

Phonological theory and the development of prosodic structure

Evidence from child Japanese^{*}

Mitsuhiko Ota
University of Edinburgh

This article presents a model of prosodic structure development that takes account of the fundamental continuity between child and adult systems, the surface level divergence of child forms from their adult target forms, and the overall developmental paths of prosodic structure. The main empirical base for the study comes from longitudinal data collected from three Japanese-speaking children (1;0–2;6). Evidence for word-internal prosodic constituents including the mora and the foot is found in compensatory lengthening phenomena, syllable size restrictions and word size restrictions in early word production. By implementing the representational principles that organize these prosodic categories as rankable and violable constraints, Optimality Theory can provide a systematic account of the differences in the prosodic structure of child and adult Japanese while assuming representational continuity between the two. A constraint-based model of prosodic structure acquisition is also shown to demarcate the learning paths in a way that is consistent with the data.

1. Introduction

1.1 Purpose of the study

This article investigates the development of prosodic structure from the viewpoint of current phonological theory. The aim of the study is (a) to examine the extent to which the properties of early syllables and words can be understood within the framework of prosodic phonology proposed for adult languages, (b) to explain why the structures of early syllables and words differ

from those of the adult targets and (c) to show how their change during the course of acquisition can be modeled in Optimality Theory.

Explanatory parsimony favors a theory of language acquisition that requires the least amount of child-specific mechanisms or representations, but the exact extent to which grammatical continuity can be assumed between early systems and the adult state is an empirical question. Just how much of the phonological structure of early child language is composed of the same prosodic constituents and representational principles that govern the organization of prosodic structure of mature grammar? As a frame of reference for adult prosodic structure, we will adopt the model of prosodic phonology proposed by Selkirk (1980a, 1980b) and developed further by Nespor and Vogel (1986), McCarthy and Prince (1986), Zec (1988), Itô (1989) and Hayes (1989, 1995), among others. In this framework, all (mature) phonological grammars are seen to contain the following prosodic units at and below the level of the word.

(1) Prosodic hierarchy (McCarthy & Prince 1986)



Of the three sub-word level constituents shown in (1), the syllable has received by far the largest amount of attention in child language research. Extensive research on infants' perceptual sensitivity to syllable boundaries and phonotactic restrictions on production indicates that at least by the time children start producing their first words, their phonological system includes the syllable as a unit of prosodic structure (Bertoni & Mehler, 1981; Eimas & Miller, 1992; Ingram, 1978; Menn, 1971; Vihman, 1992).

What remains contestable, however, is whether there is enough empirical motivation in early child phonology for the level of prosodic structure below the syllable (namely, the moraic level) and more generally, the multi-layered word-internal prosodic structure illustrated in (1), which includes the foot as another level of representation. This study presents a number of arguments in support of the hypothesis that the prosodic structure of child language between

1; 0 and 2; 0 comprises all the units in (1) along with the representational principles that regulate their organization.

To the extent that there is continuity of representational properties between early child grammar and mature grammar, one still needs to explain why the surface forms of early words still differ from those of the adult targets. Divergence from adult forms may be due to non-linguistic factors such as underdeveloped anatomy and motor control (Kent, 1992), immature perception (Macken, 1980), or memory filter (Aitchison & Chiat, 1981). However, recent research shows that extra-linguistic factors alone are unable to explain crucial properties of young children's linguistic ability. The precocious phonetic discrimination skills of infants suggest that surface form deviations cannot be simply ascribed to imperfect perception (Eimas, Siqueland, Jusczyk, & Vigorito, 1987; Jusczyk, 1998 and references therein). Articulatory explanations fail to account for chain shifts where a surface form not produced for a given target is nevertheless articulated for another (e.g., [fik] for *thick* but [θik] for *sick*, documented by Smith (1973)). In other words, children's perception seems relatively complete even though their production systematically deviates from their target adult words independent of their articulatory ability.

One line of approach to this perception/production dilemma was proposed by Smith (1973) and defended in much subsequent work in child phonology. Under this view, the child's underlying representation is assumed to be identical to the adult surface form and the locus of child-adult differences is placed in the mapping between the underlying representation and the child surface representation. The current study pursues this approach, in particular its adaptation within Optimality Theory (OT; Prince & Smolensky, 1993). The central idea of this model is that properties of child grammar in various stages are consequences of non-targetlike rankings of a universal set of violable constraints (Demuth, 1995, 1996; Gnanadesikan, 1995; Pater, 1997; Tesar & Smolensky, 1998). The analysis presented below supports this hypothesis by demonstrating that child-adult differences in the surface forms of syllables and words can be explained in terms of different rankings of the constraints that regulate prosodic structures. Furthermore, the analysis shows that an Optimality Theoretic model of prosodic acquisition correctly predicts the overall course of prosodic development, and provides an explicit mechanism of grammatical restructuring.

The remainder of the article is organized as follows: Section 1.2 describes the models of syllable-internal and word-internal prosodic structures assumed in the study, and reviews relevant previous research in child language. Section 1.3 outlines the principles of OT and its implications for language development.

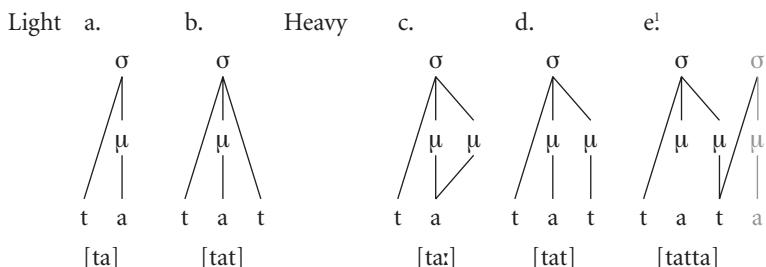
Section 2 describes the data and methods used in the main analyses. Section 3 presents evidence for moras and feet in early child language. Building on these findings, Section 4 provides analyses of child syllable-internal structure within the framework of OT. Section 5 evaluates the developmental mechanisms of OT. Section 6 concludes the article.

1.2 The prosodic hierarchy in early child language

Syllable-internal prosody

In the moraic approach to sub-syllabic constituency, the mora is seen to play two roles (Hayes, 1989; Hyman, 1985; Itô, 1989; McCarthy & Prince, 1986; van der Hulst, 1984; Zec, 1988). First, the mora functions as a phonological position. In languages with contrastive vowel length, a short vowel is associated with one mora, and a long vowel with two (cf. 2a vs. 2c). A geminate segment is associated to an underlying mora dominated by a syllable, and also linked to the following syllable as an onset (2e).

(2) Moras and syllable weight

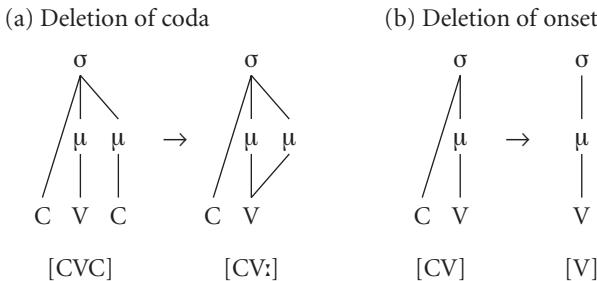


The second role the mora plays is that of a unit of weight. Syllables can be divided into two classes that differ in their degree of prominence in prosodic phenomena. In moraic theory, the difference is represented by the number of moras dominated by the syllable: a syllable with one mora is light and a syllable with two moras is heavy. A (C)VC syllable counts as heavy in languages such as English and Japanese, while it counts as light in other languages such as Lardil and Huasteco. This contrast is captured by the projection of a mora by the coda consonant (2d), which is due to the Weight-By-Position rule (Hayes, 1989), or the lack thereof (2b).

As the representations in (2) show, onset segments never project moras. The inertness of onsets at the moraic level is most clearly observed in compensatory lengthening (CL) — a process by which loss of a segment is compensated

elsewhere in the output through lengthening. The most prevalent pattern is induced by deletion of a coda, which results in the lengthening of the preceding vowel (see 3a below). In moraic theory, the mechanism that underlies this process is seen to be one that conserves mora count (moraic conservation; Hayes, 1989). Since a coda segment may project a mora, but onsets are inherently non-mora-bearing, moraic conservation predicts that CL can be induced by deletion of codas but never by deletion of onsets. This asymmetry, illustrated in (3), is robustly confirmed across languages (Hayes, 1989).

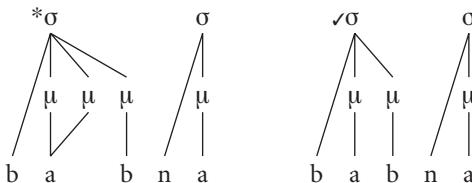
(3) Onset/coda asymmetry in CL



Even though lengthening of vowels triggered by coda deletion has been observed in child English (Stemberger, 1992), child Dutch (Fikkert, 1994) and child Japanese (Ota, 1998), no previous study has demonstrated the predicted asymmetry between onset deletion and coda deletion. This leaves room for the possibility that the lengthening in child language is caused by loss of any segment, not only by that of a mora-bearing segment. The existing data can thus be analyzed without assuming an extra layer of prosodic units below the syllable. What needs to be shown is that CL phenomena can be triggered only by restructuring of moraic segments.

Another important property of moraic theory is the markedness of trimoraic (or superheavy) syllables. Avoidance of trimoraic syllables gives rise to a phenomenon known as closed-syllable shortening, by which an underlyingly long vowel shortens in a closed syllable to make room for a moraic coda which otherwise will not fit in the bimoraic space. The following example from Cairene Arabic illustrates this process.

- (4) Closed syllable shortening in Cairene Arabic (Kenstowicz, 1994)
- baab 'door' + i 'my' → baa.bi
 - baab 'door' + na 'our' → bab.na



A similar phenomenon is observed in child English by Stemberger (1992). Until about 2;6, the subject child deleted the second half of a diphthong in a closed syllable, e.g. /klaun/ → [t^han], but cf. /kau/ → [t^hau]. While the pattern lends itself to a moraic analysis, it is also consistent with the interpretation that there is a restriction on the number of segments in the rhyme, *viz.* 2 segments, as pointed out by Bernhardt and Stemberger (1998). To show that shortening in child production is an effect of moraic phonology, we need to demonstrate that the size restriction is defined in terms of mora count.

A third type of evidence for moraic structure may be found in the generalization that consonants that can bear moras are more sonorous than those that cannot. Zec (1988) finds an implication relationship among the possible sets of moraic segments such that any language that allows moraic segments of a particular level of sonority also allows more sonorous segments to be moraic. Thus there are languages in which sonorants can be moraic but obstruents always remain non-moraic (e.g. Lithuanian, Tiv). However, no language exhibits the opposite asymmetry. Translating this generalization into the acquisition context, the prediction will be that moraic sonorant codas emerge no later than do moraic obstruent codas. Fikkert's (1994) data from child Dutch are suggestive of the type of asymmetric development allowed by this prediction. At one stage, typically around the age of 2 years, obstruent codas appear after a long vowel, while the sonorant codas after a long vowel tend to be deleted. A possible analysis, capitalizing on the bimoraic size limit discussed above, is that a long vowel saturates the two moraic slots for a syllable, only allowing a non-moraic obstruent, but not a moraic sonorant, as a syllable-mate. It remains to be seen, however, whether the acquisition prediction that moraic obstruents imply moraic sonorants holds at any stage of development.

Word-internal prosody

The organization of word-internal prosodic structure is regulated by several representational principles. First, a lexical word must be contained in a prosodic word (McCarthy & Prince, 1986; Nespor & Vogel, 1986). Following Prince and Smolensky (1993), this will be referred to as $Lx \approx PrWd$. Second, like all other constituents in the prosodic hierarchy in (1), except the mora, the foot is subject to a universal principle that ensures headedness of all the non-terminal constituents.

- (5) Proper Headedness (Itô & Mester, 1992: 12; cf. Selkirk, 1996)

Every (nonterminal) prosodic category of level i must have a head; that is, it must immediately dominate a category of level $i-1$.

Third, feet themselves are constrained by a separate principle that requires a foot to be binary, i.e., either disyllabic or bimoraic (Foot Binarity; Prince, 1980). Along with $Lx \approx PrWd$ and Proper Headedness, Foot Binarity sets the lower limit of a lexical word. Due to $Lx \approx PrWd$ and Proper Headedness, a lexical word must contain at least one foot. Foot Binarity requires that a foot be either bimoraic or disyllabic. Again, Proper Headedness demands that each syllable have at least one mora. Hence a lexical word must at least be bimoraic.

If, as a consequence of these principles, early words are subject to a bimoraic lower size limit, we should be able to observe the effects in the lexical production of young children. While attempts have been made to demonstrate a lower size limit in early English word production (e.g. Johnson & Salidis, 1996; Salidis & Johnson, 1997), data from child English are problematic for two reasons. First, since all adult English lexical items themselves are bimoraic or larger, targetlike production of adult words will automatically conform to bimoraic minimality. Second, the complex phonetic realization of phonemic vowel length contrasts in English makes it difficult to define what counts as monomoraic or bimoraic in child English. The contrast between the so-called ‘short’ and ‘long’ vowels is manifested in at least two phonetic parameters — quality (i.e., spectral structure, from an acoustic point of view) and duration. But the relative weight of these parameters in signaling the contrast is unknown in early child English.² A language that is suitable for this type of analysis is one that has a lexicon that includes items that seemingly violate the word minimality constraint and also has straightforward phonetic correlates of moras that can be reliably measured.

Although the general well-formedness conditions on the prosodic word directly set the minimal size of lexical words, they do not in themselves impose

a maximal size limit. It has been proposed, however, that there is a structurally defined upper size restriction that follows from the hypothesis that early words consist of only one binary foot.

(6) The Minimal Word Hypothesis (Demuth & Fee, 1995, pp. 2)

[C]hildren's early words are *linguistically wellformed Minimal Prosodic Words, or binary feet.* (Underlining and capitalization original)

The Minimal Word Hypothesis receives empirical support from the disyllabic word size maximum widely documented in child English (Allen & Hawkins, 1978; Echols & Newport, 1992; Gerken, 1994; Ingram, 1978) and child Dutch (Fikkert, 1994; Wijnen, Krikhaar, & den Os, 1994). The pattern of truncation that disfavors finally-stressed disyllabic outputs is also consistent with the trochaic footing in these languages, and mounts further support for the hypothesis that the output restriction is a single foot (Demuth & Fee, 1995; Fikkert, 1994; Kehoe & Stoel-Gammon, 1997; Pater, 1997).

Still, we need to reassess the rationale behind the use of truncation data as evidence for a prosodically defined upper limit of word production. Given the stress pattern in English and the distribution of early target words, the observed pattern of truncation could be explained without appealing to a disyllabic templatic restriction. For example, Echols & Newport (1992) put forth a non-templatic account, which states that the stressed syllable and the final syllable are preserved because they are more likely to be retained in the lexical representation due to their greater perceptual salience. The comparison in Table 1 shows that only some minor differences can be found in the predictions made by the two positions if the analysis is limited to a typical target pool.

The two approaches can be unambiguously distinguished if there are ample data on longer items, but words with four or more syllables are rarely targeted by English- or Dutch-speaking children — the two most frequently studied groups — and the available experimental data of multisyllabic targets before 2;0 are limited.

To circumvent this methodological problem, we need to pay attention to the interaction between possible causes of truncation and the size of target words. According to non-templatic explanations of early word truncation, independent factors, such as stress and position of syllables, bring about deletion of some elements in the target regardless of the size of the target word.

Table 1 Comparing foot-based and salient syllable preservation accounts

Target	Prediction	
	Foot-based	Salient syllable
$\acute{\sigma}_1\sigma_2$	[$\acute{\sigma}_1\sigma_2$]	[$\acute{\sigma}_1\sigma_2$]
$\sigma_1\acute{\sigma}_2$	[$\acute{\sigma}_2$]	[$\acute{\sigma}_2$]
$\acute{\sigma}_1\sigma_2\sigma_3$	[$\acute{\sigma}_1\sigma_2$] or [$\acute{\sigma}_1\sigma_3$]	[$\acute{\sigma}_1\sigma_3$]
$\sigma_1\acute{\sigma}_2\sigma_3$	[$\acute{\sigma}_2\sigma_3$]	[$\acute{\sigma}_2\sigma_3$]
$\acute{\sigma}_1\sigma_2\acute{\sigma}_3$	[$\acute{\sigma}_1\sigma_3$] or [$\acute{\sigma}_3$]	[$\acute{\sigma}_1\acute{\sigma}_3$] or [$\acute{\sigma}_3$]?

Note. An acute accent indicates primary stress and a grave accent indicates secondary stress.

Thus we expect those factors to show *consistent deletion effects across target types*. For instance, if deletion of non-final syllables is an independent reason for truncation, the omission rate of initial syllables must be higher than that of final syllables in disyllabic targets as well as in longer targets. However if the effect is only evinced in multisyllabic targets but not in disyllabic targets, it shows that non-final syllables do not cause deletion, although they may be less likely to survive truncation. If after controlling for these factors we still find an overall size limit in word production, we can attribute it to a prosodic size restriction with more confidence.

1.3 Phonological acquisition in Optimality Theory

In Optimality Theory, well-formedness of structures is determined by a universal set of violable constraints that are ranked in a hierarchy of relevance. The architecture of the grammar conforms to these basic principles:

(7) Basic tenets of OT (Prince & Smolensky, 1993)

1. *Ranking.* Constraints are ranked. The ranking of constraints is what distinguishes one grammar from another.
2. *Violability.* Constraints are minimally violable. A lower-ranked constraint can be violated in order to satisfy a higher-ranked constraint.
3. *Inclusiveness.* The constraint hierarchy evaluates a set of candidates which are admitted by very general considerations of structural well-formedness.

An OT-based grammar consists of a set of constraints shared by all languages (CON), a function that creates a candidate set of all potential outputs for a given input (GEN), and an evaluation system that assesses all the candidate

output forms in order to select the one that best-satisfies the constraint ranking (EVAL).³ The optimal candidate chosen by EVAL is the Output that is associated with the Input.

Constraints in OT can be categorized into two types: markedness and faithfulness. Markedness constraints evaluate the structural well-formedness of Outputs. Two examples are given in (8).

(8) Examples of markedness constraints

ONSET: A syllable must have an onset.

NOCODA: A syllable must not have a coda.

Faithfulness constraints govern the mapping relation between two grammatical representations. Two important constraints on Input-Output faithfulness are shown in (9).

(9) Examples of faithfulness constraints (McCarthy & Prince, 1995)

MAX(seg): Every segment in the Input has a correspondent in the Output ('No deletion').

DEP(seg): Every segment in the Output has a correspondent in the Input ('No epenthesis').

The crux of OT analysis is that all grammatical properties are seen to derive from the interactions between markedness and faithfulness constraints. For example, if we take three constraints — NOCODA, MAX(seg) and DEP(seg) — and rank them in the order DEP(seg) » NOCODA » MAX(seg), an Input such as /kæt/ will be mapped to the Output form [kæ], as the following evaluation tableau of plausible Output candidates shows. In fact, the Outputs of this grammar will always be coda-less regardless of the Input.

(10) DEP(seg) » NOCODA » MAX(seg)⁴

Input: kæt	DEP(seg)	NOCODA	MAX(seg)
a. kæt		*!	
b. kæ			*
c. kæti	*!		

There are 5 other logically possible rankings among these constraints, 6 all together, which are shown in Table 2. The different rankings yield 3 distinct grammars in terms of their Input-Output mapping.

This is the fundamental means of explaining language variation in OT, and the same mechanism is employed to account for language acquisition. The

Table 2. Constraint rankings and Input-Output mapping

Type	Ranking	Mapping
1	MAX(seg) » DEP(seg) » NoCoda; DEP(seg) » MAX(seg) » NoCoda	/CV/ → [CV] /CVC/ → [CVC]
2	DEP(seg) » NoCoda » MAX(seg); NoCoda » DEP(seg) » MAX(seg)	/CV/ → [CV] /CVC/ → [CV]
3	MAX(seg) » NoCoda » DEP(seg); NoCoda » MAX(seg) » DEP(seg)	/CV/ → [CV] /CVC/ → [CVCV]

differences between child and adult grammars are seen as consequences of different constraint rankings, but not as differences in the basic architecture of the grammar or in the number or types of constraints contained in the grammar. For example, the early stage of development during which target codas are deleted, which is attested cross-linguistically, can be treated as a stage with the Type 2 ranking in Table 2: DEP(seg) » NoCoda » MAX(seg) or NoCoda » DEP(seg) » MAX(seg). In that respect, the ‘no coda’ stage in early child language is fundamentally the same in grammatical structure as the adult languages that prohibit syllables with codas, e.g., Hua and Cayuvava. OT thus enables us to build a unified model of child language and language variation.

2. Methods

2.1 The language of investigation

The child language examined in this study is Japanese, which has several characteristics that make it an interesting testing ground for the empirical issues discussed above. First, it has both contrastive vowel length (short vs. long vowels) and consonant length (singletons vs. geminates). These add to the variety of rhyme structures through which the nature of syllable-internal prosody can be examined. The rhyme types in Japanese are summarized in (11).

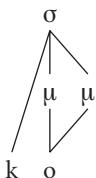
(11) Rhyme structures in Japanese

a.



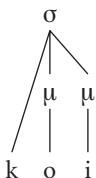
'child'

b.



'shell'

c.



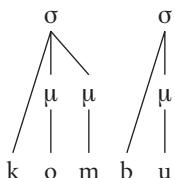
'carp'

d.



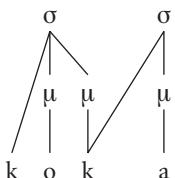
'navy blue'

e.



'kelp'

f.



'nation'

Open syllables can contain a short vowel (a), a long vowel (b) or a diphthong (c). Syllables can be closed by a singleton coda (d and e) or a geminate (f). The only non-geminate coda allowed in Japanese is a nasal, which either has to be placeless (d) or homorganic to the onset of the following syllable in place (e). The placeless nasal has a loosely defined phonetic configuration with some but not complete closure in the region that ranges between the velum and the uvula (Bloch, 1950; Maddieson, 1984; Nakano, 1969). The symbol [n] will be used in this paper as a stand-in to cover the variable phonetic realizations of this sound.

Second, the phonetic realization of moraic structure in Japanese is isomorphically temporal (Port, Dalby & O'Dell, 1987), making it possible to use durational information to identify contrasts in moraic values. Third, underived lexical items of the language contain monomoraic words, which can verify whether there is a bimoraic lower size restriction in early production. Fourth, the lack of a stress system makes Japanese a suitable case to examine whether children's early phonology shows evidence for feet even without phonetic cues from an intensity-based system of prominence.

2.2 Subjects and data collection

The data consist of longitudinal speech samples collected from three Japanese-speaking children, who were growing up in the Japanese community of Washington DC, USA.⁵ The standard dialect of Japanese was spoken in the children's households. The profiles of the three children are summarized in Table 3.

Table 3. Subjects

Name	Sex	Recording period	No. of Utterances ^a	Mean length of utterance ^b
Hiromi	Female	1;0;22–2;0.8	1,475	1.00–1.25
Takeru	Male	1;4.24–2;0.20	1,961	1.00–1.32
Kenta	Male	1;5.16–2;6.7	2,579	1.00–1.18

^a Non-linguistic production and utterances for which the adult target could not be determined were excluded.

^b The mean length of utterance (MLU) is calculated on lexical items rather than morphemes.

The children were recorded in their homes every other week unless there was some scheduling difficulty. Each recording lasted between 60 and 90 minutes. A total of 22 recordings were made with Hiromi, 15 with Takeru, and 26 with Kenta. The utterances were then transcribed in IPA. Some of the utterances were further sampled at 16 kHz for spectrogram analysis and pitch extraction. Additionally, a portion (1;5.7–2;3.0) of Miyata's (1995) Aki corpus was used in the syllable omission analysis reported in Section 3.2.

3. Representational continuity of prosodic constituents and principles

3.1 Evidence for moraic structure in early Japanese

Moraic conservation and compensatory lengthening

If moraic conservation occurs in early language, we predict an onset/coda asymmetry in the compensatory lengthening (CL) of child Japanese production. To test this, we compare the consequences of coda deletion and onset deletion.

Transcribed data indicate that when a nasal coda is deleted in production, the preceding vowel tends to lengthen.

- (12) Loss of codas⁶

- a. /wanwan/ [wo:wɔ] 'doggie' Hiromi (1;2.7)
- b. /panda/ [pa:da] 'panda' Hiromi (1;10.23)

- c. /ampamman/ [a:ma:pə] '(cartoon character)' Takeru (1;10.2)
 d. /panda/ [wa:tə] 'panda' Takeru (1;11.16)
 e. /nanda/ [nə:da] 'what?' Kenta (1;7.16)

To verify this observation, the duration of the vowels preceding a deleted coda consonant was compared with the duration of short target vowels in open syllables. For each child, 8 tokens of /CVN.CV.../ → [CVØ.CV] production (e.g. /panda/ → [pa:da] 'panda') and 8 tokens of /CV.CV.../ → [CV.CV] production (e.g. /papa/ → [papa] 'daddy') were sampled from the database to make comparisons between the first syllables, measured as the interval between the release of the first C and the release of the second C.⁷ In order to control for the effects of voice onset time and intrinsic vowel duration, the voicing of the onset consonants and the height of vowels were counter-balanced. Efforts were also made to balance the number of samples extracted from the same data file. The earliest files for which this could be accomplished were used.

Table 4. Comparison of [CVØ] vs. [CV] productions in duration (ms)

	CVØ (n=8)		CV (n=8)		<i>t</i>	(df)
	Mean	(s.d.)	Mean	(s.d.)		
Hiromi	501.21	(159.30)	224.92	(58.09)	4.61	(8.83)***
Takeru	272.20	(30.09)	219.23	(36.28)	3.18	(14)*
Kenta	477.30	(110.85)	331.93	(64.31)	3.21	(14)*

^a Adjusted *df* for unequal variances. * p<0.01, ** p<0.005 (two-tailed *t*-test)

As the results in Table 4 show, syllables with a deleted coda ([CVØ]) are significantly longer than target open syllables containing a short vowel ([CV]). The mean length of [CVØ] production was also compared with that of target long syllables sampled from the same files (n = 8 for each child). While Takeru's [CVØ] syllables are shorter than his underlyingly long target syllables [$t(8) = 2.54$, p<0.05, two-tailed], no difference is found for Hiromi [$t(12) = 1.41$, n.s., two-tailed] or Kenta [$t(12) = 1.80$, n.s., two-tailed]. Thus at least for some children, an open syllable resulting from the deletion of a nasal coda does not differ in duration from an underlyingly long syllable.

Turning now to deletion of onsets, we find examples like the following where marked segments such as /h/ and /r/ are omitted in intervocalic positions.

(13) Loss of onsets

- a. /kore/ [kɔ̝.e] 'this' Hiromi (1;0.2)
- b. /are/ [a.e] 'that' Hiromi (1;3.4)
- c. /kore/ [kɔ̝.ɛ] 'this' Takeru (1;7.4)
- d. /hebi/ [e.bi] 'snake' Takeru (2;0.20)
- e. /gohan/ [dɔ̝.ã:] 'meal' Kenta (2;3.22)

To see if there is any lengthening effect manifested in such child forms, the mean length of [CV.V] productions resulting from deletion of the second onset of CVCV targets was measured. This was compared with the mean length of the productions of VCV targets. In this comparison, the total number of segments is equal in the two output types, and there are two vowels and one onset consonant in both. If there is any lengthening in the [CV.V] productions, then, it should be reflected in the overall length of [CV.V] outputs such that they become longer than [V.CV] outputs.

Ten tokens of /CV.CV/ → [CV. ØV] productions (e.g. /muri/ → [mui], 'can't do') were sampled from the lexical item that most frequently went through this pattern of deletion. Ten tokens of /V.CV/ → [V.CV] productions (e.g. /umi/ → [umi], 'sea') were selected to match the segmental composition as closely as possible. Because there were not enough samples that satisfied these conditions in Hiromi's data, only Takeru's and Kenta's data were subjected to this procedure. The comparison given in Table 5 shows no significant difference in the overall duration of [CV. ØV] and [V.CV] productions.

Table 5. Comparison of [CV.ØV] vs. [V.CV] productions in duration (ms)

	CV.ØV (n=10)		V.CV (n=10)		<i>t</i>	(df)
	Mean	(s.d.)	Mean	(s.d.)		
Takeru	386.84	(126.38)	434.68	(86.09)	0.99	(14)*
Kenta	512.46	(109.37)	467.29	(143.85)	0.79	(14)*

The results in Tables 4 and 5 reveal an onset-coda asymmetry in the CL of child Japanese. The consequences of the segment deletion follow the predictions of moraic theory in that while loss of codas can induce prosodic restructuring, loss of onset cannot.

Two other patterns of lengthening, which involve lengthening of consonants rather than vowels, provide further evidence for moraic conservation. In the first pattern, deletion of a coda consonant is accompanied by gemination of the following consonant.

(14) Gemination as CL

- a. /ombu/ [obbo] 'carry me!' Hiromi (1;9.28)
- b. /dango/ [dakko] 'dumpling' Hiromi (1;11.23)
- c. /pengin/ [peppir] 'penguin' Takeru (1;10.2)
- d. /kentʃan/ [tett'a] 'Ken-DIM' Takeru (2;0.6)
- e. /otʃintʃin/ [dziddzi] 'penis' Kenta (1;10.26)

In the second pattern of lengthening, a singleton onset in the target is geminated when the preceding vowel is shortened.

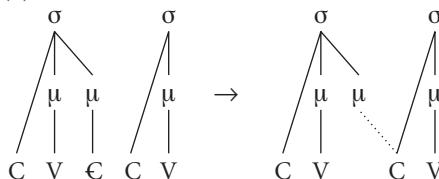
(15) Inverse CL

- a. /tʃortʃo/ [tʃuttʃui] 'butterfly' Hiromi (1;10.23)
- b. /ni:tʃan/ [dittan] 'big brother' Hiromi (1;11.23)
- c. /çikɔkki/ [kokki] 'plane' Takeru (1;10.16)
- d. /ke:ki/ [kikkri] 'cake' Takeru (1;10.2)
- e. /ke:ki/ [dikki] 'cake' Kenta (2;5.10)

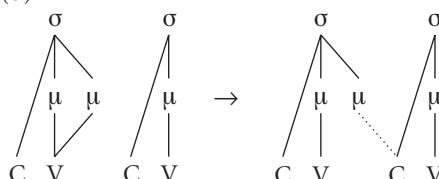
These patterns also follow from moraic conservation. In the first case (14), the deleted coda consonant of the first syllable leaves a stranded mora, which is linked to the following consonant. The re-association results in a geminate, as illustrated in (16a). In the second case (15), the shortening of a long vowel frees a mora, which is then linked to the following consonant, also creating a geminate, as in (16b).

(16) Gemination as CL and Inverse CL

(a)



(b)



On the surface, the cases described in (14) and (15) appear to be different processes from the so-called ‘classical’ CL illustrated in (3a). However, from the viewpoint of moraic phonology, they are all manifestations of moraic conservation. The generality of these processes are summarized in Tables 6 and 7. Table 6 shows that the loss of a nasal coda is compensated primarily by lengthening of the preceding short vowel, and secondarily by gemination of the following consonant. Table 7 shows that failure in realizing a long vowel is often counteracted by gemination of the following consonant.

Table 6. Production of /CVN.CV.../ targets

	/CVN.CV.../ targets produced as			
	CVN.CV...	CV:.CV...	CVG.GV...	CV.CV...
<i>Hiromi</i>				
1;0.22–1;7.17	1 (3.7%)	14 (51.9%)	8 (29.6%)	4 (14.8%)
1;8.5–1;9.28	3 (9.3%)	14 (43.8%)	12 (37.5%)	3 (9.8%)
1;10.11–2;0.8	10 (37.0%)	10 (37.0%)	4 (14.8%)	3 (11.1%)
<i>Takeru</i>				
1;4.24–1;8.13	6 (23.1%)	10 (38.5%)	8 (30.8%)	2 (7.7%)
1;9.5–1;10.16	5 (29.4%)	7 (41.2%)	4 (23.5%)	1 (5.9%)
1;11.2–2;0.20	17 (48.6%)	9 (25.7%)	5 (14.3%)	4 (11.4%)
<i>Kenta</i>				
1;5.19–1;8.27	27 (11.4%)	177 (74.7%)	2 (0.8%)	29 (12.2%)
1;9.11–2;0.16	21 (29.6%)	45 (63.4%)	3 (4.2%)	2 (2.8%)
2;1.4–2;6.7	24 (16.0%)	77 (51.3%)	39 (26.0%)	10 (6.7%)

G.G = geminate

Bimoraic maximum and syllable size restrictions

Like many other languages, Japanese enforces a bimoraic upper limit on syllables contained within a native morpheme, banning tautomorphemic (C)VVC syllables. However, morphological concatenation can provide a context for (C)VVG syllables (a syllable with a long vowel or a diphthong, closed by the first half of a geminate).⁸ The following are affixed verb forms that contain such a structure. The segmental content of the geminate [t.t] belongs to the suffix.

- (17) Heteromorphemic (C)VVG syllables are allowed
 - a. toot.te <*toor*‘pass’ + *te* (gerund) cf. *toor* + *u* (non-past) → *too.ru*
 - b. mait.ta <*mair*‘give up’ + *ta* (past) cf. *mair* + *u* (non-past) → *mai.ru*

Table 7. Production of /CV:CV.../ targets

	/CV:CV.../ targets produced as		
	CV:CV...	CVG.GV...	CV.CV...
<i>Hiromi</i>			
1;0.22–1;7.17	9 (75.0%)	3 (25.0%)	0 (0.0%)
1;8.5–1;9.28	14 (70.0%)	6 (30.0%)	0 (0.0%)
1;10.11–2;0.8	43 (90.0%)	2 (4.2%)	3 (6.3%)
<i>Takeru</i>			
1;4.24–1;8.13	12 (92.3%)	1 (7.7%)	0 (0.0%)
1;9.5–1;10.16	38 (70.4%)	13 (24.1%)	3 (5.6%)
1;11.2–2;0.20	50 (83.3%)	8 (13.3%)	2 (3.3%)
<i>Kenta</i>			
1;5.19–1;8.27	7 (63.6%)	1 (0.9%)	3 (27.2%)
1;9.11–2;2.27	7 (53.8%)	4 (30.8%)	2 (15.4%)
2;3.6–2;6.7	58 (86.6%)	6 (9.0%)	3 (4.5%)

G.G = geminate

While verbal morphology of this type is not fully productive among Japanese-speaking children before the age of 2;0, these morphologically complex forms are targeted as unanalyzed chunks. Interestingly, the marked syllables in the output forms undergo prosodic adjustment.

- (18) CVVG → CVC
- a. /haittʃatta/ [hattʃitta] ‘gone in’ Hiromi (1;11.9)
 - b. /haittʃatta/ [kattatta] ‘gone in’ Takeru (2;0.20)
 < hair‘enter’ + tyaw‘(aspect marker)’ + ta‘(past)’
 - c. /maitta/ [matta] ‘give up’ Kenta (2;6.7)

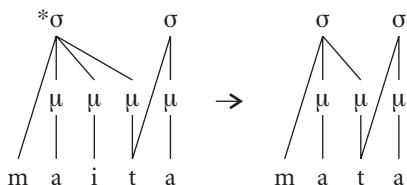
As can be seen in (18), the second vowel of the diphthong in a syllable closed by a geminate is deleted. This is not due to the unavailability of diphthongs *per se*, as targetlike production of diphthongs in open syllables is observed in the same files for Hiromi and Takeru (see 19a and 19b). Kenta does frequently delete the second vowel of a diphthong even in open syllables, as (19d and 19e) show, but the monophthongization in this context is always accompanied by the lengthening of the first vowel. If this were the same mechanism for the monophthongization in (18c), we would expect to see a similar lengthening effect, i.e., /maitta/ → *[mattta], but this is not attested.

(19) Production of diphthongs

- a. /hai/ [hai] 'yes' Hiromi (1;11.9)
- b. /nai/ [nai] 'all gone' Takeru (2;0.20)
- c. /hai/ [ai] 'yes' Kenta (2;6.7)
- d. /nai/ [naɪ] 'all gone' Kenta (2;6.7)
- e. /taija/ [da:tə] 'tire' Kenta (2;6.7)

The data in (18) must therefore be interpreted in different terms. Under moraic theory, we can understand the deleted vowel to have been crowded out of the syllable closed by a geminate, which would otherwise be trimoraic. This explains why the deletion occurs only in closed syllables in Hiromi's and Takeru's data.

(20) Avoidance of trimoraic syllables



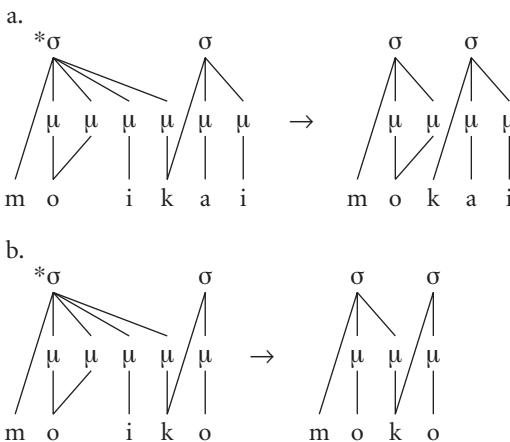
A more extreme case is observed in unanalyzed phrases that create a sequence of a long vowel followed by a short vowel and a geminate. The target forms listed below consist of two separate words.

(21) CV:VGGV → CV.CV / CVG.GV

- a. /moiikkai/ [mo:kai] 'once again' Hiromi (1;11.9)
- b. /moiikko/ [mokko] 'once more' Takeru (1;7.17–2;0.6)

The child forms suggest that hiatus of the long vowel and the short vowel is avoided by parsing both vowels and the first half of the following geminate into a single syllable. Potentially, this creates a quadrimoraic vowel. Different strategies are adopted by Hiromi and Takeru in repairing this offending structure. Hiromi deletes the short vowel and changes the geminate to a singleton (22a). Takeru shortens the long vowel and deletes the short vowel (22b). While the resulting structures are different, both repairs accomplish the same prosodic effect: they keep the syllable size to two moras.

(22) Avoidance of potentially quadrimoraic structure



Crucially, this analysis shows that what defines the upper size limit of syllables is not segment count but mora count. Thus two types of syllable reduction data in child Japanese can receive a unified account under the assumption that syllables are maximally bimoraic.

Sonority threshold of moraic segments and the development of geminates

Another way to examine the existence of moraic structure in early phonology is to test the predictions of Zec's (1988) typological observation that the moraicity of a given segment in a language implies the moraicity of a more sonorous segment in the same language. Although the generalization was originally proposed for structurally assigned moras (i.e., moras assigned to codas by virtue of their structural position in the syllable), it can be extended to inherent moras (e.g. those underlying geminates) as well.⁹ The acquisition prediction is that any developmental stage that allows obstruent geminates should also allow sonorant geminates.

Such a prediction can be tested in Japanese, which has obstruent and nasal geminates. If the sonority threshold of moraic segments holds, nasal geminates should develop no later than do obstruent geminates. Table 8 summarizes the production of geminates by each child.

Between 1; 7.16 and 1; 11.2, most of Kenta's target nasal geminates are realized as geminates, but all of the target obstruent geminates are reduced to singletons. Thus Kenta goes through a stage where only nasals can become geminates. Hiromi appears to have a similar stage (1;0.22–1;4.22), although the

Table 8. Production of target geminates

	Obstruent geminates produced as		Nasal geminates produced as	
	geminates	singletons	geminates	singletons
<i>Hiromi</i>				
1;0.22–1;4.22	1 (33%)	2 (66%)	3 (100%)	0 (0%)
1;6.18–1;7.17	7 (100%)	0 (0%)	0	0
1;8.5–1;10.11	7 (88%)	1 (13%)	11 (92%)	1 (8%)
<i>Takeru</i>				
1;4.24–1;7.4	4 (80%)	1 (20%)	0	0
1;7.17–1;10.2	180 (97%)	6 (3%)	6 (100%)	0 (0%)
1;10.16–2;0.20	233 (97%)	7 (3%)	10 (83%)	2 (17%)
<i>Kenta</i>				
1;5.19–1;7.2	0	0	2 (25%)	6 (75%)
1;7.16–1;11.2	0 (0%)	8 (100%)	20 (87%)	3 (13%)
1;11.11–2;6.7	127 (92%)	11 (8%)	53 (76%)	17 (24%)

Target geminates produced as singletons involve the reduction of geminates [VG.GV] to a simple onset consonant [V.CV], as illustrated by the following examples:

- a. /oppai/ [obbai] ‘breast’ Hiromi (1;4.9)
- b. /nenne/ [ne.ne] ‘sleep’ Takeru (1;11.16)
- c. /motto/ [ma.do] ‘more’ Kenta (1;8.27)

number of available targets is too small to be conclusive. This asymmetry is a possible stage according to the sonority prediction, which allows nasal geminates without obstruent geminates. What the prediction rules out is the opposite asymmetry where obstruent geminates are reduced to singletons even though nasal geminates are successfully produced. The data confirm this. In all children when obstruent geminates are faithfully produced, target nasal geminates do not reduce.¹⁰ Thus the developmental pattern of geminates is consistent with the prediction that the existence of obstruent geminates implies that of sonorant geminates.

Section summary

This section has presented three arguments for the existence of moraic structure in the language of Japanese-speaking children around the age of 2 years. First, the data show that compensatory lengthening can be triggered by loss of codas and shortening of vowels but not by loss of onsets. The same triggers can cause gemination of neighboring consonants instead of lengthening of vowels. Both of these findings indicate that moraic conservation is at work. Second, sequences of a diphthong or long vowel followed by a geminate are shown to undergo

reduction in accordance with a bimoraic maximal restriction on syllables. Third, the development of geminates is consistent with the generalization stated by Zec (1988), which states that the more sonorous the segment is, the more likely it is to project a mora. Taken together, these observations provide clear evidence that the mora is part of the prosodic system of young children.

3.2 Evidence for foot structure in early Japanese

Minimality effects as evidence for foot structure

As discussed in Section 1.2, one of the consequences of the representational principles of word-internal prosody is the condition on the minimal lexical word size. The standard dialect of Japanese, the variety to which subjects of this study have been exposed, happens to be one of the languages that impose bimoraic minimality only on derived lexical words (Itô, 1990). Underived lexical words escape this condition, as can be seen in the large number of monomoraic lexical items such as *me* ‘eye,’ *te* ‘hand,’ *ha* ‘teeth,’ *ki* ‘tree,’ and *hi* ‘fire.’ If these words are repaired to bimoraic structures in children’s production, it will confirm a lower size restriction on early words, as such restriction cannot be a simple reflection of the size of target words.

As a matter of fact, children’s initial productions of target monomoraic lexical words frequently undergo lengthening. Some examples are given in (23), and the generality of this phenomenon is summarized in Table 9. The vowel lengthening is first applied to almost all monomoraic targets, although it diminishes rapidly over the following few months.¹¹ Under the analysis that vowel length contrasts are realization of different moraic values, the change in (23) will be seen as augmentation of monomoraic structure to bimoraic structure.¹²

(23) Lengthening of monomoraic targets

- a. /me/ [me:] ‘eye’ Hiromi (1;9.11)
- b. /ki/ [ki:] ‘tree’ Hiromi (1;9.28)
- c. /me/ [me:] ‘eye’ Takeru (1;8.13)
- d. /te/ [te:] ‘hand’ Takeru (1;11.2)
- e. /ki/ [di:] ‘tree’ Kenta (2;2.27)
- f. /ʒi/ [di:] ‘letter’ Kenta (2;2.27)

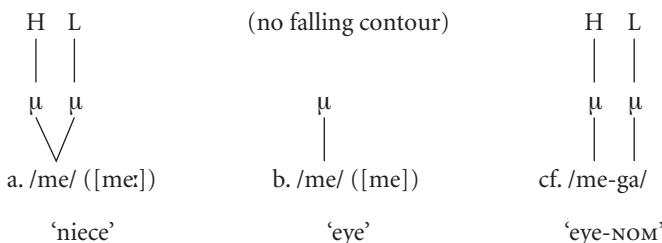
This analysis receives independent support from another prosodic phenomenon in Japanese: pitch accent. Pitch accent in Japanese is realized as a high-low contour — a rapid downfall in fundamental frequency (F_0). This pitch pattern is analyzed as a sequence of a high (H) tone and a low (L) tone, which are

Table 9. Proportion monomoraic targets produced with vowel lengthening

Hiromi	1;9 100.0% (19/19)	1;10 69.2% (9/13)	1;11 0.0% (0/2)	2;0 – (0/0)
Takeru	1;8 100.0% (2/2)	1;9 – (0/0)	1;10 25.0% (1/4)	1;11 50.0% (4/8)
Kenta	2;2 83.3% (5/6)	2;3 50.0% (5/10)	2;4 0.0% (0/8)	2;5 0.0% (0/3)
				2;6 – (0/0)

realized over two moras (cf. Pierrehumbert and Beckman 1988). Thus, while an accented bimoraic word can exhibit the falling pitch contour, an accented monomoraic word in isolation cannot (although it can carry the contour in conjunction with the following morpheme).

(24) Pitch patterns of accented monosyllabic words in Japanese



When monomoraic targets undergo lengthening in children’s production, they exhibit this HL contour. Figure 1 illustrates the pitch pattern of Hiromi’s production of /me/ (‘eye’), a target H monomoraic word. The F_0 of the single vowel displays a downfall that patterns with the global contour of /mama/ (‘mama’), a HL bimoraic word (Figure 2), rather than the pitch of the final monomoraic H syllable in /kore/ (‘this’) (Figure 3). Both the duration and F_0 contour indicate that the child production of a monomoraic target word has more in common with a bimoraic target word than with a monomoraic syllable in a disyllabic target word.

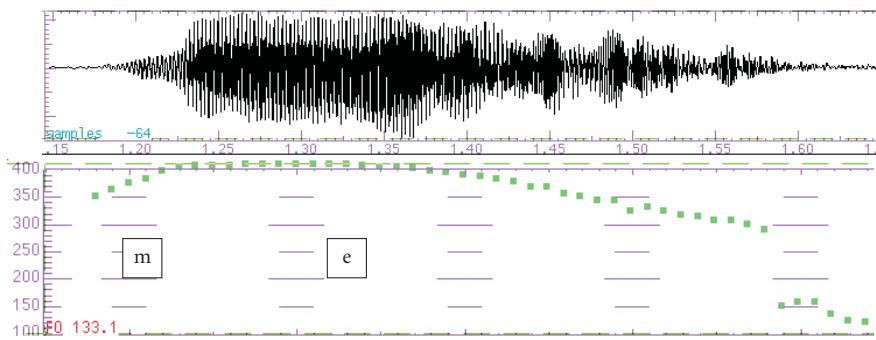


Figure 1. Hiromi's production of /me/ ('eye') at 1;9.12 (Target pitch pattern H)

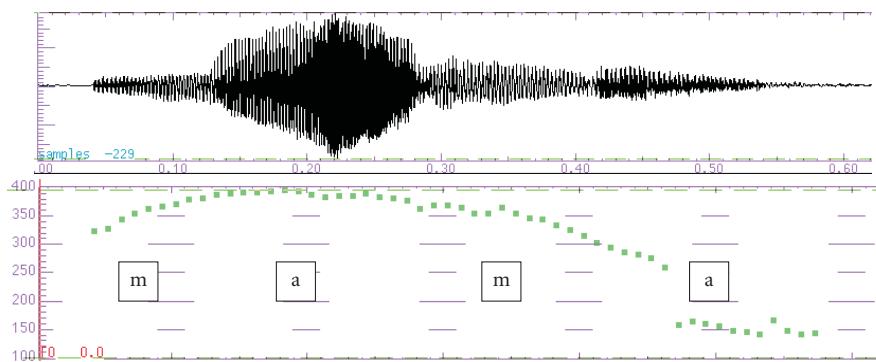


Figure 2. Hiromi's production of /mama/ ('mama') at 1;9.12 (Target pitch pattern HL)

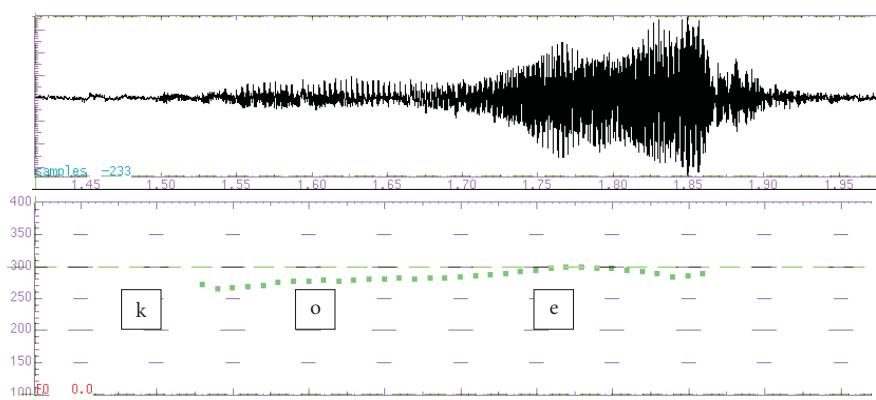


Figure 3. Hiromi's production of /kore/ ('this') at 1;9.12 (Target pitch pattern LH)

In sum, there is evidence that monomoraic adult target words in Japanese are initially produced as bimoraic structures. This provides a stronger argument for bimoraic minimality than the claim that English-speaking children do not produce monomoraic structures. Bimoraic minimality is a property that derives from Foot Binarity along with $Lx \approx PrWd$ and Proper Headedness. The results therefore support the hypothesis that these representational principles exist in early phonology.

Factoring out non-templatic causes of truncation

In Section 1.2, it was pointed out that in order to demonstrate an upper size limit on early words, factors that contribute to syllable deletion independent of the target word size must be eliminated. This section performs this procedure to identify such factors and remove their effects on word truncation.

Vowel devoicing

In Tokyo Japanese, a high vowel is devoiced between voiceless obstruents regardless of the pitch, and word-finally if it is low-pitched and follows a voiceless obstruent (Vance, 1987). Target syllables with devoiced vowels are frequently missing in the child's production, as seen in the following examples.

- (25) Omission of target syllables with devoiced vowels
 - a. /kʊ̥tsuʃɪta/ [tsutta] 'sock' Hiromi (1;11.9)
 - b. /kʊ̥tʃi/ [tʃi] 'mouth' Takeru (1;11.2)
 - c. /kiʃa/ [da] 'train' Kenta (2;4.15)
 - d. /dekiṭa/ [detta] 'done' Aki (2;2)

Table 10 shows that for all children, the omission rate of target syllables with devoiced vowels is significantly higher than that of syllables with voiced vowels both in disyllabic and multisyllabic targets. This means that the effects of devoicing are felt in the children's productions regardless of target size. Thus if a trisyllabic target with one devoiced vowel truncates to a disyllabic target, it could well be due to devoicing. Such data cannot be used to argue for a disyllabic word maximum. To avoid interaction with the other factors examined below, all target syllables with a devoiced vowel are excluded from the remainder of the analysis.

Marked segments

Certain marked segments are subject to deletion in early production, and in some cases cause total omission of syllables. One pattern of segmental deletion

Table 10. Proportion of syllables omitted as a function of devoicing in adult target syllables (%)

In disyllabic target words			In multisyllabic target words		
Devoiced	Voiced	$\chi^2(1)$	Devoiced	Voiced	$\chi^2(1)$
Hiromi 21.1 (4/19)	0.9 (19/2026)	52.13**	66.7 (4/6)	21.8 (34/156)	4.22*
Takeru 52.0 (39/75)	3.1 (57/1816)	354.19**	43.5 (47/108)	9.7 (79/815)	89.72**
Kenta 30.4 (34/112)	2.2 (50/2224)	234.99**	64.2 (52/81)	30.6 (285/931)	36.35**
Aki 57.8 (52/90)	3.6 (39/1084)	333.62**	52.9 (18/34)	19.8 (90/454)	18.25**

* p < 0.05, ** p < 0.01; with Yates' correction factor.

that consistently leads to syllable deletion involves a flap positioned after a long vowel. In all the examples found in the data, this vowel and the vowel that follows the target flap are back vowels.

(26) Omission of syllables with a flap onset

- a. /bo:rw/ [bo:] ‘ball’ Hiromi (1;3.25–1;10.28)
- b. /bo:rw/ [bo:] ‘ball’ Takeru (1;4.24–1;10.16)
- c. /pu:rw/ [bu:] ‘pool’ Kenta (2;5.10)
- d. /do:ro/ [do:] ‘street’ Kenta (2;5.24)
- e. /bo:rw/ [bo:] ‘ball’ Aki (1;6.10–2;2.22)

A possible explanation of this syllable omission is that the deletion of a flap leads to adjacency of identical or similar vowels, which can result in hiatus of these vowels or a trimoraic syllable. As we have seen in Section 3.1, there is evidence that hiatus and trimoraic syllables are generally avoided in child Japanese, which may be why the entire syllable is deleted.

Whatever the details of the mechanism, there are reasons to believe that the total omission of the syllable is caused by the deletion of the flap and not by a templatic output condition. First, the children occasionally produced the final syllable with a substitute consonant for the flap (e.g., /bo:rw/ → [bo:ww, [bo:bw] ‘ball’). This indicates that the prosodic structure of the targets is not the issue. Second, words with the same prosodic structure, CVVCV, do not undergo such truncation during the same period of production (e.g., /bo:si/ → [bo:ti], ‘hat’; /keki/ → [di:di], ‘cake’). Again, this shows that there is nothing problematic about the prosodic shape CVV.CV. And finally, the truncation pattern given in (26) persists long after the children start producing longer targets.

It can be concluded therefore that omission of /rV/ syllables is largely due to segmental markedness and not templatic effects. In addition to devoiced vowels, targets that contain this structure are removed from further analysis.

Accent and pitch

In Japanese, an accent marks the location in a word where the pitch falls from high (H) to low (L) (Haraguchi, 1977; McCawley, 1968). A lexical item has at most one accent; that is, there are words with one accent ('accented') and those with no accent ('unaccented'). The default pitch is H, but all syllables after the accented syllable are L. The initial mora receives low pitch unless the syllable that contains it has an accent. The relation between lexical accent and pitch in syllables can be schematized as in (27). The important point to note is that all accented syllables receive high pitch on their first mora, but unaccented syllables can be either high or low in pitch depending on their positions.

- (27) Lexical accent and pitch of syllables



This mapping relation allows us to isolate the effects of accentuation and pitch. If lexical pitch has any bearing on the pattern of syllable preservation/omission, we expect to see a difference in the behavior of accented and unaccented high syllables independently of the contrast between high and low unaccented syllables. If we find a difference between high and low pitch unaccented syllables, however, the effects may be reducible to that of the individual pitch of each syllable.

The comparison of omission rates between accented and high unaccented syllables given in Table 11 reveals a main effect of accent, but only when there are three or more syllables in the target word. The omission rates between accented and high unaccented syllables are significantly different in multi-syllabic targets for three of the four children. But no significant effects are found in disyllabic targets.

As for pitch itself, it shows no effect on syllable deletion. The omission rates of unaccented high and low syllables, given in Table 12, are not significantly different.

In sum, we have seen that accent protects syllables from deletion in long targets. The preservation effect of accented syllables depends on target size but cannot be reduced to the effect of pitch itself. This excludes accent (and pitch) as a cause of early word truncation.

Table 11. Comparison of omission rates between accented high and unaccented high syllables (%)

	In disyllabic target words			In multisyllabic target words		
	Accented	Unaccented	$\chi^2(1)$	Accented	Unaccented	$\chi^2(1)$
Hiromi	0.3 (2/631)	0.2 (1/409)	0.14	0.0 (0/34)	15.5 (9/58)	4.22*
Takeru	0.1 (1/774)	1.2 (3/250)	3.11	6.1 (11/179)	7.1 (17/241)	0.04
Kenta	0.7 (7/960)	1.7 (5/291)	1.31	15.1 (38/251)	36.4 (90/247)	28.47**
Aki	0.5 (2/416)	2.6 (7/272)	3.80	7.3 (9/124)	24.6 (28/114)	12.26**

* p<0.05, ** p<0.01; with Yates' correction factor.

Table 12. Comparison of omission rates between unaccented high and low syllables (%)

	In disyllabic target words			In multisyllabic target words		
	High	Low	$\chi^2(1)$	High	Low	$\chi^2(1)$
Hiromi	0.2 (1/409)	0.4 (4/949)	0.00	15.5 (9/58)	25.0 (16/64)	1.14
Takeru	1.2 (3/250)	2.6 (21/796)	0.01	7.1 (17/241)	9.1 (34/375)	0.00
Kenta	1.7 (5/291)	3.2 (31/984)	0.65	36.4 (90/247)	36.2 (157/434)	0.54
Aki	2.6 (7/272)	6.1 (24/395)	0.58	24.6 (28/114)	20.5 (42/205)	0.49

Syllable position

Research in child English and child Dutch has shown that word-final syllables are less susceptible to omission. A similar pattern obtains in child Japanese, although the effect of syllable position also interacts with accentuation. Let us examine the accented and unaccented syllables separately. As shown in Table 13, preservation of accented syllables is not affected by their positions within the word. No significant difference is found in the omission rates of accented syllables in different positions, either in disyllabic targets or multisyllabic targets.

Table 13. Proportion of accented syllables omitted as a function of position in adult target words (%)

	In disyllabic target words			In multisyllabic target words			
	Initial	Final	$\chi^2(1)$	Initial	Medial	Final	$\chi^2(2)$
Hiromi	0.3 (2/578)	0.0 (0/51)	0.77	0.0 (0/27)	0.0 (0/4)	0.0 (0/27)	N/A
Takeru	0.0 (0/602)	0.6 (1/173)	0.01	5.3 (4/76)	8.0 (7/88)	0.0 (0/15)	1.58
Kenta	0.7 (6/855)	1.0 (1/98)	0.78	13.2 (12/91)	17.1 (25/146)	7.1 (1/13)	1.41
Aki	0.0 (0/245)	1.2 (2/172)	0.94	0.0 (0/39)	11.1 (9/81)	0.0 (0/4)	2.08

Thus no matter what position they occupy in the target word, accented syllables tend to escape deletion. The following examples are illustrative. The location of accent is indicated by an acute accent mark.

(28) Retention of accented syllables

- a. /bídeo/ [bijə] ‘video’ Hiromi (1;7.17)
- b. /bánana/ [bana] ‘ball’ Hiromi (1;10.23)
- c. /obá:tʃa/ [ba:] ‘gramma’ Takeru (1;4.24)
- d. /dʒidó:ʃa/ [dorda] ‘car’ Kenta (1;7.16)
- e. /tjimpándʒi/ [paʒe] ‘chimpanzee’ Aki (1;11.29)
- f. /mužukafí/ [kaʃi] ‘difficult’ Hiromi (1;7.3)

On the other hand, syllable position does influence the omission of unaccented syllables, albeit only in multisyllabic targets. The comparison is given in Table 14. While medial unaccented syllables in multisyllabic targets words are more likely to be omitted than are unaccented final syllables (and initial syllables in Hiromi’s data), no difference in omission rates of unaccented syllables due to their position is found in disyllabic targets.

Table 14. Proportion of syllables omitted as a function of position in unaccented adult target words (%)

In disyllabic target words			In multisyllabic target words			
Initial	Final	$\chi^2(1)$	Initial	Medial	Final	$\chi^2(2)$
Hiromi 0.7 (3/416)	0.1 (1/941)	1.91	9.5 (2/19)	55.8 (23/52)	20.9 (9/43)	11.01*†
Takeru 0.0 (0/63)	3.2 (5/156)	0.89	3.4 (1/29)	13.0 (16/123)	0.0 (0/89)	8.63*‡
Kenta 0.0 (0/43)	6.7 (11/165)	1.98	17.2 (5/24)	66.7 (46/69)	10.8 (4/33)	39.57**‡
Aki 7.4 (7/95)	4.0 (6/151)	0.74	18.5 (5/23)	51.9 (14/27)	3.2 (1/31)	21.62**‡

* $p < 0.05$, ** $p < 0.01$

† Initial < Medial ($p < 0.05$); Medial > Final ($p < 0.05$), ‡ Medial > Final ($p < 0.01$).

What these data mean is that, when unaccented, medial syllables are generally more likely to be deleted than final syllables. But other things being equal, initial syllables in disyllabic targets are not more likely to delete than are final syllables. Thus syllable position is yet another factor that depends on target size. We conclude that syllable position by itself does not cause syllables to delete.

Disyllabic maximality

The preceding subsections identified two factors that render syllables more susceptible to deletion regardless of the size of the adult target: vowel devoicing and marked segments between homorganic vowels. These are independent

factors of syllable omission whose effects should not be confused with putative templatic effects imposed by structural restrictions on possible output forms.

When the effects of devoicing and marked segments are removed, there is little omission observed in disyllabic targets. Table 15 gives the proportion of disyllabic targets produced as monosyllabic forms. Target words containing devoiced vowels or /r/ are excluded from consideration. At most, approximately 10% of the disyllabic targets may be truncated to monosyllables, but the majority of disyllabic targets maintain both syllables.

Table 15. Proportion of disyllabic targets produced as monosyllabic forms (%)

	-1;6	1;7–1;8	1;9–1;10	1;11–2;0
Hiromi	4.3 (17/394)	3.2 (2/62)	2.3 (9/394)	0.6 (2/349)
Takeru	2.7 (1/37)	8.5 (12/142)	2.7 (14/504)	0.2 (1/560)
Kenta	0.0 (0/35)	0.0 (0/198)	0.8 (1/126)	1.2 (1/81)
Aki	0.0 (0/4)	10.5 (2/19)	8.3 (1/12)	6.7 (5/75)

In contrast, the production of targets that are trisyllabic or longer exhibits a very different pattern, which is presented in Table 16. Until around 1;8, most of these targets produced by Hiromi and Takeru are reduced, particularly, to disyllabic structures. Although Kenta and Aki produce too few multisyllabic target words to draw reliable conclusions, their data are also consistent with this pattern.

Thus there is an early stage of production where targets larger than disyllables are truncated while disyllabic targets are left intact, indicating that there is a disyllabic maximum on prosodic words during this period. This stage overlaps with the period when monomoraic targets are augmented — a phenomenon attributed to bimoraic minimality. In other words, the initial stage of production is characterized by prosodic words which are minimally bimoraic and maximally disyllabic. These are precisely the minimal and maximal sizes of a single binary foot. Following the Minimal Word Hypothesis of Demuth and Fee (1995), we can analyze the earliest Japanese words as having the following structures.

- (29) Licit PrWds in the ‘minimal word’ stage
- a. $\text{PrWd}[\text{Ft}(\sigma_{\mu\mu})]$
 - b. $\text{PrWd}[\text{Ft}(\sigma\sigma)]$

The minimal size effect derives when the prosodic word is monosyllabic. Since a monosyllable must satisfy Foot Binarity at the moraic level, it must contain two moras. The maximal size effect obtains because the earliest words are the

Table 16. Proportion of trisyllabic and longer targets produced as monosyllabic or disyllabic forms (%)

	-1;6	1;7–1;8	1;9–1;10	1;11–2;0
<i>Hiromi</i>				
Monosyllabic	0.0 (0/18)	0.0 (0/31)	0.0 (0/19)	0.0 (0/18)
Disyllabic	100.0 (18/18)	96.8 (30/31)	42.1 (8/19)	27.8 (5/18)
<i>Takeru</i>				
Monosyllabic	33.3 (1/3)	3.1 (1/32)	0.0 (0/95)	0.0 (0/189)
Disyllabic	66.7 (2/3)	81.3 (26/32)	24.2 (23/95)	5.8 (11/189)
<i>Kenta</i>				
Monosyllabic	— (0/0)	0.0 (0/5)	0.0 (0/4)	0.0 (0/3)
Disyllabic	— (0/0)	80.0 (4/5)	50.0 (2/4)	100.0 (3/3)
<i>Aki</i>				
Monosyllabic	— (0/0)	0.0 (0/1)	100.0 (1/1)	8.3 (1/12)
Disyllabic	— (0/0)	100.0 (1/1)	0.0 (0/1)	50.0 (6/12)

minimal structures that fulfill the structural requirements of the prosodic word. Any structure that contains more than two syllables will exceed the maximal size of a well-formed binary foot.

It should be noted that these early words are not prosodically ‘minimal’ at all levels of representation. The disyllabic form in (29b) is not necessarily minimal in terms of moras because they are allowed to contain heavy syllables. Thus the analysis here counts forms such as $_{\text{PrWd}}[\text{Ft}(\sigma_{\mu\mu}\sigma_{\mu})]$ and $_{\text{PrWd}}[\text{Ft}(\sigma_{\mu\mu}\sigma_{\mu\mu})]$ as ‘miminal words’ consisting of a single binary foot. This is particularly interesting in light of the evidence that feet in adult Japanese are consistently bimoraic (Poser, 1990). The size restrictions of early production in Japanese therefore seem to reflect the universal effects of Foot Binarity, which can be satisfied disjointedly either at the syllable or mora level, rather than that of the language-specific foot structure in Japanese.

Section summary

Two types of evidence have been presented for the internal prosodic structure of early Japanese words: (a) Bimoraic minimality effects as attested in the lengthening of monomoraic lexical items; (b) Disyllabic maximality effects in the early production of multisyllabic words. These restrictions can be unified under the analysis that the child’s word form is a prosodic word with a single binary foot. The templatic restrictions observed in a language such as Japanese, which does not have a stress system or a bimoraic minimality condition on all

lexical words, present a strong case for the existence of word-internal structure with feet in early phonology.

4. Divergence of early phonological forms

4.1 Optimality Theory and child-adult differences in prosodic structure

The analysis so far shows that early phonological grammar does not differ fundamentally from mature grammar with respect to the set of constituents that make up prosodic structures and the ways in which those constituents are organized within a particular structure. This leaves us with the task of explaining the apparent divergence of early prosodic forms from the adult targets. Why do the shapes of early syllables and words differ from that of adult targets if their internal organization is regulated by the same mechanisms? The account presented here builds on the Optimality Theoretic idea that each stage of the child grammar differs from the adult grammar in how it prioritizes the representational conditions. These structural requirements are stated as constraints.

- (30) Relevant markedness constraints
 - a. NoCoda (Prince & Smolensky, 1993): A syllable must not have a coda.
 - b. * $\mu/\langle\text{seg}\rangle$ (Morén, 1999; cf. Zec, 1988): Moras must not be associated with a particular segment.
* μ/obs : No moraic obstruents.
* μ/son : No moraic sonorants.
 - c. FTBIN (Foot binarity; Prince, 1980): Feet must be binary under syllabic or moraic analysis.
 - d. PARSE- σ (Prince & Smolensky, 1993): Syllables must be parsed into feet.
 - e. ALLFTLEFT (McCarthy & Prince, 1993): Every foot must be left-aligned with a prosodic word.
- (31) Relevant faithfulness constraints (McCarthy & Prince, 1995; McCarthy, 2000)
 - a. MAX(seg): No deletion of segments.
 - b. DEP(seg): No epenthesis of segments.
 - c. MAX(μ): No deletion of moras.
 - d. DEP(μ): No epenthesis of moras.
 - e. NODELINK(μ, seg): Mora-segment associations in the Input must be maintained by the corresponding elements in the Output.

- f. NoSPREAD(μ , seg): Mora-segment associations in the Output must be maintained by the corresponding elements in the Input.

$\text{MAX}(\mu)$, $\text{DEP}(\mu)$, $\text{NoDELINK}(\mu, \text{seg})$ and $\text{NoSPREAD}(\mu, \text{seg})$ are faithfulness constraints on moraic structure. $\text{MAX}(\mu)$ and $\text{DEP}(\mu)$ prohibit deletion and insertion of moras, respectively. $\text{NoDELINK}(\mu, \text{seg})$ and $\text{NoSPREAD}(\mu, \text{seg})$ ensure that the association between moras and segments is maintained between the Input and the Output. $\text{NoDELINK}(\mu, \text{seg})$ demands that there be an association between an Output segment and an Output mora if there is a segment-mora association between their Input correspondents. $\text{NoSPREAD}(\mu, \text{seg})$ is the opposite mechanism: it requires that an Input segment and an Input mora be associated if there is a segment-mora association between their Output correspondents.

If we adopt the hypothesis that learning starts off with a constraint hierarchy in which all markedness constraints dominate all faithfulness constraints, the initial ranking will be as below.¹³

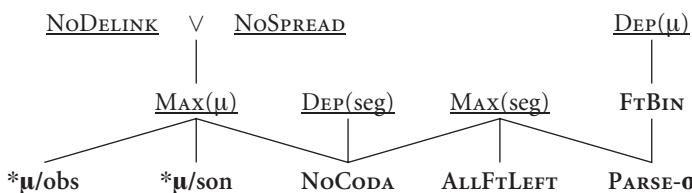
- (32) Initial-state constraint ranking
- NoCODA, * μ/obs , * μ/son , FTBIN, PARSE- σ , ALLFTLEFT
 (Markedness)
 »
 MAX(seg), DEP(seg), MAX(μ), DEP(μ), NoDELINK, NoSPREAD
 (Faithfulness)

The end state of learning must include the following domination relations of constraints. (a) Adult Japanese allows codas, so both $\text{MAX}(\text{seg})$ and $\text{DEP}(\text{seg})$ must be ranked above NoCODA (refer to the ranking demonstration in Table 4): $\text{MAX}(\text{seg}), \text{DEP}(\text{seg}) \gg \text{NoCODA}$. (b) To allow sonorant and obstruent geminates, the faithfulness constraint that protects underlying moras must be ranked above the markedness constraints that ban moraic sonorants and moraic obstruents: $\text{MAX}(\mu) \gg *\mu/\text{obs}, *\mu/\text{son}$. (c) NoCODA must be ranked below $\text{MAX}(\mu)$ to let underlyingly moraic consonants surface as geminates (which violates NoCODA): $\text{MAX}(\mu) \gg \text{NoCODA}$. (d) An underlying mora associated to a consonant cannot be re-associated to a neighboring vowel in order to avoid violations of $*\mu/<\text{seg}>$. Because such a repair violates both NoDELINK and NoSPREAD, either one of these constraints must be ranked above $*\mu/\text{obs}$ and $*\mu/\text{son}$: $\text{NoDELINK} \vee \text{NoSPREAD} \gg *\mu/\text{obs}, *\mu/\text{son}$. (e) Assuming that Proper Headedness always requires a prosodic word to contain at least one foot, FTBIN is violated in Japanese by monomoraic words, which must have a monomoraic foot. The violation is forced by a faithfulness constraint that prohibits open-

thesis of moras, thus: $\text{DEP}(\mu) \gg \text{FTBIN}$. (f) A prosodic word with the structure $\sigma_\mu\sigma_\mu\sigma_\mu$ has a syllable that cannot be incorporated into a binary foot, e.g., $(\sigma_\mu\sigma_\mu)\sigma_\mu$. The leftover syllable violates $\text{PARSE-}\sigma$, but the violation is not avoided through deletion of segments that compose the syllable. Nor is it avoided by forcing a third syllable into a foot, thereby violating FTBIN . Therefore, both $\text{MAX}(\text{seg})$ and FTBIN must be ranked above $\text{PARSE-}\sigma$: $\text{MAX}(\text{seg}), \text{FTBIN} \gg \text{PARSE-}\sigma$. (g) There are also longer prosodic words that contain more than one foot, e.g., $(\sigma_\mu\sigma_\mu)(\sigma_\mu\sigma_\mu)$. Such structures violate ALLFTLEFT , but deletion of segments is not employed as a strategy to avoid the violation. Hence: $\text{MAX}(\text{seg}) \gg \text{ALLFTLEFT}$.

These ranking relations are summarized in the schematization shown below where a domination relation is indicated by a line connecting a dominating (higher) constraint and a dominated (lower) constraint. Markedness constraints are shown in boldface and faithfulness constraints are underlined. Note that many of the Markedness » Faithfulness relations in the initial state are now reversed.

(33) End-state constraint ranking



Each developmental stage then realizes some interim ranking that stands between the initial-state ranking in (32) and the end-state ranking in (33). The following subsections show how child phonology phenomena can indeed be seen as consequences of such interim rankings, or in some cases, the initial ranking. Due to space limitation, we will focus on two aspects of the data: first, the asymmetric production of geminates and nasal coda targets, and second, the size limits of early words.

4.2 Production of geminate and nasal coda targets

The data analyzed here are taken from the second identifiable stage in the development of rhyme structure.¹⁴ In the first stage there are no post-vocalic consonants: all geminates are reduced to singletons and non-geminates are deleted. The second stage is characterized by two general patterns. First, geminates are only available in nasals, and obstruent geminates are reduced to

singleton consonants in Hiromi's and Kenta's data (34a-d). Second, nasal codas are deleted variably (e vs. f). When deleted, they trigger compensatory lengthening (f-h).

(34) Production of geminate and nasal coda targets in Stage 2

- a. /napnna/ [nanna] 'kitty' Hiromi (1;1.20)
- b. /oppai/ [o:bai] 'breast milk' Hiromi (1;4.9)
- c. /mamma/ [mamma] 'food' Kenta (1;7.16)
- d. /motto/ [madɔ] 'more' Kenta (1;8.27)
- e. /nanda/ [nanda] 'what's (that)?' Kenta (1;8.27)
- f. /nanda/ [na:da] 'what's (that)?' Kenta (1;8.27)
- g. /osembe:/ [me:mɛ:] 'rice cracker' Hiromi (1;3.25)
- h. /dʒampu/ [da:kʊ] 'jump' Takeru (1;7.17)

In the following analysis of the data, the Input to the grammar is taken to be the target surface form. Phonetically detectable length contrasts are encoded in the underlying representation. For example, long vowels come with two underlying moras, and short vowels and geminates come with one underlying mora. Some prosodic structures may not be phonetically apparent. These are assigned temporary underlying prosodic structures, whose full motivation will be given in Section 5.

We start with the asymmetry between nasal and obstruent geminates, which can be explained by postulating the following ranking among $*\mu/\text{obs}$, $*\mu/\text{son}$, $\text{MAX}(\mu)$ and NoCoda .

(35) $*\mu/\text{obs} \gg \text{MAX}(\mu) \gg *\mu/\text{son}, \text{NoCoda}^{15}$

Input: $m\alpha^\mu m^\mu a^\mu$ 'food'	$*\mu/\text{obs}$	$\text{MAX}(\mu)$	$*\mu/\text{son}$	NoCoda
a. $m\alpha^\mu m^\mu$ [mama]		$*!$		
b. $m\alpha^\mu m^\mu a^\mu$ [mamma]			*	*

The constraint $*\mu/\text{obs}$ is irrelevant to the evaluation of nasal geminates. The decision is handed down to the other constraints. Candidate (a) is eliminated because it incurs a fatal violation of $\text{MAX}(\mu)$. The geminate candidate (b) is the winner despite its violation of $*\mu/\text{son}$ and NoCoda .

When evaluating obstruent geminates, $*\mu/\text{obs}$ exerts its effects. In (36) the faithful candidate (b) violates $*\mu/\text{obs}$, and the degeminated candidate (a) violates $\text{MAX}(\mu)$. Due to the ranking between these constraints, the degeminated candidate (a) is the winner. This ranking therefore explains the different treatments of target nasal geminates and obstruent geminates.

(36) $*\mu/\text{obs} \gg \text{MAX}(\mu) \gg *\mu/\text{son}$, NoCODA

Input: mo ^μ t ^μ o ^μ 'more'	μ/obs	$\text{MAX}(\mu)$	μ/son	NoCODA
a. mo ^μ t ^μ [moto]		*		
b. mo ^μ t ^μ o ^μ [motto]	*!			*

Next, we will consider the different repairs applied to the deletion of place-assimilated nasal codas and the degemination case. As shown in (34), deletion of (non-geminate) nasal codas is variable at this stage. Several approaches to variability within OT have been proposed. Here, we will adopt the proposal by Anttila (1995) in analyzing such variability as free ranking of constraints. When two constraints A and B are ranked freely, there will be two alternating ranking instantiations: A » B and B » A. Thus if NoCODA and MAX(seg) are freely ranked, two different domination relations arise: NoCODA » MAX(seg) and MAX(seg) » NoCODA. This is illustrated below in a twin tableau with the two ranking instantiations. When the free ranking realizes as NoCODA » MAX(seg), the candidate with nasal coda deletion is optimal (37c). When it realizes as MAX(seg) » NoCODA the faithful candidate (d) is the winner.

(37) $\text{DEP}(\text{seg}) \gg \{\text{NoCODA}, \text{MAX}(\text{seg})\}$

Input: nanda 'what'	$\text{DEP}(\text{seg})$	NoCODA	$\text{MAX}(\text{seg})$
a. nanda		*!	
b. nanida	*!		
c. nada			*

Input: nanda 'what'	$\text{DEP}(\text{seg})$	$\text{MAX}(\text{seg})$	NoCODA
d. nanda			*
e. nanida	*!		
f. nada		*!	

When the nasal coda is deleted, it induces vowel lengthening. Since this is clearly a case of moraic conservation, we need to postulate that the mora that lengthens the vowel originates in the Input, being associated with the nasal. This assumption runs counter to the standard understanding of (under)specification, which eliminates predictable elements from the underlying material. The justification of this decision will be given in the next section. For now, we will proceed with the stipulation that the nasal is underlyingly moraic. The force that preserves this mora after the deletion of the nasal coda must be $\text{MAX}(\mu)$,

but conserving the mora through re-association to the preceding vowel violates NoSPREAD. Because it is better to violate NoSPREAD than to violate MAX(μ), MAX(μ) must dominate NoSPREAD.

(38) MAX(μ) » NoSPREAD

Input: na ^μ n ^μ da ^μ 'what'	MAX(μ)	NoSPREAD
a. na ^{μμ} da ^μ [na:da]		*
b. na ^μ da ^μ [nada]	*!	

However, there is a problem in applying the ranking of these two constraints to Kenta's repair of geminates. The data show that he simply reduces obstruent geminates to singleton without compensatory lengthening, e.g. /motto/ → [moto] 'more.' But the ranking so far wrongly chooses an Output candidate with compensatory lengthening.¹⁶

(39) * μ /obs » MAX(μ) » NoSPREAD

Input: mo ^μ t ^μ o ^μ 'more'	* μ /obs	MAX(μ)	NoSPREAD
a. mo ^μ to ^μ [moto]		*!	
b. mo ^{μμ} to ^μ [mo:to]			*
c. mo ^{μt^μo^μ [motto]}	*!		

What appears to be marked about candidate (b) is that the mora-segment association in the Output does not match that in the Input. Consequently, the faithfulness constraint on mora-segment association, NoDELINK, must be ranked above MAX(μ). The expanded constraint ranking is given in (40).

(40) Kenta: * μ /obs, NoDELINK » MAX(μ) » NoSPREAD

Input: mo ^μ t ^μ o ^μ 'more'	* μ /obs	NoDELINK	MAX(μ)	NoSPREAD
a. mo ^μ to ^μ [moto]			*	
b. mo ^{μμ} to ^μ [mo:to]		*!		*
c. mo ^{μt^μo^μ [motto]}	*!			

Candidate (b), which was the unwanted winner in (39), is now correctly eliminated due to its failure to respect NoDELINK. The second mora in the Input is associated with /t/, but in the Output it is associated with [o] instead of the corresponding [t]. This constitutes a violation of NoDELINK. The actual winner (a), on the other hand, does not violate NoDELINK. The second mora in

the Input is missing a correspondent in the Output. Therefore, the correspondent of /t/, which is associated with the deleted mora in the Input, does not have to be associated with it in the Output. Thus (a) vacuously satisfies NoDELINK. Crucially, this ranking does not affect the evaluation of (39), as the expanded tableau in (41) demonstrates. Here again, the reassociation of a mora induced by nasal coda deletion does not violate NoDELINK, in this case because the lack of a corresponding segment in the Output means that the second mora has no prescribed association line to maintain.

(41) Kenta: NoDELINK » MAX(μ) » NoSPREAD

Input: na ^μ n ^μ da ^μ 'what'	NoDELINK	MAX(μ)	NoSPREAD
a. na ^μ da ^μ [na:da]			*
b. na ^μ da ^μ [nada]		*!	

We must not forget, however, that another child, Hiromi, exhibits compensatory lengthening accompanied by degemination, e.g. /oppai/ → [ɔ:pai] 'breast.' In her case, then, NoDELINK must be ranked below MAX(μ).

(42) Hiromi: * μ /obs » MAX(μ) » NoDELINK, NoSPREAD

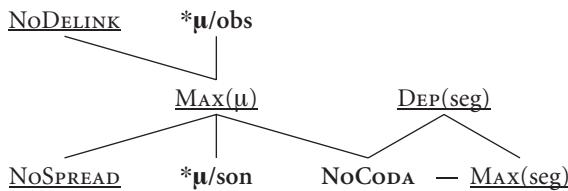
Input: o ^μ p ^μ a ^μ i ^μ 'breast'	* μ /obs	MAX(μ)	NoDELINK	NoSPREAD
a. o ^μ p ^μ a ^μ i ^μ [opai]		*!		
b. o ^μ p ^μ a ^μ i ^μ [ɔ:pai]			*	*
c. o ^μ p ^μ a ^μ i ^μ [oppai]	*!			

In sum, we can explain the asymmetric behaviors of nasal and obstruent geminates and the deletion and repair of nasal codas in terms of the ranking of markedness and faithfulness constraints. The overall ranking that accounts for this aspect of the data is summarized in (43). As with the adult ranking summary in (33), markedness constraints are shown in boldface and faithfulness constraints are underlined. Several indications of the intermediate nature of the ranking can be found in the hierarchies of both children. For example, MAX(μ), which is ranked below * μ /obs and * μ /son in the initial state but above both * μ /obs and * μ /son in the end state, is ranked between them. The free-ranking between MAX(seg) and NoCoda, marked by a horizontal line, suggests a transitional stage between the initial ranking 'NoCoda » MAX(seg)' and the end-state ranking 'MAX(seg) » NoCoda'. Certain adult-rankings, such as 'Dep(seg) » NoCoda', are already achieved. Finally, a close inspection of the

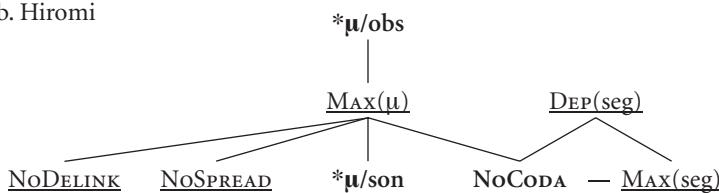
two hierarchies shows that the only difference in ranking between the two children resides in the ranking of NoDELINK with respect to MAX(μ).¹⁷

(43) Overall rankings

a. Kenta



b. Hiromi



4.3 Minimal and maximal size limits of early words

Let us now turn to the size limits of early Japanese words revealed in the augmentation of monomoraic targets and the truncation of targets with three or more syllables. Both phenomena can be seen as consequences of the initial ranking pattern with domination of faithfulness constraints by markedness constraints. The relevant markedness constraints are FTBIN, PARSE- σ and ALLFTLEFT, and the relevant faithfulness constraints are MAX(seg) and DEP(μ).

That the ranking 'FTBIN, PARSE- σ , ALLFTLEFT » MAX(seg)' gives rise to the disyllabic maximum of early words has been convincingly demonstrated by Pater and Paradis (1996) and Pater (1997) using English data. The same analysis applies to the Japanese data.¹⁸

(44) ALLFTLEFT, PARSE- σ , FTBIN » MAX(seg)

Input: tomodatſi 'friend'	ALLFTLEFT	PARSE- σ	FTBIN	MAX(seg)
a. $F_t(t\cdot o\cdot m\cdot o)_{F_t}(d\cdot a\cdot t\cdot ſi)$	*!			
b. $F_t(t\cdot o\cdot m\cdot)o\cdot d\cdot a\cdot t\cdot ſi$		**!		
c. $F_t(t\cdot o\cdot m\cdot o\cdot d\cdot a\cdot t\cdot ſi)$			*!	
d. $F_t(d\cdot a\cdot t\cdot ſi)$				****

The tableau in (44) shows the evaluation of a quadrisyllabic input in this hierarchy. Candidate (a) contains a second foot in violation of ALLFTLEFT. Trying to avoid this violation by leaving two syllables unparsed (Candidate (b)) or parsing all syllables in one foot (Candidate (c)) incurs violations of PARSE- σ or FTBIN, respectively. Candidate (d) satisfies all ALLFTLEFT, PARSE- σ and FTBIN at the expense of MAX(seg) violations, but because MAX(seg) is ranked below the other three constraints, this truncated candidate is the winner. This ranking therefore sets the upper limit of the size of the prosodic word at two syllables.

Next, the augmentation of monomoraic target words can be explained as the effect of the domination of the faithfulness constraint DEP(μ) by the markedness constraint FTBIN.

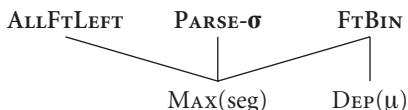
(45) FTBIN » DEP(μ)

Input: me $^\mu$ 'eye'	FTBIN	DEP(μ)
b. $F_t(me^\mu)$ [me]	*!	
a. $F_t(me^{\mu\mu})$ [me:]		*

As shown in (45), the targetlike realization of the monomoraic word will lose to an augmented Output candidate if FTBIN is ranked above DEP(μ) because it is less costly to insert a mora than to have a non-binary foot.¹⁹ The lengthening of the short vowel follows from this ranking.

Putting together the rankings in (44) and (45), the overall ranking of this stage of early phonology is summarized in (46). As the general pattern of Markedness » Faithfulness is maintained, (46) represents the intial-state domination relations of these constraints.

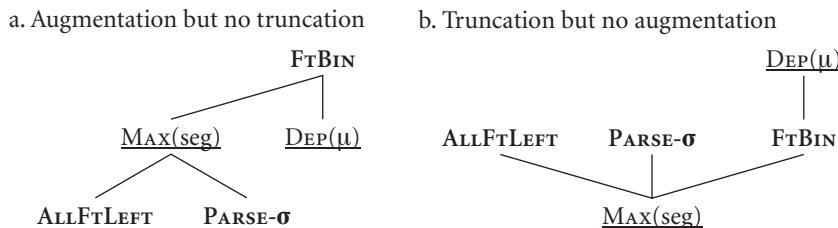
(46) Overall ranking for bimoraic minimum and disyllabic maximum



In the end-state ranking, some of these domination relations are reversed so that ALLFTLEFT and PARSE- σ are ranked below MAX(seg), and FTBIN and PARSE- σ below DEP(μ). The data indicate that the re-ranking does not necessarily happen all at once such that both the truncation and augmentation phenomena disappear simultaneously. Hiromi has a short period between 1;10–1;11 during which trisyllabic or longer targets are truncated while monomoraic

targets are no longer augmented. Kenta has a stage with a reversed pattern between 2;4 and 2;6 when no augmentation of monomoraic targets is observed but longer targets still undergo truncation. These two patterns of transitional stage can be seen as realizations of different interim rankings. Ranking (47a) exemplifies a grammar that augments sub-minimal targets, but does not truncate long targets, while ranking (47b) represents a grammar with truncation but not augmentation.

(47) Two possible interim rankings



These different transitional stages reflect the involvement of several relevant constraints that can be ranked independently of each other, and support the analysis that the so-called ‘minimal word’ stage is due to the interaction of these constraints, as illustrated in (46), rather than a single mechanism that prescribes a size restriction on early words.

4.4 Section summary

This section has presented OT analyses of the asymmetric production of geminates and nasal codas, and the size limits of early words. It was demonstrated that the divergence from the adult phonology can be explained without abandoning the idea that representational units and principles of prosodic organization remain unchanged over the course of the development. If those representational principles are implemented as rankable constraints, the same set of constraints, ranked differently, can account for both the adult grammar and the specific properties of early phonology. These rankings exhibit properties of a hypothesized initial constraint hierarchy and an interim ranking that stands between the initial state and the end state. An OT model of prosodic acquisition therefore offers a principled explanation of why the structures of early syllables and words differ from those of the adult targets.

5. Prosodic development in Optimality Theory

5.1 Conditions on re-ranking

An important criterion in evaluating a theory of language acquisition is the extent to which the model correctly predicts a common path of development while at the same time allowing for the individual differences attested in the data. A concern that is likely to be raised against an OT approach to prosodic development is that it is too powerful, allowing too wide a range of possible developmental patterns. The purpose of this section is to show that the case is otherwise. A constraint-based model of acquisition makes some precise predictions about the course of prosodic development, which are supported by the data analysis from Section 4. There are at least three types of conditions that regulate the possible patterns of development: (i) the assumption of the initial ranking, (ii) a priori universal rankings of markedness constraints and (iii) the inherent properties of constraint interaction.

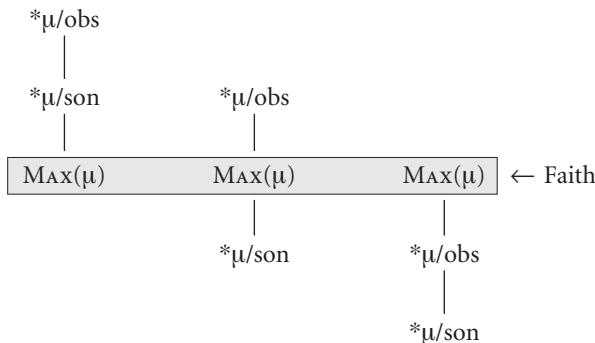
The first condition is demonstrated by Smolensky (1996a, 1996b), who argues that learnability considerations demand that the process of re-ranking be limited to steps that change the ranking of the type \mathcal{M} arkedness » \mathcal{F} aithfulness to \mathcal{F} » \mathcal{M} . Such re-ranking only requires positive evidence in the ambient data showing that a certain structure Σ , which violates \mathcal{M} , is allowed in the outputs of the grammar. Then \mathcal{M} can be demoted below \mathcal{F} , where \mathcal{F} is a faithfulness constraint that ensures the realization of Σ . In contrast, re-ranking \mathcal{F} » \mathcal{M} to \mathcal{M} » \mathcal{F} requires negative evidence that \mathcal{M} is not allowed. Since the \mathcal{M} -violating Σ is absent in the environment, no positive evidence is available to induce the re-ranking. This learnability argument leads to the conclusion that the initial state must be \mathcal{M} » \mathcal{F} , and the basic process of re-ranking involves the demotion of a markedness constraint below a relevant faithfulness constraint. Otherwise, some properties that arise from the interaction of the \mathcal{M} » \mathcal{F} type will never be acquired.

The second source of restrictions on constraint re-ranking is the a priori ranking among certain markedness constraints. For example, because of the implicational relation that holds cross-linguistically on the sonority threshold of moraicity, the constraints $^*\mu/\text{obs}$ and $^*\mu/\text{son}$ are universally ranked as $^*\mu/\text{obs}$ » $^*\mu/\text{son}$. That is, moraic obstruents are always more marked than moraic sonorants. Since this fixed domination relation is also expected to hold at any time during the development, the interaction between these constraints and others will be restricted.

Let us apply the first and second types of ranking restrictions to the constraints $\text{MAX}(\mu)$, $*\mu/\text{obs}$ and $*\mu/\text{son}$. Assuming a stepwise re-ranking process, the only possible pattern of development is the following.

(48) Interaction between $*\mu/\langle \text{seg} \rangle$ and $\text{MAX}(\mu)$

a. Initial state → b. → c. End state



This re-ranking schema predicts that the initial state permits no geminates. If the target language has both sonorant and obstruent geminates, the sonorant geminates appear before the obstruent geminates (or simultaneously, if Step b is to be skipped). This is precisely what we observe in the child Japanese data. Initially, there is a stage where both nasal and obstruent geminates are reduced to singleton consonants. Then for some children, there is an asymmetric stage in which only nasal geminates are available. This is followed by the adultlike stage that allows both nasal and obstruent geminates. More generally, we predict that in languages that have both sonorant and obstruent geminates, obstruent geminates never develop before sonorant geminates. In languages without geminates, we predict that there is never a stage in which children produce geminates.

The third source of restriction emerges from the inherent properties of constraint interaction. Aside from the markedness over faithfulness assumption and some universally fixed rankings, the rankings among most constraints are not prescribed. But the mathematical combination of a set of constraints does not translate to the number of possible grammars. Some grammatical patterns are never generated no matter how the constraints are ranked.

Take for example the constraints NoDELINK , $\text{MAX}(\mu)$ and NoSPREAD , whose ranking yields different repair strategies for the deletion of moraic

segments. If the whole range of permutations can occur during development, we will obtain six different rankings. These are given in Table 17.

Table 17. Ranking NoDELINK, MAX(μ) and NoSPREAD

Ranking	Repairs	
	Degemination	Coda deletion
a. NoDELINK » MAX(μ) » NoSPREAD	No CL	CL
b. NoDELINK » NoSPREAD » MAX(μ)	No CL	No CL
c. MAX(μ) » NoDELINK » NoSPREAD	CL	CL
d. MAX(μ) » NoSPREAD » NoDELINK	CL	CL
e. NoSPREAD » MAX(μ) » NoDELINK	No CL	No CL
f. NoSPREAD » NoDELINK » MAX(μ)	No CL	No CL

The right column shows the expected repair strategies for degemination and deletion of non-geminate codas. We see that even though there are six rankings, they only yield three possible patterns: (i) no compensatory lengthening for either degemination or coda deletion; (ii) no compensatory lengthening for degemination, but compensatory lengthening for coda deletion; and (iii) compensatory lengthening for both degemination and coda deletion. Pattern (i) is attested in the early stages of the Japanese children's development. Kenta's second stage fits Pattern (ii) as he shows no CL when reducing obstruent geminates (e.g. /totte/ → [tote]), but he compensates the deletion of nasal coda with lengthening (e.g. /nanda/ → [na:da]). Pattern (iii) corresponds to the second identifiable stage of Hiromi's development where both degemination and nasal coda deletion are accompanied by CL (e.g. /oppai/ → [ɔ:bai], /wanwan/ → [wa:wə]). However, the pattern excluded by Table 17 is not attested. That is, no child seems to go through a stage where degemination causes compensatory lengthening, but deletion of non-geminate codas is not repaired by lengthening. This prediction should apply to learners of any language that has geminates and non-geminate codas.

We identified three types of conditions that regulate the way constraints can be re-ranked to generate paths of developments. The possible patterns of development are bound by the initial ranking condition, a priori rankings of certain markedness constraints and the nature of the interaction between certain constraints. The upshot of this discussion is that OT properly demarcates the possible range of developmental variability and permits flexibility only within the limits.

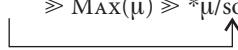
5.2 Mechanisms of re-ranking

The standard view on constraint re-ranking is that the adjustment is driven by ‘error,’ or by detecting the mismatch between what the learner hears and what the learner’s grammatical system produces (Tesar & Smolensky, 1998). An important assumption of this model is that the relevant information that flags such a mismatch is phonetically detectable. This seems like a reasonable assumption, particularly in the domain of segmental structure, and, to some extent, in the area of prosodic structure as well. Thus, for example, by noticing distinctive consonant length the learner can mark violations of relevant markedness constraints (i.e., $*\mu/\langle \text{seg} \rangle$) and use the information for re-ranking.

However, some prosodic contrasts are not surface detectable, at least not directly. For example, there is no reliable phonetic cue that distinguishes a moraic coda from a non-moraic one. That is, CV^μC and CV^μC^μ will have the same phonetic realization. One way to tell the difference is to learn whether CVC syllables pattern with CV syllables or CVV syllables. In a stress language, there appear to be many cues that provide the child with the relevant information (Dresher, 1999). However, in Japanese this type of evidence is confined to peripheral metrical structure and prosodic morphology, which is unlikely to be accessible to children before the age of 2.²⁰ How do Japanese-speaking children know that codas are moraic in their language?

Mechanisms of constraint re-ranking in OT provide a solution to this puzzle. In constraint-ranking terms, to know that a nasal coda is moraic is to know that the constraint that imposes weight-by-position (WxP) is ranked above the constraint that militates against moraic nasal ($*\mu/\text{son}$). Due to the condition on the initial-state ranking, these markedness constraints start off above all faithfulness constraints, including MAX(μ). When the learner detects consonant weight distinction through the existence of nasal geminates, $*\mu/\text{son}$ will be demoted below MAX(μ). Because MAX(μ) is ranked below WxP, it follows that WxP now outranks $*\mu/\text{son}$.²¹

(49) Establishing a ranking without direct phonetic evidence

1. The initial state: $\text{WxP}, *\mu/\text{son} \gg \text{MAX}(\mu)$
2. Length contrast of nasals detected: $\text{WxP} \qquad \gg \text{MAX}(\mu) \gg *\mu/\text{son}$

3. Moraicity of nasal codas established: $\text{WxP} \gg *\mu/\text{son}$

The interesting question to ask now is whether this re-ranking has any impact on the underlying representation of nasal codas. The assumption that the child's underlying form is the target surface form does not help much. For example, the difference between the Outputs [na^μn^μda^μ] and [na^μnda^μ] cannot be determined from the surface phonetics. On top of that, there are many Inputs, including /na^μn^μda^μ/ and /na^μnda^μ/, which can be mapped to these Outputs. The decision can be made unambiguously if we credit the learner with a systematic strategy in analyzing the underlying structure through a phonetically interpreted target structure.

(50) Lexicon Optimization (Prince & Smolensky, 1993, pp. 192)

Suppose that several different inputs I_1, I_2, \dots, I_n when parsed by a grammar G lead to corresponding outputs O_1, O_2, \dots, O_n , all of which are realized as the same phonetic form Φ — these inputs are all *phonetically equivalent* with respect to G . Now one of these outputs must be the most harmonic, by virtue of incurring the least significant violation marks: suppose this optimal one is labeled O_k . Then the learner should choose, as the underlying form for Φ , the input I_k . (Italics original)

Lexicon optimization can inform the learner which Input should be stored as the underlying representation of a given lexical item, when more than one Input form leads to multiple Output forms that match the surface phonetic form of the adult target. An analytic device called the ‘tableau-des-tableaux’ (Itô, Mester, & Padgett, 1995) allows us to see how simultaneous optimization of the Input and Output can be attained in ambiguous cases.

(51) Optimizing the input for the moraicity of non-final codas

Input	Output	WxP	*μ/son	DEP(μ)
A na ^μ n ^μ da ^μ	a. na ^μ n ^μ da ^μ		*	
	b. na ^μ nda ^μ	*!		

Input	Output	WxP	*μ/son	DEP(μ)
B na ^μ nda ^μ	? a. na ^μ n ^μ da ^μ		*	*💀
	b. na ^μ nda ^μ	*!		

In (51) there are two Input forms. In Input (A), the coda has an underlying mora. In Input (B), the coda is not moraic. For each Input, two Outputs are

evaluated. Both Output forms are phonetically equal, although their prosodic structures differ in a similar way to that in which Inputs (A) and (B) differ. The four Input-Output combinations are evaluated against the ranking $WxP \gg *μ/son$ and the constraint $DEP(μ)$ whose ranking with respect to the others is unknown. However, it is not necessary to know the precise ranking of $DEP(μ)$ to pick the optimal combination. Candidate combination (A-a) fares better than any other pairs in the evaluation against $WxP \gg *μ/son$ and that against $DEP(μ)$. Thus the best Input for this lexical item (indicated by ‘ $\ddot{\alpha}$ ’) has an underlying mora associated with the nasal coda.²²

Abstract prosodic structures that lack apparent phonetic realizations can present a problem to the learner. The discussion in this section has shown how OT provides an explicit mechanism that induces restructuring of the prosodic grammar through indirect phonetic evidence. It has also explained how the learner can specify the prosodic structure of the underlying representation using the process of Lexicon Optimization.

6. Conclusions and further issues

In this article, we first examined the existence of syllable-internal and word-internal prosodic structure in early language. Data from Japanese were shown to provide convincing evidence that the phonology of children between 1;0 and 2;0 includes a moraic structure and a word-internal structure that comprises feet, syllables and moras, which are regulated in terms of Proper Headedness and Foot Binarity. In this respect, this study buttresses the existing arguments for the continuity of fundamental prosodic representation between early child language and adult language.

These findings prepared us for an Optimality Theoretic analysis of the development of syllable-internal structure that assumes full access to the prosodic constituents and organizational principles, the latter being interpreted as violable constraints. It was shown that Optimality Theory not only succeeds in explaining the non-targetlike properties of early syllable-internal prosody, but also makes accurate predictions about the overall course of prosodic development and provides an account for the acquisition of prosodic structures that seemingly lack phonetic cues.

There are several relevant issues that could not be fully addressed in the study, and therefore had to be left for future research. One important question that requires further investigation is the exact division of labor between

universal representational principles and language-specific input in early phonology. For example, the fact that compensatory lengthening is clearly observable in child Japanese could be related to the mora-timing of the language, which provides unmistakable phonetic cues for skeletal prosodic positions. The observed augmentation of monomoraic targets and the disyllabic upper limit could be linked to the relative infrequency of monomoraic or multisyllabic words in early child directed speech. The sum of evidence collected here convincingly converges on the interpretation that these phenomena reflect the inherent properties of prosodic organization in human language rather than being artifacts of the surface input pattern. Nevertheless it is interesting to note that the manifestations of those properties can vary from one child language to another, resonating with the language-specific characteristics of the input.

Second, while Optimality Theory has contributed to our understanding of prosodic development, it has also brought some unresolved issues to the fore. One of the problems that came to light in this study is the nature of underlying representations in early phonology. The assumption that the child's lexical representation is identical to the adult surface form must certainly be subjected to further scrutiny. How the early lexical representations develop into adultlike representations is yet another question that has not been sufficiently addressed in previous research, but one that has to be tackled in order to make further advancement possible in this area.

Finally, certain predictions made by the model have to be tested against a wider variety of languages. Among them are the predictions that obstruent geminates do not develop ahead of sonorant geminates, and that in no child language should compensatory lengthening be induced only by degemination. Unfortunately, cross-linguistic data of geminate development appear to be too scant to test these cases. It is hoped that future research will generate the relevant descriptive work that allows refinement of the model presented here.

Notes

* This is a summary of my doctoral dissertation, which owes much to the guidance of the committee members, Donna Lardiere, Elizabeth Zsiga, Katherine Demuth and Laura Benua. I wish to express my gratitude to Frank Wijnen, Bruce Morén and two anonymous ARLA reviewers for helpful suggestions and comments on this version. Thanks are also due to Karen Kay for editorial assistance. All errors are mine.

1. The heavy syllable in (2e) is the first syllable closed by the first half of the geminate. The second syllable is only given to illustrate the prosodic structure of the geminate.
2. This appears to be the reason why there is no consensus in the literature as to when English-speaking children acquire a vowel length contrast (compare for example Demuth & Fee, 1995 with Salidis & Johnson, 1997).
3. To avoid confusion between the use of the word ‘input’ in this context and that in the sense of the ambient language children are exposed to, the capitalized ‘Input’ will be used hereafter in reference to a form that enters the computation of an OT grammar.
4. The constraints are placed in the order of domination from left to right. ‘*’ indicates a violation of the constraint. ‘!’ marks a fatal violation — one that excludes the candidate from consideration because there is a candidate that fares better in the evaluation. Shadowed cells are irrelevant to the evaluation because the decision is made by higher constraints. The optimal candidate is marked by ‘~~!~~’.
5. Even though all three households were essentially monolingual, the children did have some exposure to English through television and limited contact with speakers of English. However, no idiosyncrasy was discovered in a transcription-based comparison with data collected from children growing up in Japan (Fujiwara, 1977; Miyata, 1992, 1993, 1995; Noji, 1974–1977; Okubo, 1980, 1993).
6. Adult target forms are given between slashes. Child forms are shown in square brackets.
7. The point of release was operationalized as the left edge of a burst, fricative noise or formant structure, whichever appeared first depending on the segment type.
8. Some loanwords also have tautomorphemic (C)VVC syllables, e.g., [tʃe:N] ‘chain,’ [ko:N] ‘corn.’
9. See Morén (1999) for a different view on this issue.
10. In Takeru’s Stage 1, there are no productions of nasal geminates despite targetlike productions of obstruent geminates. This does not constitute counter-evidence to the sonority threshold prediction as lack of production does not by itself show that the relevant structure is unavailable in the system.
11. There are no monomoraic targets in earlier files. One possible explanation is that children are not exposed to many monomoraic words initially because in child-directed speech, they are often augmented through reduplication and prefixation: e.g., /me/ ‘eye’ → /o-meme/, /te/ ‘hand’ → /o-tete/.
12. A comparison with the second syllable of CV.CV targets shows that this lengthening is not due to a general final lengthening effect. When Hiromi’s productions of /me/ (‘eye’) and the final syllable of /mama/ (‘mama’) are compared, the former is found to be significantly longer than the latter [613.09 vs. 274.28 ms, $t(34)=5.53$, $p<0.01$].
13. The motivation for this hypothesis is explained in Section 5.1.
14. The timing of this stage varies from child to child. Hiromi: 1;2–1;5, Takeru: 1;5–1;9, Kenta: 1;7–1;10.

15. When there is no evidence available to rank two constraints with respect to each other, they are separated by a comma instead of a ‘‘.’’ The same relationship is indicated by a dotted line in the evaluation tableaux.
16. The bomb symbol in the tableau indicates a winner candidate that is not the actual output.
17. See Section 5.1 for further discussion of such individual differences.
18. For the sake of brevity, Pater and Paradis (1996) and Pater (1997) count Max violation in terms of the number of syllables deleted. The original proposal by McCarthy and Prince (1995) is maintained here in counting segmental violations. The difference is not crucial to the analysis.
19. Given that Proper Headeness is universally respected in all phonological representations (Selkirk, 1996), it is assumed that the requirement that each prosodic word to contain a foot is unrevokable. Thus the unfooted $_{\text{PrWd}}[\text{me}]$ is rejected as a candidate.
20. For example, accent assignment in compounds and loanwords reveals the CVC=CVV equation (McCawley, 1968; Tsujimura & Davis, 1987). Bimoraicity of CVC is also evident in prosodic morphology such as hypocoristic formation, compound abbreviations, rustic girls’ names (Itô, 1990; Mester, 1990; Poser, 1990). But there are no reports that young children use these operations productively.
21. An anonymous reviewer points out that this account of acquisition makes a typological prediction that all languages that have geminate consonants also observe weight-by-position. There is in fact typological evidence that corroborates this prediction (Tranel, 1991). Morén (1999), however, finds a partial exception to the generalization in Standard Swedish, which has geminates but also a weight distinction in coda consonants (i.e., some single coda consonants are non-moraic). The constraint ranking model proposed here will be supported if children acquiring Standard Swedish undergo a period of overgeneralization during which all non-geminate codas are taken to be moraic.
22. The reader can refer back to the analysis in Section 4.3 where it was stipulated that the nasal coda is underlyingly moraic. The arguments presented here motivate that assumption.

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