THE ACQUISITION OF /p/ AND /k/ WORD-MID CODAS OF ENGLISH (L2) BY LEARNERS FROM SOUTHERN BRAZIL (L1): A GESTURAL ANALYSIS IN STOCHASTIC OPTIMALITY THEORY

A AQUISIÇÃO DAS CODAS MEDIAIS /p/ e /k/ DO INGLÊS (L2) POR APRENDIZES DO SUL DO BRASIL (L1): UMA ANÁLISE GESTUAL NA TEORIA DA OTIMIDADE ESTOCÁSTICA

Bruna Koch Schmitt[*]
Ubiratã Kickhöfel Alves[**]

Abstract: In this article, we formalize the acquisition of word-mid /pt/ and /kt/ sequences in English (L2) by learners from Southern Brazil. The participants, who presented a basic proficiency level in English, had their productions recorded both in English and in Brazilian Portuguese, which allowed for an analysis of the acoustic patterns found in the production of /p/ and /k/ obstruent codas. The acoustic patterns produced by the learners were analyzed using the Stochastic-Optimality Theory, and the constraints used in the analysis were based on the framework of Gestural Phonology (BROWMAN & GOLDSTEIN, 1992) and in the gestural landmarks proposed by Gafos (2002). We conclude that a gestural analysis allows for the formalization of a wider range of acoustic patterns which tended not to be considered in traditional accounts of phonology, as these patterns assume a different status since they are then considered to be part of the grammar.
Keywords: Phonetic-phonological Acquisition; Gestural Phonology; Stochastic Optimality Theory.

Resumo: Neste artigo, formalizamos a aquisição, por parte de aprendizes do Sul do Brasil, das sequências /pt/ e /kt/ em posição medial de palavras do inglês (L2). Os participantes, que apresentavam um nível básico de proficiência na língua estrangeira, tiveram suas produções orais gravadas tanto em português quanto em inglês, para a posterior verificação dos padrões acústicos encontrados nas tentativas de produção das codas /p/ e /k/. Estes padrões acústicos foram analisados à luz da Teoria da Otimidade Estocástica, e as restrições utilizadas na análise foram baseadas no modelo da Fonologia Gestual (BROWMAN & GOLDSTEIN, 1992) e na noção de pontos de ancoragem gestuais proposta por Gafos (2002). Concluímos que uma análise gestual permite a formalização de uma série de padrões acústicos que tendiam a ser desconsiderados pelas análises fonológicas tradicionais, uma vez que tais padrões assumam um status diferenciado, como componentes da gramática do indivíduo.
Palavras-chave: Aquisição Fonético-Fonológica; Fonologia Gestual; Teoria da Otimidade Estocástica.

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[*] Bachelor in Languages (Universidade Federal do Rio Grande do Sul) and member of the Research Group "Cognition and Foreign/Second Language Acquisition: A Psycholinguistic Account" (CNPq / UFRGS).
[**] Professor at the Graduate Program in Linguistics - Universidade Federal do Rio Grande do Sul, Brazil - and researcher at the Conselho Nacional de Desenvolvimento Científico e Tecnológico – CNPq (Process number 308721/2012-8).

Introduction

In this article, we aim to formalize the acquisition of word-mid /p/ and /k/ codas in English by Southern Brazilian learners. English and Brazilian Portuguese (BP) syllable patterns differ in terms of the segments allowed in coda position: Brazilian Portuguese does not allow obstruents in codas, with the exception of /S/ (Coda Condition, BISOL, 1999), whereas English permits all consonants, with the exception of /h/, to be in coda position (HAMMOND, 1999; ALVES, 2008). However, in some dialects of Brazilian Portuguese, the coda obstruent may surface variably (Coda Condition Weakening, BISOL, 1999), which may occur due to either intra-speaker or inter-dialectal variation.

As we consider the 'gaúcho' dialect of Brazilian Portuguese (spoken in the state of Rio Grande do Sul), the /p/ and /k/ in word-mid codas may surface either as the coda of the syllable or as the onset of a new syllable, by means of inserting an epenthetic vowel and the consequential resyllabification of the stop segment: "rapto" – [xa.pi.tu]~[xap.tu] (LUCENA & ALVES, 2010). As the stop consonant may emerge variably in this dialect, this might cause phonetic-phonological transfer from Brazilian Portuguese (L1) to English (L2). In this sense, many of the phonetic patterns which occur variably in the learners' L1 may also be found in their productions of English (L2).

These facts considered, this study seeks to formalize, in Stochastic Optimality Theory (BOERSMA & HAYES, 2001), the emergence of the acoustic patterns found in the oral production of learners who present a basic level of proficiency in English. By using phonological gestural landmarks as primitives (GAFOS, 2002), we intend to capture the acoustic patterns produced by these learners and account for the grammar responsible for their output patterns. Simulations of the stages of the acquisition were performed using the Gradual Learning Algorithm in *Praat 5.2.21* (BOERSMA & WEENINK, 2011).

The present study aims to address the following research questions:

a) What are the acoustic patterns produced by Southern Brazilian learners in the acquisition of English word-mid /p/ and /k/ codas? How can these patterns be formalized in an Optimality-theoretic framework, using gestures as phonological primitives?

b) Which gestural constraints are involved in the acquisition of the English word-mid /p/ and /k/ codas by Brazilian learners?

c) What are the theoretical implications of using gestures as the main phonological primitive in the formalization of the interlanguage grammar?

This article is organized in 05 sections. In what follows, we present the literature review, followed by a detailed description of the method. The data are then described and formalized under a Gestural Optimality Theory. Finally, in the conclusion, we provide answers for the research questions and suggestions for further research.

1 Review of Literature

1.1 Differences between English and Brazilian Portuguese Syllable Patterns

From a traditional perspective, the phonological template of Brazilian Portuguese does not allow obstruents in coda position, but /S/ (ALVES, 2008; BISOL, 1999; CARDOSO, 2007; HUF & ALVES, 2010; LUCENA & ALVES, 2010). According to the syllabic template (Coda Condition) proposed by Bisol (1999) for BP, the consonant in the coda must be [+son], with the exception of /S/. English, however, permits a larger set of consonants in simplex coda position, since all English consonants, with the exception of the fricative [h], may appear in simplex codas. Although the Coda Condition states that phonological codas in BP cannot be filled by an obstruent, mid codas in BP may surface variably, as in [rap.tu]~[ra.pi.tu] (LUCENA & ALVES, 2010). This may arise from dialect variation (BISOL 1999), as we will see in the data analyzed in the present study.

Learners depart from their L1 grammar towards the L2 when acquiring a second language. Thus, when the syllable patterns differ, the learner will tend to use "repair" strategies when producing the L2. In the case of the acquisition of obstruent codas of English, the insertion of an epenthetic vowel tends to be employed so as learners can resyllabify the obstruent, so as to conform their productions to the syllable template of Brazilian Portuguese (ALVES, 2008, 2009, 2011; CARDOSO, 2007; HUF & ALVES, 2010; LUCENA & ALVES, 2010). Therefore, in terms of grammar, Brazilian learners will have to acquire a syllabic pattern which differs from that of their first language, departing from variable epenthetic patterns (L1) to a categorical production of the obstruent segment in coda position. This may be formalized in Stochastic Optimality Theory through

computational simulations of the three stages of the acquisition (L1 grammar, L2 target grammar and the interlanguage grammar), as it is performed in the analyses of the present study.

1.2 Optimality Theory

This section presents an overview of Optimality Theory in its Stochastic version, considering the Gradual Learning Algorithm (GLA).

Standard OT and its corresponding algorithm (TESAR & SMOLENSKY, 1996) cannot account for language variation: once a ranking is established, the grammar will always produce the same output for a given input. Therefore, Standard OT and its algorithm (TESAR & SMOLENSKY, 1996) cannot account for:

a) variation within a language or dialect: a speaker may produce, for example, the lexical item "rapto" as [xa.pi.tu] or [xap.tu]. Thus, both forms should emerge from the grammar of the same speaker.

b) variation in L2 acquisition: a learner may produce, in the process of acquiring a language, variant forms towards the target grammar. For example, while acquiring English, a Brazilian learner may produce for the lexical item "doctor" the outputs [dɔ.ki.tər] and [dɔk.tər].

In Stochastic OT, for each constraint under analysis, a *constraint value* is assigned, in a way that higher values correspond to higher-ranked constraints. This constraint value is the center of a range of possible values which it may assume. At each instance of linguistic production (e.g., every time a speaker talks) - called *evaluation time* - the ranking of constraints is re-evaluated, and a value from this range is assigned. This value, called *disharmony value* or *selection point*, is used to rank the constraints for that particular *evaluation time,* at which higher values correspond to higher-ranked constraints. In this sense, "the grammar is regarded as *stochastic*: at every evaluation of the candidate set, a small noise component is temporarily added to the ranking value of each constraint, so that the grammar can produce variable outputs if some constraint rankings are close to each other." (BOERSMA & HAYES, 2001, p. 46).

Let us consider some examples. In Figures 01, 02 and 03, the ranking values of the constraints are displayed in the bottom row, and the range of these values is

displayed in the top row. In Figure 01, the grammar produces the categorical output [big] for the input /big/. This is derived from the fact that, at each evaluation time, each constraint will be assigned to a disharmony value (selection point) within their range of ranking values. Thus, the constraint ranking in every evaluation time will always be MAX>>DEP>>*{STOP}coda. In Figure 02, the grammar produces the categorical output [bigi] for the input /big/. Again, the output is categorical, since the ranges of the constraint values do not overlap. In Figure 03, on the other hand, the constraints DEP and *{STOP}coda are overlapping, meaning that their range of ranking values are close enough for this overlap to occur. This allows for variable outputs, because at each evaluation time, a noise value will be added to or taken from the ranking value, allowing the disharmony values of each constraint to vary. As a consequence, the ranking relations between the constraints may change at different evaluation times:

1) *{STOP}coda assumes the disharmony value of 51 and DEP assumes the disharmony value of 44. The ranking, then, will be *{STOP}coda >> DEP, producing the output [bigi].

2) at another evaluation time, DEP assumes the disharmony value of 47 and *{STOP}coda assumes the disharmony value of 46. The ranking, then, will be DEP >> *{STOP}coda, producing the output [big].

Figure 1: Categorical Ranking (MAX >> DEP >> *{STOP}coda)

/big/ - big

70		60	55		45	40		30
	MAX			DEP			*{STOP}coda	
	65			50			35	
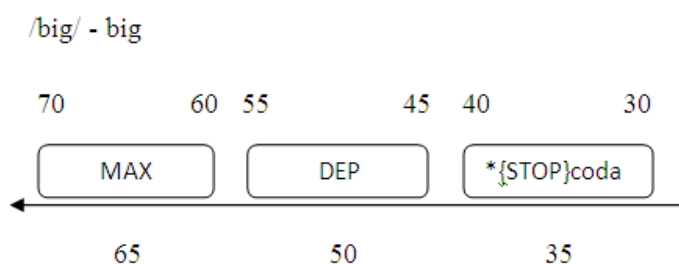
Figure 2: Categorical Ranking (MAX >> *{STOP}coda >> DEP)

/big/ - bigi

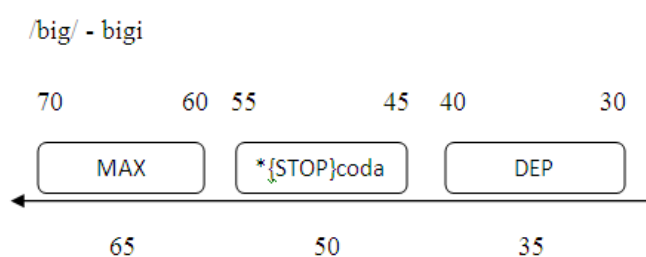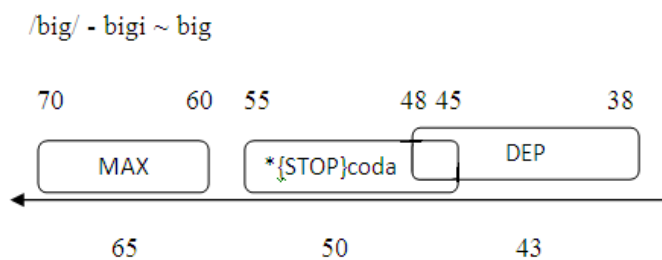| 70		60	55		45	40		30
	MAX		*{STOP}coda			DEP		
	65		50			35		

Figure 3: Overlapping of Constraints (MAX >> *{STOP}coda ~ DEP)

/big/ - bigi ~ big

Therefore, the categorical or variable nature of the output patterns depends on the overlapping of the constraints. Depending on the degree of overlapping, the algorithm can simulate the frequency of occurrence of the outputs. If two constraints overlap completely – meaning that they have the same ranking value – the frequency of occurrence of each output is 50%[1]. The algorithm used to carry out the simulations is the Gradual Learning Algorithm (GLA, BOERSMA & HAYES, 2001). This algorithm is used to simulate the three acquisition stages of English mid codas /p/ e /k/ by Brazilian learners, as it will be seen in our analysis.

1.3 The Framework of Gestural Phonology and Gestural Landmarks

Our analysis departs from the adoption of gestures as phonological primitives. Gestures are defined as "events that unfold during speech production and whose consequences can be observed in the movements of the speech articulators. These events consist of the formation and release of constrictions in the vocal tract."[2] (BROWMAN & GOLDSTEIN, 1992, p. 23). These constrictions are given by the following tract variables:

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[1] For more details about Stochastic OT and the GLA, we suggest the reading of BOERSMA (1997), BOERSMA & HAYES (2001), FERREIRA-GONÇALVES (2010) and ALVES (2012).

[2] For a more complete introduction to Gestural Phonology, we suggest the reading of Browman & Goldstein (1986, 1992) and Albano (2001). For gestural accounts of Optimality Theory, see Gafos (2002) and Ferreira-Gonçalves & ALVES (2013).

Figure 4: Tract Variables and Associated Articulators (BROWMAN & GOLDSTEIN, 1992, p. 24)


The tract variables proposed by Browman & Goldstein (1992) represent gestural abstractions of the movement of the articulators used in speech. These gestures are in their physical aspects correlated to tract variables, which in turn are correlated to their corresponding movements of the articulators. For example, a bilabial sound presents a lip aperture which is a linguistic abstraction for the lips and jaw movements made while producing a bilabial sound. However, for this sound to be voiced or voiceless, another tract variable is required to work in conjunction with our lip aperture variable: a velic aperture. Moreover, these tract variables assume different degrees of constriction, such as closed/released for a lip aperture, in order to model the different states of articulation the same tract variable may assume, such as the opening and closing of the lips. These "moments" may be plotted in a gestural score, as it is shown below.

Therefore, as opposed to traditional linguistic entities, in which segments are theorized to be made up of matrices of distinctive features (as in linear phonology) or geometry of features (as in autosegmental phonology), gestures present a spatiotemporal dimension and, although they are abstract phonological primitives/entities, they incorporate phonetic aspects, since they are entirely based on the articulatory movements of the vocal tract. Therefore, they make it possible for

overlapping phonetic patterns to be accounted for in the grammar. These overlapping phonetic patterns are coordinated into larger structures called gestural constellations, where the gestures are presented in their phasing in relation to each other, and are represented in (simplified) gestural scores, as shown below:

Figure 5: Gestures Scores for "add" and "had" (BROWMAN & GOLDSTEIN, 1992, p. 25)
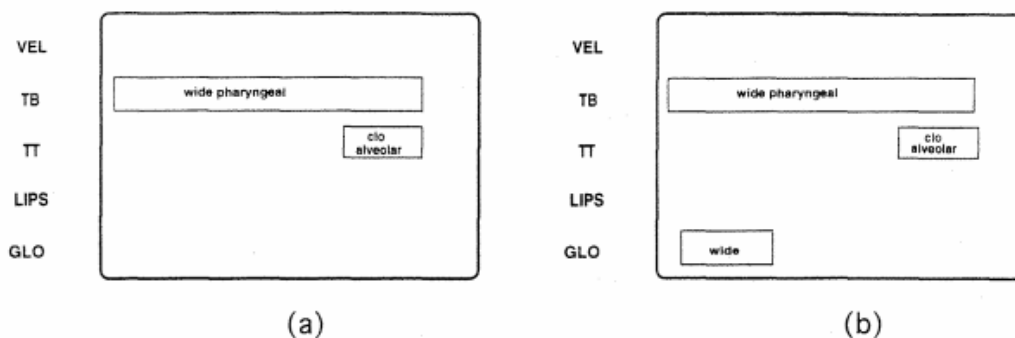
The gestural scores shown above represent the conjunction of the tract variables and their degrees of constriction together with the patterns they present when segments are articulated, as it occurs in speech.

This may account for overlapping patterns, such as an unreleased stop followed by another stop, or the presence of a vowel-like pattern between two adjacent stops. These patterns, under an Optimality-theoretic account, are presented by gestural landmarks (GAFOS, 2002), as will be seen in the next section.

1.4 Gestures represented by Landmarks

In order to account for gesture coordination in a gestural framework, Gafos (2002) proposed that gestures can be represented in the following structure, using what the author calls "landmarks":

Figure 6: Gesture in a Representation Using Landmarks (DAVIDSON, 2006, p. 842)
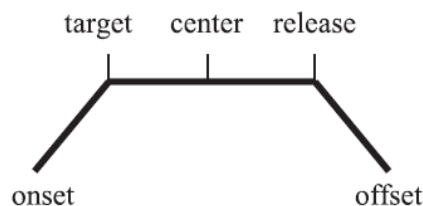
In his Optimality-Theoretic account, Gafos proposes that "[...] constraints *in the grammar* refer to temporal relations between gestures". (GAFOS, 2002, p. 2), since languages present different overlapping patterns (French and German, cf. ASHBY & MAIDMENT, 2005) and this is what characterizes the different grammars of the languages, as far as the gestural primitive is concerned. Therefore, the grammar must account for overlapping patterns, such as the following ones, suggested by the author:

Figure 7: Examples of Temporal Relations (GAFOS, 2002, p. 2)
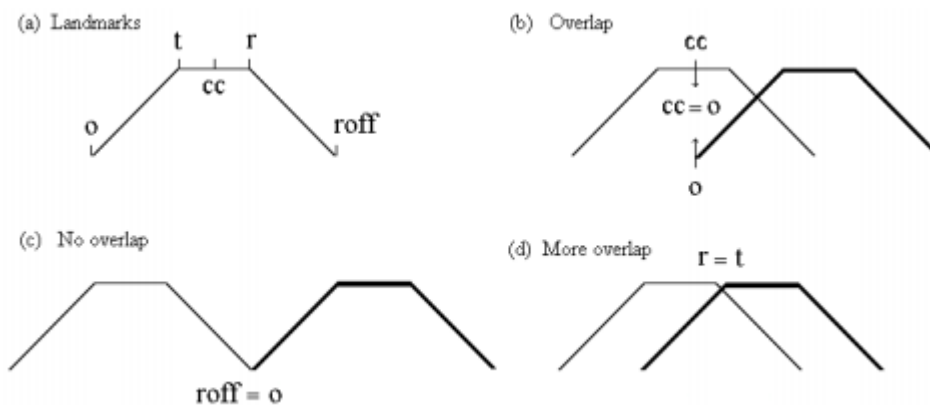
These temporal relations are discussed in section 4.2, regarding our OT analysis.

Gafos (2002) also proposes gestures as being made up of 3 temporal units Δ, or 6 temporal units τ:

> As a working hypothesis, it is assumed that the temporal distance between the onset-target landmarks and the target-release landmarks is the same, Δ. The c-center further divides the plateau between target and release into two halves, each of distance $\tau = \Delta/2$. This τ will be the minimal unit of temporal distance employed in gradient evaluation of coordination constraints. (GAFOS, 2002, p. 10)

We can see these temporal units in the representation that follows:

Figure 8: Temporal Representation of Landmarks (our illustration based on Gafos, 2002)
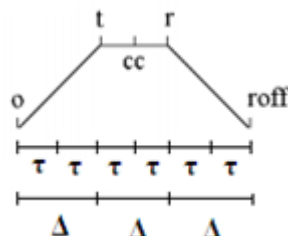
This temporal representation is also adopted in this paper as we propose a constraint that refers to temporal units, in the Results section.

2 Method

Seven Brazilian learners from the Southern state of Rio Grande do Sul were recorded, both in Portuguese and in English, in a reading task composed of carrier-sentences with the target-segment ("Say <target word>" and "Diga <target word>")[3]. The reading task was composed of the following words:

Table 01 - Words of the Reading Task[4]

ENGLISH		PORTUGUESE	
/p/	**/k/**	**/p/**	**/k/**
baptize	doctor	apto	pacto
captain	active	réptil	néctar
reptile	dictate	rapto	cacto
chapter	lactate	optar	detector
		captar	conectar
		adaptar	caracter

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[3] Since the acoustic patterns produced in English codas are well documented in the literature (LADEFOGED, 1993), we found it needless to include a control group of native speakers of English.

[4] The larger number of words in BP, as well as the position of the target words in the sentences, may be explained by the fact that the lexical items in Table 01 are part of a much larger data collection instrument, which consisted of a larger number of types and took other variables into consideration.

Each word was read twice. The software Audacity[5] was used to record the data. The only independent variables controlled were learners´ dialect and L2 proficiency. Concerning proficiency, all subjects took the Oxford Proficiency Test (ALLAN, 2004), which indicated they presented a basic level of proficiency in English. Participants also read and signed a Consent Form, in which they agreed to participate in the study. All the informants lived in the city of Porto Alegre, in the state of Rio Grande do Sul. Summing up, the data consists of 168 tokens for BP (7 participants x 12 words x 2 repetitions) and 112 tokens for English (7 participants x 8 words x 2 repetitions).

The recordings were acoustically analyzed using the free software Praat v. 5.2.21[6] (BOERSMA & WEENINK, 2011). The acoustic patterns were then organized for the formalization of the phenomenon within the framework of Stochastic OT.

3 Results

In this section, we will describe the acoustic patterns produced by the learners and their relative frequencies of occurrence, which are to be reproduced by the Gradual Learning Algorithm (GLA). We will also carry out the simulations of the learners' grammar. Finally, we will present a discussion of the gestural constraints used in the formalization of the acoustic patterns as well as the simulations using the Gradual Learning Algorithm.

3.1 Acoustic patterns and their relative frequencies

The following spectrograms illustrate the acoustic patterns produced by the learners:

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[5] The software Audacity may be downloaded at http://audacity.sourceforge.net/.
[6] The software Praat may be downloaded at http://www.fon.hum.uva.nl/praat/.

Figure 9: Spectrogram of an Unreleased Stop
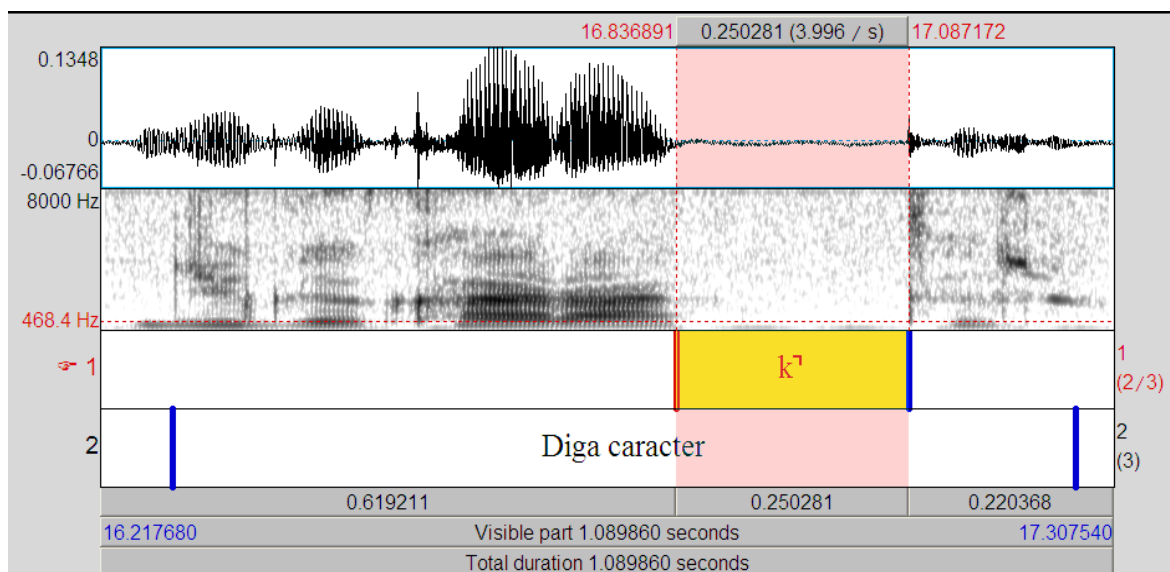
Unreleased Stop: In the spectrogram presented in Figure 09, the burst that characterizes the stop /k/ is not visible, characterizing an unreleased consonant. The closure length is much longer, as it accounts for the closures of both the coda and the onset consonant.

Figure 10: Spectrogram for a Stop with Short Release

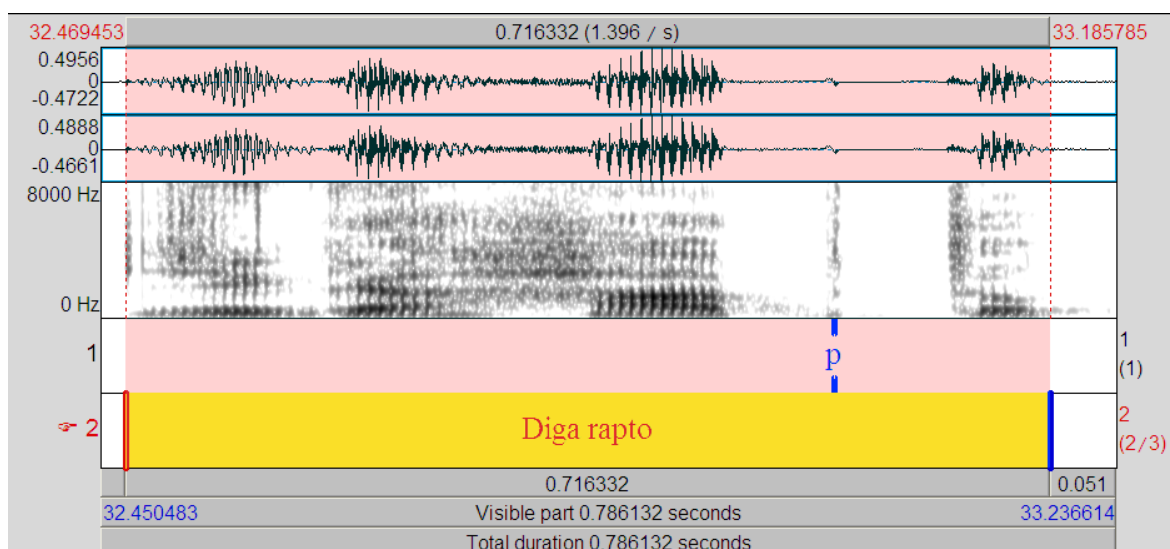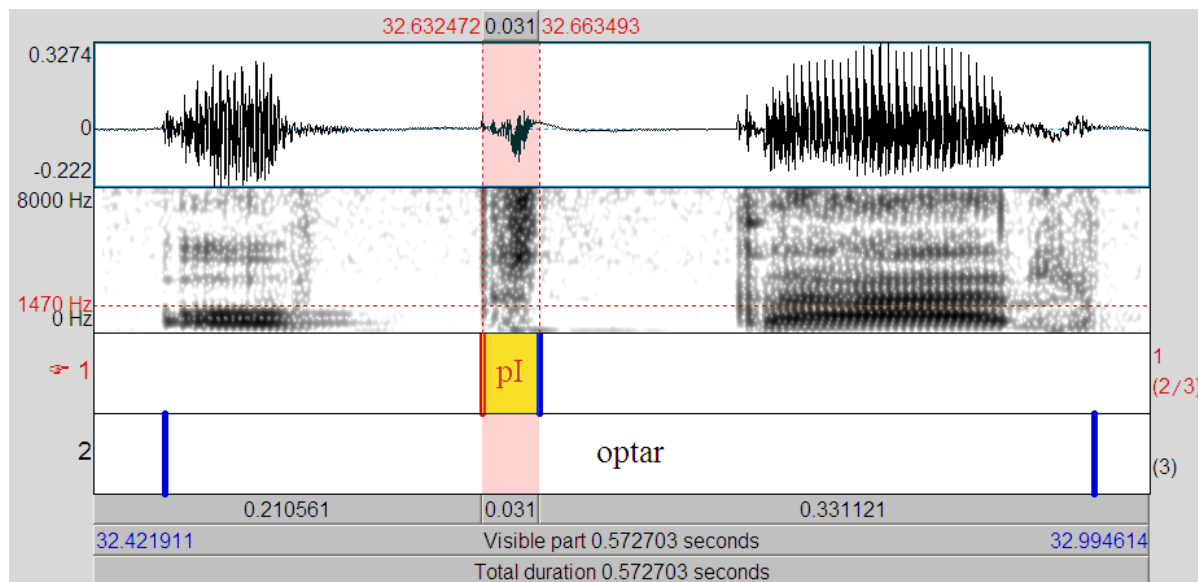Stop with short release: The spectrogram in Figure 10 presents a clear burst, but the release of air which follows is short. In this study, we consider "a short release" to last no more than 80 ms (HUF & ALVES, 2010).

Figure 11: Spectrogram for a Transitional (Voiceless) Vowel[7]

Transitional Vowel: The spectrogram in figure 11 presents a voiceless articulation after the release of stop that is inconsistent with a typical stop release. We assume in this study that this pattern, which presented high rates of production among the learners, is consistent with the landmark proposed by Gafos (2002) presented in section 4.2. This landmark is also used by Davidson (2006) to represent a transitional schwa or transitional vowel (hence our use of the term, even though in our study we have not carried out an articulatory analysis of this pattern, which is needed for future studies).

The following table presents the acoustic patterns produced by the participants, as well as their relative frequencies, expressed in percentages.

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[7] In the lack of an adequate phonetic symbol, we use the symbols I and ‚ə interchangeably to represent a transitional vowel (or what Davidson (2006) calls a transitional schwa), as well as the terms 'transitional vowel' and 'transitional schwa'.

Table 2 - Acoustic Patterns of /p/ and /k/ Codas in Brazilian Portuguese and in English (with their Absolute and Relative Frequencies):

ACOUSTIC PATTERN	/p/ - BP	/k/ - BP	/p/ - EN	/k/ - EN
Unreleased [pˋ] or [kˋ]	0% (0/84)	1.2% (01/84)	23.2% (13/56)	21.4% (12/56)
Short Release [p] or [k]	34.5% (29/84)	34.5% (29/84)	66.1% (37/56)	50% (28/56)
Voiceless Epenthesis [pə̥] or [kə̥]	65.5% (55/84)	59.5% (50/84)	3.6% (02/56)	19.6% (11/56)
Voiced Epenthesis [pə] or [kə]	0% (0/84)	0% (0/84)	0% (0/56)	0% (0/56)
Eliminated Tokens	0% (0/84)	4.8% (04/84)	7.1% (4/56)	9% (05/56)
Total	100% (84/84)	100% (84/84)	100% (56/56)	100% (56/56)

As we can see in Table 01, the same acoustic patterns were found in the productions in both Brazilian Portuguese (L1) and English (L2). In this table, four main acoustic patterns may be found: despite what predicted by traditional accounts of Brazilian Portuguese-English interphonology (cf. SILVEIRA, 2004; ALVES, 2008; LUCENA & ALVES, 2010), the participants in this study did not produce fully voiced epenthetic vowels, neither in their L1 nor in their interlanguage. Besides this pattern, consonant sequences were also found. Table 01 shows that word-mid /p/ and /k/ in /pt/ and /kt/ sequences were produced either with no burst or with a short release. It is interesting to mention that productions of /p/ and /k/ with a long release (longer than 80 ms, following Huf & Alves, 2010) were not found in our data, mainly due to the effect of anticipatory co-articulation, which prevents the first stop from presenting a long release in view of the articulation of the following segment.

Besides the three patterns described above, we should also mention a pattern which will be called in this paper as "voiceless epenthesis". This pattern is characterized by the production of a voiceless vowel-like [ə] between the two stop consonants. This pattern, which occurs both in Brazilian Portuguese and in Brazilian Portuguese-English interlanguage, does not occur in English codas. More details on the production of this pattern will be provided in the following section.

As we addressed the issue of whether the constraints to be employed in our analysis should necessarily make reference to a specific stop segment, /p/ or /k/ in this

case, we ran a statistical analysis in order to attest if there is any significant difference between the frequency of each of these stops, which could indicate a markedness hierarchy between them, as being attested in phonology. We ran a Wilcoxon Signed Ranks Test between the acoustic patterns, and none of them were significant. Further studies are needed so that we can verify if the constraints should make reference to a specific tract variable (in this case, LIPS CLOSURE and TONGUE BODY CLOSURE) in order to account for a potential markedness relation between stops[8].

In order for the GLA to reach the frequencies of occurrence of the acoustic patterns above, we calculated the relative frequencies of the valid tokens and then the average of their frequencies of /p/ and /k/, which can be shown in the table below:

Table 3 - Average Frequencies for /p/ and /k/

	Unreleased Stop	Released Stop	Voiceless Epenthesis	Voiced Epenthesis	TOTAL
BP	0.5	35.5	64	0	**100**
EN	24	63	13	0	**100**

3.2 Gestural Landmarks and Gestural Constrains in a Stochastic OT Model

We propose, based on Gafos's analysis of Moroccan Colloquial Arabic (2002), the following coordination patterns between adjacent stops, as corresponding to the acoustic patterns produced by the participants of this study.

a. An unreleased stop (e.g. [tʃæpˀ.tɝ]) corresponds to the following configuration of landmarks:

Figure 12: Representation of an Unreleased Stop

r = t

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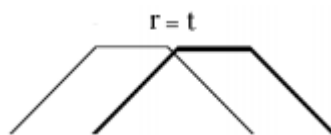
[8] For a non-gestural Stochastic OT analysis whose constraints refer to specific places of articulation in order to account for markedness relations between stops, see ALVES (2008, 2012).

This represents a close transition of gestures, which in the case of two adjacent stops makes the first stop to be unreleased, due to the fact that the active articulation of the second stop will have reached its target by the time of the release of the first stop.
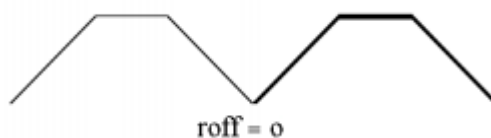
b. A fully released stop (e.g. [tʃæp.tɜɹ]) corresponds to the following configuration of landmarks, considering that the two adjacent consonants have different places of articulation (heterorganic sequence):

Figure 13: Representation of a Fully Released Stop

roff = o

c. A voiceless epenthetic vowel (epenthetic co-articulation) corresponds to the following configuration of landmarks when the consonantal gestures are voiceless:

Figure 14: Representation of a Voiceless Vowel-Like Epenthesis:

cc

cc = o

o
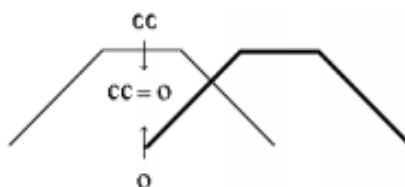
This corresponds to an open transition:

> In a number of languages and in the relevant environments whose identity is not important in the present context, a sequence of two heterorganic consonants is produced with an intervening acoustic release, also known as an 'open transition' (Bloomfield 1933). For example, in Moroccan Colloquial Arabic (henceforth, MCA), the active participle of the verb 'to write' is [katᵊb], with a schwa-like vocalic transition in the final CC cluster. [...] The relation in (2b) is such that the onset of movement for the lips gesture for /b/ is initiated around the mid-point of the tip-blade gesture for /t/, the c-center of /t/ – indicated as 'cc = o'. As a consequence of this relation, the achievement of the target for the /b/ gesture, lip closure, takes place after the release of the /t/ gesture. There is, thus, a period of no constriction in the transition between /t, b/ that is identified as a schwa-like vocalic element. (GAFOS, 2002, p. 03).

Considering that this vowel-like transition occurs in our study between voiceless consonants, it emerges as voiceless as well. This is due to the fact that this transition does not constitute a gesture itself, therefore a velic aperture needed to produce voicing would not arise since both consonants are voiceless and could not present a voicing articulation. In contexts where this transitional vowel does occur between voiced consonants, we would expect it to be much shorter than a really voiced epenthetic vowel (which we assume to be a vocalic gesture inserted between two stops, as described below), since the voicing would belong to either voiced consonant of the cluster. Since our study did not employ formant and duration analysis of the vowels and epenthetic vowels and/or an articulatory analysis, because of the lack of a control analysis (comparing epenthetic, lexical, and transitional vowels), we assume that full epenthetic vowels (which, it is worth mentioning, have not been found in our data) incur violations in DEP, since they are represented as vowel gestures as opposed to transitional vowels, which in our case present no voicing due to the clusters chosen for our experiment. Therefore, the voicing of the transitional vowel derives from the voicing of the cluster involved in the coordination. Further studies are needed to compare these segments acoustically and articulatorilly, in order to incorporate the findings into the landmark representations and the OT analysis.

d. A voiced epenthetic vowel corresponds to the following configuration of landmarks:

Figure 15: Representation of an Epenthetic Vowel

This corresponds to the insertion of a V gesture between two plosive sounds. Although we acknowledge that, in traditional Articulatory Phonology, gestures cannot be added or deleted, since this is an Optimality-Theoretic account, we assume that the GEN module is able to produce outputs with insertion or deletion. It is relevant to mention that, in an OT framework, the GEN module cannot be limited in the way it

produces candidates, being the task of the constraints to evaluate the best one at a certain evaluation time. It is also worth mentioning that, in the data of the present study, this voiced pattern has not been found, which leaves the discussion on the relevance of this theoretical account for follow-up studies.

Based on the framework of Gestural Phonology (BROWMAN & GOLDSTEIN, 1986, 1992), we propose that the input must be represented as phonological gestures, as opposed to distinctive features. In the input, gestures do not exhibit phasing specifications, which means that the coordination patterns between gestures are produced by the grammar. The candidates, equally, are represented as gestures, but with phonologically relevant phasing specifications. Since overlapping patterns differ among languages (ASHBY AND MAIDMENT, 2005, p. 126)[9], we conceive that such patterns should emerge from a grammar system.

The constraints are assumed here to be universal and innate, as in Standard OT. Considering that this analysis simulates the acquisition process, we assumed that the constraints in the grammar are ordered in the first stage of L1 acquisition with MARKEDNESS outranking FAITHFULNESS constraints (M >> F), since children tend to present a highly unmarked oral production in the first stages of language acquisition (GNANADESIKAN, 1995, p. 01). Therefore, the constraint values will follow this premise at the initial stage of L1 acquisition.

The constraints we propose for the present analysis are:

a. ALIGN[10] (G1, release, G2, target) – based on Gafos (2002). In two contiguous C gestures, this constraint assigns one violation mark for each output representation whose phasing does not align the release of the first gesture with the target of the second gesture.

b. ALIGN(G1, c-center, G2, onset) – based on Gafos (2002). Gafos also calls it CC-COORD[11]:

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[9] "In general, the release of the first plosive in a sequence is inaudible in English. It is worth noticing that languages may handle this situation in different ways. For instance, both French and German regularly show an audible release for the first of the two plosives in a sequence. These examples show that languages can differ in their coarticulatory patterns." (ASHBY AND MAIDMENT, 2005, p. 126)

[10] The first two constraints we used are from the ALIGN family of constraints proposed by GAFOS (2002, p. 10): "ALIGN(G[1], landmark[1], G[2], landmark[2]): Align landmark[1] of G[1] to landmark2 of G[2]
Landmark[i] takes values from the set {ONSET, TARGET, C-CENTER, RELEASE}"

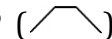[11] "The coordination relation above refers to *gestures*. The MCA facts show releases in final sequences of *consonants*, as in [t$^\circ$b], [m$^\circ$n]. The distinction between 'consonant' and 'gesture' is important here. In the general case, each consonant consists of a set of gestures. These segment-internal gestures are temporally

In this relation, the c-center of C1's oral gesture is synchronous with the onset of C2's oral gesture, that is, ALIGN(C1, C-CENTER, C2, ONSET). The annotation 'open vocal tract' indicates that there is a period of time between the articulatory release of the first gesture and the achievement of the target of the second gesture. This period of time corresponds to the acoustic release that is characteristic of an open transition. (GAFOS, 2002, p. 14-15).

c. *COMPLEX(oral closure gestures). This constraint is defined as[12] "Assign one violation mark iff two contiguous C gestures present the TV (tract variable) VELUM as CLOSED and their Oral TVs (LA or TT or TB) as CLOSED (characterizing closure segments or stops)."

This militates against a CC pattern, prohibiting two stops or oral closure gestures from occurring contiguously. A more general constraint could be used for C gestures in general, such as *COMPLEX(CC) or *COMPLEX(GG), for preventing two consonants or landmarks to occur. It is also worth noting that this constraint does not make reference to a specific syllabic position (onset, coda) since, in Gestural OT, the syllabic structure has not been fully established.

d. TIME-IO (τ) – A violation is assigned to each temporal unit τ that is present in the input and absent or in overlap in the output.

The role of this constraint may be clearer as we consider the following case: in Figure 12, an unreleased plosive presents 6 temporal units τ in its input representation; however, in the output representation, it will present only 2 non-overlapping temporal units τ, since the target of the second gesture will align to the target of the unreleased plosive. Therefore, an unreleased plosive will be assigned 4 violations of TIME-IO. This applies to all the gestures shown in the figures 12, 13, 14, 15, and DEP ($\diagup\diagdown$) – A violation is assigned if a gesture is inserted.

Following the idea that M >> F in the initial stages of L1 acquisition, the constraint values of the constraints for the grammar in its initial stage in BP as L1 are: ALIGN, TIME IO, DEP and ALIGN = 50; *COMPLEX = 100. Although alignment constraints are neither faithfulness nor markedness constraints, we considered them as having the

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organized in a characteristic way particular to that segment. [...]I assume that CC-COORD coordinates *consonants* by reference to their *oral gestures*." (GAFOS, 2002, p. 15)

[12] The *COMPLEX constraint traditionally has the following definition: "*Complex (cf. PRINCE & SMOLENSKY, 1993) No complex syllable margins." (KAGER, 1999, p. 288). The definition we propose is broader than this one, since it does not refer to a specific syllable position.

same value as faithfulness constraints, since markedness constraints militate against marked structures, favoring simpler or easier ones, and the alignment constraints which are used in our study do not favor unmarked forms or structures which tend to be produced more frequently in L1 acquisition.

In the next section, we see the aforementioned constraints in action, as they interact to account for the learners' grammar system.

3.3 GLA Simulations

In this section, we present the results of the simulations of the acquisition of the heterosyllabic /pt/ and /kt/ sequences by Brazilian Learners in Stochastic Optimality Theory. In order to run the simulations, we used the Gradual Learning Algorithm which is available on the software Praat v. 5.2.21 (BOERSMA & WEENINK, 2011).

In what follows, we present the tables generated by the software representing each one of the developmental stages of the grammar, as well as the Output Distributions[13] for each grammar. The algorithm was fed with an input of approximately 100,000 tokens of the grammar we want to simulate, with the ranking values for each constraint, the plasticity values (standard value 0.1), and the disharmony values. The optimal candidate was indicated by a pointing hand.

The section is organized as follows: firstly, we present the grammar of English, which corresponds to the target system to be acquired. After that, we analyse the interlanguage grammar: we start by simulating the learners' L1 system (Brazilian Portuguese) and then, by using the L1 grammar as an initial stage, we present the grammar responsible for the interlanguage patterns shown in Table 03.

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[13] In simulations using the GLA, we must provide the algorithm with the constraints to be used and their initial values, as well as candidates and their respective violations marks, prior to the learning of the grammar. Then the data (rates of occurrence for each pattern) must be fed to the grammar (learning phase). In order to confirm whether the grammar leads to accurate rates of occurrence found in the data, Praat allows us to generate a set of 'Output Distributions', whose simulation evaluates the grammar n times and gives a table of all their outcomes, showing us whether the variable output rates obtained by the grammar in the simulation are correct or not (that is, if they are close to the ones found in the real data).

3.3.1 Simulation of the Target Grammar

In this section, the results of the simulations of English (target grammar) are presented. Departing from an initial stage in which M >> F, we set the algorithm so that the grammar could produce two acoustic patterns, which are found among native speakers of English (ALVES, 2008): unreleased stops and released stops. Since the rates of occurrence between these two patterns vary depending on the dialect of English, for the purposes of the present analysis, we set the algorithm so that it could present an equal distribution of these two patterns.

In the initial stage of acquisition, in which M>>F, the grammar leads to an unmarked candidate, as we can see as follows[14]:

Figure 16: OT Grammar for M>>F

	ranking value	disharmony	plasticity
*COMPLEX(oral clo G)	100.000	100.000	1.000000
ALIGN(c-o)	50.000	50.000	1.000000
ALIGN(r-t)	50.000	50.000	1.000000
DEP	50.000	50.000	1.000000
TIME IO	50.000	50.000	1.000000

/stop + t/	*COMPLEX(oral clo G)	ALIGN(c-o)	ALIGN(r-t)	DEP	TIME IO
unreleased	*!	*			****
released	*!	*	*		
voiceless	*!		*		***
☞ voiced		*	*	*	

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[14] It is important to mention once again that, although the input is represented as /stop+t/ in the tableaux that follow, we conceive the input structure as made up of gestures that do not present phasing specifications or overlappings between each other. It is the role of the grammar, therefore, to account for the phasing specifications between gestures (which will result in the acoustic patterns that correspond to the candidates).

Figure 17: Output Distributions for the Grammar when M>>F

row	1 ?	2 ?
1	/stop + t/ → unreleased	0
2	/stop + t/ → released	0
3	/stop + t/ → voiceless	0
4	/stop + t/ → voiced	100000

With highly-ranked *Complex (which is set to 100 in the initial stage of L1 acquisition), the only candidate allowed to emerge presents a voiced epenthetic vowel. In other words, the unmarked candidate emerges, as the markedness constraint prevents the stop sequence from emerging. Since both unreleased and released codas, but not epenthetic vowels, occur in English, the acquisition process in English will imply the demotion of the markedness constraint and the promotion of DEP. The grammar of English, as well as the Output Distributions indicated by the GLA, are presented in Figures 18 and 19:

Figure 18: OT grammar for English

	ranking value	disharmony	plasticity
DEP	81.912	81.924	1.000000
*COMPLEX(oral clo G)	68.088	67.684	1.000000
TIME IO	51.483	51.396	1.000000
ALIGN(r-t)	51.512	47.739	1.000000
ALIGN(c-o)	41.238	37.997	1.000000

/stop + t/	DEP	*COMPLEX(oral clo G)	TIME IO	ALIGN(r-t)	ALIGN(c-o)
unreleased		*	*!***		*
☞ released		*		*	*
voiceless		*	*!**	*	
voiced	*!			*	*

Figure 19: Output Distributions for the English Grammar

row	1 ?	2 ?
1	/stop + t/ → unreleased	50380
2	/stop + t/ → released	49619
3	/stop + t/ → voiceless	1
4	/stop + t/ → voiced	0

As we can see in Figure 18, the acquisition of the English grammar implies the promotion of DEP, since, in English, no epenthetic vowels are produced in order to block heterosyllabic /pt/ and /kt/ clusters. With the promotion of DEP and the demotion of *COMPLEX (oral clo G), the two constraints are far enough so that voiced epenthetic vowels are impeded, and, therefore, heterosyllabic /pt/ and /kt/ sequences are allowed to emerge.

The acoustic pattern to be produced in the first stop depends on the role played by TIME-IO, ALIGN(r-t) and ALIGN (c-o). As both unreleased and released stops occur variably in English, TIME-IO and ALIGN(r-t) present overlapping variables. Since we set the rates of occurrence to be equal for each of the two patterns, their ranking values are practically the same: 51.483 and 51.512, respectively. At each evaluation time, the disharmony values of these constraints might change their ranking – in Figure 18, Time I-O (51.396) outranks ALIGN(r-t) (47.739). The ranking between these two constraints is subject to change at each evaluation moment, as indicated by the output distributions in Figure 19 – since both constraints present practically the same ranking values, the chances of one outranking the other are practically the same (50%).

ALIGN(c-o), on the other hand, was demoted in the acquisition of English, so that its ranking value (41.238) could be low enough not to overlap with TIME-IO or ALIGN(r-t). This given, ALIGN(c-o) will always be outranked by all the other constraints, which prevents voiceless epenthetic vowels from occurring in English.

Given the grammar and its output distributions presented above, we were able to formalize the production of unreleased or released coda stops, as well as the non-production of voiceless epenthetic vowels. In our account, the presence/absence of these patterns results from the grammar of English, in a way that these phonetic patterns have a status in the phonology of the language. As we will see in what follows,

voiceless epenthetic vowels emerge from the grammar of both Brazilian Portuguese (L1) and BP-English interlanguage; our Stochastic grammar must be able to account for this fact.

3.3.2 L1 Simulation

In this section, we will present the simulations for the acquisition of the /p/ and /k/ mid-codas of Brazilian Portuguese. The resultant grammar is going to be used as the initial stage of the learners' interlanguage grammar. Once again, we depart from an initial stage M>>F, which results in a categorical epenthetic vowel, as shown in 22. This might be the grammar of some dialects of Brazilian Portuguese, should we consider the possibility that there are dialects that do not accept word-mid /p/ and /k/ codas. However, as shown in Table 02, the speakers investigated in this study produced unreleased and released /p/ and /k/ in codas as well as voiceless epenthetic vowels, but not voiced epenthetic vowels. The grammar that accounts for the production patterns in Table 02 is presented in Figure 20, and the output distributions resulting from this grammar are shown in Figure 21.

Figure 20: OT Grammar in Southern Brazilian Portuguese

	ranking value	disharmony	plasticity
DEP	82.504	83.532	1.000000
*COMPLEX(oral clo G)	67.496	68.815	1.000000
ALIGN(c-o)	53.445	55.058	1.000000
TIME IO	52.241	50.835	1.000000
ALIGN(r-t)	47.402	46.716	1.000000

/stop + t/	DEP	*COMPLEX(oral clo G)	ALIGN(c-o)	TIME IO	ALIGN(r-t)
unreleased		*	*!	****	
released		*	*!		*
☞ voiceless		*		***	*
voiced	*!		*		*

Figure 21: Output Distributions for the Gaucho Dialect

```
              1              2
row           ?              ?
 1    /stop + t/ → unreleased   489
 2     /stop + t/ → released   33214
 3    /stop + t/ → voiceless   66297
 4      /stop + t/ → voiced       0
```

As we consider the grammar that accounts for the Brazilian Portuguese data presented in Table 03, we see that, in a similar fashion to what occurred in the English grammar, DEP must fully outrank *COMPLEX (oral clo G), which, in the participants' dialect, needed to be demoted. Since the Brazilian Portuguese productions also presented occurrences of voiceless epenthetic vowels, ALIGN(c-o), Time I-O and ALIGN(r-t) need to overlap so that the three patterns (voiceless epenthetic vowels, released and unreleased codas) can emerge. At the evaluation time shown in Figure 20, ALIGN(c-o), which assumes a disharmony value of 55.058, outranks the other two constraints (TIME-IO: 50.835; ALIGN(r-t)- 46.716) and, therefore, allows voiceless epenthetic vowels to surface as the output. As indicated by the ranking values and the output distributions themselves, this tends to be the most common output pattern obtained from this grammar (reflecting, therefore, the data shown in Table 03), although there shall be moments at which TIME-IO or ALIGN(r-t) will take the lead in order to account for the emergence of released and unreleased stop codas, respectively. Since voiceless epenthetic vowels do not occur in English (as shown in the target grammar shown in 18), the acquisition of the L2 grammar would imply a lower position of ALIGN(c-o). This will be seen as follows.

3.3.3 Brazilian Portuguese-English Interlanguage

Departing from the L1 grammar values (shown in Figure 20 above), we simulated the learners´ developmental grammar that accounts for the output patterns presented in Table 03.

Figure 22: OT Grammar for the Interlanguage Grammar

	ranking value	disharmony	plasticity
DEP	82.504	83.009	1.000000
TIME IO	76.086	80.589	1.000000
ALIGN(c-o)	73.644	71.579	1.000000
ALIGN(r-t)	74.530	70.798	1.000000
*COMPLEX(oral clo G)	67.496	66.536	1.000000

/stop + t/	DEP	TIME IO	ALIGN(c-o)	ALIGN(r-t)	*COMPLEX(oral clo G)
unreleased		*!***	*		*
☞ released			*	*	*
voiceless		*!**		*	*
voiced	*!		*	*	

Figure 23: Output Distributions for the Interlanguage Grammar

row	1 ?	2 ?
1	/stop + t/ → unreleased	24583
2	/stop + t/ → released	62401
3	/stop + t/ → voiceless	13016
4	/stop + t/ → voiced	0

As seen in Table 03, the output patterns produced in the learners' interlanguage were the same ones found in their L1: unreleased stops, released stops and voiceless epenthetic vowels (which do not occur in native-like English). Despite the fact that the output patterns were the same, the rates of occurrence for each pattern were different: the data in Table 03 show that voiceless stops, unlike what happens in their L1, is the least frequent pattern, which indicates that the learner´s interlanguage grammar is developing towards a system from which only released and unreleased codas might be allowed to emerge.

The grammar presented in Figure 22, as well as the output distributions in Figure 23, indicate this fact. Once again, TIME-IO (76.086), ALIGN(r-t) (74.530) and ALIGN(c-o) (73.644) are overlapping, which allows the three patterns (released codas, unreleased codas and voiceless epenthetic vowels) to emerge. However, the ranking values shown

above indicate that ALIGN(c-o) has already started its demotion process in relation to the other two constraints, which causes voiceless epenthetic vowels to become less frequent. We believe that, as learners progress towards the target language, they might reach a stage at which ALIGN(c-o) does not overlap the other two, in a similar fashion to the target grammar of English in Figure 18.

Conclusion

In this article, we investigated the production of heterosyllabic /pt/ and /kt/ sequences in Brazilian Portuguese (gaucho dialect) and Brazilian Portuguese-English interlanguage. Our data showed us that, even in their L1, learners already produce coda stops showing different acoustic patterns, such as unreleased stops and released stops. Both in their L1 and in their interlanguage, an additional acoustic pattern, which does not occur in English, was also be found: a voiceless epenthetic vowel between voiceless stops.

In order to account for these multiple acoustic patterns in the grammar, we made use of constraints based on Gestural Landmarks (GAFOS, 2002). The adoption of gestural primitives allowed us to show that the decision between unreleased or released stops, for example, is not a simple matter of phonetic implementation, since it is derived from the grammar. In other words, based on our account, the grammar of a language should be able to account for different acoustic patterns which tend not to be considered by traditional phonological accounts.

We believe that the analysis presented above might prove relevant to the field of L2 phonological acquisition. In traditional accounts of Brazilian Portuguese-English Interlanguage (cf. ALVES, 2008), the analysis of Brazilian Portuguese-English grammar was based on the emergence of two single patterns: production of codas and emergence of voiced epenthetic vowels. Unreleased and released codas, in this sense, tended to be characterized under the same label: absence of epenthesis. Our present account, on the other hand, allows for a more complete mapping of the learner's output forms in the grammar.

It is also important to mention that our account assumes phonological gestures to be present in the input. This assumed, the role of an OT grammar is to explain the

different phasing relation between gestures, as languages differ from each other in view of the timing and phasing relations presented by gestures. The adoption of a gestural input is also in accordance with Goldstein & Fowler (2003), who argue in favour of a single primitive in both perception and production. Further studies, which should also insert the perceptual component of the grammar, might be relevant so as we can go further in the discussion on phonological primitives in L1 and L2 acquisition, as well as on phonological theory itself. The present analysis, which conceives that more fine-grained phonetic detail should be implemented by the grammars of the world's languages, represents an attempt towards this relevant research agenda.

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