ACQUISITION OF THE AFFRICATE /t^s/ IN GREEK: A CASE STUDY

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Abstract: The present research examines the acquisition of affricates by one Greek-speaking child so as to investigate their phonological status in the underlying representation. For this reason, a comparison is made between the affricate [t^s] and the clusters [ks], [ps] to see if their phonological status is same or different. The child's data reveal a preference of the [-continuant] over the [+continuant] feature in reductions in all the aforementioned categories. However, the child manages quite often to utter [t^s] faithfully, while clusters do not present any faithful production. So, the acquisition of [t^s] precedes that of clusters. These findings support Lombardi's (1990) Unordered Component Hypothesis, according to which the features [−continuant] and [+continuant] of affricates are unordered and are represented on two different tiers. In other words, their features are considered single-valued, namely, they are either present or absent. For the analysis of child's tokens, Maximum Entropy Grammar is used (Goldwater & Johnson 2003), which can adequately account for the various handling of affricates.

Keywords: affricates, language acquisition, phonological representation, Maximum Entropy Grammar

1. Introduction

The majority of researchers agree that phonetically affricates are represented as *complex* segments composed of ordered [−continuant] and [+continuant] specifications (e.g. Sagey 1986, Lombardi 1990, Rubach 1994). However, they have been a long-standing topic of discussion due to their phonological status, which constitutes a matter of dispute. Four main analyses have been proposed leading to four different underlying representations of affricates. As far as the first proposal is concerned, they are considered bipositional clusters consisting of a stop [t] and a fricative [s] (see for Greek: Newton 1961, Setatos 1974, among others). This claim is based on the fact that only vowels can follow after [ts] and [dz] (e.g. Newton 1961). Another argument concerns the occurrence of [ts] as well as both members of it separately in the same phonetic environment, namely, they create minimal pairs (example 1).

(1) [paˈtsas] (tripe) - [paˈtas] ((you) press) - [paˈsas] (pasha)
(Greek, Setatos 1969: 50)

In the second view, they are thought of as monopositional *contour* segments in which the features [−continuant] and [+continuant] are ordered, that is, the stop precedes the fricative and they are subordinated to a single root node (Sagey 1986). The reason why Sagey (1986) suggests affricates as contour segments is due to the emergence of edge effects at their margins, namely, they act in phonological processes as stops regarding their left edge and as fricatives regarding their right edge. For instance, in order for two adjacent sibilants to be licensed, epenthesis of vowel [i] must take place between them (examples 2a-b).

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(2) a. /bʌs+z/ [bʌsiz] *buses*
b. /tʃɜ:(r)tʃ + z/ [tʃɜ:(r)tʃiz] *churches*

(English, Sagey 1986: 93 - 94)

Epenthesis is used so that Obligatory Contour Principle (Goldsmith 1976: 163), which prohibits adjacent segments that have the same specification for one distinctive feature, should not be violated. An instance that shows affricates act as stops on their left edge constitutes a rule in Zoque (Wonderly 1951), which enforces the voicing of a [−continuant] consonant after a nasal (examples 3a-b).

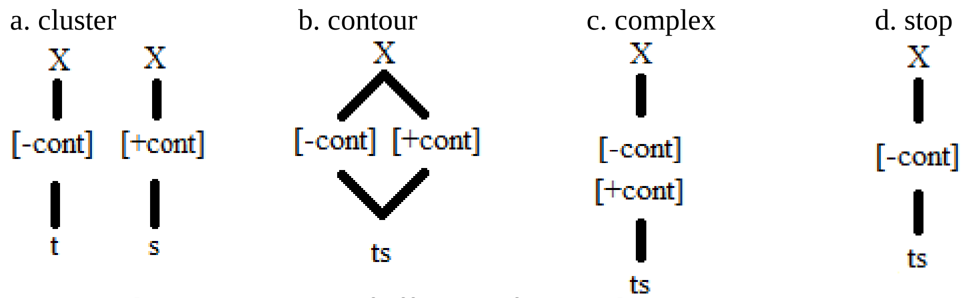
(3) a. /nʌm + pa/ [nʌmba] 'he says'
b. /pʌn + tɕʌki/ [pʌndʑʌki] 'figure of a man'

(Zoque, Wonderly 1951: 120)

In Greek, some researchers consider affricates as contour segments since [tˢ] can appear simultaneously in the first and second syllable of a word especially when the vowels bear the same distinctive features as in [tˢaˈtˢaɾa] (comb), something that does not happen with clusters (Householder 1964).

According to a third suggestion, affricates are characterized as complex segments with their features to be unordered and single-valued which means that they are either present or absent (Lombardi 1990). Given that in English two adjacent tautosyllabic strident segments are prohibited due to the Obligatory Contour Principle, if the features of affricates are ordered, then clusters containing [s + affricate] will be permitted since the left member of affricate is specified as [−continuant]. However, the same researcher claims that such clusters are also disallowed by the Obligatory Contour Principle leading to the absence of forms with [tˢs] and [stˢ], which would otherwise be expected.

According to the last proposal, affricates are viewed as simple stops; stridency is not represented in the underlying representation and it is added in order for affricates to be perceptually more salient (e.g. Jakobson, Fant & Halle 1951, Rubach 1994, Kehrein 2002). This analysis is based on the common properties of stops and affricates on the phonological level and it is argued that the latter are uttered as affricates on the phonetic level, which may be due to the idiolect of a speaker or the dissimilation with another segment that has the same place of articulation in order for a sound to be perceived easier (Kehrein 2002). All the aforementioned analyses of affricates are illustrated below, in Figures 1a-b.



Figures 1a-d. Representations of affricates (from Tzakosta & Vis 2009: 559)

The aim of the present study is to provide acquisitional evidence regarding the underlying representation of affricates. The structure of the paper is the following: section 2 includes literature review concerning previous research dealing with affricates in language acquisition. In section 3 the research methodology is presented. Section 4 contains the description and discussion of the child's tokens of the affricate [t^s] in comparison to those of the clusters [ks] and [ts], while in section 5 the analysis of the data based on *Maximum Entropy Grammar* (Goldwater & Johnson 2003: 112) is presented. In section 6 the main findings of our study are summarized.

2. Studies on affricates in language acquisition

There are not enough researches in many different languages investigating affricates' underlying representation in child speech. In most of them a comparison between the acquisition of affricates and clusters containing especially [stop + s] and [s + stop] sequences is made. A non-controversial hypothesis essential to these researches is that the development of syllable structure begins from the least complex to the more complex ones (e.g. Lleó & Prinz 1997). So, the core CV syllable is followed by CVC and then the additional branching of onset and rhyme is accomplished leading to CCVC and CCVCC structures if they are permitted by the target language. The same researchers assume that in language acquisition C and V are not symbols for consonants and vowels but abstract units on a skeletal tier as in metrical phonology. Taking these assumptions into consideration, it is assumed that if affricates behave as clusters, then their acquisition should be similar to that of the latter, while if they are contour or complex segments, then they should be acquired before clusters.

The first study concerns five monolingual German and four monolingual Spanish-speaking children aged 1;5 – 2;2 years old (Lleó & Prinz 1997). German includes four affricates in its inventory and, more specifically, [pf], [ts], [tʃ], [ʤ], while Spanish only one, [tʃ]. The comparison between affricates and clusters reveals that the former are acquired earlier than the latter, while there is a stage where both categories present cases of *reduction* to one consonant, the choice of which is proposed to be driven by *directionality* of syllable structure assignment (Lleó & Prinz 1996). In particular, left to right syllabification leads to the production of the first consonant and right to left to the second one, resulting in the German-speaking children uttering the [−continuant] segment and the Spanish-speaking toddlers the [+continuant], since the direction of syllabification is attributed to the target language, with German being rightwards and Spanish leftwards[1]. The principle of directionality presupposes two members in affricates, a [-continuant] and a [+continuant] part where the former precedes the latter. This way evidence is provided in favor of Sagey's (1986) Ordered Component Hypothesis, in which affricates are seen as contour segments with their features ordered.

In the next study, monolingual Greek-speaking children are examined (Kappa 1998). In Greek, [t^s] and [d^z] belong to the category of affricates. The data of children are

[1] Unfortunately, it is not possible to cite any example here, since only tokens with faithfulness are provided in this study, but we hope that the description on its own suffices to make the proposal clear.

discussed in comparison to the previous research. Given that directionality is leftwards in Greek (see Drachman 1990, Kappa 1995, among others), the second member of affricates and clusters is expected to be uttered, namely, the fricative. However, in the first developmental stage children produce the [−continuant] consonant, as shown in the following examples (4a - b).

		Adult's output	→ Child's output	Child: Age
(4)	a.	[ˈet^{s}i]	→ [ˈeti] 'so'	Child 1: 2 - 2;6
	b.	[ˈkat^{s}o]	→ [ˈkato] '[I will] sit down'	Child 3: 2 - 2;6

(Greek, Kappa 1998: 32 327)

Thus, in the first acquisition stage of children, reductions cannot be explained by the directionality of syllabification. On the other hand, the *Sonority Hierarchy Hypothesis* (Kiparsky 1979: 432) is argued to interpret sufficiently these specific reductions, according to which the less sonorous consonant is preferred over the more sonorous one in onset position. In affricates and clusters, for instance, the stop is preferred as it is the least sonorous on the sonority scale (Figure 2).

stops > fricatives > nasals > liquids > glides > vowels

less sonorous ⟶ more sonorous

Figure 2. Sonority Scale (drawn from Kiparsky 1979: 432)

In the second developmental stage though, where more marked structures arise, there is a preference for the utterance of the [+continuant] segment, as in (5a-b):

		Adult's output	→ Child's output	Child: Age
(5)	a.	[kalˈt^{s}aci]	→ [kaˈsaci] 'sock, diminutive'	Child 2: 2;9 - 3
	b.	[ˈkat^{s}o]	→ [ˈkaso] '[I will] sit down'	Child 3: 2;9 - 3

(Greek, Kappa 1998: 327)

From these facts the research concludes that ordering in the underlying feature component is not presented and the data seem to conform to Lombardi's (1990) Unordered Component Hypothesis.

Another study conducted on seven monolingual Greek-speaking children aged from 1;7.5 to 3;5 years old compares affricates with all types of clusters in the intermediate developmental phase during which they are observed to utter unmarked, relatively unmarked, relatively marked and fully faithful outputs (Tzakosta 2009). Two similarities between these two categories are ascertained. In the first, all of them undergo reduction. The consonant produced is either the least sonorous or the most adjacent to syllabic nucleus satisfying in the last case contiguity, that is, the continuous string of adjacent segments (McCarthy & Prince 1995: 371, Kager 1999: 250). Representative examples are given in (6a-f):

		Adult's output	→ Child's output	Child: Age
		Adult's output	→ Child's output	Child: Age
(6)	a.	[ˈvle.po]	→ [ˈle.po] '[I] see'	B.M.: 2;2.12
	b.	[a.ˈvli]	→ [a.ˈvi] 'garden'	I: 2;9.7
	c.	[spi.ˈta.ci]	→ [pi.ˈta.ci] 'house, diminutive'	Kon: 1;11
	d.	[ˈpse.ma]	→ [ˈpe.ma] 'lie)'	B.M.: 1;11.1
	e.	[e.le.ˈni.tsa]	→ [ˈni.ta] 'Eleni, diminutive'	B.M.: 1;9.22
	f.	[mu.ˈdzu.ɾa]	→ [mu.ˈdu.ɾa] 'stain'	I: 3;1.3

(Greek, Tzakosta 2009: 368-369)

In the second, they exhibit cases of fusion, a process in which the produced segment inherits place and manner features from both consonants of the cluster (Kager 1999: 59, Kappa 2004: 210), as represented below (examples 7a - d).

		Adult's output	→ Child's output	Child: Age
(7)	a.	[ˈða.xti.lo]	→ [ˈka.ci.lo] 'finger'	B.M.: 2;2.18
	b.	[mi.ˈkro]	→ [mi.ˈto] 'small'	F: 2;5.1
	c.	[tsi.ˈba.i]	→ [θe.ˈfa.i] 'he/she/it bites'	B.M.: 2;2.5
	d.	[pe.ˈtse.ta]	→ [pe.ˈθe.ta] 'towel'	F: 2;9.5

(Greek, Tzakosta 2009: 366, 369)

The conclusion drawn from children's data is that the common way in which these two processes (6 - 7) are applied to all the aforementioned categories provides indications for the assumption that affricates are considered consonantal clusters (Tzakosta 2009), agreeing with some other researchers' views (e.g. Newton 1961, Setatos 1974). The substitution of simple segments by affricates, as in (8a-c), constitutes another indication:

		Adult's output	→ Child's output	Child: Age
(8)	a.	[mo.ˈɾa.ci]	→ [mo.ˈɾa.tsi] 'baby, diminutive'	I: 3;0.24
	b.	[ˈe.pe.sa]	→ [ˈe.pe.tsa] '[I] fell'	F: 2;2.24
	c.	[bu.ˈzu.ci]	→ [bu.ˈdzu.ci] 'bouzouki'	Kon: 2;0.30

(Greek, Tzakosta 2009: 372)

Another study deals with affricates in a child aged 1;6.15 – 2;9.5 years old whose mother tongue is the east Cretan dialect, from which the child receives most linguistic stimuli and less from Modern Greek (Papoutsakis 2018). The Cretan dialect contains two affricates, [t^{ɕ}] and [d^{ʑ}] which are investigated along with those of Modern Greek. All of them are viewed as less complex than clusters as they maintain their manner at 43%, while [stop + s] and [s + stop] clusters are not faithfully uttered until the end of the study (examples 9a-c)[2].

[2] All adult's outputs are listed here in the Cretan dialect, which is the main language the child hears and receives from its parents.

		Adult's output	→ Child's output	Child: Age
(9)	a.	[e.ˈtɕi]	→ [e.ˈtɕi] ('here'	Zax: 2;4.3
	b.	[ˈpsar.ʑa]	→ [ˈta.ʑa] 'fishes'	Zax: 2;4.13
	c.	[ve.ˈdᶻi.na]	→ [ˈdᶻi.na] 'petrol'	Zax: 2;1.19

(Greek, Papoutsakis 2018: 35-36, 48)

Furthermore, affricates present fewer faithful productions in relation to stops, while they preserve their manner more in comparison to stridents. So, affricates seem to constitute a separate natural class, the acquisition of which together with stridents follows the acquisition of stops and precedes that of clusters (Papoutsakis 2018).

3. Research methodology

Before the meetings with the child, the parents provided verbal and written consent. The data comes from a monolingual girl with typical linguistic development, with Modern Greek as her mother tongue. The researcher came in contact with the child in order for a relationship of familiarity to be established till the recordings began. The meetings took place in a nursery. For the collection of data, the professional tape recorder Marantz PMD661MKII was used. In total 6.246 tokens transcribed from spontaneous speech and picture naming via a laptop have been gathered. The pictures were drawn from another study in Greek child speech (see Kappa & Paracheraki 2014) with some modifications for the needs of the present study, which include everyday words, such as animals, foods, vehicles, plants, professions, household utensils, buildings. They were created in a certain way in order for the child to have the opportunity to utter all types of consonants and clusters regarding their place, manner and *voice* in every position within a word (initial, middle, final unstressed or stressed syllable). In addition, spontaneous speech was collected through activities inside kindergarten or in its courtyard, such as reading books, playing with balls, dolls, cars, painting, fun in slide, swings, seesaw. All recordings were accomplished in colorful and full of toys rooms in order for the child to feel comfortable and not to be distracted. This way her productions do not come from hesitation or lack of concentration. Her speech was recorded 1-2 times per week and the research lasted about 1 year and 3 months, while the duration of each meeting was 15-30 minutes. The child's age during the investigation was from 1;6.26 to 2;9.12 years old. Our assumptions are based on 89 tokens containing [tˢ], 65 of [ks] and 14 of [ps]. As far as [dᶻ] is concerned, it is excluded from the present study, since it is traced only in 5 tokens and we cannot deduce any generalizations from these. With exception of one token ([ˈkse.ɾo] → [ˈtˢe], (I) know, 1;7.19), all the others emerge in the intermediate developmental stage, namely, after the age of 2 years old, where more marked structures arise as clusters, polysyllabic words, consonants specified as fricatives and generally at this developmental stage all types of consonants are uttered to a different degree. According to some researchers, the emergence of codas, clusters, fricatives, the production of trisyllabic or longer words with *faithfulness* to the number of syllables and words with marked syllables as V, VC, CVC, CCV constitute indications for the transition from the early stage, in which mostly unmarked structures appear, to the intermediate one (see for Greek: Kappa 2000, Tzakosta 2003, Tzakosta & Kappa 2008).

For the reproduction, processing and conversion of audio material into phonetic tokens the Audacity software was used, while the tokens were recorded and organized via Microsoft Office Word. It should be noted at this point that we did not use any software for the phonetic analysis of child's tokens and the transcription was done by ear only. For this reason, only data in which there is a high degree of certainty of child's utterances have been included. Moreover, the International Phonetic Alphabet is used for the phonetic rendering of words.

4. Comparison between affricates and [stop + s] clusters

The comparison of the affricate [t^{s}] and the clusters [ks], [ps] leads to the results summarized in Tables 1 and 2 below:

Table 1. Processes observed

Process	[t^{s}]	[ks]	[ps]
Deletion	14 / 89 (15.7%)	4 / 64 (6.2%)	1 / 14 (7.1%)
Reduction	51 / 89 (57.3%)	49 / 64 (76.6%)	11 / 14 (78.6%)
Faithful utterance	24 / 89 (27%)	0 / 64 (0%)	0 / 14 (0%)
Substitution with [t^{s}]		9 / 64 (14.1%)	2 / 14 (14.3%)
Substitution with [d^{z}]		2 / 64 (3.1%)	0 / 14 (0%)

Table 2. Segment uttered after reduction

Segment	[t^{s}]	[ks]	[ps]
Stop	37 / 51 (72.5%)	31 / 49 (63.3%)	7 / 11 (63.6%)
Fricative	14 / 51 (27.5%)	18 / 49 (36.7%)	4 / 11 (36.4%)

At first glance, all categories present two major similarities. The first concerns the most systematic process traced, which is reduction to one segment (Table 1, [t^{s}] 57.3%, [ks] 76.6%, [ps] 78.6%). Indicative tokens are cited next (examples 10a-f).

		Adult's output	→ Child's output	Child: Age
(10)	a.	[ˈt^{s}a.da]	→ [ˈta.da] 'bag'	Girl: 2;4.28
	b.	[pe.ˈt^{s}e.ta]	→ [pe.ˈte.ta] 'towel'	Girl: 2;8.21
	c.	[ˈksi.la]	→ [ˈci.la] 'wood, plural'	Girl: 2;2.2
	d.	[ˈda.ksi]	→ [ˈda.ci] 'ok'	Girl: 2;3.22
	e.	[psa.ˈɾa.ci]	→ [pa.ˈla.ci] 'fish, diminutive, m[3]'	Girl: 2;5.8
	f.	[psi.ˈla]	→ [si.ˈa] 'highly'	Girl: 2;9.12

[3] (m) = mimicry. The direct utterance of a token by the child immediately after the utterance of the same token by the adult is characterized as mimicry. The strategy of mimicry from child constitutes a learning process. In other words, the child hears the token, processes it and utters it after having heard it again by itself. We assume that the process of information transfer between adult and child contributes to the in-depth understanding of the information. For this reason, the child's mimicries are included in the present research.

The second has to do with the preferred consonant in case of reduction Table 2. In all the categories the stop is usually uttered, while the percentages of stop's and fricative's production frequencies are close to each other, since the former is selected a lot more frequently than the latter. Consider the examples below:

		Adult's output	→ Child's output	Child: Age
(11)	a.	[ko.ɾi.ˈtˢa.ci]	→ [i.ˈta.ci] 'girl, diminutive'	Girl: 2;5.15
	b.	[ˈe.ka.tˢa]	→ [ˈe.ka.sa] '[I] sat'	Girl: 2;6.20
	c.	[a.ˈma.ksi]	→ [ˈma.ci] 'car'	Girl: 2;5.1
	d.	[a.ˈma.ksi]	→ [ˈma.si] 'car'	Girl: 2;6.20
	e.	[ˈpsa.ɾi]	→ [ˈpa.i] 'fish'	Girl: 2;6.27
	f.	[psi.ˈla]	→ [si.ˈa] 'highly'	Girl: 2;9.12

This way, the child selects to satisfy mainly the Sonority Hierarchy Hypothesis (Kiparsky 1979: 432) and less contiguity (McCarthy & Prince 1995: 371, Kager 1999: 250). The determining factor for the choice of the segment that is uttered more systematically is its degree of acquisition in the intermediate developmental stage. [t] is always produced faithfully. [p] (99.6%) has been acquired, while [k] (84.7%) has almost been acquired[4]. All of them bear higher percentages than [s] (45.7%). These differences in percentages are attributed to their order of acquisition and *markedness*. Stops are observed to be acquired first in Greek child speech (Magoula 2000) and cross-linguistically they are considered the most unmarked in relation to other categories of consonants (see for English: Battistella 1990, for Greek: Tzakosta 1999, 2001, among others). Fricatives, on the other hand, constitute one of the last categories that are acquired in children's linguistic development (see Fikkert 1994 for Dutch, Magoula 2000 for Greek, among others). So far, we could claim that in this child affricates constitute clusters. However, they present one important difference in relation to clusters regarding tokens appearing with faithfulness. The child manages to utter affricates faithfully at 27% (examples 12a-b), while the corresponding percentage of [ks] and [ps] is 0%.

		Adult's output	→ Child's output	Child: Age
(12)	a.	[ˈka.tˢo]	→ [ˈka.tˢo] '[I] sit'	Girl: 2;4.26
	b.	[ˈkal.tˢa]	→ [ˈka.tˢa] 'sock'	Girl: 2;6.27

The faithful utterance of [tˢ] may not be high enough, but its percentage compared to that of clusters has a significant variance. This variance reveals that the acquisition of [tˢ] precedes that of clusters and agrees with studies pointing out that complexity at the level of syllable follows complexity at the level of segment (Lleó & Prinz 1997, Gierut & Champion 1999). In addition, the preference for either the stop or the fricative even to a different degree shows that the direction of syllable structure assignment does not affect the produced consonant in reductions. In contrast, it seems to provide indications in favor of Lombardi's (1990) Unordered Component Hypothesis where the features [-continuant]

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[4] Following the methodology of Papadopoulou (2000), as acquired consonants in the present research count these uttered in percentage ≥ 90%.

and [+continuant] of affricates are single-valued and either present or absent with the presence of the former feature to be more systematic than the presence of the latter in this child. Our data also agree with another study on Greek (Kappa 1998) with the difference that affricates in our child emerge only in the intermediate developmental stage and not in the early one, leading to three different strategies being employed for their handling to a different degree, though: deletion, reduction and faithful utterance. Some processes observed, such as deletion and substitution with [t^s], [d^z] in the categories in Table 1 are not discussed since they cannot affect the generalizations deduced between affricates and clusters due to their low frequency of emergence.

One more issue identified in the child's affricates is that in reductions a harmonized form emerges more frequently, as in (13a-b), than the corresponding non-harmonized one, as in (13c - d), when a [+voiced] consonant is located at distance or nearby:

		Adult's output	→ Child's output	Child: Age
(13)	a.	[ˈt^{s}a.da]	→ [ˈda.da] 'bag'	Girl: 2;2.2
	b.	[ˈt^{s}a.da]	→ [ˈða.da] 'bag'	Girl: 2;3.1
	c.	[ˈt^{s}a.da]	→ [ˈta.da] 'bag'	Girl: 2;2.23
	d.	[ˈt^{s}a.da]	→ [ˈsa.da] 'bag'	Girl: 2;4.28

In tokens (13a-b), [t^s] is reduced to the stop or the fricative consonant and then assimilated to the [+voiced] distinctive feature of [d]. As for their frequency, [ˈda.da] appears 19 times over 4 of [ˈta.da] and [ˈða.da] 4 times over 2 of [ˈsa.da]. We assume this happens due to differences in the degree of acquisition between [t] and [d] as well as between [s] and [ð]. More specifically, both stops are always uttered faithfully. However, consonant [d] is produced more often as from 71 cases traced in adult's words, it is uttered 244, while [t] is produced 1956 times out of 1762 cases. These additional utterances arise from other processes such as consonant harmony, that is, the assimilation between two non-adjacent consonants to some or all distinctive features (cf. Pater & Werle 2001: 119, 2003: 385). Between fricatives, the degree of acquisition of [ð] (325 / 533 tokens, 61%) is higher than that of [s] (370 / 810 tokens, 45.7%). Thus, when the appropriate conditions are met, namely, when there is already a [+voiced] consonant in a word that has been acquired by the child, then the harmonized forms are preferred because they include consonants that are used more frequently by the child. One more indicator pointing to this pattern is that assimilations are not applied when [+voiced] consonants located at distance or adjacent to [t^s] are deleted (examples 14a-c).

		Adult's output	→ Child's output	Child: Age
(14)	a.	[ko.ɾi.ˈt^{s}a.ci]	→ [i.ˈta.ci] 'girl, diminutive'	Girl: 2;5.15
	b.	[ˈkal.t^{s}a]	→ [ˈka.ta] 'sock'	Girl: 2;6.27
	c.	[t^{s}u.ˈli.θra]	→ [su.ˈi.θa] 'slide'	Girl: 2;9.12

Liquids are considered cross-linguistically difficult and among the last categories that emerge and which children acquire, especially [r] (Mann & Hodson 1994, Macken 1995, Magoula 2000, Kappa 2009, Idemaru & Holt 2013, Amoako, Stemberger, Bernhardt &

Tessier 2020). The same is true of the present child ([l] 241/749 tokens, 32.2%, [r / ɾ] 39/ 519 tokens, 7.5%). It should be noted at this point that [d] and the liquids are the only [+voiced] consonants found in words containing additionally affricates.

Before the analysis of the child's tokens, it should be clarified why examples such as (13a) constitute consonant harmony and not partial or full reduplication. Reduplication is the production of two identical or partially identical syllables and involves consonant or vowel harmony (see Klein 2005: 71), as in examples (15a-c):

	Adult's output	→ Child's output	Child: Age
(15)	a. [dɔr]	→ [dɔdo] 'door'	
	b. [buk]	→ [buku] 'book'	
			(English, Klein 2005: 71, 74)
	c. [pɔ]	→ [pɔpɔ] 'pot'	Child: 1;8
			(French, Ingram 1974: 56)

Two reasons are suggested. First, we agree with the view which supports consonant harmony to take place at the lower levels of prosodic hierarchy, namely, the segment and distinctive feature, while reduplication at the upper levels, that is, the syllable and the *foot* (see for Greek: Tzakosta 2007). Second, for partial reduplication to take place presupposes the deletion of [tˢ] first and according to Table 1, deletion constitutes the last process employed by the child in the intermediate developmental stage. On the other hand, reduction seems to be the favoured process for the handling of affricates. So, we assume in this type of data that it is more likely reduction to stop or fricative to take place initially and after the surviving consonant assimilates the voice of a [+voiced] consonant nearby or at distance.

5. Analysis of the data

5.1 An overview of Maximum Entropy Grammar

Maximum Entropy Grammar (Goldwater & Johnson 2003: 112, Jäger 2007: 470, Hayes & Wilson 2008: 382) constitutes a probabilistic version of Harmonic Grammar (Legendre et al. 1990: 888, Potts et al. 2010: 78) with the difference that the harmony value of candidate outputs is mapped onto probabilities. Harmonic Grammar bears common properties with Optimality Theory (Prince & Smolensky 1993: 2), as in both models outputs corresponding to one input are evaluated based on markedness and faithfulness constraints in order for the optimal output to arise, while the remaining are rejected. However, contrary to Optimality Theory where constraints are strictly ordered and conflicts between them are resolved based on their ranking with the higher ranked to prevail, in Harmonic Grammar constraints are not strictly ranked and have weight that expresses their strength (Legendre et al. 1990: 889). An example containing the basic properties of Harmonic Grammar is illustrated in Table 3 below:

Table 3. Selection of optimal output based on Harmonic Grammar (Flemming 2021: 3)

weights	15	8	8	
/input/	C_1	C_2	C_3	h_i
a	−1			−15
b		−2		−16
c		−1	−1	−16

Violations here are negative integers which state the number of times a constraint is violated by an output. The comparison of outputs lies to the sum of their weighted constraint violations, namely, the harmony which is calculated based on the formula in (16):

(16) $$h_i = \sum_{k=1}^{N} w_k c_{ik}$$

(from Flemming 2021: 4)

N denotes the number of constraints, w_k the weight of constraint k, c_{ik} the violation score of output i by constraint k. In other words, every violation is multiplied by the weight of the respective constraint yielding the score of a candidate. In Table 3, for example, the optimal output is [a] due to its highest harmony.

Maximum Entropy Grammar is considered a stochastic form of Harmonic Grammar, which maps harmonies of outputs onto probabilities, as represented in (17):

(17) $$P_i = \frac{e^{h_i}}{\sum_j e^{h_j}}$$

(Flemming 2021: 5)

P is the probability of output i, h_i its harmony and j ranges over candidate outputs. The probability of output [a] in Table 4, for instance, is e^{-15} divided by $e^{-15} + e^{-16} + e^{-16}$, and the result is 0.58:

Table 4. Probabilities based on Maximum Entropy Grammar (Flemming 2021: 5)

weights:	15	8	8		
/input/	C_1	C_2	C_3	h_i	P_i
a	−1			−15	0.58
b		−2		−16	0.21
c		−1	−1	−16	0.21

The probability of an output is proportional to the exponential of its harmony e^{h_i}. In order for the probabilities of all outputs to sum to 1, the exponential harmony of every output must be divided by the sum of all outputs' exponential harmonies. In conclusion, Maximum Entropy Grammar is a model which depends on information theory. It includes all possible known information provided by the data without making any additional assumptions and it has become a tool for the analysis of *variation* and gradient acceptability in phonology (e.g. Goldwater & Johnson 2003, Flemming 2021). Variation is the utterance of multiple different outputs that correspond to one input.

5.2 Analysis of the affricate [t^s]

For the different processes used by the child regarding the handling of affricates, the following markedness and faithfulness constraints are adopted: *Complex, which prohibits complex segments (Prince & Smolensky 1993: 96), MAXIMALITY-IO, which demands every segment of the input to have a correspondent in the output and MAXIMALITY-IO (MANNER), which requires every manner of the input to have a correspondent in the output (McCarthy & Prince 1995: 264). There are two possible ways to analyze the tokens: the paper and pencil or the Maxent Grammar Tool (Goldwater & Johnson 2003, Wilson 2006, Hayes & Wilson 2008). For the needs of the present study we will use Maxent Grammar Tool, as it is considered safer than the paper and pencil method as it provides more precise values. Having supplied the software with all the relevant information, the calculation of constraints' weights is the following:

(18) |weights| after optimization:

*Complex	(mu = 0.0, sigma^2 = 100000.0)	0.7470860141085878
MAX-IO	(mu = 0.0, sigma^2 = 100000.0)	1.3347500663429486
MAX-IO (MAN)	(mu = 0.0, sigma^2 = 100000.0)	0.0

An explanation of the calculation of weights with this specific software can be found in Hayes & Wilson (2008). The final results are illustrated in Table 5:

Table 5. Handling of affricates

weights			0.74	1.33	0.0	
/ˈkat^{s}o/	Observed	Predicted	*Complex	MAX-IO	MAX-IO (MAN)	H
[ˈkato]/ [ˈkaso]	0.57	0.575715518463021	0.0	0.0	-1.0	0.0
[ˈkat^{s}o]	0.27	0.27274236537402247	-1.0	0.0	0.0	-0.74
[ˈkao]	0.15	0.15154211616295643	0.0	-1.0	-1.0	-1.33

In the first line of Table 5, the weights of constraints are listed with the most important one having the highest value (MAX-IO, 1.33) and less important the lowest value (MAX-IO MAN, 0.0). Constraints with higher weights are more likely to lower the probability of outputs that violate them (e.g. Hayes & Wilson 2008). Further, the prediction of each token's emergence conforms to its frequency. So, the most uttered tokens, which are the ones incurring reduction to stop or fricative consonant (e.g. [kato]/ [kaso]) bear the highest harmony score and, more specifically, 0.0. The less uttered, that is, the ones incurring deletion (e.g. [kao]) present the lowest harmony score (−1.33).

In order for the variation presented in child's reductions to be accounted for, the aforementioned constraints are adopted and the next markedness and faithfulness constraints need to be added: *MARGIN/FRICATIVE, which states that fricatives cannot associate to margin nodes, namely, onset and coda (Prince & Smolensky 1993: 96), AGREE (VOICE), which requires consonants to agree to some distinctive features and for the needs of the present study to voice (Pater & Werle 2001: 123, 2003: 386), INPUT-CONTIGUITY, which demands the segments of output to form a contiguous string as the corresponding of input (McCarthy & Prince 1995: 371) and IDENTITY-IO, which requires faithfulness in segments to their distinctive features between input and output (McCarthy & Prince 1995: 264). Below, the calculation of each constraint's weight is listed (19).

(19) |weights| after optimization:

*Complex	(mu = 0.0, sigma^2 = 100000.0)	0.0
MAX-IO	(mu = 0.0, sigma^2 = 100000.0)	0.0
MAX-IO (MAN)	(mu = 0.0, sigma^2 = 100000.0)	0.0
*M/FRIC	(mu = 0.0, sigma^2 = 100000.0)	1.4248228310813502
I-CONTIG	(mu = 0.0, sigma^2 = 100000.0)	0.0
AGREE (VOI)	(mu = 0.0, sigma^2 = 100000.0)	1.4248228310814235
IDENT-IO	(mu = 0.0, sigma^2 = 100000.0)	0.0

Each token's emergence frequency is represented in Table 6:

Table 6. Multiple different outputs in reduction

weights			0.0	0.0	0.0	1.42	0.0	1.42	0.0	
/ˈtˢada/	Observed	Predicted	*Complex	MAX-IO	MAX-IO (MAN)	*M/FRIC	I-CONTIG	AGREE (VOI)	IDENT-IO	H
[ˈdada]	0.65	0.6497865227098978	0.0	0.0	−1.0	0.0	−1.0	0.0	−1.0	0.0
[ˈtada]	0.13	0.1563068482527332	0.0	0.0	−1.0	0.0	−1.0	−1.0	0.0	−1.42
[ˈða.da]	0.13	0.1563068482527332	0.0	0.0	−1.0	−1.0	0.0	0.0	−1.0	−1.42
[ˈsada]	0.06	0.03759978078463585	0.0	0.0	−1.0	−1.0	0.0	−1.0	0.0	−2.84

As shown in Table 6, the token most frequently produced by the child ([ˈdada]) bears the highest possible harmony score as the sum of violated constraints is 0.0. The next more systematic produced tokens are [ˈtada] and [ˈða.da], both having −1.42 harmony, while in the least preferred token [ˈsada] the lowest harmony is traced, namely, −2.84. So, in Maximum Entropy Grammar the probabilities of outputs rely solely on their differences in harmony scores (e.g. Hayes & Wilson 2008, Flemming 2021) as has been suggested and can also be seen from Tables 5 and 6. This is the way in which this model can analyze and interpret all processes employed by the child for the treatment of affricates as well as the variation emerging in one process such as reduction.

6. Conclusions

In this paper we focused on the acquisition of affricates in one Greek-speaking child, as we wanted to investigate their phonological status in the underlying representation based on their comparison with clusters containing [stop + fricative] sequences. All categories present two similarities. First, the most common process in the acquisition of all of them is reduction. Second, in reductions the proportion of stop production over fricative is almost in the same rate, namely, the former is uttered at 63-72% and the latter at 27-36%. However, one crucial difference between [t^s] and [ks], [ps] is observed. The child manages to produce [t^s] faithfully at 27%, while the faithfulness of clusters is 0%. This difference leads to the assumption that affricates are acquired earlier than [stop + fricative] clusters showing that in this child the acquisition of complexity in segments precedes the acquisition of complexity in syllables, as in other researches has been proposed (Lleó & Prinz 1997, Gierut & Champion 1999). In addition, in reductions the preference sometimes of stop and sometimes of fricative seems to be in favor of Lombardi's (1990) view, who considers affricates as complex segments with their features to be unordered and single-valued. In reductions, tokens presenting consonant harmony in voice arise more often than the corresponding ones without harmony, when there is a nearby [+voiced] consonant. The reasons for the emergence of such forms reside in the trigger which is a consonant that has been fully acquired and used systematically in processes such as assimilations, as well as in the degree of acquisition of the consonant that survives, where higher percentages are ascertained in the harmonized [+voiced] than the non-harmonized [−voiced] outputs. For the analysis of this child's tokens, we relied on the statistical framework of Maximum Entropy Grammar, which can model constraint-based phonology. Its basic property is the learning of categorical and stochastic grammars from a training corpus of input-output pairs. In other words, it is supplied by the data and yields results based on different probabilities attributed to outputs. This way, it can adequately account not only for the frequency of different processes the child uses for the handling of affricates but also for the emergence of multiple different outputs in one process, as in the case of reduction. Finally, it should be noted that the conclusions regarding the status of affricates in the underlying representation and their handling concern only this child and cannot be generalized cross-linguistically. For this purpose, a study with more subjects needs to be done so that a clear aspect of them in child speech to have. However, our research provides insights into the various treatments of affricates in case they are not fully acquired by pointing out some processes with their relevant tokens that may be observed in future cross-linguistic studies.

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