Johnson 2004; Méndez Dosuna 1985) due to airflow and timing constraints.[15] Second, as more phonological information becomes available to the listener earlier in the word, facilitating lexical selection, the relative importance of phones later in the word decreases (File-Muriel 2007).

Finally, age is shown to be a significant predictor in *sigma* and *nu* for the interview data, and *sigma, nu*, and *tau* for the read data. Figure 7 shows the overall results for age and percent voicing seen in the models, whereby percent voicing increases as age increases. That is, older participants exhibit more voicing, both in terms of percent voicing and 100 % voiced tokens, than younger participants. Furthermore, according to the results for *sigma*, older participants exhibit less variation in voicing than younger participants. While this could suggest that older speakers of Costa Rican Spanish tend to deviate more from the standard than younger speakers, these results must be interpreted cautiously given the relatively small number of participants per age group (6 speakers under the age of 30, 6 speakers between 30 and 50, and 6 speakers above the age of 54) and the relationship between age and gender. Although no significant interaction was found between age and gender, it was observed in the coding of the data that a few of the most consistent "voicers" are older male participants. Speaker was included in each model as a random effect,[16] but interspeaker differences may still be responsible for the age effect. This is especially evident

15 This is referred to as polysyllabic shortening.
16 Random intercepts and random slopes were not used in the models.

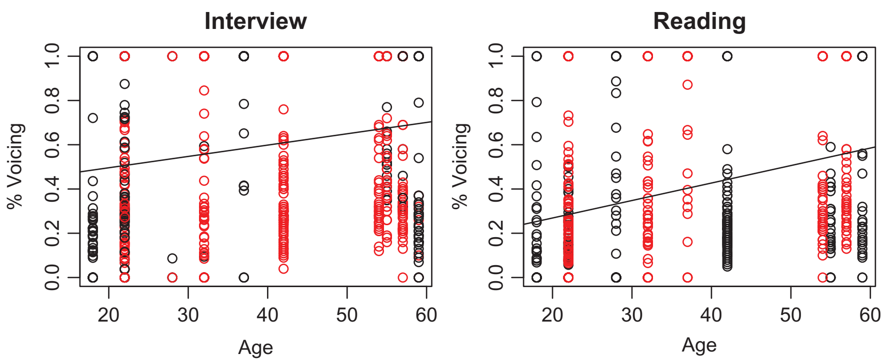

Figure 7: Relationship between age and percent voicing across speakers in the interview and reading task (Red dots represent male speakers, black dots represent female speakers.)

in the interview data: the left graph contains many red (male) dots at 40 % voicing or higher as age increases.

5.2 Effect of gender, F2, and f0 on voicing

The preceding section responded to research question #1, which asked what social and linguistic factors predict intervocalic /s/ voicing. Now that we have detailed the effect of position, following stress, speech rate, and age on intervocalic /s/ voicing, the present section investigates research question #2, which sought to untangle the effects of socially learned behaviors and physiological differences on /s/ voicing. Consequently, the effect of gender, F2, and f0 are discussed in this section, and we begin by addressing which measurement is a better predictor of voicing.

Unsurprisingly, the data confirmed that men voice significantly more than women. The same result was confirmed for lower F2 and f0; as extrapolated from the speakers' F2 and f0, those with longer oral cavities and thicker vocal folds tend to voice significantly more than those with smaller oral cavities and thinner vocal folds. Figure 8 graphically depicts the result that percent voicing increases for men, lower f0, and lower F2.

Figure 8 also shows that there is a clear division between men and women's average F2 and average f0 measurements; the clustering of red dots to the left of the AB lines and the clustering of black dots to the right shows that there is little overlap between the groups. In other words, measurements of gender, F2, and f0 overlap considerably, making it difficult to disentangle socially learned

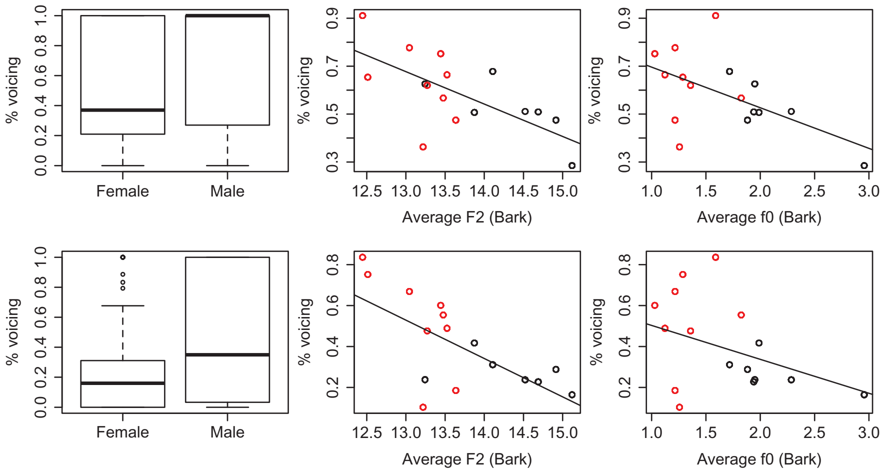

Figure 8: Percent voicing by gender, average F2, and average f0 in the interview (above) and reading task (below). Red dots represent men and black dots represent women.

linguistic behavior from physiologically governed production. Additionally, the interview models show that gender, F2, and f0 are similarly good predictors of /s/ voicing in Tables 3–5 ($p < 0.001$ for each independent variable), and the AIC, which shows goodness of fit, is similar for each model: 1132.42, 1124.725, and 1153.963, respectively. The only difference in terms of the models' main effects emerges in the read data. The AIC is similar for each reading model (814.98, 815.39, and 855.53, respectively), and gender and F2 are similarly successful predictors of voicing ($p < 0.001$) in Tables 6 and 7. However, f0 is not a significant main effect in Table 8. This result suggests that oral cavity size and gender are better predictors of /s/ voicing than vocal fold thickness.

Based on a comparison of the models in Section 4.2, we have determined that gender and F2 are both similarly good predictors of voicing and f0 also predicts voicing to a lesser extent, but this comparative analysis has not yet allowed us to determine whether the /s/ voicing so prevalent in Costa Rican men's speech is the result of physiological differences or learned, socially motivated behaviors. However, the physiological explanation does make certain predictions about voicing behavior, and an exploration of these predictions may resolve this question.

A clear prediction of the physiological approach is that both men and women have the same intervocalic target, voiceless intervocalic [s], but men's longer oral cavities and thicker vocal folds render vocal fold cessation more

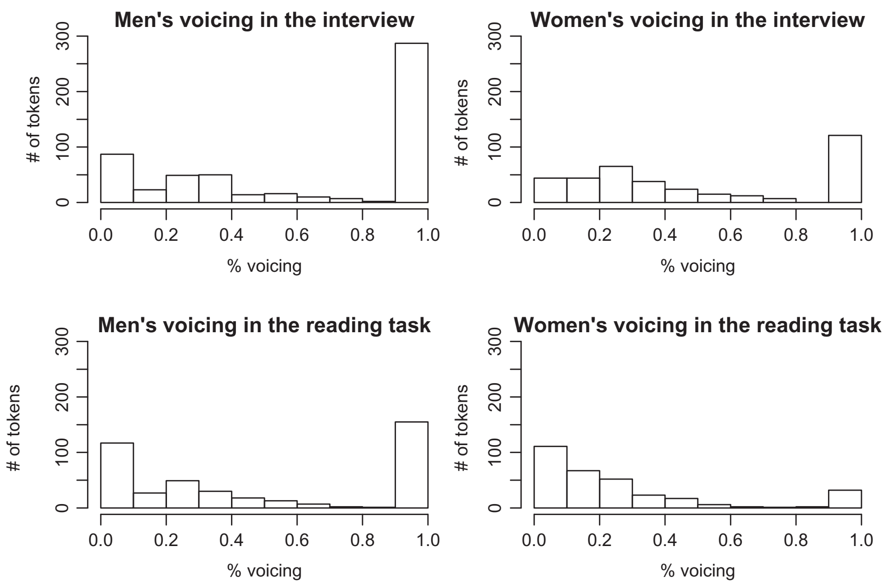

Figure 9: Histograms of percent voicing for men and women in the interview and reading modes.

difficult. If this assumption is accurate, men should produce more gradient voicing than women, as they require more time to stop vocal fold vibration and reach the voiceless target. Figure 9 shows the male-female gradient voicing patterns in the interview and reading tasks, and, contrary to the physiological approach's prediction, male speakers' intervocalic /s/ realizations are more categorical than female speakers, showing higher rates of /s/ production involving both 0 % voicing and 100 % voicing.

The same more categorical voicing behavior holds true for speakers with lower F2 and f0, visible in the *nu* and *tau* parameters of the models presented in Tables 4 and 5, as well as Tables 7 and 8. In other words, in addition to producing significantly higher percent voicing, men are more likely to produce /s/ with both 0 % voicing and 100 % voicing than women, as are individuals with lower F2 and f0. Contrary to the expectations of the physiological approach, women and speakers with smaller oral cavities and thinner vocal folds are more gradient in their intervocalic /s/ voicing, the result of some gestural overlap with the preceding and following vowel.

Men are not simply slower to reach the voiceless [s] target; rather, the data suggest that men may be aiming for two completely different targets: full voicelessness and full voicing. When considered in light of the matched-guise results in Chappell (2016), this more categorical behavior makes more sense. Chappell (2016) finds that listeners evaluate male speakers who produce intervocalic [z] as less educated and lower class, but they are also found to be more masculine, more confident, nicer, and more local. The male speakers who produce intervocalic [s] access the positive social meanings indexed by [s], presenting themselves as higher class and more educated. On the other hand, the male speakers who produce intervocalic [z] show themselves to be masculine, nicer, confident locals.

Based on the production results, there do appear to be two clear targets that male speakers approximate, but these targets are not as clearly defined for female speakers. Chappell (2016) found that although Costa Rican women are not evaluated more negatively than men for producing intervocalic [z], they are not able to access the covert prestige associated with intervocalic [z] as men can. It stands to reason that women's intervocalic /s/ production may be the result of gestural overlap or lack thereof, while men's intervocalic /s/ production involves two phonetic targets that are imbued with social meaning. These targets and social meanings may not be entirely conventionalized at the present moment, which can explain why there is still some gradience in men's behavior; however, the difference between men and women's productions, combined with the social evaluations indexed by [z], suggest a process of conventionalization.

We have now established that physiological factors are not necessarily better predictors of intervocalic /s/ voicing than gender, as men are more categorical in their voicing of /s/ than women and this less gradient behavior may actually be due to two distinct phonetic targets for men associated with indexical social meaning. Given these conclusions, what can we gather about the origin and spread of this intervocalic voicing? It is well known that variants are interpreted locally in relation to broader social stereotypes (Eckert 2008), but it is entirely possible that the origin of social meaning can lie in the body itself. That is, men's larger vocal tracts may be more prone to /s/ voicing, and intervocalic [z], in turn, becomes indexically linked to masculinity. This link between a variant, the male body, and social associations of male behavior (confidence, localness, niceness) could help explain the origin and social meaning of intervocalic [z] in Costa Rican Spanish. Physiological factors may serve as the original source of the voicing, and the community's conception of masculinity could lead to the extension of the variant's social meanings like confidence, niceness, and localness.

However, this possibility is not conclusively supported by the current dataset, and the social meaning indexed by the intervocalic /s/ variants actually serves to obscure the origin and extension of [z]. In order to convincingly argue that intervocalic [z] originated as a result of the physiology of the male body, future studies must identify /s/ voicing either in its nascent stage, before any social meaning can be associated with the variant, or in a variety where sociophonetic perception studies demonstrate that no social meaning is indexed by the variant. Non-contact dialects of Spanish with rather low rates of /s/ voicing may provide fertile soil for this investigation.

6 Conclusion

Based on our statistical analysis of intervocalic /s/ voicing in Costa Rica, we find that intervocalic [z] is a lenited variant, most likely to be realized in faster speech, before an unstressed vowel, and word finally, supporting previous research on intervocalic [z] (Davidson 2014; C. García 2015; Hualde and Prieto 2014; Strycharczuk et al. 2013). Also in line with past studies (C. García 2015; File-Muriel et al. 2015; Nadeu and Hualde 2013; Torreira and Ernestus 2012 among others), we confirm a gender difference in terms of the production of intervocalic [z]: men voice more than women, with statistically significant differences between men and women's intervocalic /s/ voicing. However, we do not find support for the argument that physiological factors like f0 (indicative of vocal fold size/thickness) and F2 (indicative of vocal tract size) are better predictors of voicing than gender. When included in separate models due to the collinear relationship between physiological measurements and gender, both gender and F2 were equally good predictors of voicing with minimal differences between the models. f0 was also found to condition percent voicing but was a less successful measurement than F2 in the reading task. Given these results, we cannot conclude that physiology accounts for intervocalic /s/ voicing differences better than gender.

We also explored the hypothesis that men's voicing will be more gradient than women's voicing. If, as the physiological argument proposes, male speakers have more difficulty ceasing vocal fold vibration between vowels, the greater gestural overlap should result in more variable /s/ voicing than women. However, we find the opposite: women are more gradient voicers, while men tend to behave more categorically, producing fully voiced [z] or fully voiceless [s] between vowels more than women. Again, this finding does not support the argument that physiological factors are more predictive of voicing than gender.

We conclude that while it is possible that certain linguistic changes can originate in the body itself, the present work does not support the argument. Other authors attempting to resolve this question must take two key issues into account. First, the sound statistical treatment of the data is crucial. Any analysis that combines physiological factors and gender in a single statistical model in spite of their collinear relationship could potentially confound the statistical results. Second, even if a change originates in the body, indexical social meaning may become associated with a phonetic variant, which would obscure the origin of the phenomenon (see Eckert 2008; Silverstein 2003). If social meaning is indexed by a phonetic variant, its production becomes socially motivated rather than indicative of a physiological response.

This appears to be the case with intervocalic [z] in Costa Rica. The social meaning associated with [z] in this variety obfuscates the origin of intervocalic [z], as male speakers approximate categorical productions of /s/ to index certain social meanings. Future studies attempting to disentangle social and physiological factors must explore indexical social meanings; without such an investigation, it is impossible to exclude the possibility that performative gendered behaviors affect /s/ voicing in ways physiology alone cannot explain. Only with additional analyses of the social meaning indexed by intervocalic [z] can we determine whether intervocalic /s/ voicing across varieties of Spanish is motivated by the same factors.

Acknowledgements: We thank Terrell Morgan and Scott Schwenter for planting this seed of an idea in our heads years ago, the University of Texas at San Antonio's College of Liberal and Fine Arts and Department of Modern Languages and Literatures for their support of this project, the amazing Maricel Quintero for her help recruiting Costa Rican Spanish speakers, the participants whose voices made this article possible, and three anonymous reviewers for their productive feedback on an earlier version of this paper. Any remaining mistakes are ours and ours alone.

References

Adams, Catalina. 2002. *Strong assibilation and prestige: A sociolinguistic study in the Central Valley of Costa Rica*. Davis, CA: University of California dissertation.

Agüero, Arturo. 1962. *El español de América y Costa Rica*. San José, Costa Rica: Antonio Lehmann.

Bárkányi, Zsuzsanna. 2014. Reflexiones sobre la asimilación de sonoridad de la /s/. In Zsuzsanna Fábián, Ildikó Szijj, Imre Szilágyi & Balazs Déri (eds.), *Studi di linguistica neolatina per i 60 anni di Giampaolo Salvi*, 25–36. Budapest: Eötvös Loránd Tudományegyetem.

Bjorndahl, Christina. 2015. The phonetics and phonology of segment classification: A case study of /v/. In Eric Raimy & Charles E. Cairns (eds.), *The segment in phonetics and phonology*, 236–250. Malden, MA: John Wiley & Sons.

Browman, Catherine & Louis Goldstein. 1989. Articulatory gestures as phonological units. *Phonology* 6. 201–252.
Bybee, Joan. 2001. *Phonology and language use*. Cambridge: Cambridge University Press.
Calvo Shadid, A. & M. Portilla Chaves. 1998. Variantes retroflejas de /ɾ/ and /r/ en el habla culta de San José. *Revista Káñina* 22(1). 81–86.
Campos-Astorkiza, Rebeka. 2014. Sibilant voicing assimilation in Peninsular Spanish as gestural blending. In Marie-Hélène Côte, Éric Mathieu & Shana Poplack (eds.), *Variation within and across Romance Languages*, 17–38. Philadelphia: John Benjamins Press.
Carrasco, Patricio. 2008. *An acoustic study of voiced stop allophony in Costa Rican Spanish*. Urbana-Champaign, IL: University of Illinois at Urbana-Champaign dissertation.
Carrasco, Patricio, José I. Hualde & Miquel Simonet. 2012. Dialectal differences in Spanish voiced obstruent allophony: Costa Rican vs. Iberian Spanish. *Phonetica* 69. 149–179.
Chappell, Whitney. 2011. The intervocalic voicing of /s/ in Ecuadorian Spanish. In Jim Michnowicz & Robin Dodsworth (eds.), *Selected proceedings of the 5th workshop on Spanish sociolinguistics*, 57–64. Somerville, MA: Cascadilla Proceedings Project.
Chappell, Whitney. 2016. On the social perception of intervocalic /s/ voicing in Costa Rican Spanish. *Language Variation and Change* 28(3). 357–378.
Cole, Jennifer, José Ignacio Hualde & Khalil Iskarous. 1999. Effects of prosodic and segmental context on /g/ deletion in Spanish. In Osamu Fujimura, Brian D. Joseph & Bohumil Palek (eds.), *Proceedings of the fourth linguistics and phonetics conference*, 575–589. Prague: The Karolinum Press.
Cooper, André M. 1991. *An articulatory account of aspiration in English*. New Haven, CT: Yale University dissertation.
Davidson, Justin. 2014. A comparison of fricative voicing and lateral velarization phenomena in Barcelona: A variationist approach to Spanish in Contact with Catalan. *Romance Languages and Linguistic Theory* 6. 223–244.
Eckert, Penelope. 2008. Variation and the indexical field. *Journal of Sociolinguistics* 12(4). 453–476.
Fant, Gunnar. 1960. *Acoustic theory of speech production*. The Hague: Mouton.
Fant, Gunnar. 1966. A note on vocal tract size factors and non-uniform F-pattern scalings. *Speech Transactions Laboratory Quarterly Progress and Status Report* 4. 22–30.
File-Muriel, Richard. 2007. *The role of lexical frequency and phonetic context in the weakening of syllable-final lexical /s/ in the Spanish of Barranquilla, Colombia*. Bloomington, IN: Indiana University dissertation.
File-Muriel, Richard & Earl K. Brown. 2011. The gradient nature of s-lenition in Caleño Spanish. *Language Variation and Change* 23(02). 223–243.
File-Muriel, Richard, Earl K. Brown & Michael Gradoville. 2013. La contribución de los rasgos fisiológicos y del aprendizaje social en los procesos sociofonéticos: Datos de la realización de s en el español de Barranquilla, Colombia. Presentation given at the Universidad Nacional de Colombia, Bogotá.
File-Muriel, Richard, Earl K. Brown & Michael Gradoville. 2015. Disentangling the physiological from the socially-learned in gradient, sociophonetic processes: Evidence from s-realization in Barranquilla, Colombia. Unpublished manuscript.
Fuchs, Susanne & Martine Toda. 2009. Do differences in male versus female /s/ reflect biological factors or sociophonetic ones? In Susanne Fuchs, Martine Toda & Marzena Zygis (eds.), *An interdisciplinary guide to turbulent sounds*. Berlin: Mouton de Gruyter.

García, Alison. 2013. *Allophonic variation in the Spanish sibilant fricative*. Milwaukee, WI: University of Wisconsin-Milwaukee dissertation.
García, Christina. 2015. *Gradience and variability of intervocalic /s/ voicing in Highland Ecuadorian Spanish*. Columbus, OH: The Ohio State University dissertation.
González, Julio. 2004. Formant frequencies and body size of speaker: A weak relationship in adult humans. *Journal of Phonetics* 32(2). 277–287.
Gradoville, Michael Stephen. 2011. Validity in measurements of fricative voicing: Evidence from Argentine Spanish. In Scott M. Alvord (ed.), *Selected Proceedings of the 5th Conference on Laboratory Approaches to Romance Phonology*, 59–74. Somerville, MA: Cascadilla Proceedings Project.
Hardcastle, William J. & Nigel Hewlett (eds.). 1999. *Coarticulation: Theory, data and techniques*. Cambridge: Cambridge University Press.
Hazen, Kirk, Jordan Lovely, Margery Webb, Emily Vandevender & Kiersten Woods. 2015. The sociophonetics of z devoicing. Available at https://ncsu.edu/linguistics/lavis_secol/pdfs/hazen_etal_devoicing.pdf
Hualde, José Ignacio & Pilar Prieto. 2014. Lenition of intervocalic alveolar fricatives in Catalan and Spanish. *Phonetica* 71(2). 109–127.
Hualde, José Ignacio, Miquel Simonet & Marianna Nadeu. 2011. Consonant lenition and phonological recategorization. *Laboratory Phonology* 2. 301–329.
Jenkins, J.S. 1998. The voice of the Castrato. *Lancet* 351. 1877–1880.
Johnson, Keith. 2004. Massive reduction in conversational American English. Spontaneous speech: Data and analysis. In Kiyoko Yoneyama & K. Maekawa (eds.), *Proceedings of the 1st session of the 10th international symposium*, 29–54. Tokyo: The National International Institute for Japanese Language.
Lincoln, Canfield, D. 1981. *Spanish pronunciation in the Americas*. Chicago: University of Chicago Press.
Lipski, John M. 1994. *Latin American Spanish*. New York: Longman.
Lucero, Jorge C. & Laura L. Koenig. 2005. Phonation thresholds as a function of laryngeal size in a two-mass model of the vocal folds. *Journal of Acoustical Society of America* 118. 2798–2801.
Machuca Ayuso, María J. 1997. *Las obstruyentes no continuas del español: Relación entre las categorías fonéticas y fonológicas en habla espontánea*. Barcelona: Universitat Autònoma de Barcelona dissertation.
McKinnon, Sean. 2012. *Intervocalic /s/ voicing in Catalonian Spanish*. Columbus, OH: The Ohio State University honors thesis.
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 José L. Melena (ed.), *Symbolae Ludovico Mitxelena Septuagenario Oblatae*, 647–655. Vitoria, Spain: Universidad del País Vasco.
Michnowicz, Jim, Scott Despain & Rebecca Gorham. 2016. The changing system of Costa Rican pronouns of address: Tuteo, voseo, and ustedeo. In Susana Rivera-Mills & María I. Moyna (eds.), *Forms of address in the Spanish of the Americas*, 243–266. Amsterdam: John Benjamins.
Morgan, Terrell A. 2010. *Sonidos en contexto: Una introducción a la fonética del español con especial referencia a la vida real*. New Haven: Yale University Press.
Moser, Karolin. 2003. En torno a las formas de tratamiento para la segunda persona en el español de Costa Rica. *Káñina Revista De Artes y Letras* 17(2). 153–161.

Moser, Karolin. 2010a. Las formas de tratamiento verbales-pronominales en Guatemala, El Salvador, Panamá (y Costa Rica): Hacia una nueva sistematización en la periferia centroamericana. In Martin Hummel, Bettina Kluge & María Eugenia Vázquez Laslop (eds.), *Formas y fórmulas de tratamiento en el mundo hispánico*, 271–292. Mexico City: El Colegio de México.

Moser, Karolin. 2010b. San José (Costa Rica): Desde los significados pragmáticos del ustedeo en el registro coloquial actual hacia sus primeras manifestaciones en el valle central (siglo XVIII). In Martin Hummel, Bettina Kluge & María Eugenia Vázquez Laslop (eds.), *Formas y fórmulas de tratamiento en el mundo hispánico*, 671–714. Mexico City: El Colegio de México.

Nadeu, Marianna & José Ignacio Hualde. 2013. Reinterpretation of biomechanics as gender-conditioned variation in the origin of diachronic intervocalic voicing. Available at: http://washo.uchicago.edu/pub/workshop/nadeu.pdf

Quesada Pacheco, Jorge A. 1984. *La variación de la /s/ en el área metropolitana de San José: análisis cuantitativo*. San José: Universidad de Costa Rica master's thesis.

Quesada Pacheco, Jorge A. 1988. Análisis sociolingüístico de la /s/ en el área metropolitana de San José. *Revista de Filología y Lingüística de la Universidad de Costa Rica* 14(2). 167–172.

Quesada Pacheco, Miguel A. 1996. El español de América Central. In Manuel Alvar (ed.), *Manual de dialectología hispánica: El español de América*, 101–115. Barcelona: Ariel.

Quesada Pacheco, Miguel A. 2010. Formas de tratamiento en Costa Rica y su evolución (1561-2000). In Martin Hummel, Bettina Kluge & María Eugenia Vázquez Laslop (eds.), *Formas y fórmulas de tratamiento en el mundo hispánico*, 647–670. Mexico City: El Colegio de México.

Quesada Pacheco, Miguel A. & Luis Vargas Vargas. 2010. Rasgos fonéticos del español de Costa Rica. In Miguel A. Quesada Pacheco (ed.), *El español hablado en América Central*, 155–176. Madrid: Iberoamericana.

Quilis, Antonio. 1993. *Tratado de fonología y fonética española*. Madrid: Gredos.

R Core Team. 2014. *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing.

Robinson, Kimball. 1979. On the voicing of intervocalic s in the Ecuadorian Highlands. *Romance Philology* 33(1). 137–143.

Rohena-Madrazo, Marcos. 2011. *Sociophonetic variation in the production and perception of obstruent voicing in Buenos Aires Spanish*. New York City, NY: New York University dissertation.

Rojas Blanco, Lylliam. 2003. A propósito del voseo: Su historia, su morfología y su situación en Costa Rica. *Revista Educación* 27(2). 143–163.

Romero, Joaquín. 1999. The effect of voicing assimilation on gestural coordination. In John J. Ohala, Yoko Hasegawa, Manjari Ohala, Daniel Granville & Ashlee C. Bailey (eds.), *Proceedings of the fourteenth international congress of the phonetic sciences*, 1793–1796. Berkeley: University of California.

Sánchez Corrales, Víctor. 1986. Escisión fonológica de /ɹ/ en el español de Costa Rica. *Revista de Filología y Linguística* 12. 129–133

Schmidt, Lauren B. & Erik W. Willis. 2011. Systematic investigation of voicing assimilation of Spanish /s/ in Mexico City. In Scott M. Alvord (ed.), *Selected proceedings of the 5th conference on laboratory approaches to Romance phonology*, 1–20. Somerville, MA: Cascadilla Proceedings Project.

Silverstein, Michael. 2003. Indexical order and the dialectics of sociolinguistic life. *Language and Communication* 23. 193–229.
Stasinopoulos, Mikis, Bob Rigby, Calliope Akantziliotou & Vlasios Voudouris. 2015. Generalized additive models for location, scale and shape. *R package version* 4.2-7.
Stevens, Kenneth N. 1971. Airflow and turbulence noise for fricative and stop consonants: Static considerations. *Journal of the Acoustical Society of America* 50(4). 1180–1192.
Stevens, Kenneth N. 1989. On the quantal nature of speech. *Journal of Phonetics* 17. 3–45.
Strycharczuk, Patrycja, Marijn Van't Veer, Martine Bruil & Kathrin Linke. 2013. Phonetic evidence on phonology-morphosyntax interactions. *Journal of Linguistics* 50(2). 403–452.
Takemoto, Hironori, Kiyoshi Honda, Shinobu Masaki, Yasuhiro Shimada & Ichiro Fujimoto. 2006. Measurement of temporal changes in vocal tract area function from 3D cine-MRI data. *Journal of the Acoustical Society of America* 119(2). 1037–1049.
Tomás, Navarro Tomás. 2004. *Manual de pronunciación española*, 28th edn. Madrid: Consejo Superior de Investigaciones Científicas.
Torreblanca, Máximo. 1986. La 's' sonora prevocálica en el español modern. *Thesaurus* 41. 59–69.
Torreira, Francisco & Mirjam Ernestus. 2011. Realization of voiceless stops and vowels in conversational French and Spanish. *Laboratory Phonology* 2(2). 331–353.
Torreira, Francisco & Mirjam Ernestus. 2012. Weakening of intervocalic /s/ in the Nijmegen Corpus of casual Spanish. *Phonetica* 69(3). 124–148.
Toscano Mateus, Humberto. 1953. *El español en el Ecuador*. Madrid: Revista de Filología Española.
Umaña Aguilar, J. 1981. *Variable vibrants in middle-class Costa Rican Spanish*. Washington, DC: Georgetown University master's thesis.
Vargas, Carlos A. 1974. El uso de los pronombres vos y usted en Costa Rica. *Revista de Ciencias Sociales* 8. 7–30.
Vásquez Carranza, Luz M. 2006. On the phonetic realization and distribution of Costa Rican rhotics. *Revista de filología y lingüística de la Universidad de Costa Rica* 32(2). 291–309.
Vega González, Rómulo A. 1995. El voseo y tuteo en la televisión de Costa Rica y Argentina. *Revista Comunicación* 8(1). 45–51.
Villegas, Francisco. 1963. The voseo in Costa Rican Spanish. *Hispania* 46(3). 612–615.
Watt, Dominic, Anne Fabricius & Tyler Kendall. 2011. More on vowels: Plotting and normalization. In Marianna Di Paolo & Malcah Yaeger-Dror (eds.), *Sociophonetics: A student's guide*, 107–118. New York, NY: Routledge.