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Harmonic domains and synchronization in typically and atypically developing Hebrew-speaking children

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Abstract

This paper presents a comparative study of typical and atypical consonant harmony (onset–onset place harmony), with emphasis on (i) the size of the harmonic domain, (ii) the position of the harmonic domain within the prosodic word, and (iii) the maximal size of the prosodic word that exhibits consonant harmony. The data, drawn from typically and atypically developing Hebrew-speaking children, reveal the following characteristics: (i) The harmonic domain is usually limited to two consonants in typical harmony, but may span to up to four consonants in atypical harmony. (ii) The harmonic domain usually aligns with the left edge of the prosodic word in typical harmony, but may also align with the right edge of the prosodic word in atypical harmony. (iii) Typical consonant harmony is usually limited to maximally trisyllabic productions, while atypical harmony is also found in quadrisyllabic productions. In addition, the sporadic variation characterizing early typical speech appears in advanced stages in atypical speech. With reference to the hierarchical structure of the word, these distinctions are analyzed here in terms of (a-)synchronization between the development of the prosodic word layer (number of syllables) and the segmental layer. The formal analysis is couched within the framework of Optimal Domains Theory (Cole, J., Kisseberth, C., 1994. An optimal domain theory of harmony. Studies in the Linguistic Sciences 24, 1–13, ROA-22; Cole, J., Kisseberth, C., 1995a. Paradoxical strength conditions in harmony systems, ROA-48; Cole, J., Kisseberth, C., 1995b. Nasal harmony in optimal domain theory, ROA-49; Cole, J., Kisseberth, C., 1996. Restricting multi-level constraint evaluation: opaque rule interaction in Yawelmani vowel harmony, ROA-98; Cassimjee, F., Kisseberth, C., 1997. Optimal domain theory and Bantu tonology: a case study from Isixhosa and Shingazidja, ROA-176; Cassimjee, F., Kisseberth, C., 1998. Tonal variation across Emakhuwa dialects, ROA-289; Cassimjee, F., Kisseberth C., 1999. A conspiracy argument for optimality theory: Emakhuwa dialectoloy, ROA-331), a branch of optimality theory (Prince, A., Smolensky, P., 1993. Optimality theory: Constraint Interaction in Generative Grammar. Ms. Rutgers University and University of Colorado, Boulder).

Keywords: Language acquisition; Consonant harmony; Dyspraxic speech; Hebrew; Synchronization; Variation

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1. Introduction

Studies of consonant harmony (hereafter C-harmony) in children's speech have focused mainly on directionality, i.e. whether C-harmony is progressive (e.g. *túti* for *túki* 'parrot') or regressive (e.g. *kúki* for *túki* 'parrot'). These studies address the role of the features in determining directionality, with reference to theoretical issues such as markedness, underspecification, alignment of features, and segmental patterns (among others, Vihman, 1978, 1996; Berg, 1992; Stoel-Gammon and Stemberger, 1994; Levelt, 1994; Goad, 1996; Pater, 1997; Werle, 2001; Pater and Werle, 2001, 2003; Fikkert and Levelt, 2006).

In this paper, I study C-harmony from a different angle, remaining mute with regard to the role of the features. The focus of the study is on the harmonic domain (of onset–onset place harmony), with reference to its size and position within the prosodic word. Two other issues addressed here are variation, and the relation between C-harmony and the size of the prosodic word.

The data presented in the above-mentioned studies consist mostly of mono- and disyllabic productions, and a handful of trisyllabic productions. This distribution is expected, given Grunwell's (1982) chronology of phonological processes (in the acquisition of English), according to which C-harmony stops applying in children's speech while syllable truncation is still pervasive. That is, when the children reach trisyllabic productions, C-harmony starts fading, and it is practically extinct when they reach quadrisyllabic productions. For example, the German-speaking child (2;7.15–2;11.08) studied in Berg (1992) produced 64 words with place harmony (labial), out of which only 11 (17%) consisted of more than two syllables.

The same state of affairs is found in Ben-David's (2001) study of typically developing Hebrew-speaking children, where C-harmony is found in mono- and disyllabic productions, and to a lesser extent in trisyllabic productions. As in other languages, there are cases of onset–coda harmony (e.g. *fuf* for *yanʃúf* 'owl', *otót* for *maftexót* 'keys'), onset–onset harmony (e.g. *tatán* for *katán* 'small', *dída* for *glída* 'ice cream'), and a few cases of coda–coda harmony (e.g. *ikfók* for *lidfók* 'to knock'). In trisyllabic productions there is mostly onset–onset harmony (e.g. *gagólet* for *tarnególet* 'hen', *tatína* for *klemantína* 'tangerine'), just like in English (e.g. *tənɛktə* 'connector'; Smith, 1973), German (e.g. *purnbɔitəl* for *turnbɔitəl* 'sports bag'; Berg, 1992), Finnish (e.g. *kaketti* for *paketti* 'parcel'; Kukkonen, 1994), and Dutch (e.g. *pipóto* for *kipóto* 'dump truck'; Levelt, 1994).

As the data of C-harmony presented in the literature were limited mostly to mono- and disyllabic productions, the following questions, related to the harmonic domain, have not been addressed: (i) What is the size limit on the harmonic domain? (ii) What is the preferred position of the harmonic domain within the prosodic word? Such questions are, indeed, of little interest when much of the C-harmony data are restricted to maximally disyllabic words, in which case the harmonic domain coincides with the prosodic word (though final codas are often left out; e.g. *lulás* for *meʃuláʃ* 'triangle', *ʃéʃet* for *ʃéket* 'quite').

The data of onset–onset place harmony obtained from typically developing Hebrew-speaking children reveal that the harmonic domain is usually restricted to two onsets, and aligned with the left edge of the prosodic word. In addition, as seems to be the case in other studies, there are hardly any instances of C-harmony in quadrisyllabic productions.

The above generalizations hold only for a subset of the data obtained from dyspraxic Hebrew-speaking children (Tubul-Lavy, 2005), which exhibit C-harmony in productions up to four syllables, where the harmonic domain spans 2–4 onsets.[1] In addition, the harmonic domain may align with either the left or the right edge of the prosodic word. That is, dyspraxic speech exhibits structures that are rarely found in typical Hebrew speech. The richness of these data is compatible with reports on the great degree of variation encountered in disordered speech in general, and dyspraxic in particular (Davis et al., 1998; Forrest, 2003; Marquardt et al., 2004).

In the light of these data, the present paper concentrates on the harmonic domain (limited to onset–onset place harmony), its size, position within the prosodic word, and its relation to the size of the prosodic word. The proposed analysis manipulates the hierarchical structure of word, with reference to the prosodic word

[1] I use the term dyspraxia with reference to Childhood Apraxia of Speech (CAS), which is also known as Developmental Verbal Dyspraxia (DVD) and Developmental Apraxia of Speech (DAS). The different names reflect the controversy with regard to the source of the impairment, whether it is due to an impaired phonological representation, an impaired speech motor control, or a failure in the transmission from the former to the latter (see Forrest, 2003; Jacks et al., 2006; and references therein).

layer and the segmental layer. It is argued that the unusual structures attested in the dyspraxic speech are due to a-synchronization between the development of the prosodic word and the contrast among the consonants in the word. While the prosodic word gradually develops up to quadrisyllabic productions, the development of the contrast among the consonants in the word remains in its initial state. Assuming that the initial state is characterized by free ranking of the markedness constraints, its persistence throughout the development of the prosodic word results in atypical structures and pervasive variation.

Data and generalizations are provided in Section 2, starting with the typically developing children (Section 2.1), whose speech reveals the expected properties of C-harmony, and continuing with the dyspraxic children (Section 2.2), whose productions are comparatively unusual, in quality and quantity. A brief review of the Optimal Domains Theory is given in Section 3, with reference to the constraints relevant to the issues addressed here. The analysis of typical C-harmony is offered in Section 4, providing the constraint (re)ranking which accounts for the development of the segmental contrast in the word, throughout the gradual increase in the number of syllables. The notion of a-synchronization is introduced in Section 5, followed by an analysis of C-harmony in dyspraxic speech, based on the analysis of typical C-harmony. The concluding remarks in Section 6 mention two other cases of a-synchronization and address some questions for further study.

2. Data and generalizations

The data obtained from typically developing Hebrew-speaking children (Ben-David, 2001; Adam and Bat-El, 2008), allow identification of the typical restrictions on C-harmony relevant for the present study (Section 2.1). A comparison with the data obtained from the dyspraxic children (Tubul-Lavy, 2005) reveals that these restrictions do not hold for a relatively large portion of the productions (Section 2.2).

2.1. Typically developing children

Children's early speech exhibits reduction in the number of contrastive consonants in the word. The reduction may be due to prosodic simplification, involving truncation of a syllable (e.g. *ta* for *mitá* 'bed') and/or elimination of a syllable margin, either a coda (e.g. *gu* for *kóf* 'monkey') or onset (e.g. *áta* for *sáfta* 'grandma'). While these types of reduction in consonant contrast are a byproduct of prosodic simplification, C-harmony is a strategy directly manipulated for reducing the contrast among the consonants in the word. In productions with C-harmony, the different consonants in the target correspond with identical (or similar) ones in the child's production, regardless of prosodic simplification (e.g. *kúki* or *túti* for *túki* 'parrot').

In the majority of cases, C-harmony is restricted to two consonants. This generalization is drawn from the data obtained from typically developing Hebrew-speaking children, as well as from data provided in studies of C-harmony in other languages (see references in Section 1). C-harmony can be between onset and coda, as in *panán* or *pasás* for *panás* 'torch', or two onsets, as in *nanás* or *mamás* for *panás* 'torch'. In this paper, I only discuss place harmony among onsets, since there are relatively few productions with codas in dyspraxic speech (see Section 6).

As shown below, onset–onset place harmony in typically developing children appears in productions with two onset positions (1a) as well as with three (1b). In the latter case, however, harmony is still restricted to two consonants only, where the harmonic domain is aligned with the left edge of the prosodic word, with a possible intervening vowel, as in *azíza* for *televízja* 'television'.[2] The data are drawn from Ben-David (2001), with the addition of one child (SR), whose phonological development is studied in Adam and Bat-El (2008). Both studies are longitudinal, providing naturalistic data obtained from spontaneous speech and picture/object naming.

[2] The possible intervening vowel, as the reviewer noted, is unstressed. This is a direct outcome of the priority of the stressed and final syllables in early speech, leaving the initial third syllable necessarily unstressed.

(1) C-harmony in typically developing children
a. Two onset positions – two consonants in a harmonic domain

Output	Target	Gloss	Child	
kúki	túki	'parrot'	SR	1;04
gagó	kaftór	'button'	SR	1;04
túti	túki	'parrot'	SR	1;05
dída	glída	'ice cream'	SR	1;05
mamás, nanás	panás	'torch'	SR	1;06
gegól	tarnegól	'rooster'	SR	1;07
totám	ipopotám	'hippopotamus'	SR	1;07
kakán	katán	'small'	SR	1;07
azíza	televízja	'television'	DA	1;10

b. Three onset positions – two consonants in a left-aligned harmonic domain

Output	Target	Gloss	Child	
tatína	klemantína	'tangerine'	AR	2;04
memalá	nemalá	'ant'	AR	2;05
gagólet	tarnególet	'hen'	AR	2;04
tótolat	ʃókolad	'chocolate'	DA	1;06
mamajá	laxmanjá	'bread roll'	NV	2;02

C-harmony gradually fades with the development of the prosodic word (Grunwell, 1982). There are fewer cases of C-harmony in trisyllabic productions (1b) than in disyllabic productions (1a), and hardly any in quadrisyllabic productions.

The data sample above allows identification of the following restrictions on C-harmony in the speech of the typically developing Hebrew-speaking children:

(2) Restrictions on C-harmony in typical speech (onset–onset, place of articulation)

a. *Domain limit – two consonants*	
There is an upper limit of two consonants (or two onset positions) in a harmonic domain	*memalá* for *nemalá*
There are hardly any productions where three or more consonants share a place feature in the output but not in the input	∗*memamá*
b. *Alignment – left*	
The left edge of the harmonic domain coincides with the left edge of the prosodic word (with a possible intervening vowel)	*tatína* for *klemantína*
There are hardly any productions where the two onsets sharing a consonant are preceded by a different consonant	∗*manína*
c. *Word limit – trisyllabic*	
C-harmony rarely appears in productions consisting of more than three syllables	*tatína* for *klemantína*
There are hardly any quadrisyllabic productions with two onsets with identical consonants	∗*memantína*

C-harmony serves as a simplification strategy in the development of the prosodic word, as it often applies when a new syllable is added to the prosodic word (Ben-David, 2001), as in ***góget*** > *gólet* > ***gagólet*** > *tagólet* for *targnególet* 'hen'. As demonstrated in Ben-David (2001) and Adam (2002), Hebrew-speaking children expand the size of the prosodic word from right-to-left, one syllable at a time, starting with the two rightmost syllables. This development coincides with the observation made in Echols (2001), among others, that the first syllables produced by children are the final and the stressed ones. Since stress in most Hebrew words is final or penultimate, the first two syllables produced by children correspond to the two rightmost syllables in the target (Adam and Bat-El, 2008). Consequently, the expansion of the prosodic word is from right-to-left, and the harmonic domain is at the left edge of the prosodic word, where the newly added syllable is. Thus, C-harmony is not due to the order of the acquisition of the segments, as noted in Stoel-Gammon and Stemberger (1994), but rather of the syllables.

The first two restrictions in (2), the two consonant domain limit and the left-alignment, can be viewed as a "trade-off" (Ferguson and Farwell, 1975; Garnica and Edwards, 1977; Stemberger et al., 1999), where the expansion of the prosodic word is at the expense of faithfulness on the segmental layer. This coincides with other evidence, suggesting that when children start producing new structures, the transition may involve simplification of already acquired structures. For example, Watterson (1978) shows that consonantal contrasts acquired in early stages, have been simplified in words acquired later on, at the stage where the syntactic complexity has increased. Similarly, Bat-El (2006a) shows that the marked foot structure already acquired in the production of nouns, does not appear in the first verbs, which start appearing a few months later.

Ben-David (2001) also shows that the syllable is not added as a unit, but rather in stages, first the vowel and then the onset. It is thus expected that with the addition of a vowel to the prosodic word (CV > V.CV) there will also be vowel harmony. Indeed, there are cases of vowel harmony in children's speech precisely for this reason (e.g. *igíl* for *agíl* 'earring', *apá* for *kipá* 'skullcap'). However, vowels are perceptually more accessible than consonants (they are more sonorous and more contrastive) and the vowel inventory is acquired rather early. Therefore, vowel harmony in children's speech is not as common as consonant harmony (Stoel-Gammon and Stemberger, 1994), and it does not persist much beyond the onset of speech.

As the development of the prosodic word is contingent upon the stress pattern, and C-harmony is contingent upon the development of the prosodic word, it is expected that the left-alignment restriction (2b) will vary depending on the stress patterns in the ambient language. In particular, when the stress pattern is antepenultimate, the development of the prosodic word usually proceeds from $\acute{\sigma}_1\sigma_3$ to $\acute{\sigma}_1\sigma_2\sigma_3$, where the newly added syllable is in the middle, i.e. σ_2. Since C-harmony is often regressive (though depending on the particular features), the harmonic domain may align in such cases with the right, rather than the left edge of the prosodic word ($\acute{\sigma}_1[\sigma_2\sigma_3]$). For example, Smith (1973) provides the form *mɔ́:kəka:* 'motor-car', where stress is antepenultimate and the harmonic domain is right-aligned (cf. left-alignment in *tənɛ́ktə* 'connector'). C-harmony due to morphological (rather than phonological) novelty is presented in Vihman (1978), where the newly added inflectional suffix is harmonized in the speech of an Estonian-speaking girl, and thus the harmonic domain is not left-aligned (e.g. *jæŋku-k* for *jænju-t* 'bunnies').

The effect of novelty is worn out by the time the children produce quadrisyllabic words, and thus there is no C-harmony when the fourth syllable is added to the word (2c). At this point, the children are rather close to the end of their phonological development, and their maturation allows them to be faithful to the target right away, without the transitional facilitation of harmony. For example, the development of the Hebrew word *klemantína* 'tangerine' is *tína* > ***tatína*** > *matína* > *kemátina* (*∗memantína*), where there is C-harmony in the transition from di- to trisyllabic productions, but not from tri- to quadrisyllabic productions.

The restrictions in (2) are not exception-free. The following is an exhaustive list of exceptions, obtained from 370 one-hour sessions (of eleven children).

(3) Rare forms

	Output	Target	Gloss	Child
Harmony beyond two onsets	xaxexót	maftexót	'keys'	AR 2;04
	gagegól	tarnegól	'rooster'	CL 1;06
	bububá	ceubá	'yellow fm.sg.'	GN 1;08
Harmony in quadri-syllabic productions	gagególet	tarnególet	'hen'	EZ 2.06
	itototám	ipopotám	'hippopotamus'	GN 2.00
Harmonic domain not left-aligned	jatatá	ipopotám	'hippopotamus'	SR 1;05
	ʒijája	ʤiráfa	'giraffe'	SR 1;05
	giléle	tarnególet	'hen'	SR 1;05

These rare forms, which deviate from the properties given in (2), appeared at rather early ages, less than a year after the onset of speech.

2.2. Dyspraxic children

The rare forms in the speech of the typically developing children (3) are relatively common in the speech of dyspraxic ones (Tubul-Lavy, 2005).[3] In addition to the forms conforming with the typical properties (4a), there are forms where the harmonic domain spans beyond the upper limit of two consonants (4b-i), others where the harmonic domain is not aligned with the left edge of the prosodic word (4b-ii), and yet others where C-harmony appears in quadrisyllabic words (4b-iii). Of course, with the qualitative differences discussed here, there is a notable age gap. All the typically developing children reached faithful productions before the age of 2;06 (most of them even earlier), while the dispraxic children maintained their unfaithful productions way into their fourth year (and presumably later, as the study ended before they reached faithful productions, also in terms of the development of the prosodic word).

(4) C-harmony in dyspraxic children
a. *Typical C-harmony*

Output	Target	Gloss	Child	
i. Two onset positions – two consonants in a harmonic domain				
titá	mitá	'bed'	SF	3;10
búbi	dúbi	'teddy bear'	RY	3;07
isése	miʃkéfet	'binoculars'	MN	4;09
gikáa	gitára	'guitar'	RY	3;07
ii. Three onset positions – two consonants in a left-aligned harmonic domain				
tatemá	maclemá	'camera'	SF	3;10
susajá	sukarjá	'candy'	TR	3;06
pipijá	mitrijá	'umbrella'	RI	2;06
gagébet	magévet	'towel'	SF	3;10

[3] I am grateful to Gila Tubul-Lavy, who got me acquainted with the dyspraxic speech, where the issue of synchronization became relevant.

b. Atypical C-harmony

i. C-harmony beyond the upper limit of two consonants[a]

	Output	Target	Gloss	Child	
3 σ's	gagegól	tarnegól	'rooster'	RF	4;07
	kagukál	kadursál	'basketball'	RY	3;07
	lólola	ʃókolad	'chocolate'	TR	3;06
	séseso	télefon	'phone'	MN	4.09
4 σ's	kukukujón	akordijón	'accordion'	IO	4;09
	nananái	naaláim	'shoes'	IO	4;09
	tetedía	televízja	'television'	MN	4;09
	pepipópe	elikópter	'helicopter'	IO	4;09

ii. Harmonic domain not left-aligned

	Output	Target	Gloss	Child	
3 σ's	sujajót	sukarjót	'candies'	TR	3;06
	kotétet	kofécet	'jumps fm.sg.'	IO	4;09
	binána	piʤáma	'pajama'	MN	4;09
	nagegól	tarnegól	'rooster	RY	3;07
4 σ's	mekikáim	meciltáim	'cymbals'	RY	3;07
	elikóke	elikópter	'helicopter'	RY	3;07
	teledída	televízja	'television'	RT	4;07
	terezíza	televízja	'television'	IO	4;09

iii. C-harmony in quadrisyllabic productions

L-aligned	kakuéde	kadurégel	'football'	LN	3;00
	xaxiéi	naxliéli	'wagtail'	MN	4;09
	teedía	televízja	'television'	MN	4;09
	taedólet	tarnególet	'hen'	RI	2;06
R-aligned	mekikáim	meciltáim	'cymbals'	RY	3;07
	elikóke	elikópter	'helicopter'	RY	3;07
	measése	mevaʃélet	'cooks fm.sg.'	MN	4;09
	terezíza	televízja	'television'	IO	4;09
Beyond two C's	kukukujón	akordijón	'accordion'	IO	4;09
	nananái	naaláim	'shoes'	IO	4;09
	pepipópe	elikópter	'helicopter'	IO	4;09
	tetedía	televízja	'television'	MN	4;09

[a] Productions like *cococá* for *xacocrá* 'trumpet' do not exceed the two consonant limit, since only the first onset is harmonizing, the other two correspond to the target, which happens to have identical consonants. However, when two identical target consonants harmonize with another consonant, as in *tututám* for *ipopotám* 'hippopotamus', the harmonic domain exceed the two consonants limit.

In addition, there were four examples (out of 376 production types with more than two onsets) where there was a different consonant between the harmonizing consonants: *nar̲anái* for *naaláim* 'shoes' (IO 4;9), *kus̲ukí* for *maʃrokít* 'whistle' (MN 4;9), *kil̲agól* for *xilazón* 'snail' (RY 3;7), and *sesev̲ísa* for *televízja* 'television' (TR 3;6). These forms are not considered here, since due to their scarcity, no generalization can be made.

While the typically developing children provided 8 unusual production types (for 6 target types) obtained from 370 one-hour sessions, the dyspraxic children provided 30 such production types (for 23 target types) obtained from only 118 one-hour sessions. In addition, Ben-David's (2001) study of the typically developing children followed the children until they produced faithful forms, but when Tubul-Lavy (2005) stopped following the dyspraxic children, their productions were far from faithful, as truncation and segmental errors were still pervasive in productions corresponding to tri- and quadrisyllabic targets.

The data available from the dyspraxic children consist of 438 production types of 3–4 syllables.[4] I did not consider mono- and disyllabic productions, as these are not potential forms for atypical onset–onset harmony. Out of the 438 production types, 376 (86%) were potential for C-harmony, as the other 62 had only one onset, or no onset at all (e.g. *aió* or *abió* for *avirón* 'airplane', *opaáim* for *ofanáim* 'bicycles'). Out of the 376 potential production types, 87 (23.1%) exhibit C-harmony. This is a rather typical percentage of C-harmony, but for a much earlier age. Below is the distribution of the atypical C-harmony in these 87 forms:

(5) Distribution of atypical C-harmony
   a. Harmonic domain beyond two consonants (2a) – 20.7% (12 out of the 58 production types with 3–4 onsets)
   b. Harmonic domain not left-aligned (2b) – 27.6% (16 out of the 58 production types with 3–4 onsets)
   c. C-harmony in quadrisyllabic forms (2c) – 26.3% (20 out of the 76 quadrisyllabic production types with 2–4 onsets)

The goal of this paper is to provide a general model that distinguishes between typical and atypical phonological development, such that its principles will extend beyond C-harmony (see Section 6). It is argued that the distinction in the speech of these two types of populations is a matter of (a-)synchronization (Tubul-Lavy, 2005) between the development of the prosodic word (number of syllables) and the segmental layer. While the prosodic word gradually develops, the segmental layer maintains its initial state, where the markedness constraints are freely ranked. Indeed, in typical speech too, the prosodic word reaches its final state before the segmental layer, but the remaining segmental errors do not involve harmony, but rather substitution of some segments (e.g. $\theta \rightarrow f$, ð → *d*/*v* in English). C-harmony tends to vanish much earlier (Grunwell, 1982; Vihman, 1996).

3. Theoretical background

A grammar in Optimality Theory is a hierarchy of ranked constraints (Prince and Smolensky, 1993), either a totally ranked hierarchy, where all constraints are ranked with respect to each other, or a stratified hierarchy, where the strata are ranked but the constraints in each stratum are not (Teser and Smolensky, 1996). I adopt here the conventional (though not indisputable) view proposed in Smolensky (1996), and Teser and Smolensky (1996), that the initial grammar consists of a stratified hierarchy, where the markedness (structural) stratum outranks the faithfulness one. Learning a grammar involves a gradual constraint demotion towards the ranking of the ambient language.

The constraints adopted in this paper are drawn from the Optimal Domains Theory (Cole and Kisseberth, 1994; Cole and Kisseberth, 1995a; Cole and Kisseberth, 1995b; Cole and Kisseberth, 1996; Cassimjee and Kisseberth, 1997, 1998, 1999), which provides a model of feature realization within the program of Optimality Theory (see also McCarthy's (2004) Span Theory). The representational substances of the theory are the sponsor and the F-domain (feature domain). Features are sponsored by segments (or prosodic units) in the underlying representation and are parsed into F-domains in the surface representation; features that are not within a domain are not phonetically realized (like segments that are not associated with a higher prosodic unit).

As the focus in this paper is on the domain, rather than the features, the discussion is limited to three types of constraints, referring to the position of the domain within the prosodic word (6), the general faithfulness of the segments (7), and the size of the domain (9).

[4] Production type refers to any segmental and/or prosodic distinction. Given the excessive degree of variation characterizing atypical development, the 438 production types correspond to 161 target types. For example, the word *rakévet* 'train' had 16 production types (among the children): *akése*, *akéze*, *akéve*, *akébe*, *atéve*, *agébet*, *agévet*, *akébek*, *akébet*, *akéfet*, *akévet*, *atévet*, *kakébe*, *kakéve*, *rakéze*, *jakévet*.

Harmony is attributed to the markedness constraint family WIDE SCOPE ALIGNMENT, which requires an F-domain to align with the left and right edges of the prosodic word.[5]

(6) WIDE SCOPE ALIGNMENT (WSA)
 a. WSA-L: Align (F-domain, L; PrWd, L)
 b. WSA-R: Align (F-domain, R; PrWd, R)

When the WSA constraints are not dominated by competing constraints, the F-domain coincides with the prosodic word, and there is thus one domain for the feature F. When the domain is smaller than the prosodic word, its position is determined by the ranking of the WSA constraints.

The WSA constraints are in conflict with the faithfulness constraint family BASIC ALIGNMENT, which blocks harmony by requiring every sponsor to be within its own domain. That is, BA is violated whenever the F-domain spans more than one sponsor.

(7) BASIC ALIGNMENT (BA)
 a. BA-L: Align (Sponsor, L; F-domain, L)
 b. BA-R: Align (Sponsor, R; F-domain, R)
 For every left (L)/right (R) edge of a sponsor there is a left (L)/right (R) edge of a C-domain

The two members of BA account for directionality of harmony, which is not under consideration here. I thus use BA as a general faithfulness constraint, which assigns one violation mark to every candidate with consonant harmony, i.e. where two (or more) consonants in the output correspond to one consonant in the input.

While the WSA constraints favor the surface structure $\{[CVCVCV]\}_{PrWd}$, the BA constraint limits a harmonic domain to just one C, yielding $\{[CV][CV][CV]\}_{PrWd}$ (where [ ] marks a domain and { } a prosodic word). That is, the presence vs. absence of C-harmony is due to the interaction between WSA and BA.

(8) No harmony: BA $\gg$ WSA
 Harmony: WSA $\gg$ BA

The rankings in (8) reflect the competition, revealed in Kisseberth (1970), between the semantic and the phonetic poles. The semantic pole, represented by faithfulness constraints, pulls towards preservation of underlying contrasts, while the phonetic pole, represented by markedness constraints, pulls towards articulatory and/or perceptual simplicity. BA is a faithfulness constraint, whose satisfaction yields one sponsor per feature, thus preserving the feature-sponsor relations provided in the input. WSA is a markedness constraint, whose satisfaction yields one feature per prosodic word. As Cole and Kisseberth (1994) point out, the phonetic source of harmony, and thus of WSA, is perceptibility and articulator stability. A feature spanning a large domain is more perceptible and requires less articulatory changes.

One final constraint required for the analysis presented here is C-DOMAIN $\leqslant$ 2C, which puts an upper limit of two consonants on the C-domain.

(9) C-DOMAIN $\leqslant$ 2C (CD $\leqslant$ 2C)
 C-domain does not exceed two consonants

Size limit on the domain is not unusual, given the constraint NO MONOMORAIC HD (Cassimjee and Kisseberth, 1999), which puts a minimal limit of two moras on the H-domain (where H stands for high tone).

[5] See also Levelt (1994), Goad (1996), and Fikkert and Levelt (2006) for the use of ALIGN in the analysis of consonant harmony in child language. Other proposals for the harmony triggering constraint are SURFACEIDENTITY (Krämer, 1999), AGREE (Lombardi, 1999; Bakovic, 2000; Pater and Werle, 2001, 2003), ∗STRUCTURE (Ben-David, 2001), and ∗A-SPAN (McCarthy, 2004).

Although in most cases two consonant are parallel to two syllables, the constraint must refer to consonants. In forms with an onsetless syllable (e.g. *ke.a.ká* for *keará* 'bowl', *ta.e.dó.let* for *tarnególet* 'hen'), the domain spans two consonants but three syllables (note that in Hebrew adjacent vowels are heterosyllabic).

The structures relevant to the present study are listed in (10) below:

(10) Possible structures

			BA	WSA-L	WSA-R	CD $\leqslant$ 2C
a. {CV[CV]CV}	Faithful		√	*	*	√
b. {[CVCV]CV}	{[tate]má}	(← maclemá)	*	√	*	√
c. {CV[CVCV]}	{su[jajá]}	(← sukarjá)	*	*	√	√
d. {[CVCVCV]}	{[lólola]}	(←ʃókolad)	*	√	√	*

I mark a harmonic domain for every two or more onset consonants that share a place of articulation in the output but not in the input. I take [place] as a general feature, abstracting away from the independent domain assigned for every place of articulation. I also ignore here the vowels within the harmonic domain, assuming the constraint $*(\text{P}{\scriptstyle\text{LACE}}_{\text{C}}, \text{V})$, which prohibits vowels from being specified for consonantal place features. $*(\text{P}{\scriptstyle\text{LACE}}_{\text{C}}, \text{V})$ outranks Expression, where the latter requires all segments in F-domain to be specified for F. There are only a few forms in the data where a consonant triggers violation of Expression, not sufficient to draw a generalization.

With this background in hand, we can now turn to the analysis of C-harmony in the speech of typically developing children.

4. Typical C-harmony

In typical C-harmony, there is parallel development of the prosodic word and the segmental layer, identified by the gradual expansion of the number of syllables in the word along with an increase in the contrast among the consonants in the word.

The grammar of C-harmony in disyllabic forms is a standard initial grammar, where the markedness stratum, with freely ranked constraints, is ranked above the faithfulness one, i.e. CD $\leqslant$ 2C and WSA above BA.

(11) Disyllabic productions: CD $\leqslant$ 2C, WSA-R, WSA-L $\gg$ BA (*túki* 'parrot')

CVCV			*túki*	CD $\leqslant$ 2C	WSA-L	WSA-R	BA
a.		{[CV][CV]}	*túki*		*!	*	
b.	☞	{[CVCV]}	*kúki*[a]				*

[a] Recall that I ignore throughout the paper the direction of harmony, and thus do no distinguish between *kúki* and *túti*.

The initial ranking in (11) is not the only grammar that can account for the optimal candidate in disyllabic forms, since not all markedness constraints need to outrank the faithfulness constraint (see also Footnote 6). It would suffice that only one of the WSA constraints would outrank BA, and CD $\leqslant$ 2C could be positioned anywhere in the ranking, as it is vacuously respected by both candidates. However, the analysis of C-harmony in dyspraxic speech (Section 5), provides positive evidence for this ranking, in particular, for the free ranking of the markedness constraints.

With the development of the prosodic word, trisyllabic forms start appearing in the children's productions, and the restrictions on C-harmony become apparent: the harmonic domain is aligned with the left edge of the prosodic word (2b) and is limited to two consonants (2a). In order to arrive at a grammar that produces structures with these properties, WSA-R must be demoted below BA.

(12) Constraint demotion I

CD≤2C, WSA-L, WSA-R >> BA • >> CD≤2C, WSA-L >> BA >> WSA-R

When CD $\leqslant$ 2C and WSA-L are undominated, as in the resulting hierarchy in (12) above, the harmonic domain has to align with the left edge of the prosodic word (undominated WSA-L) and must span no more than two consonants (undominated CD $\leqslant$ 2C).[6]

(13) Trisyllabic productions I: CD $\leqslant 2\sigma$, WSA-L $\gg$ BA $\gg$ WSA-R (*nemalá* 'ant')

CVCVCV		*nemalá*	CD $\leqslant$ 2C	WSA-L	BA	WSA-R
a.	{[CV][CV][CV]}	*nemalá*		∗!		∗
b. ☞	{[CVCV]CV}	*memalá*			∗	∗
c.	{CV[CVCV]}	*nelalá*		∗!	∗	
d.	{[CVCVCV]}	*lelalá*	∗!		∗∗	

Cand-d violates CD $\leqslant$ 2C, since its harmonic domain spans three consonants; in the other candidates the harmonic domain spans one or two consonants, satisfying CD $\leqslant$ 2C. The faithful cand-a violates both members of WSA, as the domain in the middle does not align with either edge of the prosodic word.[7] Cand-b and cand-c violate WSA-R and WSA-L respectively, but since WSA-L is ranked above WSA-L, cand-b is optimal.

In the second constraint demotion, which leads to the target ranking, WSA-L is demoted below BA.

(14) Constraint demotion II

CD≤2C, WSA-L >> BA >> • WSA-R >> CD≤2C >> BA >> WSA-L >> WSA-R

With the resulting constraint ranking in (14), C-harmony ceases to exist, as the faithfulness constraint BA outranks the two WSA constraints. The position of CD $\leqslant$ 2C in the ranking is no longer relevant, since in the absence of C-harmony, all C-domains are restricted to one sponsor. Similarly, the ranking between the two WSA constraints is not relevant, as both are dominated by the faithfulness constraint.

(15) Trisyllabic productions II: CD $\leqslant$ 2C ($\gg$) BA $\gg$ WSA-R ($\gg$) WSA-L

CVCVCV		*nemalá*	CD $\leqslant$ 2C	BA	WSA-L	WSA-R
a. ☞	[CV][CV][CV]	*nemalá*			∗	∗
b.	[CVCV]CV	*memalá*		∗!		∗
c.	CV[CVCV]	*nelalá*		∗!	∗	
d.	[CVCVCV]	*lelalá*	∗!	∗		

At this point the children's productions are identical to the target words (with respect to C-harmony), and (re)ranking stops. Quadrisyllabic words start appearing when the children have already reached the final ranking, and therefore typically developing children hardly ever exhibit C-harmony in quadrisyllabic words (2c).

Below is a summary of the development from C-harmony to faithful productions, with emphasis on the synchronization between the development of the prosodic word in terms of number of syllables and the constraint hierarchy on the segmental layer.

[6] Note that there are other rankings that can derive the same output (see Pater, 2005; Tessier, 2006; and references therein). In particular, it is possible to just impose a ranking among the markedness constraints, WSA-L $\gg$ WSA-R, which yields CD = 2C, WSA-L $\gg$ WSA-R $\gg$ BA. I assume, however, that children actually perceive the correct target form and thus aim at deactivating the markedness constraints violated in the target form. The demotion of a markedness constraint below its faithfulness competitor ensures that the former will have no effect.

[7] The structures in (13) and in the following tableaux are simplified, but sufficient for our purpose. In practice, every consonant is within a domain, thus, for example, cand-c should be {[CV][CVCV]}. Here we are interested in domains that span more than one consonant.

(16) Synchronization

PrWd	Constraint (re)ranking	Structure	
2 σ's	CD$\leqslant$2C, WSA-L, WSA-R $\gg$ BA	{[C_jVC_jV]}	*góget*
3 σ's	CD$\leqslant$2C, WSA-L $\gg$ BA $\gg$ WSA-R	{[C_jVC_jV]C_kV}	*gególet*
	CD$\leqslant$2C $\gg$ BA $\gg$ WSA-L $\gg$ WSA-R	{[C_iV][C_jV][C_kV]}	*tagólet*
	— End Reranking —		
4 σ's	CD$\leqslant$2C $\gg$ BA $\gg$ WSA-L $\gg$ WSA-R	{[C_hV][C_iV][C_jV][C_kV]}	*tarnególet*

Note that C-harmony in the children's speech ignores the language specific restrictions on identical consonants. Hebrew has quite a few lexical items with two identical consonants, restricted to the right, rather than the left edge of the stem, which is very often also the edge of the prosodic word (e.g. *xalíl* 'flute', *simém* 'to drug', *cixkék* 'to giggle'). However, the right-alignment in the adults' language is due to mapping and parsing facilitation, as it allows a faster identification of the stem in the reduplicated form (Bat-El, 2006b). That is, the stem *xam* 'hot' is identified faster when it is at the beginning of the reduplicated form, as in *ximem*, rather than at the end, as in **xixem*. Early language development is governed mostly by perceptual and articulatory facilitation, thus giving priority to perceptually dominant positions, i.e. the right edge.

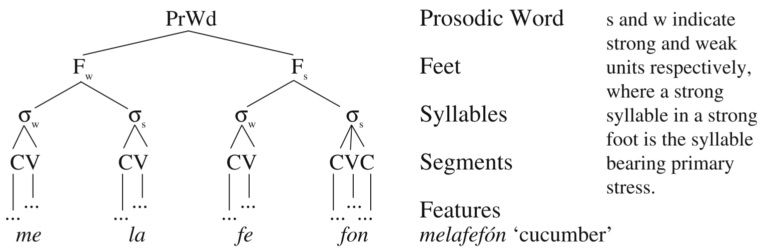
5. A-synchronization

Atypically developing children exhibit the same phonological processes as typically developing ones (e.g. syllable truncation, coda deletion, C-harmony, backing). The distinction between the two populations, as argued in Grunwell (1982), is in the chronology of the processes; in disordered speech, some processes may persist longer than usual, and consequently co-occur with patterns that appear later on. For example, during the same session, an English-speaking child produced one form with a consonant cluster (e.g. *fwɛ*d 'thread') and another with C-harmony (e.g. *kak* 'cat'). As Grunwell indicates, such co-occurrence is considered atypical, or at least unusual, since C-harmony vanishes from the children's grammar before consonant clusters start appearing.

The forms given above (*fwɛd* and *kak*) are also found in typical speech, though not during the same period. However, the co-occurrence of the two processes within the same word yields unusual structures (e.g. *griŋk* 'drink'), which are rarely found in typical speech. That is, as noted in Bonilha (2004), among others, disordered speech is not only characterized by typical structures appearing at a later age, but also by idiosyncratic structures that are rare in typical speech.

Grunwell's (1982) chronological mismatch can be viewed in structural terms, with reference to the conventional phonological structure of word.

(17) Phonological structure of the word



This phonological representation is a complex nested structure, consisting of hierarchically organized layers of elements. Such a system encompasses each layer independently as well as the relation among the layers.

When referring to phonological development, the structure above serves as a dynamic complex system, where each layer develops with reference to other layers. Phonological development can thus be viewed in terms of synchronization among the different layers of word structure, where data from typical development allow establishing the range of natural synchronization. The essence of disordered speech is the a-synchronization among the layers, where the development of one layer lags behind that of the other.

Incorporating this structure into the constraint-based approach of Optimality Theory (Prince and Smolensky, 1993), phonological development involves a gradual constraint demotion in every structural layer. This is a built-in property of the constraints, which can refer to the various phonological units (syllable, segment, feature, etc.). With reference to the example of chronological mismatch given above, in typical speech we find synchronization between the segmental layer (for C-harmony) and the syllable layer (for consonant cluster) roughly schematized in (18a), while in atypical speech we find the a-synchronization illustrated in (18b).

(18) Syllable layer (clusters) and the segmental layer (C-harmony)

a. Synchronization (typical development)

Syllable layer	***Complex $\gg$ Faith**	Faith $\gg$ *Complex
Segmental layer	**WSA $\gg$ BA**	BA $\gg$ WSA

b. A-synchronization (atypical development)

Syllable layer	***Complex $\gg$ Faith**	Faith $\gg$ *Complex
Segmental layer	**WSA $\gg$ BA**	BA $\gg$ WSA

When referring to each layer independently, there is no difference between typical and disordered phonology; the initial ranking in each layer is identical (Markedness $\gg$ Faithulness), and so is the gradual constraint demotion. The distinction between the populations arises in the synchronization among the layers, where a constraint ranking persists in one layer (WSA $\gg$ BA in (18b)), while in the other layer, reranking proceeds.[8] Consequently, a disordered grammar is identical to a typical one only at the initial phase (and the final phase, in case the atypically developing children reach the target ranking). In the course of development, a disordered grammar at a certain point cannot match a typical grammar in any point, since the former portrays various types of a-synchronization, which are not found in typical development.

Another characteristic of atypical speech noted in Secion 1 is variation. Indeed, also typical speech exhibits variation, either sporadic, in early stages of acquisition (Ferguson and Farwell, 1975; Schwartz, 1988; Boersma, 1997; Demuth, 1997a,b; Taelman and Gillis, 2002), or systematic (Kirk and Demuth, 2006), in transition between phases (Macken, 1979; Vihman, 1993; Bernhardt and Stemberger, 1998; Barlow, 2001; Adam, 2002; Sosa and Stoel-Gammon, 2006). The dyspraxic children exhibit sporadic variation at an advanced age, not related to transition between phases. For example, IO (4;9) produced four different forms for the word *mixnasáim* 'trousers' – *isái*, *sisáim*, *masasái*, *miasáim*, and his twin brother MN (4;9) produced four different forms for the word *télefon* 'phone' – *xéso*, *xéxeson*, *séseso*, and *téteso*. Note that the forms differ from one another in all layers of word structure. Free variation provides evidence for free/partial ranking (Anttila, 2002), as the different outputs of both A $\gg$ B and B $\gg$ A are attested. As argued below, the free variation in C-harmony found in dyspraxic speech is due to the persistence of the initial state in the segmental layer.

Dyspraxic children have the same starting point as typically developing children, i.e. with the constraint ranking CD $\leqslant$ 2C, WSA-R, WSA-L $\gg$ BA (11), where the markedness stratum, with the freely ranked constraints, outranks the faithfulness stratum. The distinction between the two populations becomes apparent with the first move, when the size of the prosodic word increases to three syllables. Productions with three

[8] This approach to phonological development can also draw the distinction between atypical and late speakers. Unlike the atypical speakers, the late speakers exhibit a synchronized development, like the typically developing ones, but at later age. That is, the idiosyncratic structures found in atypical speakers are not expected to appear in late speakers.

or more onsets provide evidence that the typically developing children demote WSA-R below BA (12), thus arriving at the ranking CD ⩽ 2C, WSA-L ≫ BA ≫ WSA-R (13). The dyspraxic children, however, fail to apply constraint demotion on the segmental layer, thus holding on to the initial free ranking.

Since the initial free ranking persists in trisyllabic productions, the dyspraxic children produce forms that result from any permutation of the markedness constraints. As shown below, the children exhibit three types of trisyllabic forms, each of which violates one markedness constraint (in addition to the violation of the faithfulness constraint BA).[9]

(19) Trisyllabic productions with C-harmony available with free ranking

Productions	CD ⩽ 2C	WSA-L	WSA-R	BA
a. susujá	√	√	*	*
b. sujajót	√	*	√	*
c. lólola	*	√	√	*

These three competing structures are the result of the following three distinct constraint rankings that are available, given the free ranking.

(20) Free ranking of markedness constraints – three different grammars

a. CD ⩽ 2C, WSA-L ≫ WSA-R (≫ BA): *susujá* for *sukarjá* 'candy' (TR 3;6)
Left-aligned harmonic domain, spans two onsets (typical)

CVCVCV			CD ⩽ 2C	WSA-L	WSA-R	BA
a.		[CV][CV][CV]		*!	*	
b.	☞	[CVCV]CV			*	*
c.		CV[CVCV]		*!		*
d.		[CVCVCV]	*!			*

b. WSA-R, CD ⩽ 2C ≫ WSA-L (≫BA); *sujajót* for *sukarjót* 'candies' (TR 3;6)
Right-aligned harmonic domain (atypical)

CVCVCV			CD ⩽ 2C	WSA-R	WSA-L	BA
a.		[CV][CV][CV]		*!	*	
b.		[CVCV]CV		*!		*
c.	☞	CV[CVCV]			*	*
d.		[CVCVCV]	*!			*

c. WSA-R, WSA-L ≫ CD ⩽ 2C (≫BA): *lólola* for *ʃókolad* 'chocolate' (TR 3;6)
Harmonic domain spans three onsets (atypical)

CVCVCV			WSA-R	WSA-L	CD ⩽ 2C	BA
a.		[CV][CV][CV]	*!	*		
b.		[CVCV]CV	*!			*
c.		C_iV[CVCV]		*!		*
d.	☞	[CVCVCV]			*	*

[9] Of course, like typically developing children, dyspraxic children also produce forms without C-harmony, such as *balóni* for *balónim* 'balloons' (RF 4;7) and *taláxat* for *caláxat* 'plate' (RT 4;7). However, to reduce further complication, I ignore the faithful productions in the analysis.

Unlike the typically developing children, the dyspraxic children provide surface forms for all the possible rankings. Of course, one of their rankings (20a) is identical to that of the typically developing children (13a), but the other two account for the peculiarities in their productions, which are rare in typical development (3). The ranking in (20c) allows forms where harmony spans more than two onsets, contrary to the typical property in (2a), and the ranking in (20b) provides forms where the harmonic domain is not left-aligned with the prosodic word, contrary to the typical property in (2b).

Notice that all the forms in (20) were produced by the same child during the same session, suggesting that this is not only a case of inter-child variation, but also intra-child variation. It should be noted that *k*, which assimilates in both examples (*lólola* for *ʃókolad* and *sujajá* for *sukarjá*), does appear in the segmental inventory of the child at this stage, as evident in the words *kéleb* for *kélev* 'dog' and *ukijá* for *ugijá* 'cookie'.

While trapped with the free ranking on the segmental layer, the dyspraxic children gradually develop their prosodic word, increasing the number of syllables in their productions up to four syllables. Here again, they produce the three options available with free ranking, where in each option, one markedness constraint is violated.

(21) The productions available with free ranking of markedness constraints

Productions	CD $\leqslant$ 2C	WSA-L	WSA-R	BA
a. tetezíja	√	√	*	*
b. terazíza	√	*	√	*
c. pepipópe	*	√	√	*

What we do not expect, according to the analysis proposed above, is forms where two of the markedness constraints are violated, since such forms are harmonically bounded regardless of the rankings (Prince and Smolensky, 1993). Indeed, there were no forms such as **tezezíja*, where both WSA constraints are violated, or **tezeziza*, where WSA-L and CD $\geqslant$ 2C are violated. However, there was one form, *kukukujón* for *akordijón* 'accordion', which violates both WSA-R and CD $\geqslant$ 2C. I claim that the identical consonants in this form are not due to C-harmony, but rather to syllable reduplication. As can be seen from the data in (4), while in most cases the vowels in the children's productions are faithful to their correspondences in the targets, in *kukukujón* the first three vowels are identical, corresponding to three different vowels in the target *akordijón*. Similar distinction between C-harmony and syllable reduplication can be observed in the data provided in Vihman (1978, 1996) from a child acquiring Estonian. Disyllabic productions with C-harmony and trisyllabic productions with a left-aligned harmonic domain preserved the vowels of the target; e.g. *titu*/*ʃiʃu* for *kisu* 'kitty' (1;3), *pupa* for *tupa* 'room' (1;10), *keki* for *teki* 'did (it)' (1;10), *kekiala* for *tekiala* 'blanket' (1;9), *tíntupeu* 'jingle bells' (1;10). However, trisyllabic productions with a non left-aligned harmonic domain exhibited syllable reduplication; e.g. *tásisi* for *tágasi* '(go, put, take) back', *pɔ'nini* for *pórgantit* 'carrot Obj.', *másusu* for *mágutoit* 'dessert'. Following Ingram (1974), Vihman (1978) suggests that the underlying form of the reduplicated words includes a middle empty syllable (e.g. *maσsu*), which is filled with a copy of the unstressed (final) syllable.

The rankings of the markedness constraints attested in the productions of the dyspraxic children are given in (22) below, with reference to the number of syllables in the prosodic word. Notice that there is no distinction in disyllabic productions between the dyspraxic children and the typically developing children. The differences start appearing with trisylabic productions, where the dyspraxic children employ three distinct rankings, while the typically developing children employ only one.

(22) A-synchronization (the typical rankings are in bold)

PrWd	Constraint rankings	Structure	
2 σ's	a. **CD ⩽ 2C**, **WSA-L**, **WSA-R** ≫ **BA**	$[C_jVC_jV]$	*kúki*
3 σ's	b. **CD ⩽ 2C**, **WSA-L** ≫ **WSA-R** ≫ **BA**	$[C_jVC_jV]C_kV$	*susujá*
	c. CD ⩽ 2C, WSA-R ≫ WSA-L ≫ BA	$C_iV[C_jVC_jV]$	*sujajá*
	d. WSA-R, WSA-L ≫ CD ⩽ 2C ≫ BA	$[C_jVC_jVC_jV]$	*lólola*
4 σ's	b. CD ⩽ 2C, WSA-L ≫ WSA-R ≫ BA	$[C_jVC_jV]C_kVC_lV$	*kakuéde*
	c. CD ⩽ 2C, WSA-R ≫ WSA-L ≫ BA	$C_iVC_jV[C_kVC_kV]$	*terazíza*
	d. WSA-R, WSA-L ≫ CD ⩽ 2C ≫ BA	$[C_jVC_jVC_jVC_jV]$	*pepipópe*

Like typically developing children, the dyspraxic children exhibit C-harmony in disyllabic words (e.g. *kúki* for *túki* 'parrot'), and left-aligned C-harmony spanning two onsets in trisyllabic productions (e.g. *susujá* for *sukarjá* 'candy'). However, while the typically developing children have one ranking in trisyllabic words (in addition to the ranking that provides faithful productions), the dyspraxic children have the three possible rankings provided by the free ranking. In quadrisyllabic productions, the disparity between the two types of population is enhanced, as typically developing children have no C-harmony, while dyspraxic children exhibit three different structures.

6. Concluding remarks

The peculiar properties of C-harmony found in the speech of dyspraxic children is attributed to the persistence of the initial ranking on the segmental layer, but not on the prosodic word layer. They start, like typically developing children, with free ranking of markedness constraints, but unlike typically developing children, they maintain this free ranking throughout the development of the prosodic word. The a-synchronization is schematized below, compared with a synchronized system.

(23) (A-)synchronization ('ranking' refers to markedness constraints)[a]

		Synchronized system - Typical		
Segments	Ranking	Free	I-II	II
Prosodic word	No. of σs	2	3	4
Segments	Ranking	Free	Free	Free
		A-synchronized system - Dyspraxic		

[a] The schematized development in (23) ignores the possible difference in the length of the periods. As noted in Bonilha (2004), stages of development tend to "freeze" in atypical speech, thus maintained for a much longer time than in typical speech.

The model schematized in (23) accounts for the three idiosyncratic properties related to C-harmony in dyspraxic speech: (i) Right-aligned harmonic domain, as in *sujajá* for *sukarjá* 'candy', (ii) harmonic domain exceeding two consonants, as in *gagegól* for *tarnegól* 'rooster', and (iii) C-harmony in quadrisyllabic productions, as in *tetezíja* for *televízja* 'television'. In addition, it also accounts for the sporadic free variation appearing at a rather advanced age.

The model of (a-)synchronization introduced in this paper is not specific to C-harmony, but can also be applied to other peculiar atypical structures. I briefly mention here two such structures.

Most of the tri- and quadrisyllabic productions of the dyspraxic children lack a word final coda (let alone a medial one). MT, for example, produced a final coda in 19% (30/158) of his productions (only targets with codas were considered), and not even one medial coda. This is certainly unusual, given that in the typical development of Hebrew, a word final coda usually appears before a third syllable is added to the production. For example, disyllabic productions of *jomulédet* 'birthday' can be without a coda (*éde*, *léde*, *déde*) or with a coda (*édet*, *lédet*, *dédet*), but trisyllabic productions are usually with a coda (*ulédet*, *mulédet*). Thus, codaless productions such as *abió* for *avirón* 'airplane' (RF 4;7), *magafái* for *magafáim* 'boots' (MN 4;09), and *meluléxe* for *meluxléxet* 'dirty fm.sg.' (RY 3;7), exhibited by the dyspraxic children, are atypical. This is a case of a-synchronization between the development of the prosodic word and the syllable. That is, the initial ranking of NoCoda ≫ Max, which accounts for the absence of coda, persists while the prosodic word gradually develops up to four syllables.

Another case of a-synchronization is exhibited by Hebrew-speaking dyspraxic children and hearing impaired children (Adi-Bensaid and Bat-El, 2004; Tubul-Lavy, 2005; Adi-Bensaid, 2006; Adi-Bensaid and Tubul-Lavy, 2007), as well as a Norwegian-speaking child with a cri du chat syndrome (Kristoffersen, 2003). These children produced consonant-free words, i.e. words consisting only of vowels (e.g. *íæ* for *nísə* 'gnome' (Norwegian), *oée* for *xotéxet* 'she cuts', *iaái* for *mixnasáim* 'trousers' (Hebrew)). In typical development of Hebrew (Ben-David, 2001), every word has at least one consonant.[10] This restriction is manifested by target VC words (e.g. *af* 'nose', *iʃ* 'man'), which are always produced with a coda, even during the stage where CVC words are produced without a coda (e.g. *da* for *dag* 'fish', *xa* for *xam* 'hot'). Here again, the initial ranking of ∗StructureC ≫ Max (where C refers to a consonant) persists while the prosodic word develops. As shown in Adi-Bensaid (2006) and Adi-Bensaid and Tubul-Lavy (2007), the distinction among the atypical populations lies in the number of syllables in the consonant-free words. Hearing impaired children with cochlear implants produce consonant-free words with one or two syllables, while those with a conventional hearing aids also have trisyllabic productions of consonant-free words. The disypraxic children are in the worse position, also producing quadrisyllabic words without consonants. Typically developing children, as noted above, do not produce consonant-free words.

Further study will reveal whether most properties of atypical speech can be analyzed in terms of a-synchronization. With more studies at hand, we will be able to address the following questions: (i) Is it always a lower layer in the word structure that lags behind an upper one? (ii) Is it always the initial ranking (of some layer) that persists?

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References

Adam, G., 2002. From Variable to Optimal Grammar: Evidence from Language Acquisition and Language Change. Ph.D. Dissertation, Tel-Aviv University, ROA-567.

Adam, G., Bat-El, O., 2008. The trochaic bias is universal: evidence from Hebrew. In: Gavarró, A. Freitas, M.J. (Eds.), Language Acquisition and Development: Proceedings of GALA 2007. Cambridge Scholars Publishing, Newcastle, pp. 12–24.

Adi-Bensaid, L., 2006. The Prosodic Development of Hebrew-Speaking Hearing Impaired Children. Ph.D. Dissertation, Tel-Aviv University.

Adi-Bensaid, L., Bat-El, O., 2004. The development of the prosodic word in the speech of a hearing impaired child with a cochlear implant device. Journal of Multilingual Communication Disorders 2, 187–206.

Adi-Bensaid, L., Tubul-Lavy, G., 2007. Consonants-free words: evidences from atypically developing Hebrew-speaking children. In: A Poster Presented in GALA 2007. Barcelona, Spain.

Anttila, A., 2002. Morphologically conditioned phonological alternations. Natural Language and Linguistic Theory 20, 1–42.

Bakovic, E., 2000. Harmony, Dominance, and Control. Ph.D. Dissertation, Rutgers University, ROA-360.

Barlow, J., 2001. Case study: optimality theory and the assessment and treatment of phonological disorders. Language, Speech, and Hearing Services in School 32, 242–256.

Bat-El, O., 2006a. Consonant copying and consonant identity: the segmental and prosodic structure of Hebrew reduplication. Linguistic Inquiry 37, 179–210.

Bat-El, O., 2006b. Category-specific phonology in adult and child Hebrew. In: A Paper Presented at OCP 4. Rhodes, Greece.

[10] The only exception is the word *or* 'light', which often appears as *o* (but sometimes as *ox* or *ow*), due to the late acquisition of *r*.

Ben-David, A., 2001. Language Acquisition and Phonological Theory: Universal and Variable Processes Across Children and Across Languages. Ph.D. Dissertation, Tel-Aviv University (in Hebrew).
Berg, T., 1992. Phonological harmony as a processing problem. Journal of Child Language 19, 225–257.
Bernhardt, B., Stemberger, J., 1998. Handbook of Phonological Development: From the Perspective of Constraint-based Nonlinear Phonology. Academic Press, San Diego, CA.
Boersma, P., 1997. How we learn variation, optionality, and probability. IFA Proceedings 21, 43–58.
Bonilha, G., 2004. Phonological disorders in the light of constraints. In: Second Lisbon Meeting on Language Acquisition, ROA-681.
Cassimjee, F., Kisseberth, C., 1997. Optimal domain theory and Bantu tonology: a case study from Isixhosa and Shingazidja, ROA-176.
Cassimjee, F., Kisseberth, C., 1998. Tonal variation across Emakhuwa dialects, ROA-289.
Cassimjee, F., Kisseberth, C., 1999. A conspiracy argument for optimality theory: Emakhuwa dialectoloy, ROA-331.
Cole, J., Kisseberth, C., 1994. An optimal domain theory of harmony. Studies in the Linguistic Sciences 24, 1–13, ROA-22.
Cole, J., Kisseberth, C., 1995a. Paradoxical strength conditions in harmony systems, ROA-48.
Cole, J., Kisseberth, C., 1995b. Nasal harmony in optimal domain theory, ROA-49.
Cole, J., Kisseberth, C., 1996. Restricting multi-level constraint evaluation: Opaque rule interaction in Yawelmani vowel harmony, ROA-98.
Davis, B., Marquardt, T., Jakielski, K., 1998. Developmental apraxia of speech: determiners of differential diagnosis. Clinical Linguistics and Phonetics 24, 25–45.
Demuth, K., 1997a. Multiple optimal outputs in acquisition. University of Maryland Working Papers in Linguistics 5, 53–71.
Demuth, K., 1997b. Variation in acquisition: an optimal approach. In: Davis, S. (Ed.), Optimality Viewpoints. Indiana University Linguistics Club, Bloomington, pp. 7–88.
Echols, C., 2001. Contributions of prosody to infants' segmentation and representation of speech. In: Höhle, B., Weissenborn, J. (Eds.), Approaches to Bootstrapping: Phonological, Syntactic and Neurophysiological Aspects of Early Language Acquisition. John Benjamins, Amsterdam, pp. 5–46.
Ferguson, C., Farwell, C., 1975. Words and sounds in early language acquisition. Language 51, 419–439.
Fikkert, P., Levelt, C., 2006. How Does Place Fall into Place? The Lexicon and Emergent Constraints in Children's Developing Phonological Grammar. Ms. Radboud University of Nijmegen and Leiden University.
Forrest, K., 2003. Diagnostic criteria of developmental apraxia of speech used by clinical speech-language pathologists. American Journal of Speech-Language Pathology 12, 376–380.
Garnica, O., Edwards, M., 1977. Phonological variation in children's speech: the trade-off phenomenon. Ohio State Working Papers in Linguistics 22, 81–87.
Goad, H., 1996. Consonant harmony in child language: an optimality-theoretic account. In: Hannahs, S.J., Young-Scholten, M. (Eds.), Focus on Phonological Acquisition. John Benjamins, Amsterdam, pp. 113–142.
Grunwell, P., 1982. Clinical Phonology. Croom Helm, London.
Ingram, D., 1974. Phonological rules in young children. Journal of Child Language 1, 49–64.
Jacks, A., Davis, B., Marquardt, T., 2006. Consonant and syllable structure patterns in childhood apraxia of speech: developmental change in three children. Journal of Communication Disorders 39, 424–441.
Kirk, C., Demuth, K., 2006. Accounting for variability in 2-year-olds' production of coda consonants. Language Learning and Development 2, 97–118.
Kisseberth, C., 1970. On the functional unity of phonological rules. Linguistic Inquiry 1, 291–306.
Krämer, M., 1999. A Correspondence Approach to Vowel Harmony and Disharmony. Ms. Heinrich-Heine-Universität Düsseldorf, ROA-293.
Kristoffersen, K., 2003. Phonological development in a child with cri du chat syndrome (CDCS). In: Nordlyd 31.3: Proceedings of the 19th Scandinavian Conference in Linguistics, pp. 519–531.
Kukkonen, P., 1994. Consonant harmony. In: Shore, S., Vilkuna, M. (Eds.), Yearbook of the Association of Finland, pp. 57–88.
Levelt, C., 1994. On the Acquisition of Place. Ph.D. Dissertation, Holland Institute of General Linguistics.
Lombardi, L., 1999. Positional faithfulness and voicing assimilation in optimality theory. Natural Language and Linguistic Theory 17, 267–302.
Macken, M., 1979. Developmental reorganization of phonology: a hierarchy of basic units of acquisition. Lingua 49, 11–49.
Marquardt, T., Davis, B., Jacks, A., 2004. Token-to-token variability in developmental apraxia of speech: three longitudinal case studies. Clinical Linguistics and Phonetics 18, 127–144.
McCarthy, J., 2004. Headed spans and autosegmental spreading, ROA-685.
Pater, Joe., 1997. Minimal violation and phonological development. Language Acquisition 6, 201–253.
Pater, J., 2005. Non-convergence in the GLA and variation in the CDA, ROA-780.
Pater, J., Werle, A., 2001. Typology and variation in child consonant harmony. In: Féry, C., Green, A., van de Vijver, R. (Eds.), Proceedings of HILP5. University of Potsdam.
Pater, J., Werle, A., 2003. Direction of assimilation in child consonant harmony. The Canadian Journal of Linguistics 48, 385–408.
Prince, A., Smolensky, P., 1993. Optimality Theory: Constraint Interaction in Generative Grammar. Ms. Rutgers University and University of Colorado, Boulder.
Schwartz, R., 1988. Phonological factors in early lexical acquisition. In: Smith, M., Locke, J. (Eds.), The Emergent Lexicon: The Child's development of a Linguistic Vocabulary, pp. 185–222.
Smith, N., 1973. The Acquisition of Phonology: A Case Study. Cambridge University Press, Cambridge.

Smolensky, P., 1996. The Initial State and "Richness of the Base" in Optimality Theory. Technical Report JHU-CogSci-96-4, Cognitive Science Department, Johns Hopkins University, ROA-154.

Sosa, A., Stoel-Gammon, C., 2006. Patterns of intra-word phonological variability during the second year of life. Journal of Child Language 33, 31–50.

Stemberger, J., Bernhardt, B., Johnson, C., 1999. Regressions (u-shaped learning) in the acquisition of prosodic structure. In: Poster presented at the Sixth International Child Language Congress, ROA-471.

Stoel-Gammon, C., Stemberger, J., 1994. Consonant harmony and phonological underspecification in child speech. In: Yavas, M. (Ed.), First and Second Language Phonology. Singular, San Diego, CA, pp. 3–80.

Taelman, Helena, Gillis, Steven, 2002. Variation and consistency in children's truncation patterns. In: Costa, J., Freitas, M. (Eds.), Proceedings of the GALA 2001. Associacào Portuguesa de Linguistica, Lisbon, pp. 263–270.

Teser, Smolensky, 1996. Learnability in optimality theory. Linguistic Inquiry 29, 229–268.

Tessier, Anne-Michelle, 2006. Biases and stages in phonological acquisition, ROA-883.

Tubul-Lavy, Gila, 2005. The Phonology of Hebrew-Speaking Dyspraxic Children. Ph.D. Dissertation, Tel-Aviv University (in Hebrew).

Vihman, Marilyn., 1978. Consonant harmony: its scope and function in child language. In: Greenberg, J. (Ed.), In: Universals of Human Language Phonology, vol. 2. Stanford University Press, Stanford, CA, pp. 81–334.

Vihman, Marilyn, 1993. Variable paths to early word production. Journal of Phonetics 21, 61–82.

Vihman, Marilyn, 1996. Phonological Development: The Origins of Language in the Child. Blackwell, Cambridge, MA.

Watterson, Natalie, 1978. Growth of complexity in phonological development. In: Waterson, N., Snow, C. (Eds.), The Development of Communication. Wiley & Sons, Chichester, pp. 15–442.

Werle, Adam, 2001. Variation in child consonant harmony. In: Horwood, G., Kim, S.-K. (Eds.), Rutgers Linguistics Working Papers v2, pp. 197–205.