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3 Developing phonology

1 Introduction

Language is a complex system and its acquisition involves the interaction of various principles, grammatical as well as general cognitive ones. In this paper, we concentrate on universal phonological principles that play a role during the early stages of language production. We examine language acquisition from two angles: (i) the disparity between the adults' target words and the corresponding children's productions, and (ii) the nature of the system governing the children's productions and its development.

Following Tesar and Smolensky (1998), we assume that during every stage of language development the children acquiring language L have a grammar L^m, and that the grammar gradually develops (L^m, L^n, L^o...) until it overlaps (almost entirely) with the adults' grammar L.

The principal reason for the disparity between L (adults) and $L^{m...o}$ (children) is the role of the *markedness constraints* (Battistella 1996, de Lacy 2006, Rice 2007) in early grammar. As the notion of markedness is controversial, we limit our definition to typological markedness, which is often phonetically grounded in acoustic and/or articulatory properties (Hayes et al. 2004). For example, both typological and phonetic factors support the markedness relation *t* < *t͡ʃ* (*t* is less marked than *t͡ʃ*). Phonetically, *t͡ʃ* involves more articulators than *t* and is thus articulatorily more complex. Typologically, most languages have *t* (Hawaiian being a unique exception), but many languages do not have *t͡ʃ* (Maddieson 1984). These facts also correlate with the pace of acquisition, as *t* is acquired long before *t͡ʃ*.

Markedness constraints are relevant to syllable structure. Typologically, there are languages that have only syllables without a coda (e.g. Hua, Maori), i.e. CV (and V), but there are no languages that have only syllables with codas, i.e. CVC (and VC). Acoustically, consonants in coda position are relatively weak due to the weak acoustic cue in the transition between the coda consonants and the following onset (i.e. from C_i to C_j in $VC_i.C_jV$). Here again, there is a markedness relation CV < CVC, theoretically attributed to the markedness constraint NO CODA, defined below along with two other markedness constraints (see §4).

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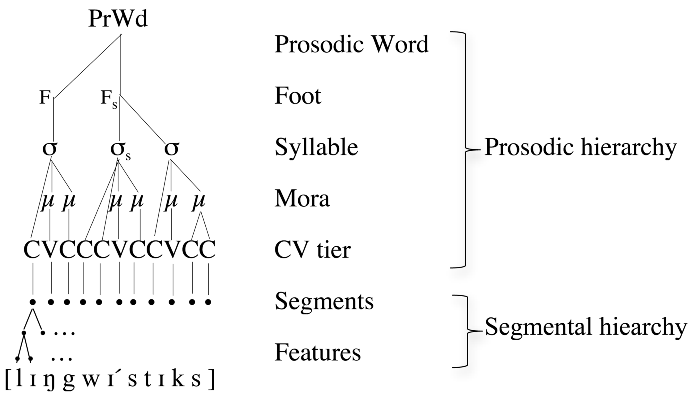
(1) Markedness constraints (Prince and Smolensky 1993/2004)

	Constraint	*Child*	*Target*		
a.	NO CODA A syllable does not have a coda	pɔ́	pɔ́p	'doll'	(Dutch; Levelt 1994)
b.	NO COMPLEX ONSET A syllable does not have a complex onset	ké	klé	'key'	(French; Rose 2000)
c.	NO COMPLEX CODA A syllable does not have a complex coda	dʌp	d͡ʒʌ́mp	'jump'	(English; Smith 1973)

Note that markedness does not necessarily correlate with structural complexity. For example, while the syllable V is structurally less complex than the syllable CV, as the former has fewer elements than the latter, the CV syllable is deemed less marked than the V syllable. Also, while children often delete a target segment to comply with a markedness principle, they may also insert a segment for this very same reason. For example, Hebrew-acquiring children delete a consonant in target clusters (e.g. *ktaná* → *taná* 'small fm.sg.'), but they sometimes insert a vowel (e.g. *ktaná* → *kataná* 'small fm.sg.'). In both cases, the children comply with the NO COMPLEX ONSET constraint (1b), though in the latter case there is additional structure.

In this paper we discuss phonological development with reference to the hierarchical organization of the phonological word:

(2) The phonological word



Within the phonological word in (2), we distinguish between the prosodic hierarchy (Selkirk 1982, McCarthy and Prince 1986, Nespor and Vogel 1986) and the segmental hierarchy (Clements 1985, Clements and Hume 1995). We start the discussion with the prosodic word (§2), where we attend to the phonological development in terms of number of syllables; in this context we emphasize the role of the MINIMAL WORD constraint. Below the prosodic word is the foot, which is responsible for the stress pattern (§3); in this context, we argue for the role of the trochaic bias. When we get to the development of the syllable structure (§4), we discuss the role of the constraints NO CODA and NO COMPLEX and contemplate on a notorious anti-universal phenomenon in the children's productions – the deletion of word initial onsets, in violation of the ONSET constraint. At this point, we reach the bottom of the hierarchy and discuss the development of the segments (§5), giving special attention to the development of contrasts. Before the concluding remarks (§7), we present our view on atypical phonological development (§6), arguing that its essence lies in the a-synchronization among layers in the phonological structure in (2).

2 The prosodic word and the MINIMAL WORD constraint

The most studied constraint relevant to the prosodic word is the MINIMAL WORD constraint (McCarthy and Prince 1986), which delimits the minimal and maximal size of the word to a binary foot (two syllables or two moras).[1] Languages use the MINIMAL WORD constraint to demarcate the *minimal* size of the prosodic word, as in Cavineña (Guillaume 2008), where monosyllabic roots undergo epenthesis to reach the disyllabic minimal size (e.g. /kʷa/ → *kʷau* 'go', /he/ → *heu* 'come').[2] Languages also use the MINIMAL WORD constraint to demarcate the *maximal* size of the prosodic word. For example, a typical verb stem in Hebrew and Arabic is limited to two syllables (Bat-El 2011), and 70% of the words in Chinese are nowadays disyllabic (Duanmu 2007, based on He and Li 1987).[3] We also witness active processes of syllable truncation in hypocoristics (e.g. Australian English *Australian* → *Aussie*, *postman* → *postie*), where hypocoristics consist of no more and no less than two syllables (Bat-El 2005).

During the **minimal word stage** (MW-stage), children's productions are limited to a maximal size of two syllables (Demuth 1996, Kehoe 2000, Fikkert 1994, Levelt et al. 2000, Lleó and Demuth 1999), like hypocoristics.

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1 Languages differ as to whether their feet are moraic (e.g. Dutch, English, and German) or syllabic (e.g. Greek, Hebrew, and Spanish).

2 This is true for major lexical items. Function words do not constitute independent prosodic words, unless under emphasis. For example, English definite article [ðə] is hosted by a prosodic word (e.g. $\{$ðəbɔj$\}_{PrWd}$ 'the boy'), unless under emphasis, in which case its size is bimoraic, [ði:], i.e. a minimal word size.

3 Monosyllabic roots in Chinese often join into a compound to form a disyllabic word (Duanmu 2007). Since the meaning of the compound is semantically identical to that of the root (e.g. *mei* 'coal' + *tan* 'charcoal' → *mei-tan* 'coal'), the trigger of compounding must be the MINIMAL WORD constraint.

(3) Truncation to meet the maximal word size requirement (2 syllables)

Greek (Kappa 2002)

Child	*Target*	
súla	xrisúla	'name'
ɣúti	jaúrti	'yoghurt'
béla	obréla	'umbrella'
pepés	kanapés	'couch, nom.sg'

Japanese (Ota 2003)

Child	*Target*	
ʒi:da	d͡ʒido:ʃa	'car'
kowa	korewa	'this is?'
meda	tadaima	'I'm back'
pa:ʒe	t͡ʃimpand͡ʒi:	'chimpanzee'

While truncation toward a disyllabic maximum is common in child language, there is little evidence of epenthesis for meeting the minimal disyllabic size (as in the example above from Cavineña). In general, epenthesis is relatively rare in language development (as opposed to deletion), in Dutch (Taelman 2004), Hebrew (Ben-David 2001), as well as in other languages. For example, target monosyllabic words in Hebrew are produced faithfully also during the MW-stage (Ben-David 2001), and the few cases of epenthesis found in Dutch do not show structural improvement in respecting the MINIMAL WORD constraint (Taelman 2004).

The MW-stage is a major stage in the children's prosodic development (Demuth and Fee 1995, Demuth 1996), but not the only one. The gradual development of the prosodic word, syllable by syllable, is demonstrated below for trisyllabic Hebrew target words with different stress patterns (Ben-David 2001, Adam 2002). The stages of development are labeled with reference to the minimal word (MW).[4]

(4) The development of the prosodic word (Hebrew)

	Stage	*matanà* 'present'	*poméla* 'pommelo'	*múzika* 'music'
a.	Sub-MW	na	me / la	mu / ka
b.	Pre-MW	na	méla	múka
c.	MW	taná	méla	múka
d.	Post-MW	mataná	poméla	múzika

When children start producing meaningful words, during the **Sub-MW stage** (4a), they produce mainly monosyllabic words, as in Spanish *bóka* → *bu* 'mouth', *ésta* → *ta* 'this', and *tâsa* → *tja* 'cup' (Macken 1978). Given this prosodic limitation, the children's production lexicon is limited, containing many homonyms (e.g. *da* for both Hebrew *jaldá* 'a girl' and *todá* 'thank you'). This stage is often too short to be observable in typically developing children, but atypically developing children (see §6), who often stretch their language acquisition over longer periods, provide solid

4 The distinction between stages is, of course, not abrupt, and during every stage there are remaining forms from the earlier stage and new forms from the subsequent stage (see Adam 2002 for intermediate stages). However, the structure characterizing a particular stage is statistically dominant.

evidence for this stage. Adam and Bat-El (2008b) show the difference between two Hebrew-acquiring boys during the same stage of lexical development (150 cumulative attempted words); 86% (159/184) of the words produced by the boy with prolonged phonological development (1;10.02–1;11.13) were monosyllables, as opposed to 22% (20/92) in the typically developing boy (1;05.15–1;05.29).

With time, the number of syllables in the word gradually expands toward the target, and the degree of contrast among the words thus grows as well (see also §4). During the following **Pre-MW stage** (4b), the children start producing disyllabic words, but mostly with penultimate stress, as this is the unmarked stressed pattern (see §3). Only later, during the **MW stage** (4c) discussed above, they produce disyllabic words regardless of the stress pattern of the target word. Truncation continues at later stages for trisyllabic and longer target words (e.g. Greek *fotoγría* → *kaía* 'photo', *poðílato* → *poðíla* 'bicycle'; Hebrew *televízja* → *evíza* 'television', *taʁnególet* → *tagólet* 'hen').

3 Stress and the trochaic bias

Under the prosodic word node in (2) stands the foot, which is responsible for the stress pattern. Due to its strong acoustic cues, stress is highly accessible and thus plays a major role in language acquisition (Echols and Newport 1992, Archibald 1995), where the perceptual saliency of stress boosts a faithful match between target and output (with relatively few cases of stress shift). Given its relative strength, stress has the power of protecting target syllables from truncation. Therefore, during the development of the prosodic word, when children truncate syllables (see §2), unstressed syllables are truncated, while stressed ones are preserved (Fikkert 1994, Wijnen, Krikhaar and Os 1994, Gerken 1996, Kehoe and Stoel-Gammon1997, Pater 1997, Prieto 2006).

(5) Preservation of stressed syllables and truncation of unstressed ones

Kuwaiti Arabic (Ayyad 2011)

Child	*Target*	
ðí:f	nəðí:f	'clean'
sna:n	ʔasná:n	'teeth'
qə́lə	bərtəqálə	'orange'
θə́lləθ	muθə́lləθ	'triangle'

Russian (Zharakova 2005)

Child	*Target*	
kápa	kápait	'it is dripping'
mʲisʲ	mɨ́ʃɨ	'mice'
bʲáka	sabáka	'dog'
sʲik	jizɨ́k	'tongue'

Children's early productions support the trochaic bias (Allen and Hawkins 1978), showing preference for the typologically unmarked trochaic foot (SW – a **s**trong/stressed syllable followed by an **w**eak/unstressed/ syllable). As in some of the examples in (5), the syllables surviving truncation form a trochaic foot also when the target word has three or more syllables with penultimate stress (see extensive discussion in Tzakosta 2004). For example, Catalan *kəput͡ʃɛ́tə* 'little hood' is truncated to the trochaic form *tɛ́tə* and not the iambic form **put͡ʃɛ́* (Prieto 2006). There are also a few examples where children shift stress to form a trochaic foot; e.g. English *kæŋgəɹú* → *wáwo* 'kangaroo' (Kehoe 1997) and Dutch *χi:tá:r* → *hí:ta:* 'guitar' (Fikkert 1994).

We note here the importance of final syllables, which are preserved more often than other unstressed syllables (Echols and Newport 1992, Kehoe 2000, Ben-David 2001, 2014). The trochaic bias cannot explain cases in which trisyllabic targets like *télefon* are truncated to *téfo*, rather than *téle*, though both are equally trochaic. Here again, it is the perceptual saliency of final syllables that protects these target syllables from truncation (Echols and Newport 1992, Albin and Echols 1996).

Much of the evidence supporting the trochaic bias is drawn from languages with a predominantly trochaic stress pattern. In these languages, however, one cannot tease apart universal preference from language-specific frequency. Hebrew, however, provides solid evidence for the trochaic bias (Adam and Bat-El 2008a, 2009, Bat-El 2015) because stress is predominantly final (iambic foot) in the language and yet children still show preference for penultimate stress (the trochaic foot):[5] They have more attempted targets with penultimate stress than with final stress and more productions with penultimate stress than with final stress (see (4b) for pre-MW stage). It should be noted that French-acquiring children do not show a trochaic bias. This is because the stress system in French has no exceptions (always final), and thus children acquire the iambic pattern before the onset of speech (Rose 2000).

The acquisition of stress patterns is a good juncture for a brief discussion on the nature-nurture debate, i.e. whether children acquire language with the aid of universal principles (Chomsky's generative approach) or they attend only to the frequency of patterns in their ambient language (usage-based approach; Tomasello 2001).

When frequency and universal principles converge, as in the case of the trochaic foot in English and Dutch, we cannot settle this dispute. Languages like French, where the non-universal pattern is consistent and exceptionless, cannot help either, since the children acquire the non-universal pattern early, without showing evidence of contemplation. The languages that can settle this dispute are those in which (i) there is no convergence between frequency and the relevant universal principle (unlike English and Dutch), and (ii) the system is irregular and cannot be easily acquired (unlike French). Hebrew stress has these two properties and thus provides solid support for Adam and Bat-El's (2008a, 2009) argument that both universal principles and frequency play a role, in this order. At the onset of speech, when

5 About 70% of the noun stems and 95% of the verb stems in Hebrew bear final stress (iambic), with marginal differences between type and token, also in child directed speech (Segal et al. 2008, Adam and Bat-El (2008a, 2009).

children cannot yet figure out the system in their language because of the irregularity in it, they resort to universal principles. Later on, the distributional frequency of the language plays a stronger role and the children start following the crowd.[6]

4 Syllable structure and the ONSET constraint

Following the phonological structure in (2), we now turn to the level below the foot – the syllable. All languages have CV syllables; some even have only CV syllables (e.g. Hua, spoken in New Guinea). Therefore, CV, often called the core syllable, is typologically the least marked syllable. Assuming that phonological structures in the children's productions develop on some markedness scale, from the least to the most marked, we expect the order of acquisition in (6), based on the hierarchy developed in Levelt et al. (2000) for the acquisition of syllable structure in Dutch (curly brackets indicated 'either-or').[7]

(6) Markedness hierarchy of syllable structure

a. b. c. d. e.

$$\text{CV} < \begin{Bmatrix}\text{CVC}\\ \text{V}\end{Bmatrix} < \text{VC} < \begin{Bmatrix}\text{CVCC}\\ \text{CCVC}\end{Bmatrix} < \text{CCVCC}$$

This order, which allows a certain degree of (inter- and intra-language) variation, is predicted from the following markedness constraints (Prince and Smolensky 1993/2004):

(7) Syllable structure constraints (partially repeated from (1))

a. ONSET: A syllable has an onset

b. NO CODA: A syllable does not have a coda

c. NO COMPLEX

   i. NO COMPLEX ONSET: A syllable does not have a complex onset

   ii. NO COMPLEX CODA: A syllable does not have a complex coda

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6 With a head-turn experiment, Segal and Kishon-Rabin (2012) showed that 80% (24/30) of the 9 months old Hebrew-acquiring infants looked longer at the highly frequent Hebrew weak-strong (iambic) patterns, suggesting, according to the authors, acquisition of the frequent pattern before the onset of speech. This perceptual preference probably plays a certain role in early productions, since otherwise the percentages of trochaic productions would have been much higher and would have lasted longer. That is, perception precedes production, but production does not start at the point where perception arrives but rather tracks back to an earlier point in the developmental path.

7 In Greek, the syllables V, VC, CCV, and CVC are attested simultaneously (Tzakosta and Kappa 2008).

The least marked CV syllable (6a) obeys all the markedness constraints on syllable structure, by having an onset (respecting ONSET), but not a complex one (respecting NO COMPLEX ONSET), and not having a coda (respecting NO CODA). The CVC and V syllables (6b) violate one constraint each; CVC violates NO CODA and V violates ONSET. In the absence of universal priority between these two constraints, the hierarchy in (6) allows inter-child and inter-language variation. The VC syllable (6c) violates both ONSET and NO CODA, and is thus more marked than CVC and V. The syllables with the complex syllable margins (6d) violate NO COMPLEX, either NO COMPLEX ONSET in CCVC or NO COMPLEX CODA in CVCC. Here again, the absence of universal priority allows variation. However, the CCVCC syllable (6e) is worse than these two due to its cumulative complexity, having both a complex onset and a complex coda.

As predicted, the least marked CV syllable is indeed the first syllable to appear in children's speech. Similarly, the most marked CCVCC syllable is reported to be the last syllable to appear. In between these two edges of the syllable markedness hierarchy there is inter-child and inter-language variation, some predicted by the hierarchy and some not. The variation is demonstrated below with reference to Hebrew vs. Dutch.

In Dutch, the order between CVCC and CCVC syllables is child-specific (Levelt et al. 2000); some children start with complex onsets, thus producing CCVC before CVCC, while others start with complex codas, thus producing CVCC before CCVC. This distinction is not relevant for Hebrew, which hardly has any words with complex codas.

In Hebrew, the order between CVC and V syllables is child-specific (Ben-David 2001). Given the target word *kapít* 'teaspoon', the first stage for all children is the CV syllable *pi*, whereas the second stage allows variation: some children first add a coda (*pi* ⇒ *pit*), thus giving priority to the CVC syllable, while others first add a syllable, starting with its nucleus (*pi* ⇒ *api*), thus giving priority to the V syllable.[8] Notably, such variation is not reported for the acquisition of Dutch, where the CVC syllable is acquired before the V syllable (Levelt et al. 2000); at the stage where children already produce CVC syllables (e.g. *pus* 'cat', *diχt* → *dɪs* 'closed') they add consonants to onsetless target words (e.g. *óto* → *tóto* 'car', *ap* → *pap* 'monkey').

An inter-language variation not predicted by the markedness hierarchy in (6) has to do with the VC syllable (6c). Unlike in Dutch, where the markedness hierarchy is followed (Levelt et al. 2000), in Hebrew the VC syllable is acquired much earlier, along with the CV syllable. However, the production of the VC syllable is often limited to monosyllabic VC target words, due to a constraint HAVE C, requiring at least one consonant in the word (Ben-David 2001). This constraint is universally supported by the important role of consonants (as opposed to vowels) in conveying

8 The arrow ⇒ indicates that the input is the child's production in an earlier stage, while the arrow → indicates a target (adult's) input.

lexical contrast (Nespor et al. 2003, Hochmann et al. 2011). That is, during the stage where target words like *kaf* 'spoon' are produced as *ka*, complying with NO CODA, target words like *af* 'nose' are produced faithfully, complying with HAVE C, which has priority over NO CODA.[9]

HAVE C is a dominant constraint in the speech of typically developing children, but atypically developing children (see §6) often violate it, producing consonant-free words (Tubul-Lavy 2005, Adi-Bensaid 2006, Adi-Bensaid and Tubul-Lavy 2009). The loss of contrast in such cases is pervasive, to the extent that Hebrew target words like *adóm* 'red', *jaʁók* 'green', *gadól* 'big', and *matók* 'sweet' are all produced as *aó*. Although the violation of HAVE C was observed in the speech of atypically developing children, Adi-Bensaid and Bat-El (2004) do not consider it an atypical phenomenon but rather residues of the pre-word babbling stage. The pace of atypical language development is often slow enough to allow observing phenomena that go undetected or are negligible in typical development. We nevertheless do find such productions in typically developing infants who start talking very early, for example, a boy aged 1;6 produced [*i*] for *dúbi* 'teddy bear' and *ʃuít* 'beans', and [*u*] for *kadúr* 'ball' and *sus* 'horse'. However, such examples are marginal within and across typically developing children.

Because the syllable types are acquired gradually, when children attempt to produce target words with syllable types not yet acquired, their productions are simplified versions of the adults' words. The most common process of simplification of syllable structure is deletion.

(8) Syllable structure simplification via consonant deletion

	French (Rose 2000)			English (Smith 1973)		
	Child	*Target*		*Child*	*Target*	
NO CODA	pi	pip	'(it) pikes'	baɪ	baɪk	'bike'
	pɪpé	bibít	'bug'	dæpú:	ʃæmpú:	'shampoo'
NO COMPLEX ONSET	ke	kle	'key'	bɛd	brɛd	'bread'
	tatœ́	tχaktœ́ʁ	'tractor'	mɔː	smɔl	'small'
NO COMPLEX CODA	pak	paʁk	'park'	wɛp	ʃɛlf	'shelf'
	pɔt	pɔʁt	'door'	dæp	stæmp	'stamp'

Simplification of complex syllable margins (onsets and codas) follows the SONORITY DISPERSION PRINCIPLE (Clements 1990), according to which sonority is maximally

9 In some cases a glottal stop is observed in onset position, but this is a sheer phonetic effect. Had the glottal stop in *ʔaf* 'nose' been considered a phonological consonant, we would expect to get **ʔa* 'nose' at the stage where we get *ka* for *kaf* 'spoon'. This does not happen in typical development.

dispersed between onset and nucleus and minimally dispersed between nucleus and coda. We assume the fairly standard sonority hierarchy below:

(9) The Sonority Hierarchy

Stops < Affricates < Fricatives < Nasals < Liquids < Glides < Vowels

When children delete one of the consonants to comply with NO COMPLEX ONSET, they follow the SONORITY DISPERSION PRINCIPLE and delete the more sonorous consonant in a complex onset.[10]

(10) Complex onset reduction

Hebrew (Bloch 2011)			Polish (Łukaszewicz 2007)			Greek (Kappa 2002)		
Child	*Target*		*Child*	*Target*		*Child*	*Target*	
gída	glída	'ice cream'	gɔ́va	gwɔ́va	'head'	fúto	frúto	'fruit'
paxím	pʁaxím	'flowers'	mɛ́kɔ	mlɛ́kɔ	'milk'	poí	proí	'morning'
tunót	tmunót	'pictures'	suf	snuf	'dream'	cílo	ksílo	'wood'
ki	ski	'ski'	tɔnt	stɔnt	'from here'	píti	spíti	'house'

Cluster reduction is the most common simplification strategy. There are a few examples of other strategies, such as epenthesis in European Portuguese (*grẽ́dɨ* → *kɨrẽ́dɨ* 'big', *mṍʃtru* → *mṍʃtiru* 'monster'; Freitas 2003) and Hebrew (*ʃnijá* → *ʃinijá* 'second fm.sg.', *dli* → *deli* 'bucket'; Ben-David 2001), as well as a handful of vowel-consonant metathesis in Hebrew (*gviná* → *givná* 'cheese', *psantéʁ* → *pastéʁ* 'piano'; Ben-David 2001), but these are relatively rare.

There is, however, a notorious anti-markedness phenomenon in language acquisition, where a target syllable with an onset corresponds to an onsetless syllable in the child's productions (Ben-David 2001, 2012, Buckley 2003; see a review in Vihman and Croft 2013). In terms of target-child output correspondence, it seems that children delete an onset, thus violating the universal markedness constraint ONSET for no obvious reason. Onset deletion is not limited to a particular segment (Karni 2012) or to a particular stress pattern, though stressed syllables seem to be better at preserving target structure than unstressed ones (see §6).[11]

10 The SONORITY DISPERSION PRINCIPLE also requires minimal dispersion between nucleus and coda. This, however, does not gain much support in children's productions due to the stronger effect of the relatively high degree of markedness of sonorants (Bat-El 2012).

11 Out of the three children studied in Karni (2011, 2012), two deleted significantly more onsets in unstressed syllables than in stressed ones, and one the other way around. See also Vihman and Croft (2007) for the role of rhythm in onsetless patterns.

(11) Word initial onset deletion

Hebrew (Karni 2011, 2012)

Child	*Target*	
adú	kadúʁ	'ball'
éve	dévek	'glue'
émeʃ	ʃémeʃ	'sun'
itá	mitá	'bed'
aʃón	laʃón	'tongue'
úki	pinúki	Name

Finnish (Savinainen-Makkonen 2000)

Child	*Target*	
ájja	nálle	'teddy bear'
áippa	váippa	'nappy'
ámppu	lámppu	'lamp'
íkko	sísko	'sister'
éppa	héppa	'horsie'
ássin	kássi:n	'into the bag'

Onset deletion in children's productions posits a challenge to markedness-based approaches (Jakobson 1941/68, Stampe 1973/79), including Optimality Theory (Prince and Smolensky 1993/2004), given the typologically and phonetically-based constraint ONSET (7a). The question is then why do children delete consonants in onset position?

The crucial observation is that onsetless syllables corresponding to target syllables with an onset are limited in their distribution, occurring mostly at the beginning of polysyllabic productions.[12] As argued in Ben-David (2001, 2012) and Ben-David and Bat-El (2016), onsetless syllables arise in the course of the development of the prosodic word (see §3), which progresses from the final, often stressed target syllable toward the initial syllable. The first target syllable produced by the child is the final and/or stressed one (e.g. Hebrew *matanáá* → *ná* 'present'). The word then gradually grows through the addition of syllables. But the addition of each syllable proceeds in stages – first the nucleus and then the onset (*ná* ⇒ *aná* ⇒ *taná*). It is within this progression, when a nucleus is added but not yet its onset, that a target syllable with an onset is produced without an onset. In terms of adult-child relation, this is manifested as deletion.

The universal principle requiring an onset is violated in the children's speech only under the assumption that there is only one input-output relation in the child's grammar, where the input is the adults' output. While maintaining the view that children match their productions against the adult's target, we also contend to the output-output approach, according to which children match their productions against their earlier productions.

(12) The rise of onsetless syllables (*matanáá* 'present')

Development →

Input – child		ná	aná	taná	ataná
Child's production	ná	aná	taná	ataná	matanáá
Input – adult			matanáá		

12 There are also a few cases where a target consonant is deleted because it has not be acquired yet or is highly marked, and may thus look like onset deletion. E.g. Hebrew *raʁá* → *raá* 'cow', *péʁax* → *péax* 'flower', *ʁóni* → *óni* 'Name' (Ben-David 2001); English *up* 'soup', *it* 'seat' (Smith 1973).

If we take *aná*, for example, and compare it with the target word *matanâ*, we see multiple deletions, including onset deletion. However, if we compare *anâ* with the child's earlier production, i.e. *ná*, there is an addition of one segment. At early stages of development, children prefer adding one segment at a time (*ná* ⇒ *aná*), even at the cost of violating the markedness constraint requiring an onset. By doing so, they avoid cumulative complexity (Ferguson and Farwell 1975, Waterson 1978, Bat-El 2012), which arises when two segments are added at the same time (*ná* ⇒ *taná*).

In this respect, child language resembles languages that prohibit onsetless syllables everywhere except word/phrase initially; for example Arameic (Mutzafi 2004), Koyra Chiini (Heath 1999), and Luganda (Tucker 1962). Word initial position is known for its important role in word recognition, thus often resisting alternation (Marslen-Wilson and Zwitserlood 1989, Goodglass *et al*. 1997, Beckman 1998, Smith 2002), sometimes at the cost of preserving a weak onset or no onset at all (Bat-El 2014). But while in the adults' language, word initial onsetless syllables are *preserved* due to their *importance* for processing, in child language they *arise* due to the relative *neglect* of the left edge of the word, given the course of development described in (12). The most important edge in the course of acquisition is the right edge, which is even more important than the stressed syllable (Ben-David 2014, Ben-David and Bat-El 2015).

5 Segmental contrast

As in the other phonological units, children's segmental inventory also grows gradually, through the addition of more and more consonants and thus contrastive features. The major contrast in adults' segmental inventories is between consonants and vowels, which carry different aspects of language: consonants play an important role at the lexical level, and vowels are more important at the prosodic and morphosyntactic levels (Nespor et al. 2003, Nazzi 2005).

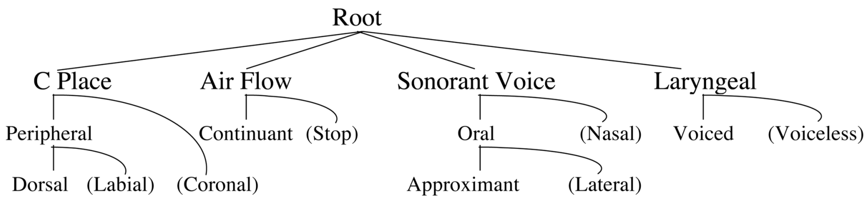
Despite this contrast, consonants and vowels share place features during the very early stages of acquisition, when every word has only one place of articulation (Levelt 1994, Fikkert and Levelt 2008; see also Vihman and Keren-Portnoy 2013 for a collection of articles on the whole word approach): [labial] words have labial consonants and round vowels, [dorsal] words have dorsal consonants and back unrounded vowels, and [coronal] words have coronal consonants and front vowels. Gradually, children start producing two places of articulation within the same word (Gierut et al. 1993).

(13) One and two Place features per word

1 Place per word; English (Fudge 1969)			2 Places per word; Dutch (Levelt 1994)			
	Child	*Target*		*Child*	*Target*	
Coronal	ti	'a drink'	Coronal + Labial	tu	stul	'chair'
	den	'again'	Coronal + Dorsal	diχ	diχt	'closed'
Labial	bo	'ball, book'	Labial + Coronal	fut	χut	'good'
	bɔm	'beating a drum'	Labial + Dorsal	puχ	bRuχ	'bridge'
Dorsal	kʌk	'cake, truck'	Dorsal + Coronal	dun	dun	'do'
	kʌgɯ	'doggie'	Dorsal + Labial	pofi	kofi	'coffee'

Segmental development is best characterized by the growth of contrast among features, in line with Rice and Avery's (1995) proposal of contrast enhancement, couched within the theoretical framework of Feature Geometry (Clements 1985, Sage 1986, McCarthy 1988, Clements and Hume 1995). Rice and Avery propose a markedness mechanism built-in within the feature hierarchy, indicating the unmarked feature (in parenthesis) for each node (due to space limitation, we ignore here the acquisition of vowels).

(14) The feature hierarchy (Rice and Avery 1995, Rice 1996)



The arguments for this (slightly modified) model are based primarily on assimilation patterns in adult languages; its power of prediction with regard to acquisition is impressive though not complete. The model makes two predictions: (i) between two sister features, the unmarked will be acquired before the marked one; e.g. stops before fricatives (continuant); (ii) before the marked feature is acquired, it will be replaced by its unmarked counterpart; e.g. fricatives will be replaced by stops.

The model makes the correct predictions with regard to obstruents (Air Flow node), since stops are indeed acquired before fricatives, which are replaced by stops (15a). However, the model makes only partially correct predictions with regard to sonorants (Sonorant Voice node). The prediction that nasals are acquired before non-nasal sonorants is born out mostly in atypical development, as in Egnlish *mɛ* 'yes' (Ingram, 1989) and *na* 'watch' (Bernhardt and Stemberger 1998). In addition, contrary to the model's prediction, laterals are acquired after approximants, and are often replaced by them (15b).

(15) The acquisition of manner features

a. Fricative → stop

German (Grijzenhout and Joppen 1998)

Child	*Target*	
dú:je	zɔ́nə	'sun'
tú:a	ʃúə	'shoe'
dátɪ	fɛ́ɐtɪç	'ready'

b. Lateral → approximant

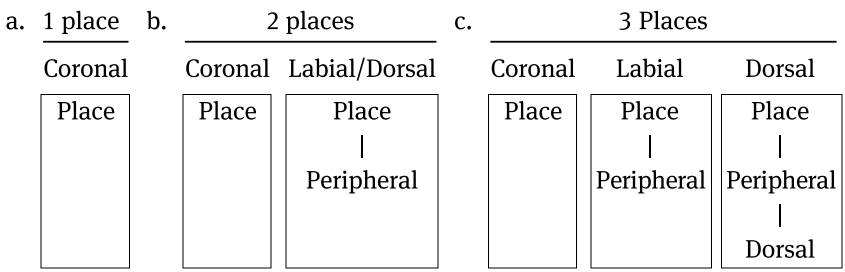
English (Ferguson and Farwell 1975)

Child	*Target*
bæ/baᵒ	'ball'
ʔokʰu/ʔaʊgʰo	'all gone'
bowu:	'balloon'

The four organizational nodes in (14) are not in markedness relation with respect to each other. Therefore, the model does not predict an order of acquisition between sonorants (Sonorant Voice) and obstruents (Air Flow). However, assuming that less structure is less marked (Harris 1990), obstruents must be less marked than sonorants.

With regard to place of articulation, it has been argued that Coronal is the least marked (Paradis and Prunet 1991), followed by Labial and then Dorsal. In lines with the view of contrast enhancement, (16) below illustrates the development of place features.

(16) The development of place of articulation (based on (14) above)



When the contrast is not yet fully developed, children substitute the marked place of articulation for the unmarked one. Substitution can be context-free (17a), but it is often due to consonant harmony (see also §7), i.e. conditioned by a neighboring consonant (17b). Quantitative studies of consonant harmony, such as Tzakosta (2007) for Greek and Gafni (2012a,b) for Hebrew show that coronal, the least marked place of articulation, is the preferred trigger, i.e. children prefer replacing other places of articulation with a coronal.

(17) Place substitution with Coronals

a. Context free

English (Stoel-Gammon 1996)	
Child	*Target*
tup	'cup'
ta:	'car'
bʊt	'book'
pɪdi	'piggy'
dus	'goose'
tʰi	'key
tʊdi	'cookie'

b. Consonant Harmony

Hebrew (Gafni 2012a,b)		
Child	*Target*	
nen	ken	'yes'
tot	tov	'good'
til	pil	'elephant'
nanáj	banáj	'builder'
natán	katán	'small'
didál	migdál	'tower'
ʃtáid	ʃtáim	'two'

There is evidence for context free substitutions of dorsals with coronals (17a) but not for context free substitution of labials with coronals, nor for the acquisition of coronals before labials. So here again, the model above gains only partial support, as it predicts the acquisition of coronals before labials.

Substitution is often restricted by position within the word, where the rightmost consonant (in syllable coda position) is faithful, while the leftmost consonant (in syllable onset position) is substituted; e.g. *tʊk* 'cook', *tɪk* 'kick' (Stoel-Gammon 1996). This follows from the right edge prominence in acquisition. That is, due to the development of the word from right-to-left (see §3), segments at the earlier acquired right edge are more faithful than segments in other positions within the word, in particular the left edge (Dinnsen and Farris-Timble 2008, Ben-David and Bat-El 2015, 2016).

6 Atypical phonological development: Cases of a-synchronization

We view the mental organization of language as a nested complex system, with interactive components, where each component is also a complex system. The phonological word presented in (2) is a complex system, with interaction among the different layers of representation. In typical development, the different layers develop in tandem, thus allowing establishing the baseline for a synchronized development.

Among children with phonological disorders, we distinguish between "prolonged development" and "atypical development". Both types of disorder often (but not always) show delayed development, which may also involve late onset of speech. However, while prolonged development is synchronized, as in typical development, atypical development is often characterized with a-synchronization among layers of representation (Bat-El 2009). A-synchronization arises when the development of one layer of representation in (2) lags behind the others.

A-synchronization between the segmental layer and the prosodic word layer is identified in productions with consonant harmony and context free segmental substitutions. Consonant harmony is a well-studied phenomenon in language acquisition (Vihman 1978, 1996; Stoel-Gammon and Stemberger 1994; Levelt 1994; Goad 1996; Pater 1997; Pater and Werle 2003; Fikkert and Levelt 2008; Tzakosta 2007; Gafni 2012a,b). Consonant harmony, which appears in children's speech regardless of the ambient language, is characterized by many-to-one correspondence between the target word and the child's production, where different target consonants within a word correspond to identical (or similar) consonants in the child's production.

(18) Typical consonant harmony (see also (17b))

	Child	*Target*	
Dutch	sɪs	vɪs	'fish'
(Levelt 1994)	kóχa	kɔ́pjə	'cup'
	pipóto	kipóto	'dump truck'
Greek	póma	stóma	'mouth'
(Tzakosta 2007)	vavó	stavró	'cross Acc.'
	gagónɛ	ðagónɛ	'bite 3rd sg. Pres.'
Hebrew	til	pil	'elephant'
(Gafni 2012a,b)	χáχal	záχal	'caterpillar'
	lalám	ʃalóm	'hello'

Consonant harmony disappears from children's production quite early, before they stop omitting syllables (Grunwell 1982) and before they start producing long words. Therefore, most examples of consonant harmony found in the literature consist of one or two syllables, and occasionally three. In general, the greater the number of syllables in the child's production the fewer instances of consonant harmony found.

While typically developing children rarely produce quadrisyllabic words with consonant harmony, atypically developing children may often do so.[13] As shown in (19a) below (data from Tubul-Lavy 2005), the number of syllables, the stress pattern and the vowels in the children's productions are adult-like, but the forms are nevertheless qualitatively atypical exhibiting surface consonant harmony in quadrisyllabic productions. At the stage where children produce words with four syllables (prosodic word layer) they are expected to have no consonant harmony (segmental layer).

13 See Bat-El (2009) for two other characteristics of typical consonant harmony and how they do not hold in atypical development.

(19) A-synchronization between the segmental layer and prosodic layer (Hebrew)

a. Atypical consonant harmony

Child	*Target*	
mekikáim	met͡sіltáim	'cymbals'
elikóke	elikópteʁ	'helicopter'
pepipópe	elikópteʁ	'helicopter'
teledída	televízja	'television'
gaegóe	tarnególet	'hen'
kakuéde	kaduʁégel	'football'
measése	mevaʃélet	'she cooks'

b. Atypical segmental acquisition

Child	*Target*	
kíka	íma	'mummy'
kóke	ʃmóne	'eight'
kakó	t͡saóv	'yellow'
kuká	bubá	'doll'
kakáki	mat͡sâti	'I found'
kakiká	xavitá	'omelet'
kikakáki	miʃkafáim	'glasses'

Although the two datasets in (19) exhibit surface consonant harmony (cf. *pepipópe* (19a) and *kikakáki* (19b)), we claim that the sources are different. The data in (19b) are drawn from a child age 3;0 with severe phonological disorders (assessed by the second author) and a consonant inventory consisting of one consonant only – /k/ (note that typically developing Hebrew-acquiring children produce at least 10 different consonants by the age of 3;00; Ben-David 2015). Thus, what looks like consonant harmony could just as well be non-assimilatory replacement of all consonants with /k/ (see Tzakosta 2007 and Gafni 2012a,b for the problems that arise when distinguishing between assimilatory and non-assimilatory replacements). The data in (19a) seems to be true consonant harmony, because the children's inventory is much richer. For example, the child (age 4:09) who produced *pepipópe* for *elikópter* 'helicopter' (19a), also had productions without harmony (during the same session), which allowed revealing his consonant inventory; e.g. *kubiyó* for *kubiyót* 'building blocks', *axatía* for *avatíax* 'watermelon', *rakéze* for *rakévet* 'train', *axiéli* for *naxliéli* 'wagtail (bird)'.

Turning now to **a-synchronization between the prosodic word layer and the syllable layer**, notice in (19) that most syllables in the children's productions, including the final ones are codaless. More data displaying codaless productions are provided in (20).

(20) A-synchronization between the syllable layer and the prosodic layer (Hebrew)

Child	*Target*	
uéde	yomulédet	'birthday'
tabaó	tabaót	'rings'
abió	avirón	'airplane'
axatía	avatíax	'watermelon'
aisái	mixnasáim	'pants'
meluléke	meluxléxet	'dirty'

These codaless productions display an a-synchronization between the prosodic word layer and the syllable layer. In typical development of Hebrew, final codas start appearing in monosyllabic productions, and at the latest in disyllabic productions (Ben-David 2001); trisyllabic productions without final target codas are rare and quadrisyllabic productions without final target codas are non-existent. The data in (19) and (20) show again that the development of the prosodic word layer is way ahead of that of the syllable level, i.e. the two did not develop in tandem as expected.

A-synchronization can also be revealed with quantitative data, as in (21) below, where two children with an almost identical pMLU are compared (Ben-David and Veig 2015).[14]

(21) A-synchronization in quantitative terms (% of correct productions)

		Typical development		*Atypical development*	
Age		2;01		2;11	
pMLU		6.68		6.69	
a.	**Prosodic Word**	**91%**	(64/70)	**100%**	(66/66)
b.	Final coda	94.3%	(51/54)	70.3%	(38/54)
c.	Non-final coda	66.7%	(17/25)	23.1%	(7/29)
d.	Initial complex onset	75%	(3/4)	17%	(1/6)
e.	Consonants mastered	83%	(15/18)	67%	(12/18)

Here again, it is the prosodic layer (21a) that runs ahead of all other layers in the atypically developing child. On this layer, the atypically developing child fares even better than the typically developing child; the former reaches ceiling while the latter is still omitting syllables. However, on all other layers the atypically developing child is way behind the typically developing one. He omits more final codas (21b) and of course more medial codas (21c); he simplifies more word initial complex onsets (20d) and has mastered fewer consonants (20e).

The data above were drawn from different types of atypical populations, but in all cases one or two layers lag behind the prosodic word level. We have not yet studied the extent at which language-specific structural properties play a role in determining the layers involved in a-synchronization, but our data from Hebrew-acquiring children differ from that presented in Grunwell (1982:48) from an English acquiring child. According to Grunwell's (1982:183) chronology of phonological processes, typically developing English-acquiring children complete the acquisition of

14 Phonological MLU (pMLU) measures the phonological complexity of words. It captures the segmental level by counting the number of correct consonants and the prosodic level by counting the number of total segments in the word, as most prosodic simplifications result in segment omission (Ingram and Ingram 2001).

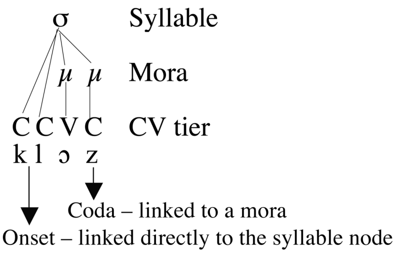
final codas before complex onsets. However, Grunwell provides data from an atypically developing child (age 8;0) with impoverished codas (only nasals) but with complex onsets consisting of a stop followed by a lateral; that is, the development of the coda seems to lag behind the development of the complex onset.

(22) A-synchronization between syllabic and sub-syllabic layers (English)

Child	*Target*	
tɬaʔ	trʌk	‘track’
plɛʔ	brɛd	‘bread’
tɬeɪʔ	greɪps	‘grapes’
tɬɔ	klɔz	‘claws’
pli	pliz	‘please’
plam	pram	‘pram’
tɬeɪʔ	greɪps	‘grapes’
plɑʊn	brɑʊn	‘brown’

Here, the **a-synchronization** is **within the syllable**, between the syllable layer to which onset is directly attached and the sub-syllabic moraic layer to which the coda is attached.[15]

(23) Syllabic and sub-syllabic layers



There are more questions than answers with respect to a-synchronization. For example, do the lower layers always lag behind the higher ones? As a-synchronization is between layers, we predict that the order of acquisition within a layer will always hold; for example, final codas will be acquired before medial codas regardless of the type of population, unless the language does not support this order, as in European Portuguese; Freitas et al. (2001). In this respect we may also inquire regarding the contribution of language specific grammar and frequencies of structures to patterns of a- synchronization.

15 See Bernhardt and Stemberger (1998) for an extensive study on atypical development with reference to markedness constraints.

7 Concluding remarks

This paper addressed the acquisition of phonology from two angles: (i) the children's grammar and (ii) the relation between the children's productions and the corresponding attempted targets. Attention has been drawn to markedness constraints, which play a major role in children's grammar, crucially, a greater role than in their ambient language. The different effect of these constraints in the adults' and children's grammars yields different surface forms, and the relation between these surface forms is expressed in terms of phonological processes in language acquisition. For example, cluster simplification in syllable onset position in the child's productions is with reference to the adults' productions. This process is due to the markedness constraint NO COMPLEX ONSET, which is "stronger" in children's grammar than in some adults' grammars (e.g. English, Hebrew). Of course, we do not expect to see cluster simplification in the speech of Japanese-acquiring children, since Japanese does not have complex onsets, meaning that the constraint is "strong" in both adults' and children's grammars.

Markedness constraints assume representations, like the phonological representation of the word (2). This hierarchical representation has been attended in this paper layer by layer, with emphasis on the course of development. The layers are, of course, connected to each other and therefore must develop in tandem. When one layer lags behind another, there is a-synchronization, which characterizes atypical phonological development. Future studies should approach atypical development from this theoretical perspective in order to arrive at the delimitations of synchronization, and the characteristics of a-synchronization.

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