*Consonant clusters in the acquisition of Greek: the beginning of the word**

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Abstract

In this paper, I study the production of consonant clusters by Greek children and examine the consequences of the acquisition data for phonological theory, with particular emphasis on the word initial position. Using a non-word repetition test, I tested the order of acquisition of word initial and word medial sT, TT and TR clusters in 59 children. The results provide evidence against any analysis that assigns identical syllabic status to word initial sT and word initial TT, such as models of extrasyllabicity, and lend support to an alternative analysis of the beginning of the word, based on Lowenstamm's (1999) initial ON hypothesis.

1 Introduction

In the study of phonology, considerable insight can be gained from first language acquisition data. The order in which children acquire various phonological structures is of particular interest, as acquisition has been shown to be influenced by markedness. Specifically, various studies provide evidence that children master the production of unmarked sounds or structures before marked ones (Demuth 1996; Jakobson 1968; Stites, Demuth, & Kirk 2004).

An area that would greatly benefit from acquisition data is that of word initial consonant clusters. Though consonant clusters have been extensively studied by acquisitionists (Barlow 1997; Demuth & Kehoe 2006; Freitas 2003; Jongstra 2003; Kirk & Demuth 2005; Lleó & Prinz 1996; Pan 2005; Pan & Snyder 2004; Vanderweide 2005) the focus of the research on the word initial position has been on obstruent-sonorant clusters (TR) and s+consonant (sC) or s+obstruent (sT) clusters. Other word initial clusters, such as obstruent-obstruent clusters (TT) have been largely ignored. These clusters (for example *ft, xt,* which are attested in Greek) are problematic for phonological theory as they do not respect the regular

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rising-sonority pattern associated with the beginning of a syllable, a fact which has led phonologists to the assumption that these clusters are extrasyllabic. Word initial TT is generally assumed to share the same structure as sT clusters, which are problematic not only in phonological theory, but also in the study of language acquisition. Consequently, studying the acquisition of TT clusters alongside sT clusters could help us understand the behaviour of sT clusters. More generally, studying the acquisition of different clusters, for example word initial clusters alongside their word medial counterparts, can be a lot more insightful than studying the acquisition of a cluster type in isolation.

Following this reasoning, in order to examine the phonology of the clusters in question, I test the production of consonant clusters by children acquiring Greek as their first language.

The paper proceeds as follows: Section 2 contains a short discussion on the word initial clusters in question. Section 3 deals with the data collection and general results, and in section 4 I proceed to the analysis; in section 4.1 some problems of the extrasyllabic theory are presented, and in section 4.2 I introduce an alternative proposal for the analysis of the data based on Lowenstam's initial ON hypothesis. A short conclusion follows.

2 Word initial consonant clusters

2.1 Word initial extrasyllabicity

Word initial sT clusters do not respect the Sonority Sequencing Generalisation (SSG, Clements (1990)) according to which sonority increases towards the syllable peak and decreases towards the edges. Initial sT breaks this generalisation, since the second member of the cluster has a lower (in the case of stops) or an equal (in the case of fricatives) sonority value when compared to the first member (*s*). This is the opposite of what the SSG dictates for onsets, namely that the second member of the cluster should be of higher sonority.

Faced with this inconsistency, several researchers have opted for a syllabification algorithm that leaves the *s* outside the onset: the *s* is extrasyllabic[1] (e.g. Halle & Vergnaud (1980), Levin (1985), Steriade (1982)). An example of such a structure is given in (1) below.

[1] Other attempts include analysis of sT as a contour-complex segment (Selkirk (1982), Weijer (1993) cf. Scobbie (1997)) and the abandoning of the SSG as a universal principle (Cairns 1988).

(1) sT extrasyllabicity: Italian *spˈirito* ‘spirit’

```
          σ           σ           σ
          |  \        |  \        |  \
          O     R     O     R     O     R
          |     |     |     |     |     |
          |     N     |     N     |     N
          |     |     |     |     |     |
     x    x     x     x     x     x     x
     |    |     |     |     |     |     |
     s    p     i     r     i     t     o
```

Later in derivation the *s* may be linked to a constituent via some kind of adjunction rule. The desired effect is thus attained: at the first stage, the SSG is not violated, since the *s* is not linked to the onset, while at the same time eventual integration to the syllabic structure is achieved.

The same extrasyllabic structure has been proposed for word initial TT clusters (e.g. Rubach & Booij (1990), Steriade (1982)).

(2) TT extrasyllabicity: Greek *xtˈeni* ‘comb’

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          σ           σ
          |  \        |  \
          O     R     O     R
          |     |     |     |
          |     N     |     N
          |     |     |     |
     x    x     x     x     x
     |    |     |     |     |
     x    t     e     n     i
```

These clusters, too, violate the SSG, and an identical phonological analysis for both sT and TT, such as extrasyllabicity, seems to be a sensible move.

2.2 Order of acquisition

In first language acquisition, sT extrasyllabicity shows unusual behaviour: sT can be acquired after, but also before TR. Several studies have shown that children start producing initial sT clusters after TR clusters (e.g. Chin (1996), Smith (1973)). However, other studies (e.g. Barlow (1997), Gierut (1999)) found that some children produce initial sT clusters first.

The variation in the order of #sT-#TR acquisition has long puzzled researchers and there have been a number of proposals developed in order to tackle this problem. For example, it has been suggested that the explanation for these data lies in the possibility that some children acquire branching onset structures (TR) before extrasyllabicity, while others acquire extrasyllabic structures first (Fikkert 1994). This assumes that extrasyllabicity and branching onsets (TR) are different, but equally marked structures, and the order of acquisition is therefore subject to variation. A different suggestion holds that, in acquisition, extrasyllabic clusters (and more generally consonantal sequences) may be structured like affricates (Barlow (1997), Lleó & Prinz (1997)). The relevant structure is shown below.

(3) sT as an affricate: Italian *spˈirito* ‘spirit’

```
    σ           σ           σ
    | \         | \         | \
    O    R      O    R      O    R
    |    |      |    |      |    |
    |    N      |    N      |    N
    |    |      |    |      |    |
    x    x      x    x      x    x
   / \   |      |    |      |    |
  s   p  i      r    i      t    o
```

As seen in (3), sT clusters are represented as complex segments with a single timing slot. According to this approach, if a child does not structure sT like an affricate, s/he will acquire it after TR (i.e. as extrasyllabic, and therefore more marked). If, on the other hand, in a developing grammar, sT is structured like an affricate, it will be acquired before TR (on the assumption that complex segments are less marked than complex onsets). This optionality of structure, it is argued, can account for the variation in #sT-#TR acquisition. However, this approach does not seem to be particularly insightful, as it does not define what circumstances regulate whether a consonantal sequence will be structured as an affricate or as a cluster[2].

The acquisition of word initial TT clusters has not received much attention. Even though researchers have shown an increasing interest in the acquisition of Greek phonology, the majority of the studies are concerned with the acquisition of stress patterns (Kappa 2002b; Tzakosta 2003, 2004) or of different sounds (Kappa 2000; Nicolaidis et al. 2004; Tzakosta 2001b) in specific positions (e.g. word final consonants: Kappa, (2001). The studies that deal with consonant clusters are mostly concerned with what consonant children preserve when they simplify consonant clusters (Kappa 2002a; Tzakosta 2001a). While these studies provide some data on children’s production of TR and TT clusters, they are typically isolated examples. There is some evidence regarding the acquisition of TR clusters as compared to e.g. other word medial clusters, but word initial TT clusters have largely been ignored (see, e.g., Kula & Tzakosta (2002)). Even when cluster types are examined separately, no distinction is made between word initial and word medial clusters (e.g. Papadopoulou 2000).

[2] See also Scobbie (1997) for a conceptually motivated criticism of the contour segment analysis.

From a theoretical point of view, an analysis that assumes extrasyllabicity of initial clusters of non-rising sonority will predict the same variation in TT versus TR acquisition as in sT versus TR acquisition. If TT is extrasyllabic like sT, and sT is acquired before or after TR, then TT is expected to be acquired before or after TR. Both analyses of sT versus TT acquisition outlined above (that extrasyllabicity can be acquired before or after TR, or that extrasyllabic clusters can be structured as complex segments in acquisition) would make the same prediction in this case. Moreover, word initial sT and TT are expected to be acquired at roughly the same time, under the assumption that they share the same (extrasyllabic) structure. Furthermore, a comparison of these clusters to their word medial counterparts can further test the theory. Though it is not clear from the theory of extrasyllabicity whether we should expect to find a difference between word initial and word medial sT, and if so, in what direction, whatever the relationship between initial and medial sT (i.e. whichever is acquired first), the same relationship should hold between initial and medial TT. Word initial and word medial TR, on the other hand, are expected to show no difference, since both positions involve the same structure (namely complex onset).

3 The experiment
3.1 Goal

The purpose of this experiment is to test the role of markedness on Greek children's production of consonant clusters. Different clusters in different positions will be tested and the results compared. The cluster pairs we are interested in are the following:

(4) #sT versus #TR
#TT versus #TR
#sT versus #TT
#sT versus -TT
#TR versus -TR
#TT versus -TT

\# word initial
\- word medial

3.2 Methods and materials

3.2.1 Subjects. Fifty-nine monolingual Greek children were tested (21 boys and 38 girls). Nine more children were excluded from the study, since they refused to cooperate or did not manage to complete the task. The age range was from 2;03 to 5;00, mean age 3;08. The experiments took place in four different nurseries in

Crete (three in Rethymno and one in Iraklio) and, in the case of one child only, in a relative's house.

The children were selected according to linguistic and general developmental criteria. The developmental criteria required normal development, i.e. no background of cognitive, behavioural, hearing or physical impairment. I asked the nursery staff whether the child had any relevant problems. All fifty-nine children participating in this study were reported by staff as being healthy. The linguistic criteria required that i) the child's native language be Greek, ii) the child be raised in a monolingual environment iii) the child have a normal linguistic development iv) the child be able to produce at least some consonant clusters. Finally, the children had to be willing to participate in a non-word repetition task.

3.2.2 Methodology. A non word repetition task was used. Children were asked to repeat novel, made-up words that had the desired structures. The task was chosen for its effectiveness in producing a large amount of relevant data, compared to spontaneous production. Also, novel words allowed me to control for familiarity effects, which would be present in imitation tasks containing existing words. Furthermore, using nonsense words allowed me to control the phonological environment of the clusters across conditions.

Non-word repetition has been used mainly as a test of working memory (e.g. Gathercole (1995), Gathercole et al. (1994), Laws (1998), cf. van der Lely and Howard (1993)) and has been proposed as a screening measure for language impairment (e.g. Dollaghan and Campbell (1998), Weismer et al (2000)), but it is also used in studies examining young children's acquisition of phonology (e.g. Kirk and Demuth (2006), Zamuner and Gerken (1998), Zamuner, Gerken, and Hammond (2004)). Kirk and Demuth (2006), for example, used a non-word repetition task in order to examine English children's production of coda consonants. Although it has been suggested that imitative speech may not tap into the child's phonological system in the same way as spontaneous speech, there are results showing that the patterns found in imitation tasks are similar to those found in spontaneous speech. For instance, a production study by Kehoe and Stoel-Gammon (2001) showed no difference in the accuracy of children's imitated and spontaneous productions.

Extra care was taken to ensure the naturalness of the task. Firstly, the words were paired with pictures of novel animals, so that the words would have a referent; I thus made sure that the task is a linguistic one (rather than a general non-linguistic sound-production task). Secondly, the children did not hear the stimuli from a recording, but from a person (the experimenter), something that is more likely to occur in everyday life. Later evaluation of the spoken stimuli words by the experimenter showed consistent use of appropriate stress and segmental content. Thirdly, the task was not presented to the children as a request to repeat words, but as a game in which they were taking active part. The game was designed in a way that reflected real life interactions (see procedure, section 3.2.4).

I have good reasons to believe that I have succeeded in making the task natural and linguistic. Apart from the reassuring fact that children were enjoying the 'game' and some were asking for more, they were making comments that indicated that they were in an everyday situation, one that could have taken place in their classroom, and not just in an artificial experimental environment; for example: 'Will my sister meet these animals, too?' (Argiro 4;01).

Moreover, some children formed diminutives out of some words, in the regular way for Greek nouns. In the case of neuter nouns this is done by adding -aki to the stem of the noun, after removing the inflectional ending. So, for example, an animal called kixrˈo became kixrˈaki.

(5) *to* *mikrˈo* *kixrˈaki*
the.N.SG little.N.SG kixro.N.SG.DIM
'the little kixro'

This involved recognising the word as a neuter singular noun by the ending *-o,* removing the ending and adding the diminutive suffix. This was a linguistic operation that could not be carried out unless the child was involved in a linguistic task.

3.2.3 Materials. The experiment consisted of six conditions: the first three conditions involved words with sT, TR and TT clusters in word initial position, and the remaining three conditions contained words with the same clusters in word medial position. Specifically, the following combinations of consonants were tested:

(6) sT *sp, st, sk, sf, sx*
TR *tr, kl, fl, xr, vr*
TT *ft, xt, vð, ɣð, vɣ*

The construction of the nonwords used in the experiment followed the phonotactics of Greek. The words were either feminine or neuter nouns, with inflectional endings *-a* (feminine), *-i* (feminine or neuter), or *-o* (neuter). No masculine endings were used, because they involve (in the nominative) a word final consonant (*-s*), and that would increase the structural complexity of these trials. All words were bisyllabic, with a voiceless stop (*p, t* or *k*) as an onset for the non target syllable. There were five stimuli in each condition. The stimuli of the word initial conditions were the following:

(7) sT *sp'oki*[3], *st'ipo, sk'api, sf'ito, sx'ika*
TR *tr'ika, kl'ito*[4], *fl'api, xr'oki, vr'ipo*
TT *ft'ipo, xt'ika, vð'ito, ɣð'oki, vɣ'api*

The stimuli used in the word medial conditions were formed by reversing the syllable order. The stimuli were the following:

(8) sT *kisp'o, post'i, pisk'a, tosf'i, kasx'i*
TR *katr'i, tokl'i, pifl'a, kixr'o, povr'i*
TT *poft'i, kaxt'i, tovð'i, kiɣð'o, pivɣ'a*

For uniformity, the target cluster always preceded the stressed vowel. This creates pairs such as *sp'oki* – *kisp'o*. Note that both members of these pairs are well-formed in Greek, which is characterised by a lexical accent system, restricted by the trisyllabic window (i.e. stress must fall in one of the last three syllables of the word).[5]

3.2.4 Procedure. I first spent some time with the children in the classroom, taking part in their activities, so that I would become familiar to the children. After selecting children according to the linguistic and general developmental criteria discussed above, I tested each of the selected children individually in a separate room. Each session lasted about half an hour.

The test items were arranged in three different pseudo-random[6] orders so as to avoid sequence effects, and each of these orders was followed for a third of the children tested. There were four warm-up items without any clusters.

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[3] Notice that *k* in Greek (and all the other velar consonants) becomes palatal before a front vowel. For example, *ɣð'oki* would be pronounced [*ɣð'oci*]. In Cretan dialects, the velar might undergo even further fronting (Newton 1972). Indeed, all children exhibited some degree of fronting, the extent of which depended on the child's background. However, that does not affect our experiment in any crucial way. The stimulus producer's dialect has moderate fronting, typical of Cretan urban areas.

[4] One of the nurseries was in an area (Iraklio) where *l* tends to be is palatalised before *i*. For example, *tokl'i* would be pronounced [*tokʎ'i*]. Indeed, some children exhibited palatalisation of *l*. However, that does not affect our experiment in any crucial way.

[5] For analyses of the Greek stress system see Arvaniti (1991), Drachman and Malikouti-Drachman (1999), Malikouti-Drachman (1989), Philippaki-Warburton (1976), Ralli (1988), Revithiadou (1999) amongst others. For the acquisition of stress in Greek see Tzakosta (2004).

[6] Items were put in a random order, and then sequences consisting of three or more items belonging to the same category were broken up.

Pictures of novel animals were put inside a Russian doll representing a wizard. The child was told that the wizard had eaten some strange animals, and that he/she could free them by calling each animal with their name. The child was then invited to open the wizard, take out the animals one by one, and say their name. If after two attempts the child was not replying, we would move on to the next animal/word, and the word would be added to the end of the list as the name of some other animal. The same (that is repetition of the word at the end) was done for words that were obscured by background noise. Designing the session in a way that involves an active task ensured that children's interest was kept throughout the experimental session.

Moreover, in order to vary the task, not all the pictures were inside the wizard-doll. Some were 'sleeping' inside a fairy's dress and the child was asked to wake them up, others were hiding inside a box with a small opening, through which only the child's hand could go, some others were absorbed in reading a book and got lost in its pages, some were in the belly of a smaller Russian doll representing a girl, where they went to keep warm, and, finally, some were hiding inside a pair of trousers, and the child was asked to find them so that I could put on my trousers. This way, the children's attention was constantly renewed and sessions were enjoyable for both the children and the experimenter.

During the session, there were spontaneous conversations between the child and the experimenter before, during, and after the task with the intention of giving the child and the experimenter some rest and keeping the child's attention. From these conversations (all DAT-recorded) information on the child's production of singletons was extracted.

3.2.5 Transcription and coding. The responses were transcribed on-line by the experimenter. The transcription was done in a fairly broad way, using the International Phonetic Alphabet. The sessions were also DAT recorded. The original transcriptions were then checked and amended off-line by the experimenter, with the aid of spectrographic analysis when necessary. Spectrographic analysis was used when a response was not entirely clear, and there was doubt as to the identity of the relevant consonants. Responses that were inaudible or covered by background noise were excluded[7].

An independent transcription was made by a second transcriber, who is a Greek native speaker and is well-trained in doing transcriptions. Ten percent of the data were cross-checked. In particular, one-tenth of the responses of each child were

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7 In all tests such cases were between 0 and 0.7 percent of total responses.

transcribed. The consistency rate between the two transcriptions, focusing on the cluster data, was 96 percent.

Moreover, notes where taken during the experiment and during the analysis of the recordings regarding any peculiarities of the child's speech. Specifically, care was taken to note any consistent substitutions that the child was making (in single consonant production). One such substitution was the substitution of *l* for *r* (9), and another common substitution was that of *θ* for *s* (10).

(9) *l* for *r* substitution (Emanouela 4;11,21)

a. Single consonant production	b. Cluster production
orˈea → *olˈea* 'pretty'N.PL	*kartˈi* → *kaltˈi*
xorˈai → *xolˈai* 'fit'3RD SG	*kixrˈo* → *kixlˈo*

(10) *θ* for *s* substitution (Kali 3;00,03)

a. Single consonant production	b. Cluster production
polˈes → *polˈeθ* 'many'F.PL	*stˈipo* → *θtˈipo*
	sfˈito → *θfˈito*

Responses that involved one of these two substitutions were coded as correct.

During the coding, only changes in the consonant cluster were considered. Changes of any other consonant, any vowel or stress were ignored. Vowels were seldom changed, and neither was the stress pattern[8].

3.3 Results

Figure 1 below contains the percentage of correct responses for each of the clusters in word initial and word medial position. Percentages were calculated on the basis of conflated raw figures. This method of calculation was possible because of the structure of the data: there was an equal amount and type of data for each child.

[8] Coding was also performed using a set of alternative criteria, whereby any responses that involve a cluster belonging to the same category as the target cluster are coded as correct, even if the cluster is not the target one. The reason for implementing this coding criterion is that such responses may be taken as an indication that the child can produce the relevant structure, even if s/he is unable to produce the segmental content of the specific cluster. The use of these criteria did not alter the findings (for more details see Sanoudaki (submitted)).

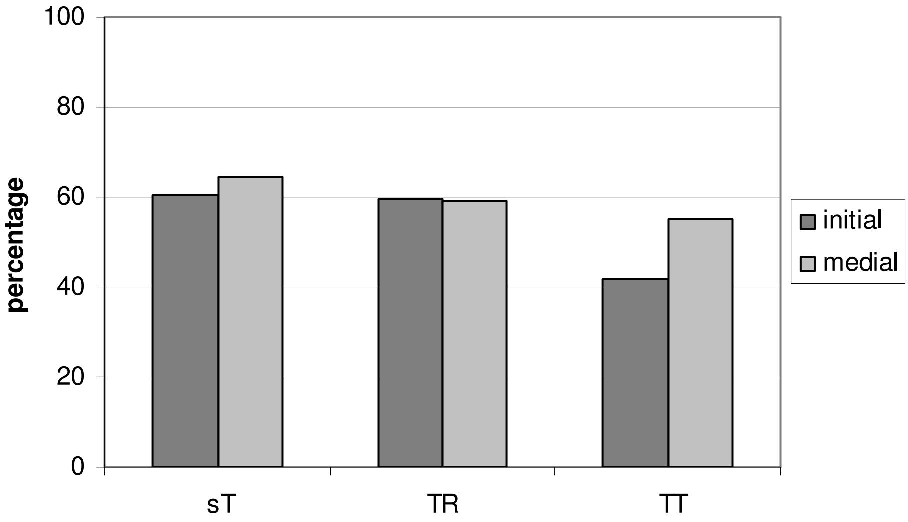

Fig. 1. Percentage of correct responses for word initial sT, TR and TT clusters in word initial and word medial position for all children combined

A visual examination of the figure indicates that only word initial TT is different. Detailed comparisons will be now presented for the cluster pairs that interest us, starting with word initial sT versus word initial TR.

The results for #sT and #TR are very similar, and no statistically significant difference was found (χ^2=0.034, p=0.859, DF=1). In addition, the table showing the number of correct responses for each child for the two conditions (#sT and #TR) is shown below (table 1). This organisation of the data allows us to look at the overall results in conjunction with the results of each individual child.

In table 1 the vertical dimension represents the number of correct responses in the #sT condition (from zero to five), while the horizontal dimension corresponds to the number of correct responses in the #TR condition (again from zero to five). One can therefore read out of the table the number of correct responses each child gave in the two conditions. For example, nine children (in the first row) gave no correct responses in the sT condition. Of these children, four (in the first cell starting from the left hand side) gave no correct responses in the TR position either, two (in the second cell) gave one correct response, two (third cell) two correct responses and so on. Children are divided into two groups, represented by the two sectors, divided by the diagonal: the top right sector contains children that performed better at TR, while the bottom left sector consists of children that performed better at sT. Children that fall on the diagonal performed the same in both conditions.

		#TR					
		0	1	2	3	4	5
#sT	0	////	//	//		/	
	1	//			//	/	
	2	/		//		/	
	3	/	/	/	//	///	/
	4	/	/	///	////	//// /	////// ///
	5				//	///	////

Table 1: Number of correct responses for # sT and #TR for each child

A visual examination of the table shows that the top right and the bottom left sector are equally populated. A one-variable chi-square test that was carried out to test the difference between the two sectors had a χ^2 value of 0.095, with an associated probability value of p=0.758, DF=1. The test found no statistically significant difference between the two sectors.

Moreover, the tally marks representing the children are scattered all over the table, showing that there is wide variation in performance. This includes children that performed almost adult-like in #sT but badly at #TR, and vice-versa, as well as children that were equally advanced in the two cluster types. Some examples of children, characteristic of the diversity, are given below. Kostantinos (11a) performed very badly at #sT and very well at #TR, while Fanouris (11b) showed the opposite pattern. Aglaia (11c) had roughly the same performance for the two cluster types, being only slightly better at #sT (3 correct responses out of 5 as opposed to 2 out of 5 for #TR).

(11) a. Kostantinos (2;11,17)

#sT: 1 out of 5 target	#TR: 4 out of 5 target
skˈapi → θkˈapi	*klˈito → klˈito*
spˈoki→ pˈoki	*vrˈipo → vrˈipo*
stˈipo → θˈipo	*xrˈoki → xrˈoki*
sfˈito → fˈito	*trˈika → trˈika*
sxˈika→ çˈiçka	*flˈapi → xlˈapi*

b. Fanouris (3;04,15)

#sT: 4 out of 5 target	#TR: 1 out of 5 target
spˈoki→ spˈoxi	*flˈapi → flˈa*
stˈipo → stˈipo	*klˈito → plˈito*
skˈapi → skˈapi	*vrˈipo → lˈipo*
sfˈito → sfˈito	*xrˈoki → lˈoki*
sxˈika→ xˈika	*trˈika → tˈika*

c. Aglaia (3;03)

#sT: 3 out of 5 target	#TR: 2 out of 5 target
skˈapi → skˈapi	*klˈito → klˈito*
spˈoki→ spˈoki	*flˈapi → flˈapi*
stˈipo → stˈipo	*vrˈipo → ptˈipo*
sfˈito → fˈito	*xrˈoki → kˈoki*
sxˈika→ xˈika	*trˈika → tˈika*

In a #TT versus #TR comparison, figure 1 shows a considerable difference in the percentage of correct responses. Children performed better at the #TR condition, and the difference is statistically significant (χ^2=18.337, p<0.001, DF=1).

As before, the table containing the number of correct responses for each child for both conditions (#TT versus #TR) was drawn.

		#TR					
		0	**1**	**2**	**3**	**4**	**5**
#TT	**0**	//// ////	//	/	//	/	/
	1		/	////	/	//	//
	2	/		//	//	///	/
	3			/	/	///	////
	4		/		///	////	///
	5				/	/	///

Table 2: Number of correct responses for #TT and #TR for each child

The vertical dimension represents the number of correct responses in the #TT condition (from zero to five), while the horizontal dimension shows the number of correct responses in the #TR condition (again from zero to five). A visual examination of the table shows that the top right sector, corresponding to children that performed better at #TR, is much more populated than the bottom left sector, which includes children that performed better at #TT. The difference is statistically significant (χ^2=14.400, $p<0.001$, DF=1). Several children performed well at #TR and badly at #TT, while the reverse pattern was uncommon[9]. In (12) I give some examples of individual children's performance. Kostantinos (12a) and Agelos (12b) performed very well at #TR and badly at #TT. Zoi (12c) performed better than the two previous children at #TT and adult-like at #TR.

(12) a. Kostantinos (2;11,17)

#TR: 4 out of 5 target	#TT: 1 out of 5 target
trˈika → trˈika	*ftˈipo → ftˈipo*
klˈito → klˈito	*vðˈito → vˈito*
xrˈoki → xrˈoki	*ɣðˈoki → ð ˈoki*
vrˈipo → vrˈipo	*vɣˈapi → ɣˈapi*
flˈapi → xlˈapi	*xtˈika → tˈixa*

b. Agelos (3;04,12)

#TR: 5 out of 5 target	#TT: 0 out of 5 target
trˈika → trˈika	*xtˈika → ftˈika*
klˈito → klˈito	*ftˈipo → stˈipo*
xrˈoki → xrˈoki	*vðˈito → vˈito*
vrˈipo → vrˈipo	*ɣðˈoki → xrˈoki*
flˈapi → flˈapi	*vɣˈapi → ɣˈapi*

c. Zoi (4;02,17)

#TR: 5 out of 5 target	#TT: 3 out of 5 target
trˈika → trˈika	*vɣˈapi → vɣˈapi*
klˈito → klˈito	*xtˈika → xtˈika*
xrˈoki → xrˈoki	*ɣðˈoki → ɣðˈoki*
vrˈipo → vrˈipo	*vðˈito → ðˈito*
flˈapi → flˈapi	*ftˈipo → xtˈipo*

[9] In the cases of children that performed better at TT, the difference between TT and TR is small: specifically, there were only cases of one response difference (3-2, 4-3, 5-4), two responses difference (2-0, 5-3) and one case of three responses difference (4-1) (see table 2).

The results for initial sT and initial TT also differ significantly (χ^2= 19.866, p<0.001, DF=1), with children performing better in the sT condition.

The table showing the number of correct responses for each child for both conditions (#sT and #TT) is given below.

		#sT					
		0	**1**	**2**	**3**	**4**	**5**
#TT	**0**	//// ///	///	/	//	//	
	1	//	/	/	/	//// /	
	2		/	//	///	///	
	3				/	//// /	///
	4				//	//// ///	//
	5					/	////

Table 3: Number of correct responses for #sT and #TT for each child

More children performed better at sT than at TT (χ^2=16.9, DF=1, p=0.001). The top right sector is much more populated than the bottom left one. There is a large number of children that performed well at sT and badly at TT, while few children performed better at TT than at sT[10]. Examples of individual children's performance are given below. Agelos (13a) and Maro (13b) performed very well at sT and very badly at TT. Zoi's (13c) performance at TT was better than that of the two previous children, and at sT her performance was adult-like.

[10] In the cases of children that performed better at TT, the difference between TT and sT is consistently small: specifically, there were only cases of one response difference (1-0, 2-1, 4-3, 5-4) (see table 3).

(13) a. Agelos (3;04,12)

#sT: 4 out of 5 target	#TT: 0 out of 5 target
sk'api → sk'api	*xt'ika → ft'ika*
sp'oki→sp'oki	*ft'ipo → st'ipo*
st'ipo → st'ipo	*vð'ito → v'ito*
sf'ito → sf'ito	*ɣð'oki → xr'oki*
sx'ika→ sk'ika	*vɣ'api → ɣ'api*

b. Maro (3;09,23)

#sT: 4 out of 5 target	#TT: 1 out of 5 target
sp'oki→ sp'oki	*ft'ipo → ft'ipo*
st'ipo → st'ipo	*xt'ika → t'ika*
sk'api → sk'api	*vð'ito → ð'ito*
sx'ika→ sx'ika	*ɣð'oki → ði'oki*
sf'ito → f'isto	*vɣ'api → vg'api*

c. Zoi (4;02,17)

#sT: 5 out of 5 target	#TT: 3 out of 5 target
sp'oki→ sp'oki	*vɣ'api → vɣ'api*
st'ipo → st'ipo	*xt'ika → xt'ika*
sk'api → sk'api	*ɣð'oki → ɣð'oki*
sx'ika→ sx'ika	*vð'ito → ð'ito*
sf'ito → sf'ito	*ft'ipo → xt'ipo*

Having examined the results in the word initial conditions, I now compare the results in the word initial position with those in the word medial position, starting with sT clusters. The percentage of target responses in word initial and word medial sT does not differ significantly (χ^2=1.225, p=0.268, DF=1).

Moreover, a table containing the number of correct responses for each child in both conditions is constructed.

		-sT					
		0	**1**	**2**	**3**	**4**	**5**
#sT	**0**	//// //	/	/		/	
	1	//		/	/	/	
	2			/	/	//	
	3			/	///	//// /	
	4			/	////// ///	//// ///	//// //
	5					//	//// ///

Table 4: Number of correct responses for #sT and -sT for each child

There is no statistically significant difference between the two sectors (χ^2=0.714, p=0.398, DF=1). Some examples of individual children's performance are listed in (14a-c) below. Emanouela (14a) performed adult-like in both conditions, while Epistimi (14b) did not give any correct responses in either condition. Finally, Maraki's performance (14c) was between that of the two previous children, with two correct responses (out of five trials) in each condition.

(14) a. Emanouela (4;11,21)

#sT: 5 out of 5 target	-sT: 5 out of 5 target
skˈapi → *skˈapi*	*piskˈa* → *piskˈa*
spˈoki→*spˈoki*	*kispˈo*→ *kispˈo*
stˈipo → *stˈipo*	*postˈi* → *postˈi*
sfˈito → *sfˈito*	*tosfˈi* → *tosfˈi*
sxˈika→ *sxˈika*	*kasxˈi*→ *kasxˈi*

b. Epistimi(2;03,08)

#sT: 0 out of 5 target	-sT: 0 out of 5 target
spˈoki→ *pˈoki*	*piskˈa* → *pijkˈa*
stˈipo → *sˈipo*	*kispˈo*→ *kipsˈo*
skˈapi → *kˈapi*	*postˈi* → *kutˈi*
sxˈika→ *sˈika*	*tosfˈi* → *tofˈi*
sfˈito → *p*^{h}*ˈipo*	*kasxˈi*→ *kakˈi*

c. Maraki (3;05,03)

#sT: 2 out of 5 target	-sT: 2 out of 5 target
spˈoki→ *spˈoki*	*piskˈa* → *piskˈa*
skˈapi → *skˈapi*	*postˈi* → *postˈi*
stˈipo → *tˈipo*	*kispˈo*→ *kipˈo*
sxˈika→ *sˈika*	*tosfˈi* → *sofˈi*
sfˈito → *θˈito*	*kasxˈi*→ *kaskˈi*

A further examination of table 4 reveals an imbalance, which might have affected the result of the statistical test. Specifically, there is a high concentration of tally marks around the bottom right corner, indicating that our sample includes a high number of children that were very advanced in sT cluster production. This concentration of children that are advanced in both conditions may have overshadowed the results coming from children at earlier stages of sT acquisition, and given overall results of no difference between the two conditions, while in fact there exists one in earlier stages of acquisition.

In order to control for this, I divide the children into three age groups so that the performance of younger children can be examined separately. Group 1 contains the youngest children (covering one-year age difference starting with the youngest one 2;03-3;05 n=24), group 3 the oldest children (one-year age difference 4;00-5;00 n=17) and group 2 the children between the two other groups (3;06-3;11 n=18). Figure 2 contains the percentage of correct responses for the two positions by age group.

The assumption behind this decision is that older children perform better than younger ones. Indeed, there is a statistically significant difference between age groups in word initial position (χ^2=26.488, p<0.001, DF=2) as well as in word medial position (χ^2=20.360, p<0.001, DF=2). A look at the results, figure 2, shows that the difference follows the expected direction; in both word initial and word medial position, performance improves with age. The results of group 3, the oldest group, are better than the results of group 2, which, in turn, are better than the results of group 1, the youngest group, in both positions.

After having checked that the assumption that older children perform better is supported, we can proceed to test whether there is a difference between children's performance in the word initial and the word medial position in each age group. No statistically significant difference was found for group 1 (age 2;03-3;05) (χ^2=1.082, p=0.298, DF=1), for group 2 (age 3;06-3;11) (χ^2=0.423, p=0.515, DF=1) or for group 3 (age 4;00-5;00) (χ^2=0.033, p=0.855, DF=1).

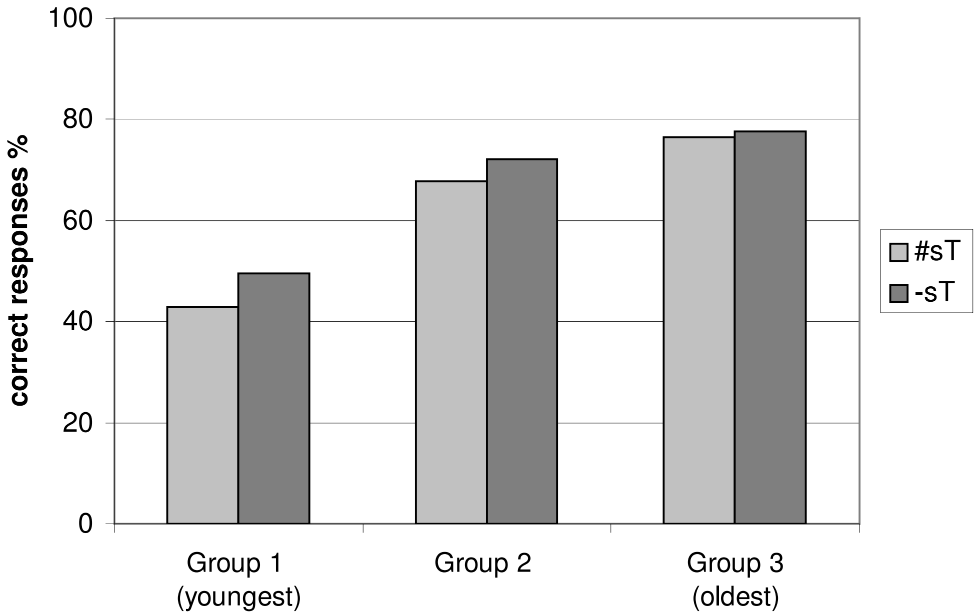

Figure 2. Percentage of correct responses for word initial versus word medial sT by age group

In a comparison of children's responses in the word initial TR and word medial TR condition, no significant difference is found (χ^2=0.007, p<0.933, DF=1).

In addition, the table showing the number of correct responses for each child for both conditions (#TR and -TR) is given below (table 5).

The top right and the bottom left sector (divided by the diagonal line), corresponding to children that performed better at #TR and -TR respectively, are equally populated (χ^2=0.111, p=0.739, DF=1).

There is a concentration of tally marks around the diagonal, indicating that children tended to perform equally well in both conditions. In (15) below, I give some examples of children's performance, illustrating this tendency. Stavros (15a) performed adult-like in both conditions, while Lena (15b) performed poorly in both conditions. Finally, Mario's performance (15c) was better than Lena's, but the child was still having problems with TR clusters in both positions.

(15) a. Stavros (3;11,24)

-TR: 5 out of 5 target	#TR: 5 out of 5 target
katrˈi → *katrˈi*	*trˈika* → *trˈika*
toklˈi → *toklˈi*	*klˈito* → *klˈito*
piflˈa → *piflˈa*	*flˈapi* → *flˈapi*

kixrˈo → *kixrˈo*   *xrˈoki* → *xrˈoki*
povrˈi → *povrˈi*   *vrˈipo* → *vrˈipo*

b.Lena (2;10,28)

-TR: 1 out of 5 target	#TR: 0 out of 5 target
toklˈi → *toklˈi*	*trˈika* → *tˈika*
katrˈi → *katˈi*	*klˈito* → *cˈito*
piflˈa → *piçfˈa*	*flˈapi* → *fˈapi*
kixrˈo → *kixˈo*	*xrˈoki* → *xˈoki*
povrˈi → *povˈi*	*vrˈipo* → *vˈipo*

c. Mario (3;03,01)

-TR: 3 out of 5 target	#TR: 2 out of 5 target
katrˈi → *katrˈi*	*trˈika* → *trˈika*
toklˈi → *klˈi*	*klˈito* → *klˈito*
piflˈa → *iflˈa*	*flˈapi* → *vlˈapi*
kixrˈo → *ixkˈo*	*xrˈoki* → *ˈoti*
povrˈi → *tovˈi*	*vrˈipo* → *vˈipo*

-TR \ #TR	0	1	2	3	4	5
0	//// //					
1	//	///		//		/
2	/		//	///	/	/
3			//	/	//// /	/
4	/		///	//	//// /	//// /
5			/	//	///	//// //

Table 5: Correct responses for initial and medial TR for each child

Finally, in a comparison of children's performance in word initial TT and word medial TT, a significant difference appears (χ^2=10.319, p<0.001, DF=1). As seen in figure 1, children's performance was better word medially.

Furthermore, I present below a table containing the number of correct responses for each child in the word initial and word medial condition.

		-TT					
		0	**1**	**2**	**3**	**4**	**5**
	0	//// //	//// /	//	/		
#TT	**1**	/	/	///	/	///	/
	2	//	/	/	//	//	/
	3			//	//// /	//	//
	4				//	///	//// /
	5					/	////

Table 6: Correct responses for initial and medial TT for each child

A visual examination of the table shows that most children performed better at medial TT than at initial TT. The top right sector is populated much more than the bottom left one, and the difference in statistically significant (χ^2=11.3, p=0.001, DF=1). There is a large number of children that performed well at -TT and badly at #TT, while there were few children that performed better at #TT than at -TT[11]. Some examples of individual children's performance are given below. Kostantinos (136a) performed adult-like in the word medial condition, while his performance in the word initial condition was very poor. Manouela's performance (136c) was very poor in both conditions, while Mario (136b) gave correct responses about half of the time in both conditions.

(16) a. Kostantinos (2;11,17)

-TT: 5 out of 5 target	#TT: 1 out of 5 target
poftˈi → *poftˈi*	*ftˈipo* → *ftˈipo*
kaxtˈi → *kaxtˈi*	*xtˈika* → *tˈixa*
tovðˈi → *tovðˈi*	*vðˈito* → *vˈito*

[11] In the cases of children that performed better at initial TT, the difference between the word initial condition and the word medial condition is consistently small: either one response difference (1-0, 2-1, 3-2, 4-3, 5-4) or maximum two responses difference (2-0) (see table 6).

kiɣðˈo → *kiɣðˈo*	*ɣðˈoki* → *ðˈoki*
pivɣˈa → *pivɣˈa*	*vɣˈapi* → *ɣˈapi*

b. Mario (3;03,01)

-TT: 3 out of 5 target	#TT: 2 out of 5 target
poftˈi → *poftˈi*	*ftˈipo* → *ftˈipo*
kaxtˈi → *taxtˈi*	*xtˈika* → *xtˈipa*
tovðˈi → *oðˈi*	*vðˈito* → *vˈito*
pivɣˈa → *tivɣˈa*	*ɣðˈoki* → *vðˈoki*
kiɣðˈo → *iɣˈo*	*vɣˈapi* → *xˈapi*

c. Manouela (2;11,19)

-TT: 1 out of 5 target	#TT: 0 out of 5 target
kaxtˈi → *ixtˈi*	*ftˈipo* → *pˈipo*
poftˈi → *xutˈi*	*xtˈika* → *pˈika*
tovðˈi → *tuvlˈi*	*vðˈito* → *θˈito*
kiɣðˈo → *tliɣˈo*	*ɣðˈoki* →*klˈoki*
pivɣˈa → *fijˈa*	*vɣˈapi* → *kˈapi*

To sum up, some children performed better at word initial sT than TR, while others performed better at TR than at sT, creating a balance in the overall results. Children's performance at word initial TT was systematically worse than at word initial sT and word initial TR. In a comparison with the word medial position, no difference was found in children's performance at sT (initial versus medial) and TR (initial versus medial), while there was a difference between word initial and word medial TT.

4 Analysis
4.1 Extrasyllabicity-problems

The results regarding initial sT versus initial TR were as expected. No overall difference was found between #sT and #TR clusters. These results were representative of the paradox that is found in the acquisition literature in other languages, with some of the children acquiring sT before TR and some following the opposite path.

These results, combined with the results for #TT and #TR are particularly problematic for the extrasyllabic analysis of sT and TT. Extrasyllabicity would only be able to account for one set of data: either the TT versus TR, or sT versus TR. The TT versus TR results could be explained by an extrasyllabicity model according to which extrasyllabic structures are more marked than regular branching onsets and are therefore expected to be acquired later. This model would explain late acquisition of TT when compared to TR, but would fail to tackle the paradox of sT versus TR variation. On the other hand, the TT versus TR data would not be covered by the amended extrasyllabicity proposals discussed in section 2.2 – namely a) that extrasyllabicity can be acquired before or after branching onsets, and b) that in some children's grammar, extrasyllabic clusters are structured like affricates, and are therefore acquired before branching onsets. Any such proposal would cover the data it was designed to explain (sT-TR variation), but would have to answer the question of why the same variation is not found in TT versus TR acquisition. Either way, the results are problematic for the extrasyllabic approach. Evidence for the different nature of sT and TT was also found in the comparison with their word medial counterparts. Although word initial TT was acquired later than word medial TT, such imbalance was not found with sT clusters.

In order to account for the data, it would be possible to add an auxiliary hypothesis that assumes two different kinds of extrasyllabicity, one for #sT and one for #TT. However, this would not be enough: we would further have to stipulate the order of acquisition of these different structures. Specifically, we would have to stipulate that sT-type extrasyllabicity is acquired before TT-type extrasyllabicity. If TT was found to be acquired before sT, extrasyllabicity could simply stipulate that it is TT that is acquired before sT, and thus be made consistent with the opposite reality.

To make matters even more complicated, in languages that have both, sT and TT show identical behaviour in some adult language phenomena. Specifically, there is evidence from languages that have both #sT and #TT that the two are syllabically the same (Seigneur-Froli 2006; Steriade 1982). A well-known example is attic Greek reduplication: past forms of roots beginning with sT and TT follow the same pattern, in contrast to verbs that begin with TR. The imperfective past forms of roots commencing with a single consonant (including *s*) are formed by reduplication; an initial syllable consisting of the first consonant followed by *e* is added (17a). In the case of roots commencing with TR clusters, reduplication also takes place (the initial syllable consists of the obstruent plus *e*) (17b). In contrast, in the case of roots commencing with TT no reduplication takes place: the vowel *e* is added word initially (17c). As for the past forms of roots starting with sT, these are formed in the same way as TT initial roots (17d).

(17)

	Present	Past	
a. CV			
	paideˈu-oo	*pepˈaideuka*	‘bring up’
	lˈuoo	*lˈeluka*	‘loosen’
	saleˈuoo	*sesˈaleumai*	‘cause to rock’
b. TR			
	krˈinoo	*kˈekrika*	‘pick out’
	klˈinoo	*kˈeklika*	‘make to bend’
	plˈeoo	*pˈepleuka*	‘sail’
c. TT			
	ptˈaioo	*ˈeptaika*	‘make to stumble’
	ktˈeinoo	*ˈektaamai*	‘kill’
	p^{h}t^{h}ˈanoo	*ˈep^{h}t^{h}aka*	‘come first’
d. sT			
	spˈaoo	*ˈespaka*	‘draw’ (a sword)
	stˈelloo	*ˈestalka*	‘arrange’
	skiˈazoo	*ˈeskiasmai*	‘shade’

Such behaviour has led phonologists to conclude that sT and TT in (ancient) Greek have the same structure (Seigneur-Froli 2006; Steriade 1982). On the other hand, our experimental results demonstrate that sT and TT are different in some way crucial to first language acquisition. The question arises, if sT and TT have the same structure, why are they not acquired together?

4.2 Towards an analysis

If we try to categorise word initial clusters based on the acquisition data, the division appears to be between TR and sT on one side and TT on the other side. The acquisition of TT clusters requires an extra step when compared to the rest of the word initial clusters.

Interestingly, this descriptive division corresponds to a theoretical division that has been suggested on entirely different grounds, based on adult language phenomena. Scheer (2000, 2004), divides (adult) languages into those that allow word initial TT clusters and those that do not. The theoretical distinction he proposes is the absence versus presence of an onset nucleus pair at the left margin of the word. The theoretical proposal is part of a system that defines structure according to relationships segments establish along the syntagmatic dimension i.e.

governing and licensing relations with what follows and what precedes, thus eliminating vertical-branching structure.

(18) Syntagmatic representations: *pˈefto* ‘(I) fall’, *mˈiti* ‘nose’, *xtˈeni* ‘comb’

```
       gov                              gov
O N O N O N       O N O N       O N O N O N
| | | | | |       | | | |       | | | | | |
p e f Ø t o       m i t i       x Ø t e n i
```

The examples in (18) show the representations of three Greek words. As may be seen, the skeleton is a sequence of onsets (consonantal positions) and nuclei (vocalic positions), which may or may not enjoy segmental instantiation. An empty nucleus Ø is allowed to exist if it is followed by a filled nucleus, which can govern the empty position.

Based on Lowenstamm’s (1999) proposal that the left margin of the word (traditionally noted as #), corresponds to an onset nucleus pair without any segmental content (ON), Scheer proposes a parameterisation of the initial ON. The existence of an initial ON pair in a language creates a ban on word initial TT clusters. This is because the empty nucleus of the initial ON would fail to be governed, since the following nucleus (within the TT cluster) is itself empty (19a). Absence of the initial ON in a language makes the existence of initial TT clusters possible (19b).

(19) Parameterisation of initial ON and typology of #TT clusters

a. ON present (English)
*#TT

```
 *        gov
O N - O N O N
  |   | | | |
  Ø   T Ø T V
```

b. ON absent (Greek)
#TT

```
  gov
O N O N O N
| | | | | |
x Ø t e n i
```

On the other hand, the presence or absence of the initial ON pair does not affect the existence of word initial TR and sT clusters, which have alternative ways of governing the empty nucleus of the initial ON (for TR see Scheer (2004), for sT see Sanoudaki (submitted)). The proposal finds independent support in diachronic lenition and fortition phenomena (Seigneur-Froli 2003; 2006).

Extending this to first language acquisition, the presence of an initial ON pair in a developing grammar creates a ban on word initial TT clusters. Word initial TT clusters only appear when the initial ON pair has disappeared from the child’s grammar[12]. This can explain the later acquisition of initial TT when compared to other word initial clusters.

(20) Acquisition stage n-1: ON present: No TT clusters
Acquisition stage n: ON absent: TT clusters

Moreover, once the initial ON pair has disappeared (in other words, when initial TT is acquired) initial sT and initial TT have the same structure, as that is defined by the governing and licensing relations in their environment[13].

(21) Word initial TT (*xtˈeni* 'comb') and sT (*stˈoma* 'mouth') in Greek

a. #TT

```
  gov
 ▼──┐
O N O N O N
| | | | | |
x Ø t e n i
```

b. #sT

```
  gov
 ▼──┐
O N O N O N
| | | | | |
s Ø t o m a
```

Thus, the discrepancy between adult language and first language acquisition whereby sT is acquired earlier, while in adult language sT and TT behave identically, is predicted.

The remaining findings are also consistent with this model. Word initial TT is acquired later than its word medial counterpart because initial TT, unlike medial TT, has the extra requirement that the ON pair be absent. There is no difference in the acquisition of sT in initial versus medial position, since no such extra requirement is involved. The same holds for initial versus medial TR. Finally, the optionality in the acquisition of sT versus TR can be attributed to optionality in the mastering of the relevant structure: along the lines of Fikkert's (1994) suggestion (see section 2.2), some children master the sT structure first and others the TR structure first. Fikkert's suggestion involves extrasyllabicity versus branching onsets, while in a syntagmatic view of phonology different structures would be involved, but the suggestion is of the same nature. For details of a model of consonant cluster acquisition based on this view on phonology, the reader is referred to Sanoudaki (submitted).

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[12] For theoretical motivation of the acquisition stages based on learnability issues see Sanoudaki (submitted).

[13] The representations in (18), (19) and (21) are simplified for expository reasons. For complete representations see work mentioned above.

5 Conclusion

Despite what most phonologists would think, sT and TT in word initial position are different. The existence of the difference would not have been discovered without the help of developmental data, which show that Greek children acquire TT later than sT. The nature of the difference was further examined by comparing children's production of different clusters in different positions. While word initial sT is acquired before TR by some children and after TR by others, TT is systematically acquired later than TR. Moreover, initial TT was acquired later than its word medial counterpart, while no such difference was found for word initial versus word medial sT. These findings point against existing extrasyllabic analyses of these clusters and indicate a division between initial sT and TR on the one hand and initial TT on the other hand, which is best captured by Lowenstamm's initial ON hypothesis.

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