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Language and Speech 2008; 51; 385

DOI: 10.1177/0023830908099071

Compensatory Vowel Lengthening for Omitted Coda Consonants: A Phonetic Investigation of Children's Early Representations of Prosodic Words

Jae Yung Song, Katherine Demuth

Brown University, U.S.A.

Key words

compensatory vowel lengthening

minimal words

Abstract

Children's early word productions often differ from the target form, sometimes exhibiting vowel lengthening when word-final coda consonants are omitted (e.g., *dog* /dɔg/ → [dɔ:]). It has typically been assumed that such lengthening compensates for a missing prosodic unit (a mora). However, this study raises the alternative hypothesis that vowel lengthening in early productions compensates for the missing coda segment. If lengthening selectively occurs with short/lax vowels but not long/tense vowels, this would provide support for the hypothesis that lengthening serves to preserve bimoraic or 'minimal word' structure. However, if lengthening occurs across the board, this would indicate that lengthening compensates for the omitted segment. In order to address this issue, matched word pairs produced with and without a coda were extracted from the spontaneous speech of three English-speaking children between the ages of 1;1 and 2;6. Phonetic analysis compared the duration of vowels in words with and without the coda. The results showed that two children lengthened both short and long vowels when the coda was omitted, whereas one child selectively lengthened only short vowels. The implications of these findings, both for the representation of prosodic words, and for theories of production more generally, are discussed.

1 Introduction

Children's early word productions are often variable in form, with the same word being produced either with or without a word-final (coda) consonant. When the

Acknowledgments: Previous versions of this work have been presented at the Brown-UMass Amherst Workshop on Phonological Acquisition, the MIT Speech Communication Group, and the 10th Conference on Laboratory Phonology. We thank those audiences, John Kingston, Claartje Levelt, Elizabeth McCullough, James Morgan, Stefanie Shattuck-Hufnagel, Donca Steriade, and Megha Sundara for helpful comments and discussion. We are also grateful to the three reviewers for their thoughtful comments on the earlier version of this paper. This research was supported in part by NIH Grant R0IMH60922.

Address for correspondence. Jae Yung Song, Department of Cognitive and Linguistic Sciences, Brown University, Box 1978, Providence, RI 02912, U.S.A.; e-mail:<Jae_Yung_Song@brown.edu>

Language and Speech; 0023-8309; Vol 51(4): 385–402; 099071; DOI:10.1177/0023830908099071
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coda is not produced, children often exhibit processes of vowel lengthening or epenthesis (e.g., *dog* /dɔg/ realized as [dɔː] or [dɔgɔ]). The underlying motivation for these surface variants has been a topic of debate, raising questions about the nature of children's early phonological representations. For example, Fikkert (1994) proposed that Dutch-speaking children exhibited vowel epenthesis due to a preference for disyllabic (rather than monosyllabic bimoraic) feet. Stemberger (1992) suggested that vowel lengthening was used to compensate for the timing unit (the mora) of the missing coda consonant. Demuth and Fee (1995) proposed a unified analysis of these phenomena, suggesting that both epenthesis and vowel lengthening served the purpose of preserving a binary foot, or "minimal word" structure (the Word-Minimality Hypothesis). However, recent findings from four American English-speaking children show that some children lengthen both short and long vowels in the case of omitted codas, suggesting that children were maintaining the anticipated duration of target word even when coda segments were not produced (Demuth, Culbertson, & Alter, 2006). This raises the question of whether children's early vowel lengthening in the context of omitted codas is compensating for a missing prosodic unit (the mora), or for a missing coda segment. A more in-depth acoustic-phonetic investigation of this issue could tell us much about the nature of children's developing phonological knowledge, and would help explain some of the variability found in children's early productions.

Languages differ in the word structures they permit, with many showing lower-bound restrictions on the size of open-class lexical items, or prosodic words (see Selkirk (1984) for discussion of the Prosodic Hierarchy). For example, languages like English require well-formed prosodic words to contain at least two moras (μμ) of prosodic structure (Hammond, 1999). The English vowel system contains both long (tense, bimoraic) vowels /i, e, ɑ, o, ɔ, u/ and short (lax, monomoraic) vowels /æ, ʊ, ɛ, ɪ, ʌ/ (Ladefoged, 1993). Thus, the shortest possible prosodic word in English must contain a bimoraic syllable with either a coda consonant (e.g., *tin*; Figure 1(a)), or a long vowel (e.g., *tea*; Figure 1(b)) or diphthong (e.g., *tie*; Figure 1(c)). Since the syllable rhyme is typically thought to contain no more than two moras of structure, a word with a long vowel or diphthong plus a coda consonant may prosodify the consonant at a level of structure higher than the syllable rhyme (e.g., *teen*; Figure 1(d)) (cf., Kager & Zonneveld, 1986). All the above constitute well-formed open-class prosodic words of English, containing two moras of structure, or a binary (bimoraic) foot. In contrast, words containing only one mora of structure (i.e., a short vowel) can only function as closed class grammatical function items in English (e.g., *the*; Figure 1(e)). An open-class lexical item in English containing monomoraic structure would be considered subminimal, or prosodically ill-formed, though a word of this shape is prosodically well-formed in a language like French (e.g., *lait* /lɛ/ 'milk').

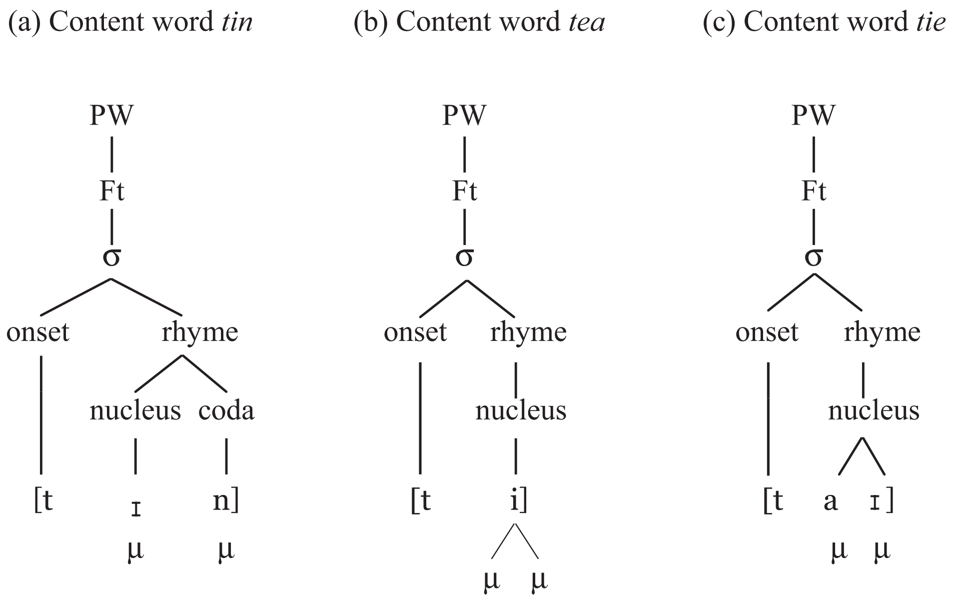
A binary foot is typically considered to be the unmarked form of prosodic words cross-linguistically (cf. McCarthy & Prince, 1990; Prince & Smolensky, 1993/2004) and various languages exhibit compensatory lengthening of short/monomoraic vowels to ensure word minimality (e.g., Sesotho */ʒa/ → [eʒa] ~ [ʒaː] 'eat') (cf. Hayes, 1989). Demuth and Fee (1995) and Demuth (1995) therefore proposed that children might exhibit an early universal stage of development where their words are minimally and maximally a binary foot (see Allen & Hawkins (1980) for similar proposals). Drawing on data from English and Dutch, they further suggested that children's word shapes followed a systematic course of development, expanding from core (CV) syllables to minimal words (binary feet), and eventually to larger, more complex phonological words (e.g., *elephant*, *banana*). Thus, they proposed that children's early use of vowel lengthening and the addition of an epenthetic vowel (e.g., *dog* /dɔg/ → [dɔ:] ~ [dɔgɔ]) could both be understood in terms of children's attempts to preserve word minimality.

Subsequent studies have attempted to evaluate the Word-Minimality Hypothesis by looking at an early stage of language development where children often produce words variably (e.g., *teeth* [tiθ] ~ [ti]). Salidis and Johnson (1997) examined productions of the English-speaking child Kyle aged between 0;11 and 1;8. The role of minimal words as a lower bound on the shape of prosodic words was supported by the low percentage of subminimal forms in the data, particularly before 1;4. Kyle also seemed to acquire vowel quality/length distinctions relatively early, rarely using long and short vowels interchangeably from the onset of production: Only one monosyllabic target word was produced with a long vowel when the coda was missing at 1;2 and 1;3 (*kick* /kɪk/ → [kɪt] ~ [ki]).

Kehoe and Stoel-Gammon (2001) examined the acquisition of the syllable rhyme by 14 English-speaking children between the ages of 1;3 and 2;0. First they examined

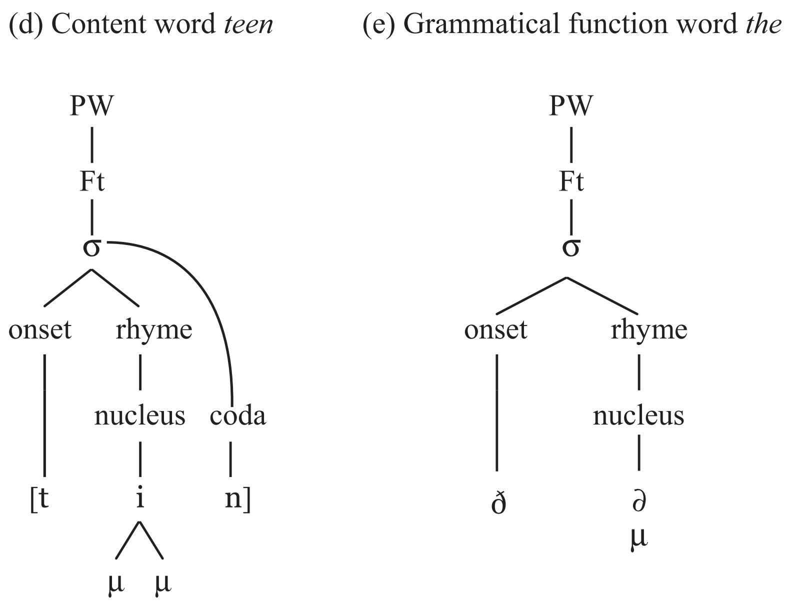
Figure 1

Prosodic structure of different lexical items



(Continued)

Figure 1 (Continued)



whether coda consonants were incorporated into children's productions earlier if the resulting prosodic word created a bimoraic foot. Since short vowels are represented as monomoraic and long vowels as bimoraic, a consonant is needed only after a short vowel to satisfy the bimoraic, word-minimality constraint. Indeed, children produced coda consonants more frequently after short than long vowels, showing sensitivity to a bimoraic size restriction. Second, the authors showed that the percentage of vowel length errors across all children was low irrespective of the percentage of codas produced. That is, children did not change vowel quality/length as a means to ensure bimoraic structure. This was shown by the fact that alternations between closed syllables with short vowels and open syllables with long vowels for the same target were relatively uncommon (e.g., *teeth* /tiθ/ → [ti] ~ [tɪʔ]). Therefore, Kehoe and Stoel-Gammon (2001) concluded that the production of minimal words came about primarily through the inclusion of coda consonants, not through changes in vowel length.

Demuth et al. (2006) evaluated the Word-Minimality Hypothesis using longitudinal, spontaneous speech data of four English-speaking children between the ages of 1 and 2. Their findings replicated those reported in Kehoe and Stoel-Gammon (2001). That is, coda consonants were more frequently produced after short/lax than long/tense vowels in monosyllabic target words. They also noted that some children showed increased duration on the target vowel when codas were omitted, as evidenced by a colon in the phonetic transcription (e.g., CV:). However, since lengthening occurred with both short and long vowels, it was proposed that this was probably compensating for the missing coda consonant, and not due to word-minimality effects. That is, it is possible that children were maintaining the anticipated duration of the target word even if some phonemes were not produced. The fact that vowel lengthening was also found on disyllabic words with missing codas provided further support for this hypothesis.

In contrast, Stemberger (1992), in a diary study of his daughter Gwendolyn, noted her change of a short (lax/monomoraic) vowel to a long (tense/bimoraic) vowel when a target coda was omitted (e.g., bib /bɪb/ → [bi:]). He suggested that the lengthening of the vowel compensates for the mora unit of the deleted segment. The phenomenon of compensatory lengthening was evidenced from the time when Gwendolyn started to produce target words ending with codas around 2 until she was 2;11, when codas were no longer omitted. Thus, in this late-talking child there was some evidence that compensatory vowel lengthening might be used to ensure word minimality.

The studies mentioned above all drew upon data from either English or Dutch, languages that exhibit word-minimality constraints. However, languages such as French, which contain many CV subminimal words, do not show such constraints. French is therefore an interesting language to examine with respect to possible early universal tendencies to show word-minimality effects. To this end, Demuth and Johnson (2003) examined the productions of a French-speaking child, Suzanne. Between 1;1–1;8 she exhibited a period of development where all her target words and productions were maximally a binary foot (CVCV), but shortly thereafter many of her CVC (and some CVCV) target words were truncated to subminimal CV form. The fact that the child produced monomoraic words without augmentation went against Demuth and Fee's (1995) proposal that all children's early words will be minimal words, or binary feet. However, it provided support for the notion that children have an early awareness of language-specific prosodic constraints, and that this may play an important role in determining the shape of children's early word productions (see also Demuth, 1996).

In contrast, Goad and Buckley (2006), in a study of a Québec French-speaking child Clara, argued that her early augmentation and truncation patterns were minimally and maximally a binary foot. They claim that subminimal target forms were augmented through either compensatory vowel lengthening (CV:) or through the addition of a syllable (epenthesis) until Clara was 1;4. Between 1;5 and 1;10, widespread vowel lengthening was no longer observed, coinciding with the abrupt increase in subminimal word forms. However, Goad and Buckley did not conduct any phonetic analysis of vowel lengthening. Thus, it is not clear how much vowels were lengthened, and how systematic this may have been. Since French vowels do not show the same moraic differences as English, it is also not clear if the reported vowel lengthening occurred for segmental or word-minimality reasons.

Japanese is another language that permits subminimal words, but it differs from French in that it is a mora-timed language. Therefore, it is possible that young Japanese learners have an early awareness of moraic structure. In a longitudinal phonetic study of three 1- to 2-year-old Japanese-speaking children, Ota (1999) found that coda consonants and diphthongs took some time to be acquired. Rather than simply omitting these segments, however, all three children showed evidence of mora preservation through compensatory vowel lengthening. Specifically, the short vowel that preceded a missing coda nasal (CVØ) was significantly longer than a short vowel in an open syllable (CV) for all three children (*Hiromi*: 501 vs. 225 ms.; *Takeru*: 272 vs. 219 ms.; *Kenta*: 477 vs. 332 ms.). Interestingly, such an asymmetry in vowel duration was not found when onset consonants were deleted, suggesting that the deletion of non-moraic segments does not lead to the compensatory lengthening of vowels.

Ota (2001) suggests that the avoidance of subminimal words in Japanese children's early productions may be a direct result of the few subminimal targets children actually hear. Although there are many subminimal CV words in Japanese (e.g., *eye* /me/, *hand* /te/), subminimal words are usually augmented in Japanese child-directed speech (e.g., *eye* /me/ → [o-meme], *hand* /te/ → [o-tete]). Thus, the relatively low frequency of subminimal words in the input children hear, combined with the possibility that Japanese learners develop early sensitivity to moraic structure, may account for why Japanese children showed compensatory lengthening when target codas were not produced.

Given that a bimoraic foot has been suggested to be the unmarked form of a prosodic word, and because English content words adhere to this constraint, English-learning children may become sensitive to this prosodic restriction early, along with the production of their first words (Demuth & Fee, 1995). Alternatively, learners of stress-timed languages such as English might initially focus on the segmental structure of words, showing awareness of moraic representations or moraic weight of words relatively late in the process of acquisition. However, a thorough investigation of this issue requires carefully controlled phonetic analysis in order to uncover possible 'covert contrasts' in children's developing phonological systems. Researchers have long noted that assessing children's productions using impressionistic methods may underestimate, or misrepresent, children's knowledge of language (e.g., Macken & Barton, 1980; Scobbie, Gibbon, Hardcastle, & Fletcher, 2000) (see Scobbie, 1998, for review of the literature on covert contrast, including studies of children with language delay). To our knowledge, Ota's (1999) study of Japanese learners' moraic preservation (compensatory lengthening) in the case of missing codas is the only one that has investigated this issue using acoustic-phonetic measures in normally developing children. This illustrates the need for a comparable phonetic analysis that examines the nature of young English learners' phonological representations, preferably from more than one child.

The purpose of the present study was therefore to conduct a phonetic analysis of English-speaking children's use of compensatory lengthening to examine their early representations of prosodic words. The omission of coda consonants in monosyllabic words results in the production of subminimal words with short/lax vowels, but well-formed minimal words with long/tense vowels. Thus, we predicted that if children are sensitive to word-minimality constraints, they would selectively lengthen short but not long vowels, thus preserving bimoraic structure. However, if children lengthen both long and short vowels, it is likely that the lengthening is motivated by segmental rather than prosodic factors.

To carry out this study we therefore wanted to focus specifically on children at a stage of development where they variably produce coda consonants for a given monosyllabic word. At this point in development children's phonologies therefore permit coda consonants, and we assume these are also part of the lexical representation of the word (see Demuth et al., 2006). When a coda consonant is not produced, we therefore anticipated that children might provide some sort of acoustic evidence (cues) to the missing consonant in terms of increased duration on the preceding vowel. In this sense, our purpose is similar in spirit to recent research on adults which provides evidence of acoustic cues to feature contrasts in certain phonological contexts (e.g., Stevens & Keyser, in press).

2 The study

2.1 Data collection and transcription procedures

The data in this study were drawn from recordings from the Providence Corpus (Demuth et al., 2006), a longitudinal corpus of spontaneous speech interactions of six mother–child dyads from the southern New England area of the United States (for further information and access to the corpus, see *CHILDES* http://childes.psy.cmu.edu/). The children and their mothers wore a wireless Azden WLT/PRO VHF lavalier microphone pinned to their collars. The child's radio transmitter was placed in a backpack which each child wore. The radio receiver was attached to the top of a small Panasonic PV-DV601D-K mini digital video recorder placed nearby.

The recordings were made in the child's home for approximately one hour every two weeks. After each session, the digital audio and video recordings were downloaded onto a computer and both adult and child speech were orthographically transcribed using CHAT conventions (MacWhinney, 2000). The child speech data were then also transcribed by trained coders using IPA transcription, which showed the phonemic-level representations of words, positions of stressed syllables, and any phonetic realizations that were noteworthy (e.g., lengthening of a vowel). Ten percent of the transcription from each session was retranscribed by a second coder. On average, agreement on transcriptions between the two coders was 85% (not counting the voicing feature of obstruents). Most of the disagreements were in vowel quality or in the presence/absence or place/manner of consonants, especially in consonant clusters.

2.2 Participants

This study focused on three of the children from the Providence Corpus. All were normally developing, monolingual speakers of American English with individual differences in the rates of language development. Naima and William's parents spoke Standard American English, whereas Alex's parents spoke a dialect typical of southern New England. Table 1 shows the gender, age range, and MLU (Mean Length of Utterance) of each participant during the period of analysis.

Demuth et al. (2006) examined coda acquisition for two of these children, William and Naima. William's first recording was at 1;4, at which point he already produced

Table 1

Description of participants (MLU = Mean Length of Utterance in words)

Subjects	*Gender*	*Age*	*MLU range*
William	Male	1;4–2;1	1.18–1.81
Naima	Female	1;1–1;6	1.42–2.54
Alex	Male	1;10–2;6	1.41–2.24

55% of codas in monosyllabic targets. By 2;1, he produced 87% of codas in monosyllabic targets. Naima was an early talker. When she began producing her first words at 0;11 she produced only 4% of target codas in monosyllabic targets. At 1;1, she produced 14% of target codas and by 1;5, her production of codas reached 88%. The third child in this study, Alex, was slower to develop. Although he began producing his first words around 1;4, he did not have enough monosyllabic CVC tokens for analysis until 1;10, and frequently omitted coda consonants from 1;10–2;6.

2.3
General data coding procedures

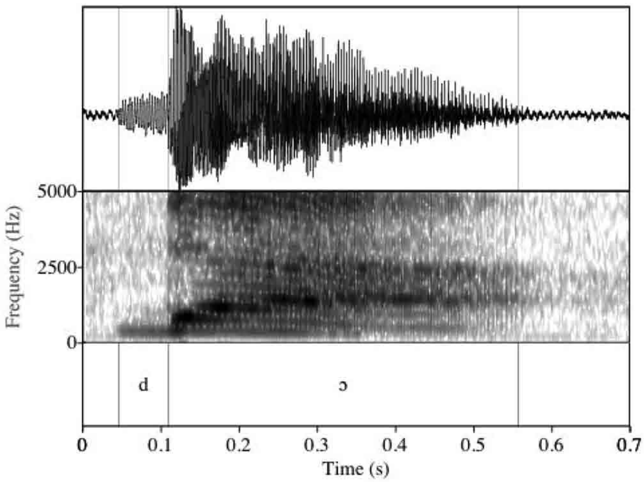
Children's target words were identified using a combination of discourse context and phonetic cues (cf. Vihman & McCune, 1994). Next, we extracted all monosyllabic content (C)VC target words ending in stops, fricatives, or affricates (e.g., *big* [bɪg], *cheese* [tʃiz], *beach* [bitʃ]) from the speech corpus of the three children. All onomatopoetic words (e.g., *beep*, *pop*, *quack*, *woof*) (251 tokens) and bimorphemic words (e.g., *says*) (11 tokens) were excluded. We then examined the phonetic transcription and identified all words where the target coda consonant was not produced. Finally, we listened to all forms, and excluded any items with unidentifiable codas or poor acoustic quality (134 tokens).

In order to compare the vowel duration of the same words that were produced with and without the final coda consonant (e.g., *dog* [dɔ] ~ [dɔg]), we identified a coda-produced match for each word with an omitted coda. In the process of finding a match, we controlled for sentence-final lengthening by comparing words from the same position within the sentence (word-medial/word-final). There were 81 tokens that did not have a coda match. These were excluded. Among the 81 tokens, 50 tokens were the word *red* produced by one child, which further justified their exclusion.

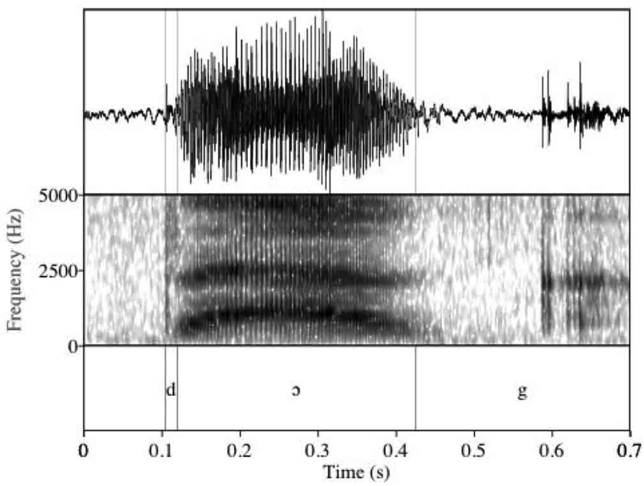
In addition, we tried to use words that were produced in the same recording session or in close sessions, in order to avoid possible effects of other factors, such as change in speaking rate. However, since we used spontaneous speech data rather than elicited speech data, we sometimes needed to use a match from developmentally distinct sessions (the issue of speaking rate will be discussed in the next section). The total number of matched word pairs used in the final phonetic analysis was 93 (William: 21, Naima: 35, Alex: 37).

Figure 2

Waveforms and spectrograms of *dog* [dɔ] (a) and *dog* [dɔg] (b)



a. dog [dɔ]



b. dog [dɔg]

We then measured the duration of the vowel in each matched word pair using Praat (Boersma & Weenink, 2005). Vowel durations were determined by visual examination of the waveform and spectrogram, combined with listening to the production of each word token. In visual inspection, we used the following criteria: Vowel onset was defined as the release of vowel energy showing clear periodicity and the onset of the steady-state for the first two formants; vowel offset was most often defined as the offset of a clear F2 energy. Figure 2 shows examples of *dog* ([dɔ] vs. [dɔg]) produced by Naima at 1;2 and 1;4, respectively.

3 Analysis and results

Preliminary analyses showed that the distribution of vowel durations is positively skewed (skewness = 1.113). In order to convert a skewed distribution closer to a normal, symmetric distribution, the raw data of vowel durations were all transformed to logarithmic values. The transformed log values showed a normal distribution with a skewness value near zero (skewness = –0.071).

Two tokens whose log-transformed durations were less than 1st quartile – 1.5 × interquartile range or greater than 3rd quartile + 1.5 × interquartile range were considered as outliers and excluded from the final analysis. Final statistical analysis included 91 word pairs (William: 20, Naima: 34, Alex: 37): 45 long vowel word pairs (i, u, o, a, ɔ) and 46 short vowel word pairs (æ, ʊ, ɛ, ɪ, ʌ). A list of the word pairs analyzed (e.g., *dog* [dɔg] ~ [dɔ]) and how often each word pair occurred are provided in the Appendix.

All parametric statistical tests used in Analyses 1–3 were conducted on both raw vowel durations and log transformed values of the raw data. Note that the analyses on both data yielded the same results with slightly different numbers. Here we report the statistical values on the raw vowel durations.

In Analysis 1 we first compared the duration of short vowels in words with and without codas produced. In Analysis 2 we repeated the same calculation for long vowels. We predicted that if children showed word-minimality effects, they would exhibit compensatory lengthening for short vowels (Analysis 1), but not for long vowels (Analysis 2) when the coda consonant was omitted.

In conducting these analyses, we assumed that the children in this study have acquired the vowel length distinction between short/lax and long/tense vowels. Salidis and Johnson (1997) showed that their English-speaking subject had acquired the vowel length distinction relatively early around 0;11. Kehoe and Stoel-Gammon (2001) showed further that most English-speaking children they examined made very few vowel length errors by 1;6. For adults, the duration of short vowels is known to be about 60–80% of the duration of long vowels (Peterson & Lehiste, 1960). An examination of vowel durations on the 91 monosyllabic words with produced codas showed that all three children in our study produced long vowels reliably longer than short vowels. For William, the duration of short vowels was 84% of long vowels. It was 82% for Naima and 49% for Alex.

The results of Analysis 1 (paired *t*-tests) showed that, for all three children, the duration of short vowels in words in which codas were omitted was significantly longer than in words in which codas were produced (e.g., *book* [bʊ] vs. [bʊk]). This is shown in Table 2.

The results in Analysis 2 (paired *t*-tests) found that two of the children (William and Naima) significantly lengthened long vowels when codas were omitted (e.g., *teeth*

Table 2

Duration of short vowels in words produced with and without codas (in milliseconds)

	Coda produced		*Coda omitted*		*Statistic*	
	M	SD	*M*	SD		
William	157	56	216	56	$t(10) = 3.06$	$p = .012$
Naima	142	54	308	146	$t(7) = 3.41$	$p = .011$
Alex	129	44	257	139	$t(26) = 5.06$	$p < .001$

[ti] vs. [tiθ]). In contrast, Alex showed no difference in vowel length whether the coda was produced or omitted. This is shown in Table 3.

Table 3

Duration of long vowels in words produced with and without codas (in milliseconds)

	Coda produced		*Coda omitted*		*Statistic*	
	M	SD	*M*	SD		
William	187	40	252	89	$t(8) = 2.99$	$p = .017$
Naima	173	59	296	104	$t(25) = 6.08$	$p < .001$
Alex	265	77	268	51	$t(9) = .14$	$p = .893$

These results indicate that Alex showed an asymmetric pattern consistent with the Word-Minimality Hypothesis. In contrast, William and Naima lengthened both short and long vowels, suggesting that their vowel lengthening is compensating for the loss of the coda segment and not due to maintaining bimoraic minimal word structure. However, even when both short and long vowels were lengthened, it is possible that short vowels were lengthened to a greater extent than long vowels. In this case, it is hard to conclude that the motivation for the lengthening is purely to compensate for the loss of segment.

Thus, in Analysis 3 we compare the amount of compensatory lengthening across short and long vowels. If the lengthening serves to compensate for the loss of coda segment, we expect short and long vowels to be lengthened by the same amount. On the other hand, if the lengthening is to preserve bimoraic structure, we expect short vowels to be lengthened to a greater degree than long vowels.

We investigated this issue by subtracting the mean duration of the vowels in words with omitted codas from the mean duration of the vowels in words with produced codas and comparing the results across long and short vowels. As expected, unpaired *t*-tests showed that there was no difference in the amount of compensatory vowel lengthening between long and short vowels for the two younger children. Only Alex, the oldest participant, showed a significant difference in the amount of compensatory lengthening, with significantly greater lengthening of short vowels. This is shown in Table 4.

Table 4

The amount of compensatory vowel lengthening across long and short vowels (in milliseconds)

	Short vowels		*Long vowels*		*Statistic*	
	M	SD	*M*	SD		
William	59	64	65	65	$t(17) = .22$	$p = .828$
Naima	167	138	122	103	$t(10) = .83$	$p = .424$
Alex	128	132	4	82	$t(26) = 3.44$	$p = .002$

The present study shows that compensatory vowel lengthening in words with omitted codas is robustly observed in the English-speaking children in this study. This suggests that despite the lack of a coda consonant in some of their early productions, these children may have an adult-like phonological representation that includes a target word-final segment. Thus, despite the lack of a coda, children provide other cues to the presence of the missing segment, lengthening the preceding vowel.

The phonetic analyses show that compensatory lengthening for two of the three children in our study occurs regardless of the length of the vowels. This contrasts with previous studies that have assumed that compensatory lengthening is to preserve bimoraic structure (the Word-Minimality Hypothesis – e.g., Demuth & Fee, 1995; Ota, 1999). However, we also found some individual variation, with the third child lengthening vowels only when needed to preserve bimoraic structure. Possible explanations for this individual variation found will be further explored in the discussion.

3.1
Speaking rate

As mentioned in the methods section, we retrieved word tokens from longitudinal, spontaneous speech corpora. This enabled us to analyze as many tokens as possible. However, since we used tokens produced at different ages, this raises the possibility that vowel duration was not independent of age. That is, it is possible that children's greater vowel length at the earlier ages of development (when codas are most likely to be omitted) is merely a reflection of early overall slower speaking rate.

We therefore wanted to know if vowel durations were independent of age. To do this we tracked the durational change of a given word for each child over time during the same time periods of Analyses 1–3 (William: 'go' (1;6–2;1), Naima: 'daddy' (1;1–1;6), Alex: 'see' (1;11–2;6)). For the analysis, we only used tokens that were fully produced with all target segments. All tokens were drawn from sentence-final position. For all three children, correlation analyses demonstrated no association between total word duration and age (William: $r(28) = .295$, $p = .114$, Naima: $r(56) = -.168$, $p = .208$, Alex: $r(17) = .186$, $p = .446$). The results indicate that children's speaking rate is more or less stable across this five- or eight-month period, and that vowel lengthening in the context of omitted codas cannot be explained in terms of changes in speaking rate.

We then conducted an additional, more fine-grained analysis to examine possible speaking rate changes between the specific two files from which the matched-pairs were drawn. Recall that we paired two words that were produced with and without codas, and compared the vowel durations between the two. For example, if a child produced *book* as [bʊ] with a vowel duration of 200 milliseconds at 400 days old, and as [bʊk] with a vowel duration of 150 milliseconds at 430 days old, for this word pair, vowel duration decreased by 50 milliseconds over the 30-day period. As such, if a pair of words comes at two different times and if we find a systematic decrease in vowel duration as distance between the two time periods increases, it is probable that vowel duration differences are dependent of age. On the other hand, if vowel duration differences between words with and without codas are more or less fixed regardless of the distance between the two time periods, it is probable that vowel durations are independent of age.

Thus, we conducted this analysis for each word pair for each child. We then employed correlation analysis to determine whether vowel duration differences between words with and without codas were associated with a change in age. For all three children, there was no strong effect of speaking rate change for either long vowels (William: $r(7) = .065$, $p = .868$, Naima: $r(24) = .161$, $p = .431$, Alex: $r(8) = .357$, $p = .312$) or short vowels (William: $r(9) = .336$, $p = .312$, Naima: $r(6) = -.477$, $p = .232$, Alex: $r(25) = .018$, $p = .931$). The results again suggested that the vowel durations measured in this study were most likely independent of age, and that elongated vowels in words with omitted codas were due to compensatory lengthening.

In sum, the results from the present study show that all three children significantly lengthened short vowels when codas were omitted. However, only the oldest child showed a significant difference in vowel lengthening between short and long vowels. These findings suggest that the two younger children are lengthening vowels to compensate for the missing segment. This raises a possibility that sensitivity to language-specific word-minimality constraints may only emerge later in development, perhaps around the age of 2–2;6 (cf. also Stemberger, 1992). We now turn to possible explanations of the data in the discussion below.

4 Discussion

English requires that open-class content words consist of at least a minimal word, or binary foot. Given that the binary foot is also considered to be the unmarked form for a prosodic word (Prince & Smolensky, 1993/2004), we expected that English-learning children would exhibit sensitivity to this type of prosodic constraint along with the production of their first words (Demuth, 1995; Demuth & Fee, 1995). Indeed, all three children in the present study avoided subminimal words by lengthening short vowels when they could not produce word-final codas in monosyllabic words. However, since lengthening occurred with both short and long vowels for the two children, it appears that the motivation for vowel lengthening is not purely to keep minimal word structure. Rather, the vowel lengthening may be compensating for the missing coda segment to maintain approximately the same target word duration.

On the other hand, one child Alex selectively lengthened only monomoraic short vowels when he could not produce a coda consonant. There are a few possible explanations for Alex's behavior. First, his different behavior in compensatory lengthening could be understood as showing a developmental trend. That is, employing compensatory lengthening as a means to preserve minimal word structure might be more typical of older and/or more linguistically advanced children who are more aware of language-specific constraints on the structure of prosodic words. Recall that Alex was the oldest child in our study. Interestingly, standardized effect sizes (Cohen's $d = 0.8$ (large), 0.5 (medium), 0.2 (small)) indicated that there was a graded effect of moraic adjustment in these children (Alex: $d = 1.13$, Naima: $d = 0.36$, William: $d = 0.10$), with linguistically precocious Naima exhibiting more bimoraic adjustment than William, though not as much as Alex. Thus, although bimoraic structure is critical to the well formedness of open-class English prosodic words, learners of stress-timed languages like English might develop sensitivity to word-minimality effects later than those learning a mora-timed language like Japanese (Ota, 1999).

Alternatively, Alex's grammar may simply be different from that of the other children. Table 3 reveals that when codas are produced, his long vowels are much longer than those of the other children and that this is the locus of his lack of compensatory lengthening on long vowels. In other words, Alex's long vowels are already extremely long when a coda consonant is present. Perhaps, then, he is already at ceiling, and lengthening his long vowels further would seem strange. A possible explanation for the length of Alex's long vowels may be the language environment to which he is exposed. Unlike Naima and William's parents, who speak a relatively standard dialect of American English, Alex's parents speak the regional dialect found in parts of southern New English (including Rhode Island and southeastern Massachusetts). This dialect is often characterized by the omission of post-vocalic /ɹ/ (e.g., car [ka:]) and a distinctive system of some vowels such as the low-back vowel /a/ (Nagy & Roberts, 2004). As shown in the Appendix, the majority of Alex's long vowel tokens involved the word *dog*, which contains the mid-back vowel /ɔ/. In contrast, the other two children have several word types for long vowels. It is therefore possible that Alex's production of long vowels is influenced by dialectal or idiolectal variation on the vowel /ɔ/. Further investigation of parental speech input to Alex, and the duration of other long vowels produced with coda consonants, might shed further light on why he showed compensatory lengthening only for short vowels.

Finally, it could also be possible that Alex's selective vowel lengthening with short vowels was due to distributional aspects of English rather than to word-minimality effects. English does not permit short/lax vowels in word-final open syllables (Jones, 1997). If children are sensitive to this type of distributional information in the input, they may lengthen short vowels when codas are omitted in order to avoid words ending in short vowels. One way to tease these issues apart would be to consider vowel lengthening in disyllabic words. If learners are lengthening vowels for word minimality purposes, there should be no lengthening of short vowels in the final syllable of disyllabic words when word-final codas are omitted. However, if learners are lengthening the vowel to adhere to the distributional regularities of English, we would expect to find vowel lengthening only in cases where the disyllabic word ends in a short vowel.

Since the majority of English-speaking children's early spontaneously produced words are monosyllabic, there were not enough disyllabic tokens in the corpora examined in the present study to assess this possibility. This is obviously an interesting area for further research, bearing on when and how learners become sensitive to different aspects of language-specific phonological structure.

Although the number of children we have examined in this study is larger than some of the previous diary case studies, the sample is still small, and shows individual variation. A larger number of children will need to be studied to draw strong conclusions about children's early word representations, and when and how children's awareness of word minimality effects arises. The results found here should therefore be taken as tentative, pending verification with more subjects.

In addition, the data in the current study are limited to American English as used in part of the New England area. Given that the English language varies widely in its vowel systems, both in phonemic inventory and vowel duration parameters, it would be interesting to investigate the extent to which children's early compensatory vowel lengthening for missing codas is robustly found across dialects of English (e.g., Matthews, 2001). Furthermore, the current study looked at words with only obstruent codas. One of the main reasons that we did not consider words with sonorant codas, which include frequent words such as *car* and *door*, was the measurement issue; liquids are much harder to separate from vowels than are obstruents. Another reason we did not examine the acquisition of liquid codas was because they are often late acquired, making it harder to find enough coda-produced tokens to compare. Dialectal issues must also be considered. Nonetheless, given that some liquids can be realized as syllabic nuclei, a comparison of young children's production of words with missing obstruent codas versus missing liquid codas might be of interest. Given our familiarity with some of this data in the Providence Corpus, we would predict that liquids would be consistently realized as a lengthened or additional vowel, regardless of the moraic weight of the preceding vowel. This is obviously an interesting area for further research.

A remaining issue raised by this study is the nature of the underlying mechanism and physiological/articulatory motivation for compensatory lengthening. We have suggested above that the children in this study have adult-like lexical representations in terms of 'knowing' that the CVC target words they are attempting have a coda consonant. Thus, vowel lengthening is used to indicate segmental content. This may occur due to articulatory issues of gestural overlap (Browman & Goldstein, 1990, 1992), where both vowel and coda consonant are 'present,' but an 'immature' target consonant gesture is overlapped or hidden by a vowel gesture. Alternatively, compensatory lengthening might reflect young children's imperfect ability to coordinate vowel–coda consonant gestures. Such a perspective may also help explain the prevalence of other types of variable productions in children's early speech, including reduplication and consonant harmony. This raises the possibility that compensatory vowel lengthening might also be found at earlier stages in a child's grammar, when coda consonants are not yet produced. This has yet to be examined in the children studied here, though it may be difficult to do so given the rapidity with which normally developing English-speaking children (and Germanic speakers in general) acquire coda consonants. Ultimately, what is needed is a developmental model of production that can account for the types and sources of variability found in early child speech, making predictions about when and where different types of variability are most likely to occur.

5 Conclusion

The purpose of the present study was to investigate children's lengthening of vowels in the context of missing word-final coda consonants to examine if vowel lengthening occurred to preserve bimoraic or segmental structure of a word. Matched target monosyllabic CVC word pairs produced with and without a coda consonant were extracted from the spontaneous speech of three children from the Providence Corpus between the ages of 1;1 and 2;6. Phonetic analysis compared the duration of the vowel with and without the coda consonant. The results showed that two of the children significantly lengthened both short and long vowels when the coda was omitted, suggesting that compensatory lengthening is used as a cue to the missing segment. However, one child selectively lengthened only short vowels raising questions regarding the nature of this individual variation.

The findings from the present study raise many issues for further experimental investigation. Such studies could investigate more thoroughly, with a larger number of children, and in other languages, the nature of learners' sensitivities to language-specific phonological and prosodic structures, and how this develops over time. It could also begin to examine more closely the types of articulatory gestures normally developing children make in attempting their early utterances. The phonetic analysis presented here is offered as a step in this direction.

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Appendix

Number of word pairs with coda produced/omitted for each child

	William		*Naima*		*Alex*	
Short vowels	*book*	4	*cat*	1	*bat*	2
	duck	1	*cup*	1	*egg*	1
	good	1	*cut*	1	*red*	23
	hat	1	*good*	2	*ship*	1
	put	1	*head*	1		
	red	1	*kiss*	1		
	sit	2	*sit*	1		
Long vowels	*cheese*	1	*beach*	1	*cheese*	2
	dog	2	*cheese*	6	*dog*	8
	Duke	3	*dog*	2		
	feet	2	*juice*	14		
	hot	1	*nose*	1		
			read	2		
Total		20		34		37