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The acquisition of nuclei: a longitudinal analysis of phonological vowel length in three German-speaking children*

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ABSTRACT

Studies of vowel length acquisition indicate an initial stage in which phonological vowel length is random followed by a stage in which either long vowels (without codas) or short vowels and codas are produced. To determine whether this sequence of acquisition applies to a group of German-speaking children (three children aged 1;3–2;6), monosyllabic and disyllabic words were transcribed and acoustically analysed. The results did not support a stage in which vowel length was totally random. At the first time period (onset of word production to 1;7), one child's monosyllabic productions were governed by a bipositional constraint such that either long vowels, or short vowels and codas were produced. At the second (1;10 to 2;0) and third time periods (2;3 to 2;6), all three children produced target long vowels significantly longer than target short vowels. Transcription results indicated that children experienced more difficulty producing target long than short vowels. In the discussion, the findings are interpreted in terms of the representation of vowel length in children's grammars.

INTRODUCTION

The current literature on phonological development reports stage-like acquisition of the syllable. It is widely proposed that the earliest syllable shape

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is consonant–vowel (CV) and that children acquiring languages with complex syllable structure go beyond this basic CV form to produce codas, complex onsets and complex codas, and complex nuclei. Despite a burgeoning knowledge base on syllable structure development in a variety of languages, including Dutch (Fikkert, 1994; Levelt, Schiller & Levelt, 1999/2000), English (Barlow, 1997; Gierut, 1999), German (Lleó & Prinz, 1996; Grijzenhout & Joppen, 1999), French (Rose, 2000), Portuguese (Freitas, 1996) and Spanish (Lleó & Prinz, 1996), some aspects of syllable structure remain understudied and are in need of further empirical documentation. For example, little is known about children's acquisition of phonologically short vs. long vowels, and diphthongs, that is, children's acquisition of simple vs. complex nuclei. The principal aim of this study is, thus, to provide further information on the development of nuclei. We consider developmental data in German, a language which contains a systematic distinction between long and short vowels and, thus, offers a good testing ground for the study of the nucleus. Current models of syllable structure, however, recognize an intimate relationship between the nucleus and the coda, and consequently, a wider aim of the study is to examine the nucleus within the entire context of the rhyme. We commence by providing an overview of German rhyme structure.

German rhyme structure

Vowels. German contains seven pairs of long and short vowels, as listed in (1). With the exception of the low vowel pair (aː/a) and an additional vowel length distinction, which exists in some dialects in German (ɛː/ɛ), long/short vowels differ not only in quantity but also in quality, leading to the longstanding debate of whether the distinction is primarily quality or quantity. By quality, we refer to vowel formant differences; by quantity, to duration differences.[1] In the former, the distinction between tense and lax vowels is relevant. Tense vowels are produced with a greater deviation from neutral vocal tract configuration and involve more accurate approximation to their intended target than lax vowels (Anderson, 1984). The overall consensus in recent years is that quantity plays the crucial role in explaining phonological facts (Hall, 1992; Ramers, 1992; Vater, 1992; Wiese, 1996). In particular, phonotactic regularities such as the absence of short vowels in word-final and stressed open syllables and the low frequency of long vowels in syllables with complex codas suggests an underlying quantity difference. Phonetically, long vowels are twice as long as short vowels (Delattre, 1965; Becker, 1998).

[1] Throughout the paper, the term 'vowel length' will refer to the abstract phonological notion of length or quantity (i.e. bipositional segment) whereas 'duration' will refer to the acoustic manifestation of length.

(1) German vowels

a. long vowels		b. short vowels	
iː, yː	uː	ɪ, ʏ	ʊ
eː, øː	oː	ɛ, œ	ɔ
aː		a	

In addition to the seven pairs of long/short vowels, there are two vowels (schwa [ə] and [ɐ]) which appear only in unstressed syllables and three diphthongs (aʊ, aɪ, ɔɪ).

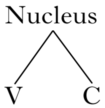
The rhyme. The rhyme part of the syllable in German is maximally three positions, composed of either a long vowel plus consonant, a diphthong plus consonant, or a short vowel plus two consonants (Mouton, 1956; Wiese, 1988; Hall, 1992). One of the fundamental phonotactic regularities of Modern Standard German is that a short vowel can always be followed by one more consonant than a long vowel or diphthong in the same monosyllabic word. This regularity is shown in (2a). Examples are adapted from Wiese (1996: 37). Final syllables may be followed by additional consonants if they are coronal obstruents (2b), in which case these elements are referred to as extrasyllabic or as belonging to an appendix.

(2)

a.	VVC		V_iV_jC		VCC	
	viel	[fiːl]	*feil*	[faɪl]	*Film*	[fɪlm]
	Bahn	[baːn]	*Bein*	[baɪn]	*Bank*	[baŋk]
b.	VVCCC		V_iV_jCCC		VCCCC	
	Dienst	[diːnst]	*raubst*	[raʊpst]	*Herbst*	[hɛʀpst]
	lobst	[loːpst]	*läufst*	[lɔɪfst]	*denkst*	[dɛŋkst]

These statements on German rhyme structure are generally agreed upon; less consensus has been reached on how the rhyme is further subdivided. One controversial issue is whether there is a branching nucleus condition in German, such that all nuclei are minimally bipositional as shown in (3) (Wiese, 1988; 1996). The C element stands not only for consonantal elements but includes the second element of a long vowel or diphthong. Under this condition, the first postvocalic consonant after a short vowel would be part of the nucleus. Only a second consonant, if present, would be dominated by the coda.

(3) Nucleus condition



The main reason for proposing this constraint is that syllables word-finally or in hiatus position cannot contain a lax vowel. In word internal position, a single consonant following a lax vowel is assumed to be ambisyllabic, thus,

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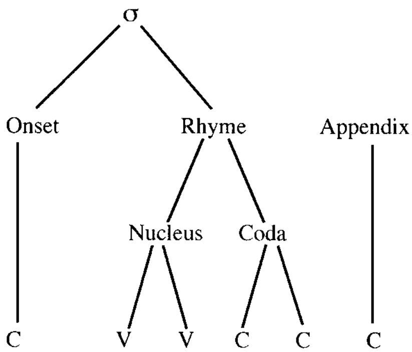

	C	V	V	C	C	C	
a. *Ku	k	ʊ					
b. Kuh	k	u	:				'cow'
c. Kuß	k	ʊ		s			'kiss'
d. Bahn	b	a	:	n			'train'
e. Bein	b	a	ɪ	n			'leg'
f. Bild	b	ɪ		l	t		'picture'
g. Wolfs	v	ɔ		l	f	s	'of the wolf'

Fig. 1. Representation of the German rhyme.

allowing the nucleus condition to be fulfilled. Other arguments include the phonotactic equivalence of VC, VV, and V_iV_j sequences, as mentioned above, and the special behaviour of /ŋ/ and /h/; /ŋ/ can only occur after a short vowel, /h/, only after a long vowel. This behaviour can be explained by positing that /ŋ/ can be realized only in the nucleus; /h/, only in onset position.

Another approach to rhyme structure is to place all sonorants (vowels or sonorant consonants) in the nucleus. Obstruents following short vowels would be placed in the coda. This possibility is entertained by Wiese (1996: 46) and is adopted by Grijzenhout & Joppen (1999) in their description of the German syllable.

Neither the nucleus condition nor the latter approach, in which the nucleus is filled by sonorant segments, are universally accepted by all authors (Hall, 1992; Vater, 1992), and for this reason we maintain the rhyme representation indicated in Figure 1, in which only vocalic elements appear in the nucleus.

Syllables containing short vowels (1c & 1f) have non-branching nuclei; syllables containing long vowels (1b & 1d) and diphthongs (1e) have branching nuclei. The German rhyme is minimally two positions (1b & 1c) and maximally three positions (1d, 1e & 1f). Syllables may also be followed by an appendix (1g).

The acquisition of the nucleus

Studying the development of the nucleus is different from studying other aspects of syllable structure, such as onsets and codas. For example, in the acquisition of complex onsets, one can observe a stage, in which children produce simple onsets and a stage, in which children produce complex onsets. This is not the case with the nucleus. The literature suggests that children do not progress from a stage in which only short vowels are produced to a stage in which long vowels and diphthongs are produced. Rather, children produce both short and long vowels from the beginning; however, they are not consistent in their productions. Given this behaviour, it is not straightforward to determine when children have acquired a phonological length distinction. One obvious way is through perceptual tests, employing methodology that accesses lexical representation in children aged 1;0–1;2 (Werker & Stager, 2000). While this study acknowledges the importance of perceptual studies for addressing the acquisition of vowel length representation, we examine this topic using production data. Possible ways of studying vowel length in production include: measuring the duration of target long and short vowels; counting tense-lax errors; and studying phonological behaviour that depends upon an underlying contrast such as syllable structure and stress assignment. In the next section, we consider transcription and acoustic analyses of vowel length. The main stance on the acquisition of phonological vowel length stems from Fikkert's (1994) longitudinal study of Dutch-speaking children. Additional studies have been conducted with German-, English-, Japanese- and Swedish-speaking children.

Transcription-based studies of vowel length acquisition

Fikkert (1994) proposed the following stages of vowel length development. We alter the wording of stages to reflect the primary focus of this study, which is nucleus rather than rhyme development.

(4) Stages of vowel length development (adapted from Fikkert, 1994)

Stage 1:	CV(V)	Core syllable
	No vowel length contrast	Monopositional vowels
Stage 2:	CV(V)C	Obstruent codas
	No vowel length contrast	Monopositional vowels

Stage 3:	CVC, CVV	Sonorant codas
	Vowel length contrast in syllables with target sonorant codas	Mono- and bipositional vowels
Stage 4:	CVC, CVVC	Sonorant and obstruent codas
	Vowel length contrast in syllables with target obstruent codas	Mono- and bipositional vowels

Fikkert observed that initially phonological vowel length was random: target long vowels were produced as long and short; target short vowels were produced as long and short. Children first produced core syllables (CV) then syllables with obstruent codas. When children started to produce sonorant codas (stage 3, age approximately 1;10 to 2;1), she observed a reciprocal relationship between vowel length and coda production such that either long vowels (without codas) or short vowels with sonorant codas were produced. At this point, she hypothesized that children had acquired vowel length representation and had access to both mono- and bipositional vowel nuclei. This effect was later observed for obstruent codas. Fikkert's findings were also supported by her findings in the domain of stress assignment. She observed that children acquire awareness of quantity-sensitivity late, an aspect of stress development which is dependent upon phonological vowel length differences.

Recently, Bernhardt & Stemberger (1998: 417) query Fikkert's (1994) claim that vowel length is non-distinctive before obstruents until the latter stages of rhyme development. If one looks at the data carefully, one observes that at stage 3, when vowel length was proposed to be non-distinctive before obstruents, children still produced the target vowel length 70 to 80% of the time. If the phonological distinction between long and short vowels were neutralized, it is hard to explain why children achieved such a high degree of accuracy. Rather, Bernhardt & Stemberger (1998) reinterpret the findings as indicating that, at stage 3, children have acquired contrastive vowel length before obstruents and can produce a three-positional rhyme; with sonorant codas, they can only produce a two-positional rhyme.

An additional query that could be applied to Fikkert's model is in the way she interprets vowel length representation at stage 3 in target rhymes with sonorant codas. Fikkert infers vowel length representation from the behaviour of vowels in phonetic contexts that are actually non-contrastive. At stage 3, long and short vowels are in complementary distribution: long vowels manifest in open syllables; short vowels, in closed syllables with sonorant codas. It is true that on the surface long vowels occupy two positions in the nucleus, whereas short vowels only one; however, this pattern may arise from a bipositional production constraint and not reflect underlying length. An allophonic rule such as (5) could account for the presence of long vowels, implying that all vowels may still be represented monopositionally.

(5) $V \rightarrow VV / \_\_ l_{\sigma}$

We turn now to an alternate model of the rhyme that has been proposed for German by Grijzenhout & Joppen (1999), based on the case study of a German-speaking child (age 1;2–1;7). Again we alter the wording of stages to reflect our focus on the nucleus.

(6) Development of vowel length in German (adapted from Grijzenhout & Joppen, 1999)
Stage 1: One consonantal place of articulation per word
Vowel length is not distinctive
Stage 2: Minimally and maximally bipositional rhymes
i. One consonantal place of articulation per word
ii. More consonantal places of articulation per word
Stage 3: Minimally two positions in the rhyme
Maximally three positions in the rhyme
Vowel length is distinctive

An important point of departure from Fikkert's (1994) model and indeed other work on syllable development is their proposal that early rhyme development is segmentally rather than prosodically driven. At stage 1 (age 1;2), their child produced target monosyllables with long and short vowels irrespective of the vowel length of the target form. The main characteristic of this stage was that the child's form consisted of a single consonantal and vocalic release, either CV(V) or V(V)C. At stage 2 (around 1;4), the child's monosyllabic productions consisted first of a long vowel; then, a short vowel plus consonant. The authors argue that this sequence did not arise from a change in the structure of the rhyme (branching of nucleus then branching of rhyme), rather from the child's ability to produce more than one place of articulation per word. At stage 2i. Bahn /baːn/ 'railroad' was produced as [baː] because the child could realize only one consonantal place of articulation (i.e. labial); at stage 2ii. Bahn was produced as [ban] because the child could produce more than one consonantal place of articulation (i.e. labial and coronal). Vowel length varied accordingly because the child was governed by a constraint requiring rhymes to be bipositional. At stage 3, the child produced rhymes consisting of a long vowel and coda (CVVC) or a short vowel and coda cluster (CVCC). It was at this stage that vowel length was acquired.[2]

Both Grijzenhout & Joppen's (1999) and Fikkerts (1994) models resemble each other in revealing an early stage in which vowel length is not distinctive,

[2] We interpolate from Grijzenhout & Joppen's (1999) study that vowel length is acquired by stage 3 and not by stage 2, although they do not state this explicitly.

and a later stage, in which a bipositional constraint is operative. In contrast, recent studies by Salidis & Johnson (1997) and Kehoe & Stoel-Gammon (2001) with English-speaking children find little support for a lack of vowel length representation in early acquisition. Salidis & Johnson's (1997) subject, Kyle, made no vowel length errors from the onset of word production (0;11), and Kehoe & Stoel-Gammon's (2001) subjects, while making some errors at the first recording sessions (1;3), produced long and short vowels relatively accurately by 1;6. Kehoe & Stoel-Gammon's (2001) subjects produced greater percentages of consonants after short than long vowels consistent with a bipositional constraint on syllable production. Whereas their subjects did this at the earliest stages of acquisition, Fikkert (1994) observed this pattern only at later stages of development (at stages 3 and 4) and Grijzenhout & Joppen (1999), at stage 2.

One reason for the different conclusions concerning early vowel length representation may relate to measurement criteria. All authors based their decisions on transcription (not acoustic) data; however, Salidis & Johnson (1997) and Kehoe & Stoel-Gammon (2001) based their decision on tense/lax substitutions, whereas Fikkert (1994) and Grijzenhout & Joppen (1999) did not make explicit their criteria for judging vowel length, meaning that they may have excluded tense-lax alternations and focused primarily on phonetic length. Alternatively, the different developmental results may reflect true language-specific effects. Neither possibility can be supported at this stage. Nevertheless, it is clear that additional attention should be paid to the phonetic correlates of phonological vowel length and to what truly counts as a vowel length error. We consider now acoustic studies of early vowel length.

Acoustic studies of vowel length acquisition

Given the joint presence of quantity and quality in the long/short vowel distinction, it is not implausible to think that children may begin by commanding one feature before the other, that is, tenseness before length, length before tenseness. Therefore it is useful to review acoustic studies in those languages in which the phonological length distinction is primarily one or the other: quantity or quality. Possible languages of the former group include Japanese and Swedish. English is a language of the latter group, in which quality is considered primary in the tense-lax distinction (Delattre, 1965).

Ota (1999) found that all three of his Japanese-speaking subjects (aged approximately 1;6) displayed significant durational differences between long and short vowels, although the quantitative realization was not as extreme as in adult Japanese. Similarly, Stoel-Gammon, Buder & Kehoe (1995) found that two-year-old Swedish-speaking children made significant durational differences for the long and short vowel pairs (iː, i), although in their study, the quantitative realizations were slightly more extreme than the adult values. In contrast, acoustic measures by Stoel-Gammon *et al.* (1995) indicated that English-speaking children did not make significant durational differences between the tense and lax vowel pair (i, ɪ) but rather distinguished tense and lax vowels on the basis of formant structure.

Considering the interplay between quantity and quality, the relative salience of one cue over the other may be instrumental in explaining patterns of acquisition. That is, in languages, in which primarily quantity is involved (e.g. Japanese, Swedish), children may acquire the quantity distinction relatively early, whereas in languages, in which primarily quality is involved (e.g. English), children may acquire the quality difference early. How are Dutch and German situated within this continuum? Contrastive analyses of vowel length indicate that quantity plays a greater role in the tense-lax distinction of German and Dutch than that of English (Delattre, 1965; Nooteboom, 1972). The different constellation of quantity and quality underlying the German and Dutch vowel length distinction as compared to English may be responsible for the different patterns of acquisition.

In the next section, we consider the special case of diphthongs.

The acquisition of diphthongs

Although both diphthongs and long vowels contain two timing units, diphthongs are more complex than long vowels, containing two separate root nodes, in contrast to long vowels, which contain only one, as shown in (7). In this study, we consider only falling diphthongs, that is, diphthongs in which the non-syllabic element (glide) is in second position.

(7) a. Long vowel b. Diphthong

An alternate representation of diphthongs is that of a short vowel plus coda in which the glide is situated in the coda. This is not the representation adopted in this study but cannot be excluded as a possible representation during development (Lleó, Kuchenbrandt, Kehoe & Trujillo, in press). One important issue is whether diphthongs behave similarly to long vowels in acquisition or display characteristics consistent with their additional complexity or with an alternate representation. Fikkert (1994) observed that the vowel substitution patterns of diphthongs were similar to those of long rather than short vowels, justifying her representation of diphthongs as complex nuclei and not as short vowels plus codas. In contrast, Bernhardt & Stemberger (1998) observed different patterning between long vowels and diphthongs. Gwendolyn (age 2;6) produced target-like diphthongs in open syllables but not in closed syllables (8):

(8) *cow* /kaʊ/ [tʰaʊ]
clown /klaʊn/ [tʰan]

She produced long vowels in closed syllables, however. Her productions of *bite* /baɪt/ included the following alternations: [bat],[biːt],[baɪ]. One possible account of these findings is that Gwendolyn had a different representation of diphthongs from that of the adult grammar, treating the glide part of the diphthong as a coda. She did not produce diphthongs in closed syllables because of a high ranking NotComplex (Coda) constraint.

Additional research is needed to know how often patterns like the latter occur in acquisition. Given the tentative evidence that not all children treat diphthongs identically to long vowels, we shall give special attention to the individual patterns of long vowels and diphthongs in our analysis of the nucleus.

Purpose of the study

The purpose of this study is to examine in detail children's acquisition of the nucleus. In so doing, we aim to resolve contradictory findings in the literature which point to late acquisition of phonological vowel length in Dutch and German and earlier acquisition in English. Specifically, we address the claims made by Fikkert (1994) and Grijzenhout & Joppen (1999) that there is an initial phase in which vowel length is random, followed by a bipositional phase in which either long vowels (without codas) or short vowels with codas are produced. Since the study employs German-speaking children's productions, the results should directly bear on Grijzenhout & Joppen's (1999) study and on Fikkert's (1994) study which is based on a related Germanic language, Dutch. If the findings do not support the above models, we intend to propose an alternate model of nucleus development.

An important aspect of this study is that we employ both phonetic transcription and acoustic analysis and, thus, offer a more complete description of children's early phonological patterns than previous studies which have employed one or the other. In the phonetic transcription, we code separately errors of tenseness and phonetic length. In addition, we expand on previous work by examining vowel length in disyllables and by giving special attention to diphthongs.[3]

[3] The decision to include disyllables as well as monosyllables is motivated primarily because disyllables are strongly represented in the database. We do not plan to make a systematic contrast between vowel length acquisition in monosyllables vs. disyllables but will refer to some of the differences in the discussion.

METHOD

Database

The database consists of the spontaneous word productions of three German-speaking children (Bernd, Thomas, and Marion), who were audio-recorded fortnightly (after 2;0, monthly) prior to the beginning of word production (0;9) through to 3;0. The children were recorded at their homes in unstructured play situations, while interacting with their mothers and one investigator. Three time points that represent the following age intervals were targeted: (1) onset of word production to 1;7, (2) 1;10 to 2;0, and (3) 2;3 to 2;6. All monosyllabic and disyllabic trochaic words from these age intervals were selected, taking into account the following criteria:

a. Onomatopoeic words and frequent interaction/greeting forms such as *ja* 'yes', *nein* 'no', *danke* 'thank you', *tschüs* 'bye', *Mama*, and *Papa* were not included.
b. Certain pronouns, articles, verb forms, prepositions, conjunctions and adverbs, which frequently have reduced variants in everyday speech, were not included (see Meinhold & Stock, 1980, pp. 96–97 for a list of such forms).
c. Only words which occurred in isolation or in phrase-final position under main stress were included.

Transcription study

All selected words were phonetically transcribed. Based on phonetic transcription, vowels were coded into five categories: (1) lax and phonetically short; (2) tense and phonetically short; (3) lax and phonetically long; (4) tense and phonetically long; and (5) diphthong. The vowels: i, y, u, e, ø, o were coded as tense; the vowels: ɪ, ʏ, ʊ, ɛ, œ, ɔ, a were coded as lax. Non-target German vowels, which appeared occasionally in the transcription (e.g. ɤ, ɵ, ʉ, ɨ, ɯ, ʌ) were coded as lax. Consonants, including glottal stops, were represented as C.

Acoustic study

A subset of words was acoustically analysed. Vowel duration was measured using Soundscope for the Macintosh. Both the time wave-form and spectrographic display were used to aid measurement. Duration was measured from the onset of F2 to the offset of F1. In disyllables, only the stressed vowel was measured. Because many factors may influence vowel duration, words containing target long and short vowels were matched on all of the following four dimensions: 1. Emotional level of the child, in which a three-point rating scale reflecting different affect levels was used (1 – low affect; 2 – normal; 3 – high affect); 2. Vowel height (low, mid, and high).

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Target words containing long high vowels were matched with target words containing short high vowels; 3. Syllable structure. In monosyllables, only vowels occurring in closed syllables were measured; In disyllables, only vowels occurring before a single intervocalic consonant were measured; and 4. Manner of articulation of the following consonant. In monosyllabic productions, words containing sonorant vs. obstruent codas were matched; in disyllabic productions, voicing of the intervocalic consonant was also taken into consideration. For example, a possible monosyllabic pair included the target words *Schiff*/ʃɪf/ 'ship' and *Sieb*/ziːp/ 'sieve', containing a short and long vowel respectively, produced by the child as [tɪt] and [diːp]. Both words were produced with high affect levels, and contained high vowels and obstruent codas.[4]

In sum, monosyllabic and disyllabic target words containing long and short vowels and diphthongs were selected from three time periods. The bulk of the analyses, however, focused on the last two time periods. At time period 1, it was not possible to find sufficient numbers of words containing target long and short vowels to conduct acoustic analyses and one child (Bernd) produced no analysable words. At time periods 2 and 3, a reduced pool of tokens was employed in the acoustic compared to the transcriptional study, due also to the difficulty of matching target short and long vowels. On average, 10 words per condition were analysed in the acoustic study and 19 words in the transcription study, where condition refers to one of the following: time period 2 vs. 3, monosyllable vs. disyllable, target long vs. short vowel (i.e. $2 \times 2 \times 2$). This resulted in the analysis of approximately 80 words per child in the acoustic and 152 words per child in the transcription study. These numbers do not refer to the words sampled at time period 1 nor to the words containing diphthongs which were analysed separately (see relevant tables for the number of words sampled in these conditions). The entire database comprised 714 words.

Finally, it should be noted that a variety of rhyme types were sampled in the transcription study; however, 94% of the monosyllabic data was accounted for by four rhyme types: VVC, V_iV_jC, VC and VCC, and 97% of the disyllabic data was accounted for by four types VVCV, V_iV_jCV, VCV and VCCV. In the acoustic study, only the types VC vs. VVC, and VCV vs. VVCV were examined.

Reliability tests

All productions were independently transcribed by two listeners. When the two transcriptions did not agree in terms of the five vowel categories

[4] It is possible that the adult target form and the child's production could vary on criteria (2) to (4). Hence both were taken into consideration in the matching of items.

(see above) and/or syllable structure (presence or absence of coda), the production was independently transcribed by a third transcriber. This occurred for 23% of productions. The final transcription was one in which two of the three transcribers agreed. If no two of the three transcribers agreed, the production was excluded. This occurred for 2% ($n=13$) of tokens.

Because criteria for duration measurement can sometimes be subjective, inter-judge reliability was calculated on a subset of tokens ($n=30$). Inter-judge remeasures produced a Pearson r correlation coefficient of 0·98 and a mean difference of 10 ms. The duration difference associated with this reliability statistic was much smaller than the duration differences of interest.

RESULTS

We focus first on the latter two time periods and return to the earliest time period later on. Results are discussed separately for phonetic transcription and acoustic analyses. We present first our findings for monosyllables and then proceed to findings for disyllables.

Transcription-based analysis: monosyllables

Figures 2 and 3 show production patterns for monosyllables containing target short and long vowels at time period 2 (1;10 to 2;0) for the three children. To remind the reader, the five vowel production patterns are: lax and short, lax and long, tense and short, tense and long and diphthong (abbreviated in the figures as v, v:, vv, vv:, and Diph respectively, where lower case letters are used to refer to the child's production). The category 'Other' ('Oth' in Figure 3) refers to rhyme splitting which occurred occasionally with target VVC rhymes (e.g. *Stuhl*/ʃtuːl/ 'chair' [ʃtu.ɛl]). Figure 2 indicates that target short vowels were transcribed predominantly as lax and short with a slight tendency to be produced as lax and long, whereas Figure 3 indicates that target long vowels were transcribed as several patterns: lax and short, tense and short, lax and long, tense and long, and as diphthongs. Examples of children's productions at time period 2 are given in (9).

(9) Children's productions of target monosyllabic words at time period 2.

Target short vowels				Target long vowels				
Bett	/bɛt/	[bæt]	1;11.25	*Buch*	/buːχ/	[bʊʔ],[buː]	Bernd	1;10.20
Mann	/man/	[man]	1;11.25	*Stuhl*	/ʃtuːl/	[bʊːl]	Bernd	1;10.20
Kuß	/kʊs/	[kʊs]	1;10.4	*hoch*	/hoːχ/	[hoχ]	Thomas	1;10.4
weg	/vɛk/	[vɛk]	2;0.6	*Zug*	/tsuːk/	[tsuk],[tsʊːk]	Thomas	1;10.4
(ka)putt	/pʊt/	[pʊχ]	1;10.5	*Buch*	/buːχ/	[bux^w]	Marion	1;10.5
Müll	/mʏl/	[mʌl]	1;10.19	*Öl*	/øːl/	[ʔø.ɛl]	Marion	1;11.25

Table 1 summarizes the transcription results for time periods 2 and 3. Accuracy scores refer to the percentage of times target short vowels were

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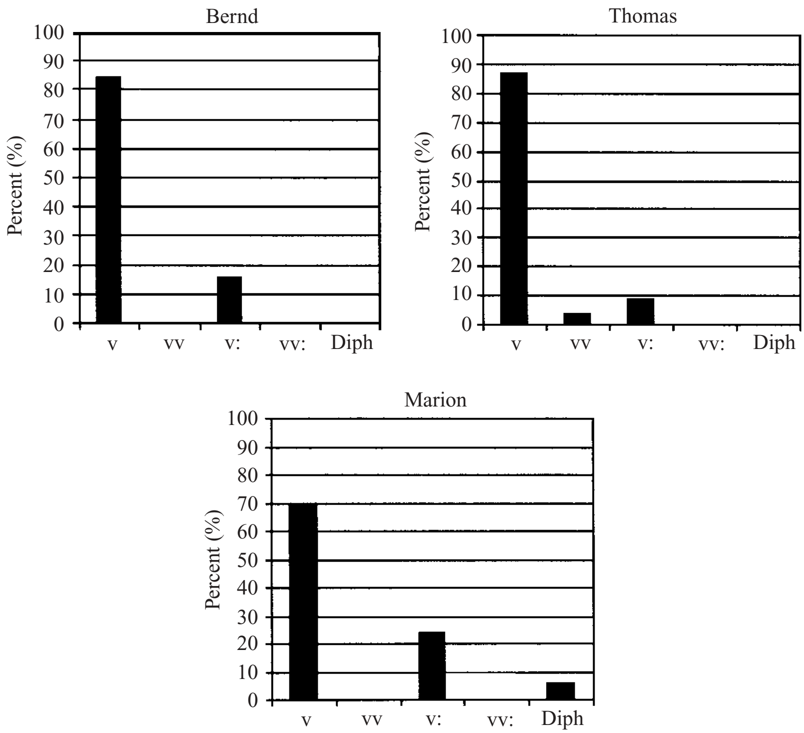

Fig. 2. Production patterns for target short vowels at time period 2 (1;10–2;0).

produced as lax and short and target long vowels were produced as tense and long or as diphthongs. Results indicate that at time period 2, 80% of target short vowels were produced accurately whereas only 58% of target long vowels were produced accurately. Chi square analysis indicated that this difference was significant ($\chi^2(1) = 11{\cdot}01$, $p < 0{\cdot}01$). At time period 3 (2;3–2;6), percent accuracy scores increased for target long vowels (80%) whereas they declined slightly for target short vowels (75%).

The findings up until now have only focused on vowel production. The percent coda production in monosyllables according to whether the target vowel was long or short is given in Table 2. At time points 2 and 3, Bernd and Marion deleted codas on an occasional basis whereas Thomas produced codas 100% of the time. When codas were deleted after target long vowels, the vowel remained phonetically long or tense (e.g. *Sieb*/ziːp/[diː] 'sieve'); when codas were deleted after short vowels (only in the case of Bernd), the vowel was lengthened in two out of 5 occasions (e.g. *Milch* /mɪlç/ [nɪː] 'milk'). If diphthongs are included along with long vowels (see later analysis of diphthongs), results indicate a mild tendency for greater coda production

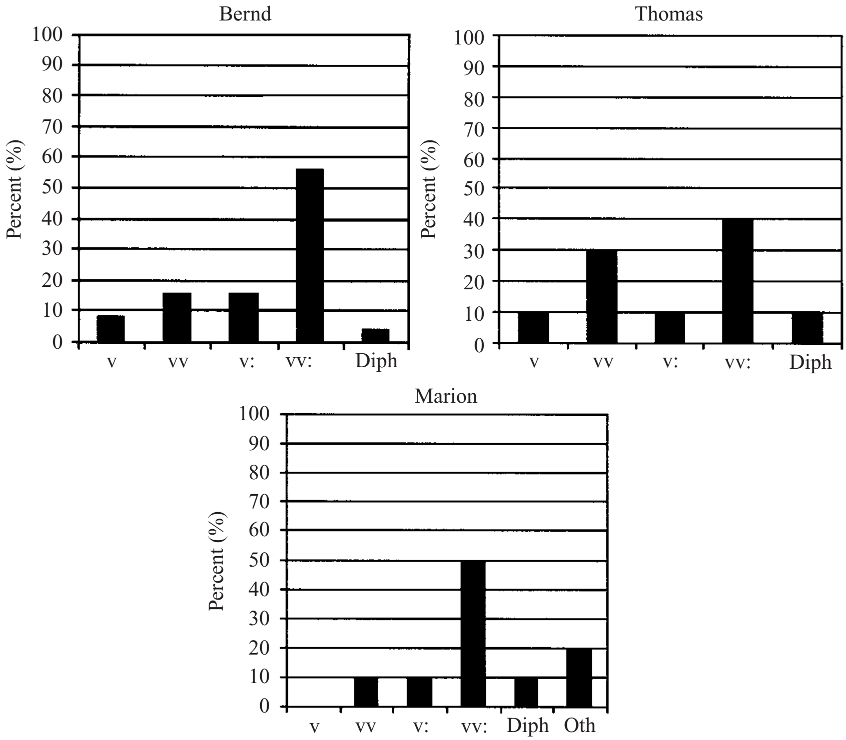

Fig. 3. Production patterns for target long vowels at time period 2 (1;10–2;0).

after short (95% or 138/144) than long vowels (88% or 125/142). A chi-square analysis indicated that this difference was significant ($\chi^2(1) = 5.89$, $p < 0{\cdot}05$).

There were only six productions of target VV syllables in the database (at time periods 2 and 3), e.g. *Tee* /teː/ [tɪː] 'tea'; *Kuh* /kuː/ [huː], [kuː], [kuː] [kɔ] 'cow'; *Zoo* /tsoː/ [tsoː] 'zoo'. In all but one occasion (*Kuh* [kɔ]) the vowel was produced as phonetically long.

Acoustic analysis: monosyllables

Figure 4 shows mean vowel duration according to target vowel length in monosyllabic productions across the two time periods. Mean values are also summarized in Table 3 along with ranges and standard deviations. All three children produced target long vowels significantly longer than target short vowels at both time periods (Paired *t*-tests: Bernd(time period)2 $p < 0{\cdot}01$; Bernd3 $p < 0{\cdot}01$; Thomas2 $p < 0{\cdot}05$; Thomas3 $p < 0{\cdot}01$; Marion2 $p < 0{\cdot}05$; Marion3 $p < 0{\cdot}01$). The magnitude of the duration difference was not as great as that reported for adult speech (ratio is approx. 2·0). At time period 2,

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TABLE 1. *Percent accuracy scores for target short and long vowels in monosyllables*

	Time period 2		Time period 3	
Children	Target short	Target long	Target short	Target long
Bernd	84% (26/31)	60% (15/25)	65% (11/17)	82% (18/22)
Thomas	87% (20/23)	50% (5/10)	81% (25/31)	77% (10/13)
Marion	70% (14/20)	60% (6/10)	76% (16/21)	79% (11/14)
Group mean	80% (60/75)	58% (26/45)	75% (52/69)	80% (39/49)

TABLE 2. *Percent coda production in monosyllables*

	Time period 2 (1;10–2;0)		Time period 3 (2;3–2;6)	
Children	Target short	Target long	Target short	Target long
Bernd	84% (26/31)	83% (20/24)	100% (17/17)	95% (20/21)
Marion	100% (20/20)	70% (7/10)	100% (21/21)	73% (8/11)
Thomas	100% (23/23)	100% (9/9)	100% (31/31)	100% (13/13)

long vowels were 1·4 to 1·7 times longer, and at time period 3, long vowels were 1·6 to 1·7 times longer than short vowels.

Analysis of disyllables

Table 4 summarizes percent accuracy scores for target long and short vowels in disyllables. The transcription-based findings of disyllables were similar to those of monosyllables except that accuracy scores tended to be higher, particularly for target short vowels. At time period 2, target short vowels were produced as lax and short 90% of the time and this value remained constant (91%) at time period 3. Target long vowels were produced tense and long or as diphthongs 64% of the time at time period 2 and this increased to 82% at time period 3. The difference between the percent accuracy of long and short vowels at time period 2 was statistically significant ($\chi^2(1)=12.01$, $p<0.01$). Examples of children's productions are provided in (10).

(10) Children's productions of target disyllabic words at time period 2.

Target short vowels				Target long vowels				
Tasse	/tasə/	[dadɪç]	1;10.20	*Tiger*	/tiːgɐ/	[tiːgal]	Bernd	1;10.20
essen	/ʔɛsn/	[ʔʌdːan]	1;11.25	*Vogel*	/foːgl/	[dodan]	Bernd	1;11.25
Koffer	/kɔfɐ/	[kɔfɐ]	1;10.4	*schniefen*	/ʃniːfn/	[niːfən]	Thomas	1;10.4
Wasser	/vasa/	[vasa]	1;11.2	*Fliege*	/fliːgə/	[vika]	Thomas	1;10.4
Koffer	/kɔfa/	[tɔta]	1;10.19	*Vogel*	/foːgl/	[dotʰə]	Marion	1;10.5
Apfel	/ʔapfl/	[ʔafən]	1;11.25	*Zähne*	/tsɛːnə/	[tɪːŋə]	Marion	1;10.19

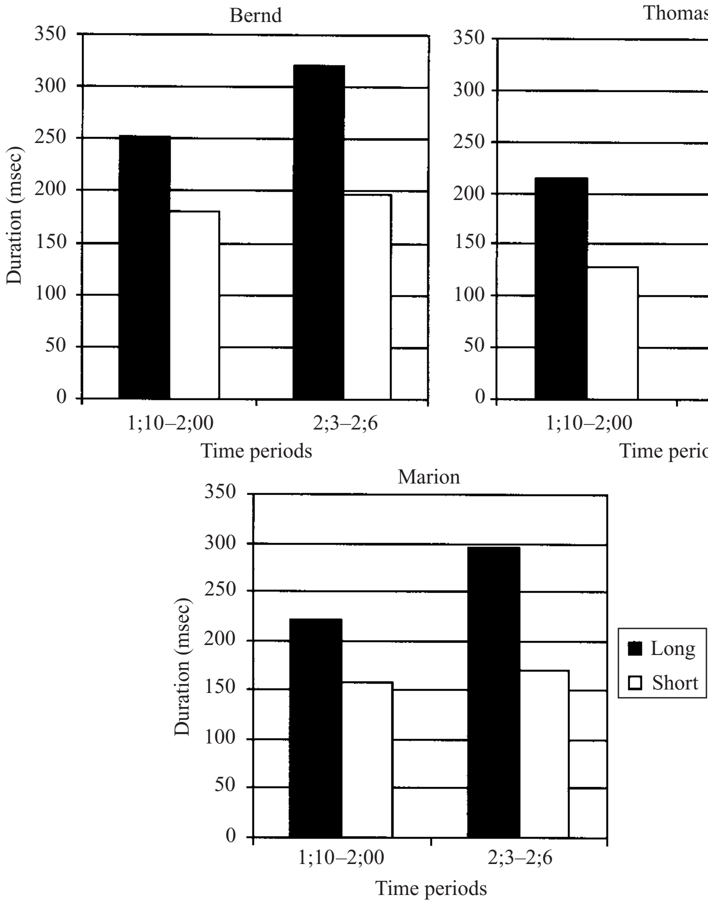

Fig. 4. Mean durations (ms) of target long and short vowels at time periods 2 and 3.

Table 5 summarizes mean duration results in disyllables. All children at both time periods produced target long vowels significantly longer than target short vowels in disyllabic words (Paired *t*-tests: Bernd2 $p<0\cdot01$; Bernd3 $p<0\cdot001$; Thomas2 $p<0\cdot01$; Thomas3 $p<0\cdot001$; Marion2 $p<0\cdot001$; Marion3 $p<0\cdot001$). The ratios of long to short vowels in disyllables were smaller than those in adult speech but approached adult values at time period 3. At time period 2, long vowels were 1·3 to 1·6 times longer and at time period 3, long vowels were 1·8 to 2·1 times longer than short vowels.

Time period 1 (*onset of word production to* 1;7)

In this section, we concentrate on children's productions from the onset of word production until 1;7. Table 6 summarizes the patterns displayed

TABLE 3. *Summary duration values (ms) for target short and long vowels in monosyllables*

Children	Target short				Target long				Ratio
	N	Mean	S.D.	Rg	*N*	Mean	S.D.	Rg	
Time period 2 (1;10–2;0)									
Bernd	16	180	47	112–316	16	253	68	155–370	1·4
Thomas	8	129	32	86–169	8	215	71	135–333	1·7
Marion	7	157	35	127–233	7	222	67	136–322	1·4
Time period 3 (2;3–2;6)									
Bernd	10	197	63	81–301	10	320	89	183–452	1·6
Thomas	13	150	39	81–200	13	259	88	134–456	1·7
Marion	8	170	26	137–217	8	296	64	162–349	1·7

TABLE 4. *Percent accuracy scores for target short and long vowels in disyllables*

Children	Time period 2		Time period 3	
	Target short	Target long	Target short	Target long
Bernd	100% (13/13)	57% (8/14)	100% (12/12)	84% (16/19)
Thomas	92% (23/25)	67% (14/21)	89% (17/19)	79% (19/24)
Marion	84% (21/25)	67% (16/24)	87% (13/15)	86% (12/14)
Group mean	90% (57/63)	64% (38/59)	91% (42/46)	82% (47/57)

TABLE 5. *Summary duration values (ms) for target short and long vowels in disyllables*

Children	Target short				Target long				Ratio
	N	Mean	S.D.	Rg	*N*	Mean	S.D.	Rg	
Time period 2 (1;10–2;0)									
Bernd	8	163	33	110–200	8	233	61	136–324	1·4
Thomas	12	148	39	95–215	12	197	56	137–301	1·3
Marion	14	136	35	80–182	14	223	60	127–334	1·6
Time period 3 (2;3–2;6)									
Bernd	9	155	40	98–233	9	284	100	167–461	1·8
Thomas	12	110	35	60–169	12	227	47	165–316	2·1
Marion	10	141	36	75–202	10	266	61	194–394	1·9

by Marion (age 1;3–1;7) and Thomas (age 1;5–1;7) in monosyllabic productions. Numbers of tokens are indicated in parentheses and the mean duration for the most prominent (italicized) production pattern is provided. As mentioned above, Bernd did not produce any analysable words during this time period. Table 6 indicates that Marion produced target

TABLE 6. *Production patterns at time period* 1 *in monosyllables (Marion and Thomas)*

	Target rhymes with long vowels			Target rhymes with short vowels		
	VV	VVC	V_iV_jC	VC_{ob}	VC_n	VC_l
Marion						
	v(v):[a] (13/13)[b]	v(v): (5/5)	*v_iv_j* (3/5) v(v): (2/5)	vC (5/5)	*vC* (3/4) v:C (1/4)	*v_iv_j* (5/6) vC (1/6)
	409 ms[c]	385 ms	373 ms	177 ms	226 ms	401 ms
Thomas						
	—	*vv*: (3/4) vv:C (1/4)	v_iv_j (1/11) vC (3/11) v(v):C (3/11) *v_iv_jC* (4/11)	vC (1/1)	—	*v_iv_j* (4/5) vC (1/5)
		361 ms	442 ms	200 ms		348 ms

[a] Lower case letters refer to the phonetic forms of the child: v (short and lax); vv (short and tense), v: (long and lax), vv: (long and tense), and v_iv_j (diphthong). v(v): refers to a phonetically long lax or tense vowel.
[b] Raw scores are indicated in parentheses.
[c] Duration measures refer to the mean vowel/diphthong duration of the most frequent production form (italicized).

rhymes containing long vowels or diphthongs as open syllables with long vowels, and target rhymes containing short vowels and obstruent and/or /n/ codas as closed syllables with short vowels. Target words containing short vowels and /l/ codas were produced as open syllables with diphthongs. Examples are given in (11). Thomas attempted fewer target words than Marion, although his patterns were consistent with Marion's; the main exception being that target V_iV_jC rhymes were also produced correctly.

(11) Marion's productions (time period 1)

a. Target VV

Zeh	/tseː/	[deː]	'toe'	1;3.19

b. Target VVC

Bad	/baːt/	[paː]	'bath'	1;3.19
Buch	/buːχ/	[huː], [hʊː]	'book'	1;5.24

c. Target V_iV_jC

Bein	/baɪn/	[baɪ]	'leg'	1;3.19
heiß	/haɪs/	[ʔaɪ]	'hot'	1;4.23

d. Target VC_{ob}, VC_n

ab	/ap/	[hap]	'up'	1;5.24
Mann	/man/	[mam]	'man'	1;6.7

e. Target VC_l

Ball	/bal/	[baɪ]	'ball'	1;3.27

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TABLE 7. *Percent accuracy scores for diphthongs in monosyllables and disyllables*

	Monosyllables Time period			Disyllables Time period		
	1	2	3	1	2	3
Be	—	100% (13)	100% (8)	—	22% (4/18)	100% (11)
Th	45% (5/11)	89% (8/9)	100% (7)	0 (0/5)	100% (13)	100% (8)
Ma	60% (3/5)	100% (9)	100% (8)	25% (1/4)	93% (13/14)	100% (8)
Mean	50% (8/16)	97% (30/31)	100% (23)	11% (1/9)	67% (30/45)	100% (27)

Concerning disyllabic productions, Marion produced 83% (10/12) of target short vowels as lax and short but only 30% (4/12) of target long vowels as tense and long. Thomas, in contrast, frequently alternated between long and short vowels for the same target word, producing the words *Tiger* /tiːgɐ/ 'tiger' and *Apfel* /ˈapfəl/ 'apple' with short and long variants (e.g. *Tiger* [ˈdɪtɐ], [ˈtʰɪːtɐ] – duration ranged from 116–346 ms; *Apfel* [ˈʔafa], [ˈaːfa] – duration ranged from 72–181 ms). The mean durations of long vowels in Marion's and Thomas's disyllabic words were respectively 227 ms ($n=11$) and 225 ms ($n=10$); The mean durations of short vowels were respectively 193 ms ($n=11$) and 180 ms ($n=10$). This resulted in a long-to-short vowel ratio of around 1·2. The difference in duration between long and short vowels was significant in the case of Marion ($p<0{\cdot}05$) but not in the case of Thomas.

Diphthong production

Table 7 reports percent accuracy scores for diphthongs across all three time periods in monosyllabic and disyllabic productions. Scores represent the percentage of times target diphthongs were transcribed as diphthongs. By time period 2, diphthongs were produced with almost 100% accuracy in both sets of words, the only exception being Bernd who experienced difficulty producing diphthongs in disyllabic words at time period 2. He realized diphthongs either as a short (10/18) (e.g. *Auto* /aʊto/ 'car' [ʔado]) or as a long vowel (4/18) (e.g. *Eimer* /aɪmɐ/ 'rubbish bin' [ʔaːmæn]). Similarly, Marion and Thomas experienced more difficulty producing diphthongs in disyllabic as compared to monosyllabic words at time period 1. The lower accuracy of diphthongs in disyllables as compared to monosyllables is noteworthy in view of the fact that vowel length accuracy was generally superior in disyllables. Also noteworthy is the higher accuracy of diphthongs as compared to long vowels (Monosyllables, time period 2: diphthongs 97%, long vowels 58%; time period 3: diphthongs 100%, long vowels 80%).

DISCUSSION

This study examined three German-speaking children's acquisition of long and short vowels and diphthongs in monosyllabic and disyllabic words. In the following sections, we compare our findings to models of rhyme development by Fikkert (1994) and Grijzenhout & Joppen (1999), and then interpret our results in terms of what they tell us about children's early representation of vowel length and syllable structure.

Comparison of findings with Fikkert's (1994) *and Grijzenhout & Joppen's* (1999) *models of rhyme development*

Fikkert's (1994) model of rhyme development includes two initial stages, in which vowel length is random – a CV stage and a stage with obstruent codas – followed by a stage in which either long vowels or short vowels plus sonorant codas are produced. The current findings do not support the first two stages of Fikkert's model of rhyme development. The earliest productions of one child (Marion) were most consistent with Fikkert's third stage of rhyme acquisition with one main difference. Marion tended to delete consonants after long vowels and to produce consonants after short vowels regardless of whether the coda was an obstruent or sonorant. The only exception was /l/ codas which were frequently vocalized after short and long vowels.

Grijzenhout & Joppen's (1999) model also includes an initial stage in which vowel length is random but their model differs from Fikkert's in that they find no evidence for a CV stage. The earliest words of their subject were characterized by exactly one consonant and one vowel, which could appear either as a CV or VC sequence. Our findings do not support this initial stage of rhyme development either. While it was true that VC sequences were present in children's earliest words, CV forms with a short vowel were virtually unattested suggesting that a bipositional constraint was active early on. Our results were thus more consistent with their second stage of rhyme acquisition in which monosyllabic words could be minimally and maximally bipositional. Grijzenhout & Joppen (1999) observed two substages in this period. The child produced a target VVC rhyme first as a long vowel and then later as a short vowel plus coda. We may also have evidence for these two substages in the data. At 1;5.24, Marion produced *Buch* /buːχ/ 'book' as [hʊː] (duration: 405 ms) and later at 1;9.1 (an interim period between time periods 1 and 2) as [pʊx] (duration: 122 ms). Unfortunately, we cannot be totally sure whether these latter forms represent a distinct substage since at 1;9.1 and later at time period 2, VVC rhymes were produced as closed syllables with long or short vowels meaning that the short vowel forms may be just one subpattern in a more general pattern in which target long vowels could be produced both short or long.

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Our current results while supporting various aspects of Fikkert's (1994) and Grijzenhouts & Joppen's (1999) models do not support all aspects. In the following section, we present the model which best supports the acoustic and transcriptional data accrued.

Early representation of vowel length

Before proceeding to a discussion of vowel length representation, it is necessary to make a methodological comment concerning interpretation of the phonetic data. The transcription analysis indicated that, at time period 2, children produced target short vowels predominantly as lax and short, whereas they produced target long vowels as several different patterns. Because the vowel length difference in German is one of both tenseness and length, the preceding analysis adopted a strict criterion, in which it counted only the productions of tense long vowels and diphthongs as 'accurate' or as 'phonologically long'. It is possible that this criterion was too strict, however, and that children's productions may not reflect their underlying representations perfectly. Children may still represent target long vowels as long but due to limited articulatory skills produce them as lax and long or as tense and short. If one were to adopt less strict criteria and accept the productions of tense (disregarding phonetic length) AND/OR phonetically long vowels (disregarding tenseness) as phonologically long, the accuracy differences between target long and short vowels would be reduced, resulting in a different phonological interpretation of the data.[5] The discussion that follows takes both the strict and less strict criteria into account in the interpretation of vowel length representation.[6]

The German data suggest the following stages of vowel length acquisition which correspond broadly to the time periods studied in this project: (1) an earlier stage in which children productions are governed by a bipositional

[5] There are several ways of interpreting the phonetic data in terms of the category 'long vowel'. If we count only productions of tense long vowels and diphthongs (strict), target long vowels would be classified as phonologically long 58% of the time in monosyllables at time period 2; if we include either tense (long or short) OR phonetically long (tense and lax) vowels (less strict), target long vowels would be classified phonologically long approximately 70% of the time; if we count tense (long or short) AND phonetically long (lax) vowels – excluding only lax short vowels (less strict again), target long vowels would be classified 93% of the time as phonologically long.

[6] Syllable structure and stress assignment provides little additional information on vowel length representation in the current situation. By time period 2, children produced codas most of the time after short and long vowels. When they did delete codas, they displayed a mild tendency to delete them more often after long vowels which would then be consistent with some form of representational difference between short and long vowels but this information does not allow us to distinguish between the interpretations of the strict vs. less strict criteria. This study has not addressed stress acquisition but the fact that very few stress errors were observed in the data provides little evidence one way or the other on vowel length.

constraint; (2) a middle stage in which an opposition is beginning to develop OR is fully developed between short and long vowels; and (3) a later stage in which a more adult-like opposition is present. We refer mainly to vowels in monosyllabic words but extend the discussion to disyllabic words later on.

(12) Stages of vowel length acquisition

Early	Bipositional rhymes				
	Target VVC	Target VC			
	Child VV	Child VC			
Middle	Beginning of opposition V vs. V(V)		or	Opposition V vs. VV	
	Target VVC	Target VC		Target VVC	Target VC
	Child VC or VVC	Child VC		Child VVC	Child VC
Later	Adult-like opposition V vs. VV				
	Target VVC	Target VC			
	Child VVC	Child VC			

At the EARLIEST TIME PERIOD, Marion adhered to a bipositional maximum by producing short vowels in closed syllables and long vowels in open syllables.[7] Fikkert (1994) interpreted this pattern as suggestive of vowel length representation; however, as indicated earlier, this pattern is not necessarily consistent with distinctive length. It is true that Marion may already represent vowel length phonologically but due to the bipositional constraint, be unable to reproduce this distinction. Her tendency to maintain the vowel length of the target form in her surface productions (target VVC was produced as VV; target VC was produced as VC) is consistent with this possibility. However, her tendency to produce target long vowels less accurately at the next stage of development (target long vowels were not always produced as long at time period 2) suggests that vowel length is not yet stable. We, thus, leave open whether long and short vowels are represented differently at this earliest stage.

At the SECOND TIME PERIOD, the data point to some form of representational difference between long and short vowels. Adopting the less strict criteria, we would claim that children, by 1;10 to 2;0, already represent target short vowels as monopositional and target long vowels as bipositional. We would make this claim because transcription results indicate that target short and long vowels are mainly produced as short/lax and long/tense respectively, and because acoustic results indicate that target long vowels are produced longer than target short vowels.[8] The acoustic results are consistent with

[7] At time period 1, Thomas was able to produce diphthongs in closed syllables, suggesting that he was already moving beyond a bipositional constraint.

[8] It should be noted, nevertheless, that the absolute duration values were considerably longer than those reported for adult speakers. Iivonen (1987) reports mean adult values of 73 ms and 166 ms for target German short and long vowels respectively, whereas our

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recent findings in adult languages showing a convergence between phonological representation and phonetic facts, specifically with respect to moraic structure and segment duration (Broselow, Chen & Huffman, 1997). We interpret the increased duration of target long versus target short vowels not simply as phonetic, because we have controlled for many factors that affect phonetic timing, including affect, segmental context, and syllable structure; rather it reflects the representation of long vowels as bipositional segments. The fact that long vowels were occasionally shortened may be the result of the bipositional production constraint that remains active even after time period 1. Target long vowels were invariably produced as long in open monosyllables, supporting the representation of long vowels as bipositional segments.

Turning to the more strict interpretation of the data, our results are still consistent with a representational difference between long and short vowels but one that is not yet complete. Children's vowel length representation at this time period consists of an opposition between a stable monopositional vowel and an unstable bipositional vowel V(V). This claim is supported by the different behaviours of long and short vowels: Target short vowels were mainly produced accurately (i.e. as lax and short) whereas target long vowels were not. Furthermore, acoustic analysis showed that the main change occurring between time period 2 and 3 was a lengthening of target long vowels rather than a shortening of target short vowels (see Figure 4). We propose that children experience more difficulty producing target long vowels because they are structurally more complex than short vowels (Anderson, 1984). Children experience less difficulty with target short vowels because they are the best phonetic instantiation of a monopositional vowel. Thus, children's earliest representation of the nucleus is that of a monopositional vowel and over time they must learn to produce a stable bipositional vowel. Fikkert (1994) also claimed that children begin rhyme development with a monopositional vowel, but whereas she assumed this from observing random behaviour on the part of short and long vowels, our results show that target short vowels pose fewer problems in acquisition. In this respect, the development of the nucleus resembles acquisition patterns in other areas of syllable structure in that children realize one element of a complex structure and then later, two.

The above discussion assumes a prosodic interpretation of the data. It cannot be excluded that other factors may be responsible for the different

subjects produced mean values of 149 ms and 218 ms respectively (in disyllables at time period 2). These results are consistent with previous phonetic studies that indicate, despite early phonological sophistication in the use of phonetic parameters, children do not develop adult-like control of speech timing until later in production (Smith, 1978).

behaviour of short vs. long vowels, including segmental complexity, methodological reasons, or input frequency. First, short vowels may have been produced more accurately than long vowels because in general short segments are easier to produce than long segments. This may be due to articulatory ease and economy. Second, in the current study, vowels were measured in environments that may have favoured the shortening of long vowels: the monosyllabic words were predominantly closed and the disyllabic words were always followed by an unstressed syllable. Both of these environments may have led to higher accuracy scores for short compared to long vowels. Third, short vowels appear to have been more frequent in the child's input than long vowels. This impression is based on the fact that it was considerably more difficult to find words containing target long than short vowels (particularly in monosyllables) in the database. Additional data to support this claim stem from a survey of another German database consisting of all words produced by a German child, aged 0;10 to over 2;10 years (Elsen, 1991). This survey shows that target words (monosyllables only) containing short vowels were present twice as often as target words containing long vowels. If any of these factors were responsible for the higher accuracy rates of target short than long vowels, this would provide additional support for the non-strict interpretation of the data, that is, that German children stably represent phonological vowel length before two years of age.

Finally, at the THIRD TIME PERIOD, children have developed an adult-like vowel length opposition as suggested by their more target-like phonetic realizations; target long and short vowels were more frequently transcribed accurately and long-to-short-vowel ratios approximated adult norms. The attainment of a stable vowel length opposition is evidenced by the presence of near minimal pairs. Examples from Thomas' productions are given in (13).

(13) Near minimal pairs in Thomas' productions (time period 3)

a.	*Hahn*	/haːn/	[haːn]	'rooster'	2;4.13
	Mann	/man/	[man]	'man'	2;4.13
b.	*hoch*	/hoːx/	[hoːχ]	'high'	2;4.13
	doch	/dɔx/	[dɔχ]	interjection	2;4.13

When we compare vowel length development in monosyllables vs. disyllables, the results indicated a tendency for vowel length to be acquired earlier in disyllables. Certain methodological factors may be responsible for this difference however. One relates to extrinsic vowel length conditioning. In disyllabic words, although we attempted to control for voicing of the intervocalic obstruent, this was not always possible because of characteristics of the German language – there are very few voiced obstruents following short vowels. This meant that in our disyllabic word pool, we included target long vowels which were followed by either voiced or voiceless obstruents but target short vowels which were followed mainly by voiceless obstruents.

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In effect, we may have been measuring not only intrinsic but also extrinsic duration effects due to the vicinity of the voiced obstruent. This possibility would have increased the likelihood that target long vowels in disyllables were produced phonetically long and, hence, more accurately. A second factor that may have resulted in differences between monosyllables vs. disyllables is the different syllable structure contexts. The monosyllables were predominantly closed syllables whereas the stressed syllable of disyllables were predominantly open. The closed syllable environment in monosyllables may have been responsible for some of the lower accuracy rates of long with respect to short vowels (due to closed syllable shortening). A thorough comparison of the monosyllabic vs. disyllabic context would require design of an experimental study, in which vowels in closed syllables in monosyllables would be compared to vowels in closed syllables in disyllables. We leave a more detailed comparison of vowel length in monosyllables vs. disyllables to future studies.

Representation of diphthongs

We now turn to the representation of diphthongs. The initial results of Marion and Thomas at time period 1 (monosyllables) are consistent with a bipositional rhyme constraint. Target forms containing a diphthong plus coda were produced as bipositional forms either by deleting the coda (Marion) or by deleting one element of the diphthong (Thomas). Examples are given in (14).

(14)	a.	$V_iV_jC \rightarrow V_iV_j$					
		Bein	/baɪn/	[baɪ]	'leg'	Marion	1;3.19
		heiß	/haɪs/	[ʔaɪ]	'hot'	Marion	1;4.23
	b.	$V_iV_jC \rightarrow V_iC$					
		heiß	/haɪs/	[has]	'hot'	Thomas	1;6.16
		Moin	/mɔɪn/	[mɔm]	'Good Morning' (Nt. German greeting)	Thomas	1;7.1

The analyses of diphthongs at time periods 2 and 3 indicated that diphthongs were produced more accurately than long vowels. That is, children produced a vowel that was perceived as a diphthong before they produced a vowel that was perceived as containing the features [+tense] and [+long]. If we assume the strict criterion, there appears to be an asymmetry between the acquisition rate of diphthongs and long vowels, which is not consistent with our assumptions on vowel length representation. Under the assumptions of the strict criterion, children do not represent bipositional vowels stably at time period 2; yet, if this is correct, why do they experience little difficulty with the production of diphthongs? Here, we would need to argue that there are two different timelines for the acquisition of diphthongs and long vowels.

TABLE 8. *Percent accuracy of target rhymes in monosyllabic words*

	VVC	V_iV_jC	VCC
Bernd	67% (16/24)	79% (11/14)	0 (0/10)
Thomas	67% (6/9)	78% (7/9)	75% (3/4)
Marion	63% (5/8)	88% (7/8)	64% (7/11)

Diphthongs are stably represented as bipositional segments earlier than long vowels, possibly due to perceptual and production factors. Diphthongs may be easier to perceive than long vowels because they involve both quality-plus-duration differences whereas long vowels involve only duration differences. From a production stance, the greater melodic complexity of diphthongs may make them less resistant to the syllable reduction processes that apply to long vowels. Under the assumptions of the less strict criteria, the high accuracy rate of diphthongs is explainable because children already represent bipositional vowels stably at time period 2.

An alternate possibility that may account for the different behaviour of diphthongs and long vowels is that diphthongs are represented as short vowels and codas rather than as long vowels. To examine this alternative, we compare the different accuracy rates of rhyme types in monosyllables at time period 2. The percentage of times target VVC, V_iV_jC, and VCC rhymes were produced correctly (i.e. as v(v):C, v_iv_jC and vCC productions respectively) is shown in Table 8. In two children the percentages of all three rhyme types were relatively similar whereas in one child (Bernd), diphthongs in closed syllables were acquired before complex codas arguing against the representation of diphthongs as VC, at least for this particular child. In Table 8, the accuracy of target long vowels is based on phonetic length. If tense short vowels were also counted as phonologically long, the accuracy scores of long vowels would be even higher than the values indicated.

Turning to disyllabic words, the findings are also relevant to our other main finding, namely, that diphthongs were not easily produced in disyllables at the earliest stages of production. Here, the accuracy rates of V_iV_j and VC tended to pattern together providing more support for the representation of diphthongs as VC. For example, Bernd at time period 2 reduced target V_iV_j and VC to V most of the time in disyllables yet still produced target VV rhymes 64% of the time.[9] In sum, diphthongs do not always behave the same as long vowels. Positing a VC representation for diphthongs does not explain their high overall accuracy in monosyllables but

[9] At time period 2, Bernd produced diphthongs in closed syllables in monosyllables but reduced diphthongs in disyllables (e.g. *heiß* /haɪs/ 'hot' [ʔaɪθ] vs. *Auto* /ʔaʊto/ 'car' [ʔado]). We have no explanation for this pattern except that diphthongs seemed to pattern as a vowel plus coda in disyllables for this particular child. There may also be a constraint on melodic complexity which is violated by CV_iV_j CV but not by CV_iV_j C.

may explain their tendency to be reduced in disyllables at the initial stages of acquisition.

Comparison of vowel length acquisition in German with English

The current findings on vowel length acquisition pertain to German-speaking children and we make no claims regarding the universality of these findings for other languages. Indeed, a comparison of the German findings with those for English reveals quite a different pattern of acquisition. The combined results of Stoel-Gammon *et al.*'s (1995) acoustic study and Kehoe & Stoel-Gammons (2001) transcription-based study indicated that English-speaking children (age 2;0) distinguished target long and short vowels primarily by quality. This study showed that German-speaking children (age 2;0) distinguished target long and short vowels by both quantity and quality, although their production patterns were not yet adult-like. While tense-lax alternations were rare in the English-speaking productions around this age, they occurred more frequently in the German productions particularly for target long vowels. Thus, the equal presence of both quantity and quality in the vowel length distinction for German may complicate the acquisition process. English-speaking children proceed by concentrating on quality whereas German-speaking children must concentrate on both.

A further point of difference between the German and English data was the presence of a strong bipositional constraint in the German data. Kehoe & Stoel-Gammon (2001) also observed a tendency for codas to be produced more frequently after short than long vowels. Nevertheless there remained several children in the English study who did not produce codas after target short vowels but maintained target vowel length, thus, producing on occasion a monopositional rhyme. In this study, German-speaking children produced codas from the beginning of word production and monopositional rhymes (target VC rhymes produced without codas) were extremely rare. The overall picture is that quantity matters more in German than in English acquisition and that some aspects of syllable structure development (i.e. codas) may proceed at a faster pace.

CONCLUSION

In conclusion, our findings suggest that there is never a period in German acquisition when phonological vowel length is totally random.[10] Our findings support three stages of vowel length acquisition: an early stage, in which childrens (monosyllabic) productions are consistent with a bipositional

[10] The only true random behaviour of vowel length documented in this study was in Thomas' production of disyllables at time period 1. Thus, if there is a period of random vowel length, it is short lived and occurs only for some children.

rhyme constraint; a middle stage, in which an opposition between a monopositional and bipositional vowel is either partially or fully represented; and a final stage, in which an adult-like opposition is present as suggested by more target-like phonetic realizations. Thus, our findings differ from previous accounts of syllable structure development, which propose that phonological vowel length is acquired late. Our analyses showed that diphthongs do not always pattern as long vowels but in some contexts pattern more like a vowel plus consonant. The greater melodic complexity of diphthongs may lead to their earlier representation as bipositional segments than long vowels.

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