
RESEARCH PAPER

sC-clusters in Brazilian Portuguese

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This paper discusses word-initial (sibilant + consonant) sequences that may or may not be preceded by a vowel in Brazilian Portuguese, as, for example, in *escola* [is'kɔlə] ~ [skɔlə] 'school' or *Skype* [is'kajpi] ~ [skajpi]. They will be referred to as sC-clusters. The vowel-zero alternation in word-initial sC-clusters is an optional phenomenon in BP, which affects native and loan words at different rates. This study tested the hypothesis that the segmental string in word-initial sC-clusters differs for native and loan words, and that such a difference could be captured by the experimental analysis. Results showed that the vowel is shorter in loan words than in native words. Results also showed that when the vowel is not manifested, the sibilant is longer than when a vowel occurs. It is suggested that the durational properties of high vowels and sibilants characterize phonetic detail, which plays a role in the implementation of the vowel-zero alternation in sC-clusters in BP. Results were examined in light of Kaye's (1992) representational model and Exemplar Models. The paper also indicates the relevance of experimental investigation in phonology, as suggested by Laboratory Phonology approaches.

Keywords: vowel deletion; epenthesis; reduction; representation; phonetic detail

1. Introduction

This paper discusses word-initial (sibilant + consonant) sequences in Brazilian Portuguese (BP) which may or may not be preceded by a vowel, i.e., sC-clusters. A set of words with sC-clusters in BP are native words, as in *escola* [is'kɔlə] ~ [skɔlə] 'school'. Another set of words comprise loan words, as in *Skype* [is'kajpi] ~ [skajpi]. These examples show that, in both native and loan words, the word-initial vowel may or may not be pronounced. Cases involving native words are assumed to have vowel deletion, whereas loan words are subject to epenthesis. In either case, the word-initial vowel-zero alternation would be transcribed by phonetic symbols as: [isC] ~ [sC].

Several works have pointed out that phonetic symbols may not adequately capture the content of segmental strings (Derwing 1992; Coleman 2002; Port 2007; 2011; Munson et al. 2010). Experimental investigation based on Laboratory Phonology principles provides a much more accurate description of segmental strings than discrete phonetic symbols, since it provides detailed information about segments (Scobbie et al. 2000; Albano 2017).

This paper posits the hypothesis that the segmental string in sC-clusters would differ in native and loan words, and that such a difference could be captured by the experimental analysis. It is suggested that the durational properties of high vowels and sibilants characterize phonetic detail, which plays an important role in the implementation of the vowel-zero alternation in sC-clusters in BP. Furthermore, this paper intends to contribute to the debate on the representation of word-initial sC-clusters (Kaye 1992; Harris 1994; Pierrehumbert 1994; Sanoudaki 2010; Goad 2011; Hermes, Mücke & Grice 2013; Polgárdi 2017; Freitas 2019).

This paper is organized as follows: section two discusses the representational nature of sC-clusters and motivates the experimental investigation. The third section presents the methodology. In the fourth section, the experimental results are presented in order to contribute to the debate on the role of phonetic detail in phonological representations. It also addresses the relevance of experimental investigation in Phonology.

2. The representation of word-initial sC-clusters

sC-clusters posit an interesting problem to phonological theory regarding their syllabification. This is because they could be syllabified either as a tautosyllabic cluster, i.e., [sC], or as a heterosyllabic cluster: [s.C]. As noted by Zec (1995), Topintzi (2010) and Goad (2011), the representation of sC as a tautosyllabic cluster violates sonority constraints in branching onsets, thus being not appropriate. In most languages, word-internal sC-clusters are said to be heterosyllabic (Goad 2011). However, word-initially, the syllabification of sC-clusters as heterosyllabic has proven to be controversial.

Kaye (1992) is a seminal work on this topic. He claims that sC-clusters represent a heterosyllabic cluster, word-internally as well as word-initially. Word-internally, the nucleus which precedes the sibilant in sC-clusters may or may not be filled. Word-initially, an empty nucleus precedes the sC-clusters. He initially argues against the branching onset syllabification by showing that in Southern British English [j] does not occur after a tautosyllabic cluster – as in *plumage* or *glue*. So, if sC-clusters were branching onsets, then [j] would not be expected to occur after sC-clusters as in *stupid* or *skew*. However, [j] does occur after word-initial sC-clusters in Southern British English: *st[j]upid* and *sk[j]ew*.

As it is consensual that word-internal sC-clusters are heterosyllabic (Goad 2011), Kaye (1992) focuses on the interpretation of word-initial sC-clusters. He provides substantial evidence from Italian, European Portuguese and Ancient Greek for word-initial sC-clusters to be syllabified as heterosyllabic clusters. Further evidence for this claim is also provided for Italian (Hermes, Mücke & Grice 2013) and for French (Prince 2014).

European Portuguese (henceforth EP) provides evidence for word-initial sC-clusters to be heterosyllabic, as discussed by Kaye (1992). The negative prefix in EP is [in] when the word begins with a vowel: *inacabado* [inaka'badu] 'unfinished'. When the word begins with a single consonant, or with a branching onset, the negative prefix is the nasal vowel [ĩ]: *incapaz* [ĩka'paʒ] 'incapable' or *intratável* [ĩtra'tavel] 'unsociable'. Words that begin with sC-clusters in EP behave in the same way as those that begin with a vowel by receiving the negative prefix [in]: *inesperado* [inʃpe'radu] 'unexpected'. Notice that a word like *esperado*, formerly had an initial vowel in EP, which is not pronounced any longer: [ʃpe'radu]. Although the initial vowel in *esperado* is not pronounced, it plays a role in the phonological representation of *inesperado* [inʃpe'radu] 'unexpected', as it receives the prefix [in] which accompanies vowels.

The representation of sC-clusters in EP has been an interesting point of debate as the sibilant may be either alveopalatal or alveolar, depending on whether it is a native or a loan word (D'Andrade & Rodrigues 1999; Henriques 2012). Native words begin with an alveopalatal sibilant, as in *esperado* [ʃpe'radu] 'expected', whereas loans begin with an alveolar sibilant, as in *stress* ['stres] or *snob* ['snɔb] (D'Andrade & Rodrigues 1999). This indicates that word-initial sC-clusters, in native and loan words, differ in EP with regard to the initial sibilant.

In BP, word-initial sC-clusters also occur in native and loan words. Native words, such as in *esperado* [ispe'radu] 'expected', are subject to weakening and loss of the word-initial high front vowel: [spe'radu]. Loan words, which present sC-clusters in BP, are said to have an epenthetic vowel word-initially to prevent an illicit cluster formed by a (sibilant + consonant). The epenthetic vowel would provide an acceptable syllable in BP: *Skype* as [isk]ype (Viana 1904; Said Ali 1931; Câmara Jr. 1970; Bisol 1999; Collischonn 2000;

Collischonn & Schwindt 2005). Notice that both native and loan words may be pronounced with or without a word-initial vowel. A question to be posited is whether native and loan words are phonologically represented in like manner or differently in BP. This is one of the contributions of this paper.

Kaye's (1992) proposal offers a categorical view as to whether a vowel occurs or not in word-initial sC-clusters. When the vowel occurs, the nucleus has phonetic content. When the vowel does not occur, an empty nucleus occurs, preceding the sibilant. Another theoretical perspective that also accounts for the expected outcome of vowel-zero alternation in sC-clusters in BP is that of Exemplar Models (Johnson 1997; Pierrehumbert 2001; 2002; Bybee 2001; 2002; 2006; 2013; Foulkes & Docherty 2006; Wedel 2006; Hanique, Aalders & Ernestus 2013; Ernestus 2014; Cristófaró Silva & Gomes 2017). From an Exemplar Model perspective, vowel weakening and loss is gradient, so that there might be temporal reorganization of segmental material. Exemplar Models also suggest that native and loan words have different representations as they are stored as different sets of exemplars, as will be discussed later. This paper considers how these two models account for the word-initial vowel-zero alternation in sC-clusters in BP. Following current tendencies for experimental investigation in Phonology, it was posited that there would be differences in the production of sC-clusters in native and loan words in BP, and that such differences might be experimentally captured. The next section presents the methodology adopted in this work.

3. Methodology

A picture-naming experiment was designed to examine the segmental string sC-clusters. Experimental stimuli consisted of 30 words. Sibilants in sC-clusters were followed by a voiceless stop: [p, t, k].¹ A set of fifteen items were selected from native and loan words, totalling 30 experimental stimuli, which were all nouns. Five stimuli were equally distributed for each of the stops [p, t, k] in native and loan words.

As loan words reflect an innovative pattern, which comprises few words, a set of 15 words were initially selected for this pattern based either on Houaiss (2009) or on the name trademarks or products that are widely available in Brazil. The other 15 words were native and chosen by their phonological similarity to the loans. The aim was to balance the words by the number of syllables and syllable structure as much as possible. The median value of the number of syllables for all of the 30 stimuli is 4 syllables. For native words, the mean value is 3.8 syllables (sd = 1.22; cv = 31.1) and, for loan words, the mean value is 3.93 syllables (sd = 1.74; cv = 45.8). Stimuli are presented in **Table 1**.

Table 1: Stimuli for native and loan words.

Loan words			Native words		
[p]	[t]	[k]	[p]	[t]	[k]
espaço	estádio	escada	spa	status	skate
espada	estojo	escama	spaghetti	stop	Sky
espetáculo	estrada	escola	SporTV	stress	Skype
espiga	estrela	escravo	spray	stripper	Skol
esponja	estudante	esqueleto	Sprite	strogonoff	squeeze

¹ In BP in general, and specifically in the community used for the study, the sibilant is always pronounced as an alveolar fricative in a postvocalic or coda position. In some areas of Brazil, such as Rio de Janeiro or some of the Northern states, a sibilant may be alveopalatal in heterosyllabic clusters (Cristófaró Silva 2013). Voice agreement is also observed depending on the consonant that follows the sibilant. It was therefore decided that the experiment would be limited to just voiceless sibilants.

The thirty experimental stimuli listed in **Table 1** were presented along with thirty-five filler items, which aimed to disguise that the purpose of the experiment was to investigate sC-clusters. A set of five fillers was presented to all participants as a training phase to familiarize them with the experiment. The remaining 30 fillers consisted of BP native and loan words in equal measure. Stimuli were randomized for each participant using the *sort_rand* macro for *Microsoft PowerPoint 2016*.

Data was collected from twenty-four participants, 12 female and 12 male, Brazilian Portuguese native speakers from the Belo Horizonte metropolitan region, in the state of Minas Gerais, Brazil.² Participants' ages ranged from 18 to 28 years old (mean age: 22.5 yrs.). All participants were graduate or undergraduate students from the Federal University of Minas Gerais, and claimed not to have any hearing or speech disorders.

Participants were instructed to say the word that corresponded to the picture they were shown on a laptop screen. Audio recordings of speakers' productions were obtained with a Zoom H4N recorder (sampling rate: 44,1 KHz; quantization: 16 bits; file format: WAV). Each slide was automatically presented on the screen for 2.5 seconds using *Microsoft PowerPoint*. Written stimuli were presented together with the picture in Arial font, size 88 pt. Picture stimuli consisted of figures of approximately 10 cm in size. Each stimulus was presented twice during the task, one immediately after the other. Initially, the slides displayed the picture and its corresponding written form. The second stage of the presentation consisted of pictures being presented without the written input. In this second stage, the stimuli contained the following instruction: "Say the word you just said again, out loud". Consider **Figure 1**.

Data was collected in an acoustically treated room at CEFALA³ in July 2018. Every participant completed the task in less than 15 minutes. Participants signed a consent form authorising their data to be used for scientific purposes and stating that their participation in the experiment was voluntary. A total of 1,440 audio files were collected (24 participants \times 30 stimuli \times 2 repetitions). The samples were edited and annotated manually using Praat TextGrids (Boersma & Weenick 2019).

Results were extracted from audio files by a script adapted from Lennes (2002). Whether or not a vowel was present in sC-clusters was determined automatically by the identification of any periodic interval in the sound wave at the beginning of a word. When a vowel was attested, its durational value was registered. The duration of the sibilant was also automatically extracted by the script when an energy distribution in frequency bands ranging from 5 Hz to 8 Hz was attested. The end of the sibilant was determined by the

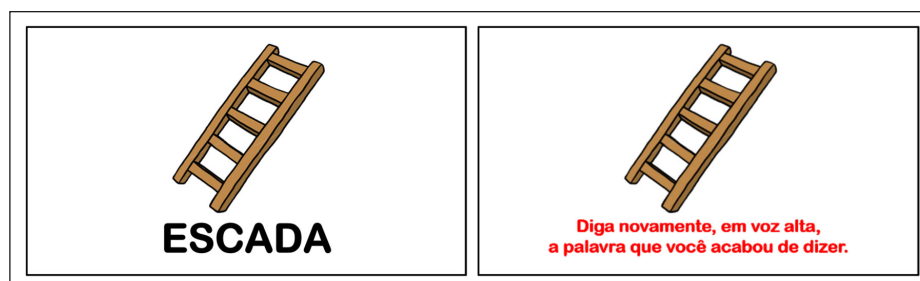


Figure 1: Example of slides used for data collection.

² This research has been approved by the ethics committee from the Universidade Federal de Minas Gerais, reference number: CAAE: 15116119.9.0000.5149.

³ Centro de Estudos da Fala, Acústica, Linguagem e música (literally translated as Centre of Studies on Speech, Acoustics, Language and Music) of the Federal University of Minas Gerais.

beginning of the stop in the sC-cluster, which is characterized by lack of energy in the acoustic signal.

Graphical and statistical analyses were carried out using R software (R Core Team 2017), by employing mixed-effects models (Baayen, Davidson & Bates 2008) using the lme4 package (Bates et al. 2015). The statistical analysis is aligned with proposals presented by Oushiro (2017) and Godoy, Weissheimer & Mafra (2018). The best fitting models were selected to test the hypothesis that there would be differences in the production of sC-clusters in native and loan words in BP. In order to test vowel absence rates, a mixed-effect logistic regression model was fit, including the presence of the initial vowel as dependent variable, word origin (loan or native) as a fixed effect and the intercepts of lexical item and speaker as random effects. To test the duration of the initial vowel and of the sibilant, mixed-effect linear models were fit, including the initial vowel or the sibilant as a dependent variable, the word origin, the presence of the initial vowel (for sibilant analysis only) and the duration of the word as fixed effects, and the intercepts of lexical item and speaker as random effects. Nested models were compared using a likelihood-ratio test that respected a chi-squared distribution. For all statistical tests, the confidence interval was 95%, or $p < 0.05$.

4. Results and discussion

Results showed that an initial vowel was not present in 57.4% of all sC-clusters, indicating that, although word-initial sC-clusters were formerly considered to be illicit in BP, they are now being manifested in more than half of the data examined. A word-initial high vowel was absent in 75.8% of cases in loan words, whereas a vowel did not occur in 39% of native words ($\chi^2 = 56.835$, $p < 0.001$).

Kaye's (1992) representational model makes no prediction as to the different rates of vowels in native and loan words. This is because, in his model, the vowel would be either present or absent, categorically. Exemplar Models, on the other hand, argue that clusters of exemplars reflect experience with language. The general rate of exemplars without a word-initial vowel (57.4%) indicates a tendency of BP to favour word-initial sC-clusters. Exemplars without an initial vowel are more robust in loan words (75.8%) than in native ones (39%). This result suggests that loan words are more advanced than native words in accommodating word-initial sC-clusters without a vowel. Results also suggest that native and loan words may present different representations. This is because native words are represented in a set of exemplars distinct from loan words. This issue will be addressed later.

An important argument in Kaye's (1992) proposal, is that although a vowel is not overtly present in sC-clusters in EP, it is as if it were, as the negative prefix in sC-clusters is [in], which occurs when a word begins with a vowel: *inacabado* [inaka'badu] 'unfinished' and *inesperado* [inʃpe'radu] 'unexpected'. If sC-clusters began with a consonant, the expected negative prefix would be [ĩ], as in *incapaz* [ĩka'pas] 'incapable' or *intratável* [ĩtra'tavel] 'unsociable', which is not the case (cf. *[ĩʃpe'radu]). Exemplar Models account for these facts by assuming that each word is lexically stored in clusters or sets of exemplars. Thus, in EP, words like *esperado* [ʃpe'radu] 'expected' and *inesperado* [inʃpe'radu] 'unexpected' are both lexically listed, each one associated with its set of exemplars. Generalizations about affixes emerge from relations formed from the semantic and phonetic similarity of sets of exemplars (Bybee 1995; 2001; 2010). A word like *inesperado* formerly had an initial vowel, and the negative prefix was [in]. As the initial vowel was not manifested any longer, the prefix [in] remained, occurring as it was, already part of the cluster of exemplars for *inesperado*. There would be no explanation for the suffix to be altered, so it remains as it formerly was.

BP offers further evidence for assuming that the prefix [in] is lexically listed. The word *inesperado* is pronounced as [inespe'radu] in BP. As expected, the negative prefix [in] occurs for a word beginning with a vowel. Notice that, in this case, a vowel [e] follows the negative prefix, which is then followed by a sC-cluster. It is interesting to observe that, without the negative prefix, a pronunciation like *[espe'radu], with an initial [e], does not occur in BP (Bisol 1981; Dubiela 2016), but rather a high vowel-zero alternation is observed: [ispe'radu] ~ [spe'radu]. These facts show that the word *esperado* has had its initial vowel raised [e]sperado > [i]sperado and, more recently, the initial high vowel has undergone reductive processes: [is]perado > [s]perado. On the other hand, in the word *in[e]sperado*, the vowel which follows the prefix [in] remains as [e], without being raised to [i], or being cancelled. This indicates that, although *esperado* and *inesperado* are semantically and morphologically related, they are categorized in different sets of exemplars. Exemplar Models also account for the claim made by Kaye (1992) that word-initial sC-clusters behave as if they are preceded by a vowel. However, rather than positing an abstract word-initial empty nucleus, Exemplar Models posit that the distribution of the negative prefix follows from the organization of different sets of exemplars.

Considering the rates for vowel-zero alternation presented above, the next step was to test the hypothesis that there would be differences in the production of sC-clusters in native and loan words in BP, and that such a difference might be captured experimentally. In order to test this hypothesis, unstressed high vowel weakening and loss in BP has to be addressed (Lemle 1966). It is known in the literature that, in several languages, high vowels may devoice when adjacent to voiceless consonants (Dauer 1980; Tsuchida 1994; Fagyal & Moisset 1999; Kondo 2005; Andreeva & Koreman 2007; Chitoran & Iskarous 2008). This is also the case in BP (Bisol & Hora 1993; Leite 2006; Dias & Seara 2013; Nascimento 2017). A number of case studies have shown that unstressed high vowels undergo vowel weakening and loss in BP when adjacent to a voiceless sibilant: word-finally as in *passe* ['pasi] ~ ['pas] 'pass' (Meneses & Albano 2015); word-medially as in *similar* [simi'lar] ~ [smi'lar] 'similar' (Souza 2014) and word-initially as in *estado* [is'tadu] ~ ['stadu] 'state' (Freitas 2019). Vowel weakening and loss are said to reflect gesture magnitude reduction followed by gestural overlap involving the high vowel and the sibilant, which is understood as gestural reconfiguration (Souza 2014; Meneses & Albano 2015). This view differs from previous ones which assumed that vowel deletion would take place, i.e., the vowel would be either present or absent. The experimental investigation will contrast the categorical and the gradient proposals for vowel deletion. If vowel deletion is categorical, it is expected that it has no impact on adjacent segments. The gradient view assumes that vowel deletion is gradual and may be experimentally observed. It is also known that segmental deletion may alter the segmental representation of adjacent sounds (Meneses & Albano 2015; Cristófaró Silva et al. 2017). Thus, in an Exemplar Model approach, it is expected that, when the high vowel is deleted, adjacent segments may be affected.

The experimental investigation considered two aspects: the duration of high vowels as well as of sibilants. It has been reported that epenthetic vowels – which are high vowels – are shorter than regular vowels in BP (Cristófaró Silva & Almeida 2008; Cantoni 2015). Thus, it is expected that the duration of high vowels will differ in native and loan words in sC-clusters. It is also expected that vowel weakening will be gradual, so that the duration of high vowels will be variable.

The second aspect to be experimentally examined was the duration of sibilants when a vowel occurs or not, within a single category, either in native or in loan words. It is expected that sibilants will be longer when the vowel is not present in sC-clusters. This is intended to address whether the segmental loss of the vowel has an impact on adjacent segments, i.e., the duration of the sibilant.

In order to test these hypotheses, the durational values of the vowel and the sibilant were considered for native and loan words.⁴ The proportional durations of vowels and sibilants in relation to the rest of the word, for native and loan words, were considered: the duration of the vowel (when it occurs), the duration of the sibilant, and the duration of the word. **Table 2** presents the mean value for the each of the measurements for native and loan words, and whether or not a vowel was produced.

Considering the results shown in **Table 2**, a ratio between the mean duration of the vowel and the sibilant vs. the mean duration of the whole word was calculated. The mean duration of the vowel and the sibilant was subtracted from the whole duration of the word, a value which was referred to as the “rest of the word”. The final result is the mean percentage that the vowel and the sibilant occupy in the word, as show in **Figure 2**.

The two top bars in **Figure 2** report cases where the vowel was produced, and the two bottom bars present results when the vowel was not produced, in loan and native words respectively. The result expressed in the two top bars addresses the first experimental aspect to be investigated, showing that, when an initial vowel occurs, it is shorter in loan words (7.1%) than in native ones (9.7%). Thus, the duration of the vowel is different in cases of epenthesis and vowel deletion ($\chi^2 = 18.73$, $p < 0.01$). This result corroborates previous findings in the literature which found that epenthetic vowels are shorter than regular

Table 2: Mean values for vowel, sibilant and word duration sampled by vowel occurrence and native/loan words.

vowel produced	word origin	vowel (ms)	sibilant (ms)	word (ms)
yes	loan	48.8	98.2	691
yes	native	68.5	98	703
no	loan	–	112	667
no	native	–	107	637

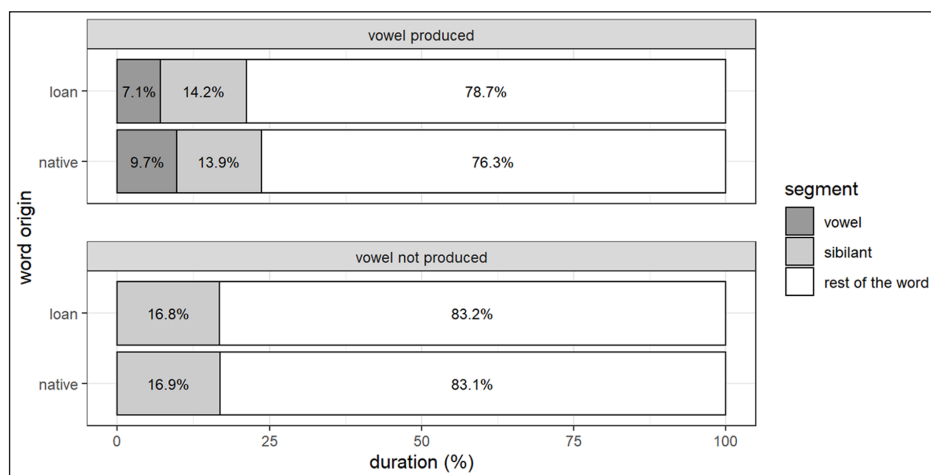


Figure 2: Relative duration by vowel occurrence for native/loan words.

⁴ The durational values of the plosives [p, t, k] were not considered in this paper due to methodological aspects. Cristófaró Silva et al. (2019) listed VOT values for voiceless plosives in BP, which were obtained in several works, showing a great variation in values: [p] 11 ms – 37.67 ms; [t]: 15 ms – 36.52 ms and [k]: 35 ms – 58.05 ms. Recent works showed an emergent aspiration in voiceless plosives in BP (Alves and Zimmer 2015; Kupske 2017). Furthermore, none of the works mentioned above refer to the BP variety reported in this paper. Considering these facts, the investigation was constrained to the initial high vowel and the sibilant in sC-clusters.

vowels in BP. Although vowel lengthening is not a contrastive property of BP phonology (Azevedo 2005), it can be posited that vowel duration plays a role in characterising the phonetic detail in word-initial sC-clusters in loan and native words in BP. Although vowel duration is a sub-phonemic property in BP, results show that shorter vowels occur in loan words, and longer vowels occur in native ones.

The representational model presented in Kaye (1992) cannot account for the patterns observed for vowel duration in sC-clusters, as sub-phonemic properties are not part of phonological representations in his model. On the other hand, Exemplar Models, which include redundant and variable properties as part of phonological representations, account for the experimental results that were just presented. The sub-phonemic property of vowel duration, where high vowels in loan words are shorter than in native words, offers evidence for sC-clusters in loan words to be grouped in a set of exemplars, which is different from the set of exemplars for native words. Within Exemplar Models approaches, vowel duration characterizes the fine phonetic detail related to high vowels in word-initial sC-clusters in BP. Thus, Exemplar Models account for the different patterns of vowel duration in sC-clusters in loan and native words. Exemplar Models also explain why loan words present a higher rate of vowel deletion (75,8%) than native words (39%). Loan words present short high vowels, which are more prone to devoicing, weakening and deletion than unstressed regular high vowels, which occur in native words (Cristófaró Silva & Almeida 2008; Cantoni 2015). The gestural reconfiguration that yields to vowel deletion is implemented at higher rates in loan words as the vowel is short. In native words, lower rates of vowel deletion are observed as the vowels subject to reductive processes are longer. Furthermore, as more and more words present a word-initial sibilant, i.e., the high vowel does not occur, Exemplar Models predict that more robust exemplar clusters are formed, which explains the general tendency of BP to favour word-initial sC-clusters (57.4%).

A comparison of sC-clusters in Brazilian and European Portuguese shows that different solutions were found to phonologically accommodate word-initial sC-clusters in each of these varieties. In EP the sibilant in loan words is an alveolar fricative, as in *stress* ['stres] or *snob* ['snɔb], whereas in native words, an initial alveopalatal fricative occurs, as in *esperado* [ʃpe'radu] 'expected' (D'Andrade & Rodrigues 1999). Alveolar and alveopalatal sibilants are in contrast in Portuguese, as in *assa* ['asə] 'to bake' and *acha* ['aʃə] 'to find'. Therefore, the phonological solution to accommodate word-initial sC-clusters in EP involves phonemic differences.

Brazilian Portuguese also accommodates sC-clusters phonologically in different ways, and such a difference is expressed by the durational properties of the initial vowel in loan and native words, as show in the top two bars in **Figure 2**. This result indicates that not only contrastive properties of sounds are phonologically represented, but also that sub-phonemic properties captured by the experimental investigation may characterize phonetic detail that is relevant in shaping phonological representations, as predicted by Exemplar Models (Bybee 2001; Johnson 2007; Bermúdez-Otero 2007; Cole & Hualde 2011). The facts discussed above indicate that Exemplar Models account for the experimental results reported for vowel duration, whereas the representational model presented in Kaye (1992) does not.

Results presented in **Figure 3** also show that sibilants in loan words have a longer duration when a vowel does not occur (16.8%), than when a vowel is produced (14.2%). In like manner, in native words, sibilants have a greater duration when a vowel is not produced (16.9%), than when a vowel is produced (13.9%). Thus, sibilants in sC-clusters are longer when the vowel is not produced (16.8% and 16.9%), than when the initial vowel is produced (14.2% and 13.9%), and that such a difference is statistically significant ($\chi^2 = 110$, $p < 0.01$ for loan words; $\chi^2 = 123$, $p < 0.01$ for native words). This result

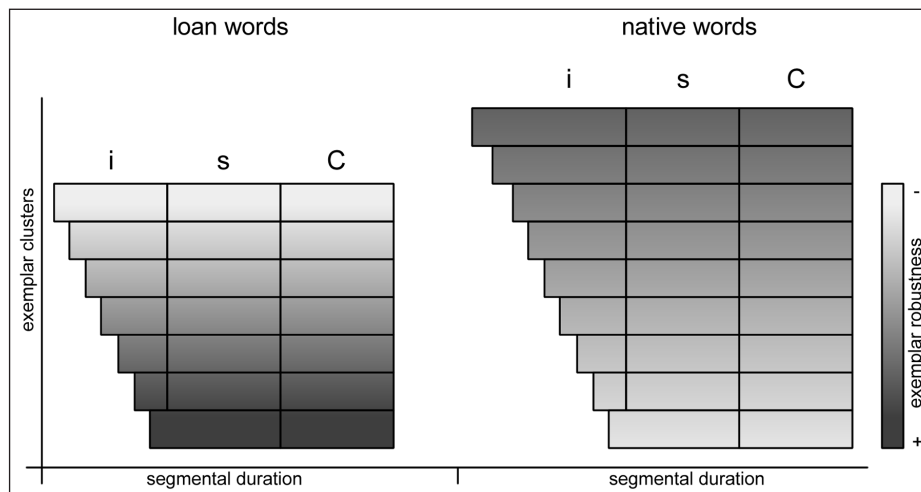


Figure 3: Exemplar representations for sC-clusters.

addresses the second aspect investigated experimentally, showing that sibilants are longer when a vowel does not occur.

Both Kaye (1992) and Exemplar Models account for the lengthening of the sibilant when the word-initial vowel is not manifested. Within Kaye's (1992) model, the sibilant will occupy its original skeletal position and the nuclear position to its right. Thus, the sibilant occupies two skeletal positions (Polgárdi 2017), which can be interpreted as a long sibilant.

In Exemplar Models, the lengthening of the sibilant, which occurs when the vowel is not manifested, is accounted for by the gestural reconfiguration involving the weakened high vowel and the adjacent sibilant in sC-clusters (Meneses & Albano 2015). Gestural reconfiguration is attested in several other contexts in BP, and it is also observed in other languages (Dauer 1980; Tsuchida 1994; Fagyal & Moisset 1999; Kondo 2005; Andreeva & Koreman 2007; Chitoran & Iskarous 2008). Within Exemplar Models the gestural reconfiguration characterizes phonetic detail, which can be modelled in different sets of exemplars for loan and native words. Consider **Figure 3**.⁵

Figure 3 illustrates sets of exemplars for sC-clusters, where the diagram on the left represents exemplars for loan words and the diagram on the right represents a set of exemplars for native words. The vertical axis indicates the robustness of exemplars, where darker shades show more robust exemplars, i.e., exemplars with a high rate of experienced cases. Lighter shades reflect exemplars which have been experienced at lower rates, thus are less robust. The horizontal axis indicates segmental duration. Each segment was associated with a specific box, which appears to characterize discrete segments. In fact, this is a limitation of the graphic design, as the boxes can be understood as a continuum, which reflects the speech chain, where gestural reconfiguration of segmental material interacts dynamically (Meneses & Albano 2015).

In both diagrams in **Figure 3**, a high vowel is present in the top rows and no vowel is present in the bottom one. This expresses that the word-initial high vowel may or may not be manifested. The exemplars in between the top and bottom rows show the gradual weakening of the high vowel. The high vowel in loan words on the left present a shorter duration than the high vowel in native words on the right. This intends to capture the experimental result that epenthetic vowels that occur in loan words are shorter than regular vowels that occur in native words.

⁵ This diagram is inspired in Bybee (1995; 2001; 2010) and Johnson (1997).

The diagrams in **Figure 3** also show that a high front vowel is present at higher rates in native words than in loans. This is expressed by the grey shading, where light grey indicates a less robust pattern. The grey shades are intended to reflect the finding that word-initial sC-clusters are favoured in loan words (75.8%), when compared to native ones (39%). The diagram in Figure 5 also expresses that the sibilant has a longer duration when the vowel is not present – as can be seen in the bottom row – than when the vowel is present (cf. previous rows compared to the bottom one). The experimental results, together with the representation in Figure 5, indicate that Exemplar Models offer a comprehensive explanation for vowel-zero alternation in sC-clusters in BP.

Although Kaye's (1992) model accounts for the sibilants being longer when a vowel is not present, it fails in explaining why the vowel is not manifested and why loan and native words present statistically significantly different rates of word-initial vowel deletion. Exemplar Models account for the different rates in the lack of vowels in sC-clusters, as loan and native words are grouped in different sets of independently organized exemplars, whose specific representations include phonetic detail regarding segmental duration'. Exemplar Models also accommodate experimental results, by explaining why high vowel reduction and loss occurs as a consequence of gestural reconfiguration, which is gradually implemented. Finally, Exemplar Models explain the lengthening of the sibilant by the interaction of the high vowel and adjacent sibilant.

Representational models, as the one proposed by Kaye (1992), contributed enormously to the development of Phonology. Besides the innovative representation in several multi-layered tiers, which provided a visual representation for phonological processes, such models contributed significantly to the expansion of knowledge of syllable typology, as well as to the understanding of the relationship between segments and prosody. However, a major limitation of representational models is that only discrete phonological segments, or empty skeletal positions, are lexically represented. In representational models, allophonic variation is derived as part of phonological processes, so that sub-phonemic, or fine phonetic detail, is not part of phonological representations.

Exemplar Models provide accounts for these limitations by assuming that detailed information is part of cognitive representations. In phonological terms, this can be translated as the incorporation of fine phonetic detail in phonological representations, as well as the lexical implementation of phonological phenomena. A prediction which follows from this view is that variation is intrinsic to language, where Phonetics and Phonology interact closely. Sets of exemplars have a dynamic organization, so that emergent phonological phenomena evolve gradually towards a specific direction, as words adopt the new pattern. In the case study presented in this paper, the emergent pattern is a word-initial (sibilant + consonant) sequence which occurs in native and loan words in BP. Variation involves whether or not a vowel is manifested in sC-clusters. The pattern with word-initial sC-clusters evolves in the lexicon, displaying phonetic gradual implementation, which can be captured by the experimental analysis presented.

An interesting aspect of experimental investigation in phonology is related to the presentation of results. Phonetics and phonology typically use discrete symbols to report results (Derwing 1992; Coleman 2002; Port 2007; 2011; Munson et al. 2010). Phonetic detail is typically reported in Phonetics, but not in Phonology. The different durational properties of vowels in loan and native words, as well as the lengthening of the sibilant when the vowel does not occur, cannot be expressed by IPA symbols, unless diacritics are used, which is not expected in phonological representations. Thus, IPA symbols do not characterize the phonological properties of vowel-zero alternation in sC-clusters reported in this paper. The full understanding of experimental results usually requires

a model where Phonetics and Phonology are integrated (Demolin 2005). The trend towards experimental approaches in Laboratory Phonology suggests a new way not only to methodological design, but also to the presentation of results in graphs or numerical tables. A representational proposal for Exemplar Models is proposed in this paper. Like any preceding theoretical approach, Exemplar Models will uncover interesting and unknown facts about the sound systems of languages.

5. Conclusion

The investigation presented in this paper contributes to a better understanding of vowel-zero alternation in word-initial sC-clusters in BP. Vowel-zero alternation is an optional phenomenon in BP, where different rates of word-initial sibilants are attested in native (39%) and loan words (75.8%). The duration of sC-clusters was experimentally investigated. When the initial high vowel occurs, it is shorter in loan words than in native words. Results also showed that vowel weakening and loss is variable, which indicates that it is gradually implemented. Additionally, experimental results showed that sibilants are longer when a high vowel does not occur, rather than when it does.

Kaye's (1992) representational model and Exemplar Models were considered to account for the experimental findings. Kaye's (1992) representational model makes no prediction as to the different rates of vowel deletion. In his model, the vowel is either present or absent, which suggests that vowels would have a fixed duration. His model does not explain either why the vowel is not manifested. Exemplar Models, on the other hand, account for the higher rate of word-initial sibilants in loan words (75.8%) than native ones (39%), as the short duration of high vowels in loan words are more prone to weakening and loss, providing more robust exemplars without a word-initial vowel. Experimental results also showed that the duration of high vowels is variable, not fixed, which captures the gradual implementation of vowel-zero alternation, as predicted by Exemplar Models. Exemplar Models also account for why a high vowel is not manifested in word-initial sC-clusters, by suggesting that gestural reconfiguration takes place between the high vowel and the adjacent sibilant.

Kaye's (1992) representational model accounts for the lengthening of sibilants when the vowel is not manifested, as a sibilant would occupy its position, as well as the position which was formerly occupied by the vowel. However, Kaye's analysis fails in providing an explanation as to why sibilants are lengthened. Based on Exemplar Models, the proposal presented in this paper explains the lengthening of the sibilant by gestural reconfiguration involving the high vowel and the sibilant.

The durational properties of high vowels and sibilants discussed in this paper characterize phonetic detail, which plays an important role in the implementation of the vowel-zero alternation in sC-clusters in BP. Thus, sub-phonemic properties captured by the experimental investigation may characterize phonetic detail that is relevant in shaping phonological representations, as predicted by Exemplar Models (Bybee 2001; Johnson 2007; Bermúdez-Otero 2007; Cole & Hualde 2011). Additionally, results reported in this paper support the view that discrete phonetic symbols do not provide an accurate description of segmental strings (Derwing 1992; Coleman 2002; Port 2007; 2011; Munson et al. 2010).

A number of issues could be investigated in future studies, such as examining the lexical implementation of the vowel-zero alternation in SC-clusters, where word frequency and phonological similarity effects would be taken into consideration. Unfortunately, the present study was not methodologically designed to explore these issues.

It will also be pertinent to examine to what extent the phenomenon investigated in this paper will apply when the sibilant is voiced in loan words, as in *slide* [iz^hlajdʒi] 'slide

(presentation)', and native words, as in *esmola* [iz'mɔla] 'alms'. It is expected that the gestural reconfiguration involving the high vowel and sibilant will be less favoured when the sibilant and adjacent consonant are voiced. This will be in line with findings in the literature that high vowel devoicing is favoured when adjacent to voiceless segments (Kondo 2005; Leite 2006; Dias & Seara 2013; Souza 2014; Meneses & Albano 2015; Nascimento 2017).

As reported in the methodology, the stimuli were presented to participants with and without their corresponding orthographic form. Freitas's (2019) results showed that whether or not the orthographic input was presented, it did not affect the production of sC-clusters in loan ($\chi^2 = 0.96$, $p = 0.62$) and native words ($\chi^2 = 1.13$, $p = 0.57$). Future work could consider in detail the role of orthography in the production of sC-clusters.

Future work could also consider the gestural reconfiguration of high vowel and sibilants in other varieties of BP in the several environments in which it takes place: word-finally as in *passe* [ˈpasi] ~ [ˈpas] 'pass' (Meneses & Albano 2015); word-medially as in *similar* [simiˈlar] ~ [smiˈlar] 'similar' (Souza 2014) and word-initially as in *estado* [isˈtadu] ~ [ˈstadu] 'state'. It is expected that similar results will be found, although the lexical implementation may be different in other varieties.

This paper showed the relevance of experimental investigation in Phonology, as suggested by Laboratory Phonology approaches (Pierrehumbert, Beckman & Ladd 2000; Cohn, Fougeron & Huffman 2012; Albano 2017). Finally, the findings of this paper provide evidence for the role of phonetic detail in shaping phonological representations, as suggested by Exemplar Models (Bybee 2001; 2013; Hawkins 2003; Harris 2007; Bermúdez-Otero 2007; Cole & Hualde 2011).

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Competing Interests

The authors have no competing interests to declare.

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