The Variable Perception of /s/ + Coronal Onset Clusters in Brazilian Portuguese English

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1. Introduction

This study provides a multidisciplinary analysis for the acquisition of /s/ + consonant onset clusters (sC) in second language (L2) phonology, adopting a variationist approach for data collection and analysis that includes insights from a variety of linguistic disciplines, including theoretical phonology, phonetics, psycholinguistics, second language acquisition, and sociolinguistics. More specifically, the study extends a previous investigation that examined the effects of markedness and input frequency in the development of English homorganic /sl/, /sn/ and /st/ among Brazilian Portuguese (BP) native speakers learning English in a classroom environment. These clusters, which do not exist in BP, are of particular relevance to assess the effects of markedness and input frequency because they make opposite predictions regarding their order of acquisition: While markedness (based on Clements' (1990) Sonority Cycle) predicts that the least marked /sl/ and /sn/ should be acquired before the most marked /st/, input frequency predicts the exact opposite, i.e. that the highly frequent /st/ should be acquired before all other (less frequent) clusters (e.g., Bybee, 2001). These predictions were compared with the results obtained in a production study that consisted of sociolinguistically-based interviews with English learners. The results of this study showed that learners acquire /sl/ and /sn/ clusters earlier than the most marked /st/, corroborating the hypothesis that markedness on sonority sequencing, and not input frequency, determines the order of acquisition of sC clusters in L2 development.

In the present investigation, we examine the development of the same homorganic sC sequences from a perceptual perspective. For the purpose of this study, we assume "perception" as the speaker's ability to aurally discriminate between a set of options (e.g., to recognize that while [st] starts with a consonant, [ist] has a vowel initiating the cluster). Influenced by the phonology of BP, in which these sC sequences can only surface if preceded by the default epenthetic vowel in the language: [i] (perceptually indistinguishable from English ɪ in unstressed syllables), BP speakers *variably* process these foreign clusters as preceded by an illusory vowel (i.e., [i]sC; see also Berent et al, 2007; Pitt, 1998 for similar views on perceptual illusions). This view is also in agreement with Best's (1993, 1995) Perceptual Assimilation Model, which posits that when listening to an unfamiliar nonnative feature (in our case, an illicit syllable structure), listeners are likely to perceptually assimilate the foreign form to the closest structure in their native phonology. As customary in variationist studies, we assume that all clusters are not created equal and, depending on each cluster's degree of markedness, perceptual salience or mere frequency in the input, the likelihood of each cluster to occur will vary.

To assess BP speakers' ability to discriminate among the three sC sequences, and between sC versus [i]sC clusters, two forced choice identification experiments were designed. The first study addressed the question of whether BP speakers in general, with no exposure to oral

English, can perceive the distinction between the three sC clusters, namely /st/, /sn/, and /sl/. The results confirm that these speakers have no problem identifying these clusters – they rely on their melodic cues and not on their syllable structures to distinguish them. Based on the assumption that highly marked forms (e.g., /st/) are more likely to be filtered by the L1 phonology (and thus trigger the perception of an illusory vowel [i]), as discussed above, we designed a second forced choice identification experiment in which participants were asked to decide whether the pseudowords that they heard initiated with a consonant (i.e., sC) or with a vowel (i.e., [i]sC). The results of the Goldvarb X (Sankoff et al, 2005) statistical analysis adopted in this study show that, as expected, sC perception increases as a function of increased proficiency. Surprisingly, the results also indicate that English learners are more likely to perceive the most marked (and highly frequent) /st/ over its less marked siblings (/st/ > /sl/ > /sn/), thus contradicting the hypothesis based on markedness involving sonority (/sl/ > /sn/ > /st/). Comparing these results with the predictions based on perceptual salience (/sl/ > /sn/ > /st/) and on a previous study involving production (/sl/, /sn/ > /st/), we conclude that the frequency with which these sequences occur in the input (/st/ > /sl/ > /sn/) best captures the perceptual development of sC sequences in interlanguage. A synopsis of the hypotheses, predictions and results obtained are provided in Table 1, where ">" indicates a hypothetical developmental sequence.

These are the general research questions that we will address in the study: (1) How does the perception of sC onset sequences evolve in the development of English as a second language? (2) What factors contribute to their acquisition? (3) How does the perceptual development of these sequences compare with that found in production and in other studies (e.g., is it gradual, systematic and influenced by general linguistic universals such as sonority sequencing and word size)?

Table 1. sC acquisition: Predictions and results – A summary

Hypothesis	**Developmental Path**	**Prediction**
Markedness Effect	sl > sn > **st**	-Marked = acquired first
Frequency Effect	**st** > sl > sn	+Frequent = acquired first
Perceptual Salience	sl > sn > **st**	+Salient = acquired first
Results		
Production study (Cardoso 2008ab):		sl , sn > **st**
Perception study (this study):		**st** > sl > sn

The paper is organized as follows. We will initially provide an introduction to some of the relevant studies and topics for the analysis of sC perception: The behavior of these clusters in Brazilian Portuguese, in BP-based and other interlanguages, the frequency of each type of sC structure in English input, and the saliency of sC sequences. The aim of this introduction is to contextualize the second part of the paper, where we will describe the two experiments that comprise the perception study and provide our research questions and hypotheses for the perceptual development of sC sequences. This will be followed by the last part of the paper, where we analyze and discuss the results, and provide our general concluding remarks.

2. Background

2.1 sC in Brazilian Portuguese

In Brazilian Portuguese, word-initial complex onsets are restricted to sets of obstruent plus liquid combinations (Ferreira Neto, 2001; Ribas, 2004): /pr/, /br/, /tr/, /dr/, /kr/, /gr/, /fr/, /vr/, /pl/, /bl/, /tl/, /kl/, /gl/, and /fl/. Accordingly, the language disallows sC branching onsets both word-initially and word-internally. Word-internally, the sC cluster syllabifies heterosyllabically as a coda-onset sequence, following a set of general principles on syllabification (e.g., de/s+t/oante → de/s.t/oante 'discordant', where a period "." indicates syllable boundaries). However, when the sC cluster appears word-initially, the same sequence can only surface if it is preceded by an epenthetic [i] (phonetically undistinguishable from English [ɪ]), in which case the sC cluster again syllabifies into two separate syllables. This can be observed in borrowings (e.g., /sl/ide → [is.l]ide 'slide', /st/and → [is.t]ande 'stand') and, diachronically, in modern Portuguese (e.g., from Latin: /st/abiliscere → [is.t]abelecer 'to establish', /st/ellare → [is.t]elar 'related to stars').

As expected, and assuming that second language acquisition is in some aspects directly influenced by the phonology of the L1 (L1 = the initial state; e.g., Archibald, 1993; Pater, 1997; Davidson et al, 2004), we posit that the initial state of sC acquisition will emulate the BP grammar, with a phonology characterized by a ban on word-initial sC clusters. As exposure to the L2 increases, the innovative sC structure is gradually incorporated into the developing system and, consequently, target-like sC sequences gradually and variably emerge. This is the topic that we will address in the following session.

2.2 sC in interlanguage

2.2.1 sC in BP-based English

Despite being the topic of heated debate over the last three decades, it is surprising that the acquisition of sC clusters by Brazilians has only recently received attention by phonologists. Due to space limitations, we present below a summary of some of the main studies involving the acquisition of English sC sequences by BP speakers. Note that under "sC order of acquisition", only the relevant clusters are shown, illustrating a developmental sequence from early to late acquisition (represented by >).

Table 2. sC clusters in BP-based English: Previous studies

Study	Participants	L1	L2	sC order of acquisition
Major (1996)	4 adults	BP	English	**st** > sl
Rebello (1997)	6 adults	BP	English	**st**, sl > sn
Rauber (2006)	10/9 adults	BP*/Spanish	English	sn, sl > **st**
Cardoso (2008ab)	10 adults	BP	English	sl, sn > **st**

Note. The asterisk indicates that there was no significant difference across the sets of clusters in the Brazilian Portuguese group of speakers.

Briefly, the studies illustrated above examined the effect of sonority within each pair of clusters as a determining factor in the development of sC sequences. Assuming a sonority hierarchy that ranges from the least sonorous stops (/t/) to increasingly more sonorous classes

such as that of fricatives (/s/), nasals (/n/), and liquids (/l/) (Clements, 1990), these studies hypothesized that the order of sC acquisition would follow a sequence determined by a combination of two linguistic principles: The Sonority Sequencing Principle (SSP) which, simply put, requires that onsets gradually rise in sonority towards the nucleus (Selkirk, 1984), and the Minimal Sonority Distance, which captures the observation that languages prefer highly sonorous elements in the second position in onset clusters (Clements, 1990). The interaction of these two principles generates a developmental path that predicts that the least marked /sl/ sequence will be acquired before /sn/ (less preferred because its second constituent /n/ is lower in sonority than /l/), which in turn should be acquired before the cluster that violates sonority sequencing because it constitutes a sonority reversal, /st/: /sl/ > /sn/ > /st/.

As the studies in Table 2 illustrate, the patterns observed for the BP-based interlanguages are far from conclusive with regards to the developmental order of sC sqeuences. Focusing on /st/ versus the other SSP-abiding clusters, note that Major (1996) and Rebello (1997) show /st/ at the leftmost (easier) end of the developmental path, thus contradicting the predictions based on sonority. Contrastively, the results of Rauber (2006) and Cardoso (2008ab) illustrate a pattern in which the SSP-violating /st/ is acquired only after the appearance of /sl/ and /sn/, exactly as predicted by a sonority-based analysis: /sl/, /sn/ > /st/. Because Cardoso's studies involved the exact variety of Portuguese and speech community from which the participants included in the perception study were recruited, we assume that his results depicted in Table 2 are representative of the productive phonology of that group of speakers. This will allow us to make more reliable comparisons and generalizations about the nature of these speakers' production and perception grammars.

In sum, the results of the production study reported in Cardoso (2008ab) show that sonority sequencing plays a crucial role in determining the developmental path of sC sequences in BP-based interlanguage. It predicts that the more marked /st/ sequence will be acquired only after its less marked counterparts have been fully mastered. Based on these results, in the forthcoming perception study, we will examine the effect that markedness on sonority sequencing may have on the perception of sC sequences. Along the lines of Berent et al (2007), Dupoux et al (1999) and Pitt (1988), for whom syllables that are marked and unattested in one's language are more likely to trigger perceptual illusion than those that are unmarked, we hypothesize that the representation of the marked input /st/ onset may be systematically distorted and thus trigger the perception of an illusory vowel, the default epenthetic vowel in BP: [i]. Accordingly, based on the markedness relationship between these clusters, we predict that the perception of sC clusters as such (i.e. without an illusory epenthetic vowel) will affect the less marked /sl/ and /sn/ sequences before the more marked /st/ is fully recognized as an onset cluster.

2.2.2 sC in other interlanguages

Problems in acquiring foreign sC sequences are not restricted to native speakers of Brazilian Portuguese. In this section, we will show that these illicit clusters are also problematic in a variety of first languages. Following the diagrammatic format utilized earlier, we summarize in Table 3 some of the most recent studies that investigate the development of sC sequences in the context of other interlanguages. Note that only relevant information is provided. Under "sC order of acquisition", for ease of exposition, note that we only provide the sequential development of homorganic sC cluster (some of the studies listed include a wider range of sC clusters, including heterosyllabic and trilateral sequences).

Table 3. sC clusters in other Interlanguages: Previous studies

Study	Participants	L1	L2	sC order of acquisition
Carlisle (1991)	11 adults	Spanish	English	sl > **st**
Carlisle (2006)	17 adults	Spanish	English	sl > sn > **st**
Tropf (1987)	11 adults	Spanish	German	ʃl, ʃn > **ʃt**
Escartin (2005)	23 adults	Spanish	English	sn > sl, **st**
Abrahamsson (1999)	1 adult	Spanish	Swedish	sn > **st** > sl
Boudaoud (2008)	30 adults	Farsi	English	sl > sn, **st**

Unlike BP-based interlanguages, note in Table 3 that the majority of the studies on sC acquisition corroborate the predictions outlined in the previous section regarding the effect of markedness. In Carlisle (1991, 2006), Tropf (1987), Escartin (2005) and Boudaoud (2008), observe that the more marked /st/ cluster only surfaces later in the acquisition process. Leaving aside the intricacies of each study (e.g., the fact that /sn/ and /st/ pattern together in Boudaoud, 2008 – for similar results in L1 acquisition, see Yavas & Beaubrun, 2006), the only exception to the predictions based on sonority is found in Abrahamsson (1999), in which the predicted order of acquisition of /sl/ with respect to /st/ is the reverse. It should be noted, however, that his study consisted of a single participant who had previous knowledge of a language that permits sC sequences, English (for an overview of these and other similar studies, see Boudaoud, 2008). What is crucial in these analyses is that they unequivocally reinforce our hypothesis, based on sonority sequencing within sC clusters, which predicts that the less marked /sl/ and /sn/ sequences should be acquired before the more marked /st/. More importantly, they corroborate the results obtained for the speech community under consideration, as discussed in the previous section.

2.3 sC in English: Input frequency

The emergence of usage-based approaches to analyze linguistic phenomena has received considerable attention over the last decade. These approaches support the notion that linguistic representation is mediated by the frequency with which certain linguistic structures occur in the language (e.g. Gass 1997, Bybee 2001, Demuth 2001, the volume edited by Bybee & Hopper, 2001; Bybee, 2007; Trofimovich, Gatbonton & Segalowitz, 2007): The more frequent a pattern is found in the language that surrounds the language learners, the more likely it is for that pattern to emerge. In the context of sC production in acquisition (e.g., Cardoso, 2008ab; discussed earlier), for instance, one could posit that the developmental sequence established (i.e., /sl/, /sn/ > /st/) may be potentially determined by the frequency with each these clusters occur in the input. Accordingly, one could speculate that the easily acquired /sl/ and /sn/ sequences are acquired earlier because they are simply more frequent in classroom environments (e.g., in the speech that characterizes that of a language teacher, "teacher talk").

In attempt to test this hypothesis and confront it against the one based on markedness involving sonority sequencing, Cardoso (2008ab) conducted an analysis of 30 hours of student-directed teacher talk from an English instructor involving the same community from which the ESL learners who participated in the production and forthcoming perception studies were recruited. The results of the frequency count are reported in Table 4, indicating that /st/ considerably outnumbers the two other clusters in student-directed teacher talk. The same applies to other frequency analyses conducted using independent corpora such as the Brown Corpus (Kucera & Francis, 1967; a written corpus extensively used in the field of corpus linguistics), and

Concordia University's ALERT corpus (Collins, Trofimovich, White, Horst & Cardoso, 2006), an oral corpus of three English teacher's input to Francophone ESL learners). Regardless of corpus used, observe that the distribution of sC clusters across the three corpora is virtually identical.

Table 4. The distribution of sC clusters in English

Corpus	Total (N)	sC-initial words (%)		
		/st/	/sl/	/sn/
a. Student-directed Teacher Talk (Cardoso, 2008ab)	837	87.4	6.4	6.2
b. Brown Corpus: Written (Kucera and Francis, 1967)	10,900	87.9	9.3	2.7
c. ALERT Corpus: L2 oral (Collins et al, 2006)	1,020	90.7	5.7	3.8

Based on the assumption that the productivity of a pattern is determined by its frequency (Bybee, 2001), the distribution of the three clusters in English predicts that the most frequent /st/ will be acquired before the considerably less frequent /sl/ and /sn/, in that order. Comparing these predictions with the results obtained in the production of sC in BP-based English (i.e., /sl/ > /sn/, /st/) and in other interlanguages, Cardoso (2008ab) conclude that input frequency cannot account for the developmental order of sC sequences observed in L2 acquisition.

2.4 sC in perception

Although there is a considerable amount of work on the production of sC sequences in developing (L1 and L2) grammars, we are not aware of any study that investigates the perception of such clusters in acquisition. Following Waterson's (1971, 1989) principle of "what is best perceived is best produced" and Goldschneider & DeKeyser's (2001) proposal that forms that are harder to perceive (less salient) are more difficult to acquire, we will establish in this section a salience hierarchy among the three sC clusters based on acoustic properties of /s/ and the three consonants that follow it. This will allow us to formulate hypotheses that will assess whether higher salience directly corresponds to higher perceptibility in the identification tasks that will be used in the forthcoming perception study.

Because the three sC sequences under consideration are homorganic and thus share the same coronal articulator, our focus will be on the acoustic properties that involve the manner of articulation of the segments that comprise these clusters. Let us start with the fricative /s/. Being a segment characterized by high-intensity noise, it is by far the most salient of the four consonants (Yip, 1993). It is so salient that its stridency often obscures following consonants and, in some languages (e.g., Cantonese), it is assumed to have a syllabic status (and thus constitutes a nucleus) in non-pre-vocalic (sC) positions (Silverman, 1992). Considering that /s/ precedes every second element in the sC clusters under consideration, the salience of each cluster will depend exclusively on the following consonant.

Among the three post-/s/ consonants, /l/ has more robust internal cues to manner (and place) of articulation than /n/ and /t/, in that order. The internal cues that set /l/ apart from the other consonants may be attributed to its clear formant structure during the entire duration of the liquid. Going down in the perceptibility scale, /n/ is characterized by less robust internal cues and

relatively less formant structure than /l/. Finally, /t/ has no formant structure, which results in this segment having less internal cues to place and manner of articulation than all the other consonants in sC sequences. For a detailed discussion of internal cues for the establishment of perceptual enhancement, see Hume (1998).

Based on the acoustic properties of the consonants that comprise the set of sC sequences, we stipulate a perceptual hierarchy based on their salience: /sl/ is the most salient among the clusters because of /l/'s robust internal cues, followed by relatively less salient /sn/. Finally, /st/ is the less salient sC sequence because of its lack of formant structure and insignificant internal cues for both place and manner of articulation. Interestingly, note that the predictions based on the acoustic properties of the four consonants coincide with those that markedness on sonority sequencing predicts: /sl/ > /sn/ > /st/. To conclude, we predict that the most salient /sl/ is more likely to be identified as an sC cluster (i.e., without the illusory [i]) than its less salient counterparts, /sn/ and /st/.

3. The perception of sC onset clusters: A variationist approach

As mentioned at the outset of this paper, one of the goals of the present study is to investigate the variable development in perception of foreign sC sequences in the interlanguage of BP speakers so that we can, among other things, draw parallels between the perception and production of these clusters. More specifically, the study aims to answer the following general questions: (1) How does the perception of sC onset sequences evolve in the development of English as a second language? (2) What factors contribute to their acquisition? (3) How does the perceptual development of these sequences compare with that found in production (e.g., is it also gradual, systematic and influenced by linguistic universals such as sonority sequencing and word size)?

To answer these questions, two studies were designed. Study 1 addresses the question of whether BP speakers with no exposure to oral English can perceive the distinction between the three sC clusters, namely /st/, /sn/, and /sl/. Study 2, on the other hand, extends the first study to include a wider range of participants, including both BP speakers with no previous exposure to English as well as ESL learners of different proficiencies in the target language. This will allow us to examine the perceptual development of sC sequences across different proficiencies. More specifically, the second study addresses the following questions: Can BP speakers with (and without) exposure to English auditorily perceive the sC versus [i]sC contrast? What factors (i.e., proficiency, sonority sequencing within clusters and word size) play a role in the developmental path observed?

3.1 Study 1

3.1.1 Participants

10 adults were selected to participate in the first study. They were four male and six female native speakers of Brazilian Portuguese with no previous formal exposure to oral English (e.g., in a language classroom or via TV), with an age mean of 39. The participants were recruited via a network of family and friends, and the experiment took place at the participants' homes, in the city of Belém, Brazil, where English is rarely heard or spoken outside of a classroom.

3.1.2 Stimulus material

42 pseudowords were created using *WordGenerator* v. 1.7 (http://billposer.org/Software/WordGenerator.html), a program that generates hypothetical words based on specifications such as segmental content and syllable structure, as provided by the researcher. To verify the effect of the same factors considered in the production analysis (reported in Cardoso, 2008ab and briefly discussed in earlier sections), the design and selection of the stimuli obeyed the following criteria: (1) word size (monosyllabic – e.g., [stik], [snʊk], [slɛk]; and disyllabic – e.g., ['stɛ.kəl], ['snæ.dəl] ['slʊ.kəl]), following sCV(V)C and sCV.CV(V)C syllable structures and a trochaic stress pattern with disyllabic words accentuated on the penultimate syllable (e.g., ['sti.bəl]); and (2) the sonority profile of the onset cluster (i.e., /st/, /sn/, and /sl/). The stimuli were equally divided into the three groups of sC clusters (14 tokens in each). In addition, the distribution of stimuli according to following vocalic environment was strictly controlled for the features that characterize English vowels: height (e.g. high: /i, ɪ, u, ʊ/, mid: /e, ɛ o, ʌ/, and low: /æ, ɑ/), frontness/backness (front: /i, ɪ, ɛ, æ/, central: /ʌ/, and back: /u, ʊ, o, ʌ/), roundedness (rounded: /u, ʊ, o/, unrounded: all other vowels included in the experiment), and tenseness (tense: /i, u, e, o, ɑ/, lax: all other vowels). A complete list of the pseudowords used in Study 1 is provided in Appendix A. Due to the nature of the experiment, the factor style or task formality adopted in the production study could not be incorporated into the study.

After the pseudowords had been carefully selected for the experiment, a phone forced choice discrimination task was designed using Smith's (1997) Windows Stimulus Presentation and Response Collection System (WNSPARCS). The 42 English pseudowords were recorded by a male English native speaker using a Marantz PMD660 Portable Solid State Recorder and a Shure SM58 Dynamic microphone. The recording was then edited (normalized and cut into single stimuli at 44.1 kHz, 16-bit resolution) using Adobe Audition 2.0, a sound editing application. Finally, the stimuli were programmed into WNSPARCS for the perception experiment.

3.1.3 Procedure and instructions

The participants sat in front of a computer screen wearing a pair of high-quality headphones (AKG K701), fed by a USB-based external sound card (Creative XMod). In the experiment, participants were asked to listen to a set of "strange-sounding" words (Appendix A) and then decide on whether they began with /st/, /sn/, or /sl/, by clicking with a mouse on the respective button on the screen. Even though the design of the pseudowords took into consideration the phonotactics of English (e.g., vowel quality and quantity, syllable structure), the participants were never provided with the information that these were possible *English* words. The task lasted approximately 15 minutes (including a 5-minute oral and written interview and a 3-minute demonstration and training session to familiarize the participants with the task). For reliability, the experiment was tested previously by two English native speakers and the average level of response accuracy was 100%. Figure 1 illustrates the interface of the experiment.

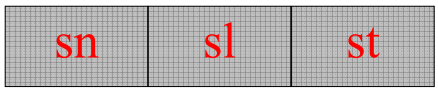

Figure 1. Study 1: sC forced choice identification task

3.1.4 Analysis, results and discussion

For consistency with the production study and, more importantly, in view of the methodology employed in our general program of research, we had planned to adopt GoldVarb X (Sankoff, Tagliamonte, & Smith, 2005) to analyze statistically the perception data collected from Study 1 (see discussion of GoldVarb X in the following section). The data obtained in Study 1, however, are not compatible with the type of analyses that GoldVarb (or any other statistical program) does: The response accuracy for each of the three clusters used in the experiment was considerably high for all the participants included, above 95%. This can be interpreted as robust evidence that native BP speakers have no problems identifying and distinguishing among the three sC clusters included in the study.

The high degree of perceptibility of the three clusters can be explained by the fact that the melodic or segmental content of sC clusters do occur in the participants' native language, albeit restricted by certain syllabic constraints that compel the two segments to syllabify heterosyllabically, as illustrated earlier in the context of data from Brazilian Portuguese. Accordingly, it is likely that native Brazilian Portuguese speakers rely on these melodic cues (and not on their syllabic structure) to distinguish among the three sC sequences, which leads them to interpret the illicit clusters filtered by the phonotactics of BP, that is, as containing the illusory epenthetic vowel [i].

To conclude, can BP speakers with no previous exposure to oral English auditorily perceive the distinction between /st/, /sn/ and /st/? The results obtained in Study 1 indicate that the answer is affirmative: BP speakers have no problems perceiving and distinguishing the three sC clusters. In the context of second language acquisition, these results suggest that, in earlier stages of English L2 acquisition, BP speakers might hear an illusory epenthetic vowel preceding the sC sequence, as is the case in their native phonology. This perceptual illusion, we hypothesize, is likely to be one of the factors that contribute to the difficulty that Portuguese speakers have in acquiring this complex, s-initial syllable constituent in English. The questions regarding whether BP speakers hear indeed an illusory vowel preceding sC sequences and what affects this perceptibility will be addressed in the following section.

3.2 Study 2

To recapitulate, Study 1 established that native speakers of BP are able to differentiate among the three sC clusters without difficulty: They rely on the melodic cues of these clusters and then match the illicit sC structure that they hear with the phonotactics of their L1, wherein the sequence can only surface if preceded by a vowel (the default epenthesis vowel [i]). This led us to conclude that BP speakers' problem with sC is not is discriminating among the three clusters but, instead, in perceiving the *absence* of a preceding non-vocalic environment (i.e., the sC sequence itself).

As shown in the production of sC study (Cardoso, 2008ab), sC sequences are not all created equal and, accordingly, we hypothesize that these clusters will behave differently in perception: While marked structures (e.g., /st/) are more likely to be perceived with the illusory vowel [ɪ], forms that are less marked (e.g., /sl/) should be selected more favorably in identification tasks. A corollary of this hypothesis from a perceptual perspective and including insights from acoustic phonetics suggests identical patterns in perception: The less an onset cluster is salient in speech (e.g., /st/), the more likely it is for this cluster to be perceived with an illusory [ɪ]. Within the same standpoint, we hypothesize that the more salient clusters /sl/ and /sn/

will be more likely to be selected as sC sequences in identification tasks because they are characterized by more salient robust internal cues (i.e., clearer formant structure).

Study 2 advances the previous study by incorporating speakers of varying degrees of proficiency in L2 English in order to determine the developmental sequence in perception of sC clusters. Based on the findings brought to light in study 1 and in previous studies involving sC production (e.g., Cardoso, 2008), the second study also investigates the participants' ability to variably discriminate between sC-initial and vowel-initial clusters, with the intention of determining what factors play a role on the accurate identification of sC sequences. In study 2, as mentioned earlier, we address the following general questions: (1) How does the perception of sC sequences evolve in the development of English as a second language? (2) What factors contribute to their acquisition? (3) Is the perceptual development of these clusters similar to that found in production, or is it motivated by different aspects of human perceptual processing? The methodology employed in Study 2 is discussed below.

3.2.1 Participants

24 participants took part in the second study. They were post-adolescent male and female Brazilian Portuguese speakers, with an age average of 27. The participants were divided into three groups based on their proficiency in English: (1) No English (N=8 participants): BP speakers without any formal exposure to English, similar to the group that participated in Study 1; (2) Intermediate (N=8 participants): Students with approximately 100 hours of English instruction, enrolled in a third or fourth level of English in a 10-level program, and recognized as being at the intermediate level by the language schools where they were recruited; and (3) Advanced (N=8 participants): English Students with more than 300 hours of exposure to the language in a classroom environment (levels nine and ten in a 10-level ESL program). The data were collected at a private language school in the same city where Study 1 was conducted, i.e., Belém, Brazil.

3.2.2 Stimulus material

As was the case in Study 1, the English pseudowords used in the second study were created in *WordGenerator* v. 1.7, using relatively similar criteria for design and selection: The 108 pseudowords used in the experiment were designed according to size (monosyllabic versus disyllabic and polysyllabic words), following sCV(V)C and sCV.CV(V)C syllable structures accentuated on the leftmost syllable (for s-initial words; e.g., ['sti.kəl]), or on the syllable containing the second element of the sC cluster, the coronal consonant (for ɪ-initial words; e.g., [ɪs.'tejp], [ɪs.'tow.pər]). Due to the addition of the vowel [ɪ] to 24 of the pseudowords (usually in a minimal pair relationship: [stik] ~ [ɪs.'tik]), some of the originally disyllabic s-initial words became trisyllabic (['stow.pər] ~ [ɪs.'tow.pər]). The words were also controlled for sonority sequencing, with a relatively balanced number of (ɪ)sC-initial tokens (st = 37, sl = 36, sn = 35). As was the case with Study 1, the vocalic environment following the sC sequences was strictly controlled for height, frontness/backness, roundedness, and tenseness (see Appendix B for a complete list of the pseudowords used in Study 2). For the computation of accurate sC perception, only the results involving sC-initial words were included in the statistical analysis (N=84); the ɪ-initial words (N=24) were used as distracters in that experiment and were therefore analyzed separately.

The selected pseudowords generated by *WordGenerator* were recorded by a male native English speaker using the same equipment for sound recording and software for sound editing adopted in Study 1. For the forced identification task, the edited and final stimuli were fed and programmed into WNSPARCS (Smith, 1997), as described earlier in the context of Study 1.

3.2.3 Procedure and instructions

Following the same procedures used in Study 1, the participants sat in front a computer screen wearing headphones and were asked "to listen to a set of English words" (see Appendix B). Immediately after hearing each stimulus, they were asked to click with a mouse on the alternative that best described the initial sound that they heard: a vowel ([ɪ]) or an [s]. To avoid random selection, the participants were also given the option of selecting a question mark to indicate uncertainty (e.g., due to distraction, fatigue). The task lasted approximately 20 minutes, including a 5-minute oral and written interview and a 3-minute demonstration and training session so that the participants could become familiar with the task. An illustration of the interface of the relevant part of the experiment is illustrated below.

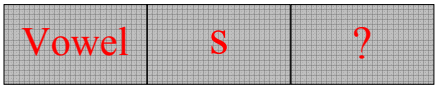

Figure 2. Study 2: sC and ɪsC perception

3.2.4 Data analysis

Based on the discussions above and the theoretical and methodological approaches adopted in this study, the stimuli used in the second experiment were stratified among the following factors for GoldVarb X (Sankoff, Tagliamonte, & Smith, 2005) analysis:

Table 5. Factor groups for GoldVarb X Analysis

Factor Groups	**1**	**2**	**3**
Response accuracy	Correct identification	Incorrect identification	
Proficiency	No English	Intermediate	Advanced
Word size	1 Syllable	2+ Syllables	
Sonority Profile	/st/	/sn/	/sl/
Participants		1 – 24	

It is beyond the scope of this paper to provide a detailed discussion of GoldVarb X and how it handles variable language phenomena. Suffice it to say that it is a statistical package widely used in variationist studies that report results that are somehow comparable to those provided by other statistical methods such as ANOVA (see Paolilo, 2002). The output of a typical GoldVarb analysis contains the quantitative information on which we can base our generalizations and test our hypotheses; e.g. the raw number and the percentage of tokens obtained for each factor under consideration, and more importantly, the factor weight, which measures the influence that each factor has in the process under investigation, based on the corpus analyzed. The factor weights provide the most accurate view of the likelihood of variant occurrence and, accordingly, the discussions and analyses presented here will be based on these

probabilistic weights. Because this study involves two dependent variables (i.e., correct and incorrect identification), weights above .50 are assumed to enhance the perceptibility of the sC cluster, while those below .50 are assumed to inhibit sC identification vis-à-vis its vowel-initial counterpart. GoldVarb also conducts a stepwise logistic regression analysis (binomial, up and down) on the data to determine which factor groups do or do not have an effect on the phenomenon. All factor groups selected in this binomial step-up/down procedure are significant at the $p < .05$ level. Finally, the input probability value indicates the likelihood of accurate sC perception, regardless of the specific contribution of particular factors (e.g., a value of .47 indicates that accurate perception is likely to occur 47% of the time, regardless of the factors included in the investigation). For a comprehensive discussion of GoldVarb, see Young and Bayley (1996), Paolilo (2002), and Tagliamonte (2006).

3.2.5 Results

Two GoldVarb statistical analyses were conducted: One with the entire factor group set, after which an interaction between the groups Participant and Proficiency was evident: Every participant inherently belongs to a proficiency group. In order to improve the analysis, and in light of the variationist methodological approach adopted ("the individual doesn't exist as a unit" because language is the property of the community – interview with Labov; Gordon, 2006), the second and final GoldVarb run was conducted without the group of participants.

The final probabilistic results are illustrated in Table 6, which show that both Proficiency and Sonority Sequencing have significant conditioning effects on the variable perception of English sC clusters as such, that is, without the presence of the illusory vowel [ɪ]. These two groups were selected in both runs of the stepwise analysis, thus indicating a level of significance ($p < .05$). Specifically, BP speakers are more likely to perceive the sC versus [ɪ]sC contrast as they develop their proficiency in English: While speakers with no exposure to English cannot discriminate the contrast reliably (weight: .34/50.9%), their ability to do so increases as they become more proficient in the target language (Intermediate: .50/65.3%; Advanced: .66/78.9%). Note that, because this is a forced choice identification task (i.e., participants were asked to select one alternative among three options), results within the 50% range (e.g., the No English group) should be interpreted as tainted with randomness. What is crucial is the overall tendency in accurate sC perception vis-à-vis the other factors. In the case of proficiency, for instance, it is clear from the results that the participants' ability to select the correct sC form increases as they become more proficient in the target language, regardless of the effects of random selection. With regards to the sonority profile within the sC sequence, the results indicate that English learners are more likely to identify the cluster correctly if it is constituted of either /st/ (.63/75.7%) or /sl/ (.51/66.2%) sequences than if the cluster has an /sn/ sonority profile (.36/53.1%).

Table 6. Likelihood of sC Perception: Significant Results (GoldVarb weights & %)

Factor Groups	**Factors**		
Proficiency	No English	Intermediate	Advanced
	.34 (50.9%)	.50 (65.3%)	.66 (78.9%)
Word Size	1 Syllable	2+ Syllables	
	.49 (47.9%)	.51 (52.1%)	
Sonority Sequencing	/st/	/sl/	/sn/
	.63 (75.7%)	.51 (66.2%)	.36 (53.1%)
Input Probability		.47	
			Chi-square/cell: .8411 / p < .001

The factor group Word Size, on the other hand, was not deemed significant, since it was not selected by GoldVarb in the two step-up/down levels of analysis and, more importantly, the weights assigned to monosyllabic and polysyllabic words are relatively similar. This indicates that, with regards to word size, BP speakers are equally likely to discriminate sC from vowel-initial ɪsC sequences across these two sets of word lengths.

4. Discussion

We will now discuss the main findings of our investigation in the context of each independent variable adopted. This will be followed by a general conclusion in which we revisit our general research questions in light of the results obtained.

4.1 Proficiency

This factor group was included so that we could monitor the development of sC sequences across three levels of proficiency and, consequently, over time, considering the cross-sectional approach adopted. As was the case in the production study, the development of sC sequences by BP learners of English follows a gradual and variably path, departing from a phonology that mirrors that of the first language (and sC sequences are less likely to be perceived as such), towards a grammar that closely resembles the one that characterizes the target language.

With the inclusion of this factor group, we were also able to assess Major's (2001) Ontogeny Phylogeny Model (OPM), a model for interlanguage phonology that posits that learners progress from an initial stage with prevalence of L1 features, to a final stage characterized by features that derive from the target language. This process is assumed to be mediated by stages during which L1 features decline (i.e., the ability to hear an L1-based illusory vowel in illicit sC sequences), and L2 features (i.e., the ability to identify sC sequences correctly) gradually rise. The OPM also posits that the effect of developmental (universal) constraints such as Word Minimality (see discussion in the following section) would rise and then decline in the course of L2 acquisition. As will be shown below, however, Word Minimality had no effect on the outcome observed.

In sum, as was the case in the production study reported in Cardoso (2008ab), the likelihood that BP speakers will perceive the sC versus ɪsC contrast increases as a function of increased proficiency, regardless of any other factor considered in the study.

4.2 Word size

The inclusion of word size as a factor to analyze the perception of words was motivated by the observation that languages (both well-formed and in development) depict patterns that favor disyllabic (or bimoraic) words over words that contain a single syllable (or mora). In the phonology literature, this has been formalized as the constraint Word Minimality, which simply put requires that words have minimally two syllables or moras (e.g., McCarthy & Prince, 1993; Demuth & Fee, 1995; Wang, 1995; Everett, 1996; Bernhardt & Stemberger, 1998; Broselow et al, 1998; see also Cardoso, 2007 for the effects of Word Minimality in the L2 acquisition of English codas within the same variety of BP-based English considered in this study). In developing grammars, Word Minimality effects are usually manifested via the insertion of an extra syllable or segment to turn an underlyingly monosyllabic word into a disyllabic unit (e.g. /dɑg/ → [dɑ.gə] in English L1 acquisition, [dɔ.gi] in BP-based interlanguage – Cardoso, 2007). Translating this generalization into the concept of markedness, one-syllable (or monomoraic) words are more marked than its disyllabic counterpart, since the presence of the former in any language presupposes the existence of the latter. Unlike Brazilian Portuguese, English strongly enforces this constraint, since all content (or stressed) words in the language are minimally bimoraic (i.e., minimal words consist of rhymes containing either a heavy vowel – e.g., [si:] 'see', or a light vowel followed by a moraic coda – e.g., [sɪt] 'sit').

Assuming that forms that are more marked or unattested in one's language are more likely to trigger the perceptual illusion of an epenthetic vowel (e.g., Berent et al, 2007; Dupoux et al, 1999; and Pitt, 1988; see earlier discussions), we hypothesized that learners would more favorably filter the structure of sC sequences via their L1 phonology in marked monosyllabic words than in less marked multisyllabic forms. In other words, we expected that participants would hear the BP epenthetic vowel [i] more frequently in words of marked monosyllabic structure. As the results in Table 6 illustrate (i.e., no significance for the word size factor group; 1 syllable: .49, 2 or more syllables: .51), this hypothesis was not borne out in our investigation.

A possible interpretation for the irrelevant effect of word size in sC perception may be related to the stress pattern that characterizes such clusters: Stress always falls on the syllable containing the sC sequence in both native English and in the sC-initial pseudowords used in the experiment). Accordingly, it could be that the salience nature of stressed sC sequences may overrule the effect of word size. Alternatively, as has been suggested in the literature (Cardoso, to appear), it could be that Word Minimality is a constraint that is manifested in production only. Due to the nature of frequently-occurring sC-initial words (i.e., they are mostly monosyllabic), the study involving sC production (Cardoso, 2008ab) was not able to examine the effect of word size. The issue is beyond the scope of this investigation, but it certainly requires further investigation.

4.3 Sonority profile: Markedness on sonority sequencing

As discussed earlier, the goal of including this independent variable was to assess the effect of markedness on sonority sequencing in determining the developmental path in perception of the three clusters included in the study. As was the case in a previous study involving the production of sC sequences (Cardoso, 1008ab), we hypothesized that the most marked structure /st/ would be more likely to trigger the perceptual illusion of the BP-based epenthetic vowel [i] than the relatively less marked /sl/ and /sn/ clusters. Along these lines, it was speculated that the perceptual acquisition of sC sequences would follow a pattern in which /sl/ and /sn/ would be

recognized as onset clusters before /st/. Surprisingly, the results obtained in this study (Table 6) contradict these expectations: Both the most marked /st/ (weight: .63) and the least marked /sl/ (.51) favor accurate sC perception in the forced identification task, while /sn/ is the most likely to be identified as being preceded by the illusory vowel [i] (.36).

A priori, there seemed to be no theoretical ground to explain why the most marked /st/ is as easily identifiable in perception as the relatively less marked /sl/, since markedness on sonority sequencing predicts that these two forms will be ranked at the opposite ends of the acquisition order spectrum: /sl/ > /sn/ > /st/. From a salience perspective, and assuming that all second consonants in the sC sequence are equally obscured by the stridency of the preceding /s/, liquids have more robust internal cues (formant structure) to manner than nasals and stops, in that order (i.e., /sl/ > /sn/ > /st/). As discussed earlier, these predictions coincide with those based on a sonority-based analysis and, therefore, cannot account for the patterns observed for BP-based interlanguage. Another viable alternative that is only partially able to account for the positioning of /sn/ at the rightmost, more difficult end of the acquisition process is one based on markedness involving continuancy (the freedom of airflow through the oral cavity), a feature that characterizes both /s/ and /l/. Because continuancy is constant in /sl/ clusters ([+continuant + continuant]), these clusters are assumed to be less marked than the ones in which continuancy varies across the two members: /sn/ and /st/. Based on this approach to markedness, one predicts that the least marked /sl/ will be more easily acquired than the [+continuant –continuant] set constituted by /sn/ and /st/: /sl/ >> /st/, /sn/ (for more details about this alternative analysis, see Yavas & Beaubrun, 2006 and Yavas & Someillan, 2005). The results obtained in the study, however, seem to contradict these predictions.

The only analysis that is able to fully capture the development of sC clusters in perception is the one based on the frequency of the different types of sC clusters in the ambient language that surrounds the ESL learner. As you will recall from earlier discussions, /st/ is the most frequently-occurring sC cluster, followed by /sl/ and /sn/: /st/ > /sl/ > /sn/. As the results in Table 6 indicate, this is exactly the order in which these forms are more likely to be identified as sC clusters (without the illusory vowel [i]). A comparison of sC perception (including the results for intermediate and advanced participants only) and sC input frequency is provided in Figure 3 (for ease of exposition, the results are repeated from previous discussions). Note that these results should not be interpreted in absolute terms, since results from a forced identification task (in which random selection is likely to occur) cannot be comparable to those obtained in a frequency count. What is crucial in these results is the tendency observed in the two types of analyses.

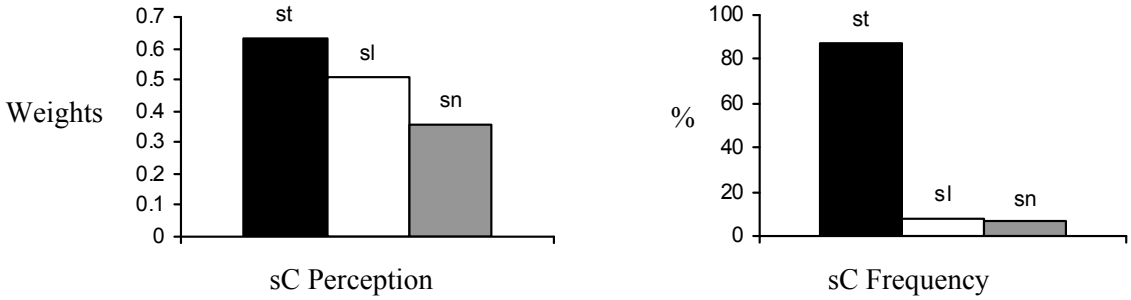

Figure 3. sC perception (weight) and sC frequency: Similar patterns

In sum, rather than markedness (as in production) or perceptual salience, it is *input frequency* that predicts the sequence in which sC perception is likely to develop. These results are compatible with the view that recognizes that learners build linguistic representations according to the frequency of structures in the input (e.g. Leonard & Ritterman; 1971, Bybee, 2001, 2007; Demuth, 2001; Munson, 2001; Bybee & Hopper, 2001).

Furthermore, these results corroborate the perception-before-production view for language acquisition (e.g., Polivanov, 1931; Flege, 1991; Best, 1993, 1995 for L2 acquisition; Stampe, 1973; Barton, 1978; Hale & Reiss, 1998 for L1 acquisition), which suggests that while the competence of L2 learners (gradually and variably) reflects that of the fully-developed target grammar, this knowledge is not always manifested in production. L2 learners fail to produce forms that they have acquired perceptually either due to their immature articulators or, as is the case in sC production, due to the marked nature of the novel target-like structure.

4.4 Conclusion

How does the perception of sC sequences (as opposed to their vowel-initial counterparts) evolve in the development of English as a second language? What factors contribute to their acquisition? The perception of these clusters evolves in a variable and gradual (across proficiency levels) manner that attempts to emulate the frequency of the different types of sC forms found in (native and/or non-native) English input. Surprisingly, the development of these clusters does not follow the same path in production and perception. While markedness involving sonority sequencing plays a definitive role in guiding sC production, it is input frequency that best accounts for the developmental path that L2 learners follow in perceiving foreign sC sequences.

5. Concluding remarks

The goal of this study was to investigate the variable development in perception of English word-initial sC clusters by Brazilian Portuguese speakers, within a multidisciplinary approach that combines insights from theoretical phonology, phonetics, second language acquisition and psycholinguistics, as well as methodological tools from (Labovian) variationist sociolinguistics. More specifically, this study examined the perceptual development of non-native homorganic /s/ + consonant clusters, a notoriously difficult cluster to produce and, as this study indicates, to perceive, because learners variably hear an illusory epenthetic vowel that inevitably compels the illicit sequence (sC) to surface as two separate syllables (ɪs.C).

The study addressed the question of how sC perception develops in the acquisition of L2 English and what factors motivate sC discrimination vis-à-vis its vowel-initial counterpart. The GoldVarb X statistical results of a forced choice identification experiment containing sC and [ɪ]sC sequences indicated that the ability of BP speakers to identify the correct cluster directly correlates with increased proficiency and, more importantly, with the input frequency with which the sC forms occur in the ambient language that surrounds the ESL leaner: The more frequent /st/ and /sl/ clusters are more easily identifiable than the less frequently-occurring /sn/ sequence. The fact that the production and perception of sC clusters do not seem to go in tandem support Hayes' (2004, p. 159) claim that there is "a clear separation between the [learner's] phonological analysis of the ambient language vs. her personal production phonology". Along these lines, it seems plausible to stipulate that two phonological grammars are necessary to explain the

perception/production dichotomy observed in this study (contra Pater, 2004). The empirical and conceptual consequences of such a view will be explored in a future analysis of the data presented here within the framework of Optimality Theory (Prince & Smolensky, 1993/2004).

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Appendix A. Study 1: List of 42 sC-initial English pseudowords

/st/		/sl/		/sn/	
/stik/	/stibəl/	/slib/	/slibɪk/	/snip/	/snipɪk/
/stɪp/	/stɪpɪʃ/	/slɛk/	/slɛkət/	/snɪk/	/snɪbər/
/stejp/	/stejpɪʃ/	/slætʃ/	/slædajt/	/snejp/	/snædəl/
/stɛk/	/stɛkəl/	/slub/	/slʊkəl/	/snɛb/	/snugəl/
/stæp/	/stʊkən/	/stowp/	/slowbɪk/	/snæd/	/snukɪŋ/
/stuk/	/stowbən/	/slʌp/	/slʌpər/	/snʊk/	/snowpən/
/stɑt/	/stʌgər/	/slɑk/	/slɑdɪk/	/snʌp/	/snʌpər/

Appendix B. Study 2: List of 108 sC and ɪsC-initial English pseudowords

/st/		/sl/		/sn/	
/stik/	/stibəl/	/slib/	/slibɪk/	/snip/	/snipɪk/
/stiz/	/stɪpɪʃ/	/sliʃ/	/ɪslibɪk/	/sniʃ/	/ɪsnipɪk/
/ɪstik/	/ɪstɪpɪʃ/	/slɪb/	/slɪbər/	/snɪk/	/snɪbər/
/stɪp/	/stejpɪʃ/	/slɪʃ/	/slejgən/	/snɪd/	/snejpəʃ/
/stɪt/	/stɛkəl/	/ɪslɪʃ/	/slejfəs/	/ɪsnɪd/	/ɪsnejpəʃ/
/stejp/	/ɪstɛkəl/	/slejp/	/ɪslejfəs/	/snejp/	/snɛkəl/
/stejb/	/stæpəl/	/slɛk/	/slɛkət/	/snɛk/	/snædəl/
/ɪstejp/	/stæθɪk/	/ɪslɛk/	/slɛpən/	/snɛb/	/snæfɪŋ/
/stɛk/	/stukən/	/slæd/	/slædajt/	/ɪsnɛb/	/ɪsnæfɪŋ/
/stɛb/	/stubər/	/slætʃ/	/slukər/	/snæd/	/snukɪŋ/
/stæp/	/stʊkən/	/slub/	/ɪslukər/	/snuk/	/snugəl/
/ɪstæpɪʃ/	/stowpər/	/slʊb/	/slʊkəl/	/snʊk/	/snʊbɪŋ/
/stuk/	/stowbən/	/ɪslʊb/	/slowbɪk/	/snowp/	/snowpən/
/ɪstuk/	/ɪstowpər/	/stowp/	/slowkədʒ/	/ɪsnowp/	/snowbər/
/stʊk/	/stʌpəl/	/slʌp/	/slʌpər/	/snʌp/	/snʌpər/
/stowp/	/stʌgər/	/slɑk/	/ɪslʌpər/	/snʌʃ/	/snɑpər/
/ɪstowp/	/stɑbən/	/slɑz/	/slɑdɪk/	/snɑp/	/snɑdɪk/
/stʌp/	/ɪstɑbən/	/ɪslɑk/	/slɑgət/	/ɪsnɑp/	
/stɑt/					