The acquisition of timing patterns in children's productions

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Oh, Eunhae. 2015. The Acquisition of Timing Patterns in Children's Productions. *Studies in Phonetics, Phonology and Morphology* 21.1, 99-113. The current study examined differences in the segmental duration of adults' and school-aged children's speech. The purpose of the study was to understand the durational patterns and rhythmic characteristics of school-aged children's speech production. The effects of vowel identity, final coda voicing and number of syllables on absolute and relative duration were explored. Similar to previous studies, segmental duration in absolute terms was found to be significantly longer for children than for adults. However, no significant differences were found between adults and children in terms of the relative timing patterns of inherent vowels, vowels before voiced and voiceless consonants or stressed vowels in multisyllabic words. An adult-like timing control found in children's production is interpreted to indicate a high level of phonological knowledge about the relative timing of sequential segments, despite some evidence of oral-motor constraints. **(Konkuk University)**

Keywords: child language production, development of durational pattern, relative timing of vowels, effects of final consonant voicing and syllable number

1. Introduction

Children must learn to produce range of speech sounds in time. It, however, requires neuromuscular control over certain phonetic parameters in their ambient language and the maturational changes in speech production ability ensue over an extended period of time. Sanders (1972) reported that children typically do not master their native speech segments until 8 years old and some other features do not fully develop until even later (Eguchi and Hirsh 1969, Kent 1976). Evidence from previous kinematic studies also suggests that properties of oral motor control system, such as lips and jaw, stay unstable until early adolescence (e.g., Green et al. 2002, Walsh and Smith 2002, Cheng et al. 2007). These studies on children's articulation development share similar results: the speech mechanism matures with increase in age.

Children's immature oral-motor control is considered to influence the temporal coordination of articulators such as slower speaking rate and longer speech segments (Chermak and Schneiderman 1986) and the refinement process of articulatory control continues to develop into early adult-hood (Sabin et al. 1979, Walker et al. 1992, Flipsen 2002). Hence, younger children are likely to show a slower rate of speech. Kowal, O'Connell and Sabin (1975) examined speaking rate in 168 American-English speaking children and the most significant differences were found between 5 and 8 years old. The results were contributed to the rapid growth of both cognitive and physical aspects of language during that period of development. Consistent with earlier studies, Amir and Grinfeld (2011) found that the articulation rate[1] for the 7 year old age group was significantly longer than that for the 9 and 11 year old groups.

Early studies have indicated that among many acoustic features duration gives a strong and stable measure of speech development. However, the mature control over segmental duration, including voice onset time, was shown to stabilize not until 11 or 12 years of age (Naeser 1970, Kent and Forner 1980, Whiteside et al. 2003). Lee, Potamianos and Narayanan (1999) compared the durations of ten monophthongal vowels produced by 436 children between age 5 to 17, and 56 adults and found that younger children produced longer segmental duration than older children. The difference was the most substantial between the age 5 and 10 and the adult-like duration was attained around age 12. Tingley and Allen (1975) and other studies (Kent and Forner 1980, Smith et al. 1995, Clark et al. 2001) reported that children tend to show less accuracy and greater range of durations in their speech productions. That is, children demonstrated poorer timing control than adults.

Previous studies on children's and young adults' productions suggest that the speech of school-aged children (between 5 to 8 years old) may represent the interim state of the language development. The present study examined children in this developmental stage to gain additional information about children's ability to accurately produce durational patterns. As will be introduced in the following section, syllabic structures were manipulated to assess whether children perform differently from adults under different conditions. We might predict that absolute duration will likely be longer in children's than in adults' productions. The current task further examined the relative measures of duration in an attempt to normalize the speaking rate and to compare the duration of each segment of interest.

2. The Current Study

The purpose of the current study was to investigate the differences in the segmental duration of adults' and school-aged children's speech. Although school-aged children are competent in their speech production, one ensuing question would be whether these children could demonstrate durational patterns in an adult-like manner. We might easily expect from previous research that over all segmental durations are likely to be prolonged in children's speech (Fletcher 1972, Di Simoni 1974, Eilers et al. 1984). Here we seek to further explore three factors influencing vowel duration; vowel identity, final coda voicing, and syllable number. Specifically, three factors were examined across adults' and children's productions to investigate

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[1] Amir and Grinfeld (2011) differentiate articulation rate from speaking rate in that sp eaking rate is more of a global measure including pauses and repetitions while artic ulation rate is more limited to oral motor control.

whether they have different effects on duration.

Klatt (1973) argued that when estimating the degree of vowel length compression the voicing of the following consonant, the number of syllables, as well as the inherent duration of a given vowel should be taken into consideration. First, inherent vowel duration should account for differences in much of the variation in segmental duration (Klatt 1976). In English, for example, tense vowels are generally longer than lax vowels and diphthongs are longer than monophthongs (Peterson and Lehiste 1960). Klatt (1975) found that around half of the variance of stressed vowel durations may be attributed to difference in vowel identity. As infants show early sensitivity to timing properties of their ambient language (Levitt, 1993), the prediction is that school-aged children will show relatively adult-like norm in distinguishing different vowels.

Second, the voicing of the final consonant affects vowel and consonant closure duration. It has been well studied that vowels are longer before voiced than voiceless consonants (Chen 1970, House 1961, Klatt 1973, Lisker 1978, Luce and Charles-Luce 1985), while consonant closures are shorter for voiced than for voiceless stops (Lisker 1957, Port 1978, 1979, 1981). Vowel duration has also been pointed out as the primary cue to voicing (Raphael 1972) and closure duration as the secondary cue in speech perception. Previous studies have shown that, although not adult-like, children as young as 21 months-of-age produce vowels longer before voiced than voiceless consonants (Naeser 1970, Raphael et al. 1980). Only a handful of studies, however, examined the acquisition of durational patterns as a function of final consonant voicing for school-aged children.

Another important factor influencing segment duration is the number of syllables (i.e., polysyllabic shortening). Research showed that duration of stressed vowels is shorter in polysyllabic words than in monosyllabic words (Johns 1932, Lehiste 1972, Port 1981). Jones (1942) stated that "the duration of English long vowels in primary stressed syllables is strongly affected by the number of following unstressed syllables within the word" (Jones 1942: 10). More recently, White and Turk (2010) examined monosyllable, disyllable and trisyllable words (e.g., *part, partner, partnership*) produced by six college students and found that stressed syllables were longest in monosyllabic words. Polysyllabic shortening reported in other languages such as Swedish (Lindblom 1968) and Dutch (Nooteboom 1972) indicates universal phonetic pressure toward compression in vowel duration as a function of syllable length. The current study examined the effect of polysyllabic shortening in children's yet developing temporal patterns to get a glimpse of their speech development. As noted in Vihman, Nakai and DePaolis (2006), the study of segmental duration provides an opportunity to look at their ability to match the durational patterning frequently observed in adult speech production.

3. Methods

3.1 Participants

Ten American-English speaking adults and ten American-English speaking children participated in the study. The adult participants (6 females and 4 males) were all college students (Mean age = 23) at the time of testing and the child participants (6 females and 4 males) ranged in age from 5;3 to 7;3 (Mean age = 6;10). All were native speakers of the West Coast variety of American English, and all were free of speech and hearing problems as determined by parental report and a pure-tone hearing screen.

3.2 Stimuli

Three groups of stimuli were created to examine the developmental changes in the durational pattern: 1) the inherent vowel duration, 2) the effect of final consonant voicing on consonant closure duration, 3) the effect of syllable number on stressed vowel duration. The first materials consisted of 11 monosyllabic words that had been recorded with a high quality microphone in digital format by a native English-speaking female adult in the frame sentence "I said _______ again." The second group consisted of 4 pairings of monosyllabic words with voiced and voiceless coda consonants with the vowel quality controlled. Another four pairings yielded stimuli of polysyllabic words. All the polysyllabic words with two, three and four syllables were produced with main stress on the first syllable. The vowel qualities of the first (and most of the second) syllables were matched across the stimuli. Although the surrounding context varied, this will not hamper interpretation because each vowel category is compared across group. The three groups of stimuli are shown in Table 1.

Table 1. Stimuli of the Study

Inherent Vowel Duration	Coda Voicing Contrast		Syllable Number	
	Voiced	Voiceless	2 syllables	3,4 syllables
bit, beet, bet, bat, but, bought, boot, boat, bait, bite, bout	bad bag cab cad	bat back cap cat	batty batter catty catter	battery batterless catalogue caterpillar

3.3 Procedure

The experiment took place in a child-friendly experiment room. The experimenter played the prerecorded (recorded by female native speaker of English) frame sentences embedded with the target words and the participants were asked to change the frame sentence to "She said _______ again." to avoid elicited imitation and to encourage the participants to produce the target word in their own terms. Several practice items were then used to ensure that participants were able to understand the task. A total of 27 target words in a frame sentence were elicited three times each in random order from each participant. Children's productions were digitally recorded using a wireless microphone that was clipped to a baseball cap or headband and located in the center of the child's forehead. The speech was recorded on a Sony DAT tape recorder at a 22,050 Hz sampling rate with 16 bit quantization.

3.4 Measurements

The duration of English vowels in both monosyllabic and polysyllabic words produced by the child and adult groups were measured in milliseconds from spectrographic and time domain waveform displays. As for the polysyllabic words, the stressed vowels of the first syllables were measured and compared to the whole word duration, beginning with voice-onset-time, for speaking rate normalization. All the vowels were measured from the onset of voicing in the vowel to the constriction of the following stops. The onset and offset of clear energy in the second formant frequency on the sound spectrogram served as a reference, along with the waveform, to determine the onset and offset of the vowel. The mean duration averaged across three repetitions was submitted to analysis. Consonant closure duration was determined from constriction of final stops to the beginning of the release burst. Out of all the words produced in phrases, over 75 % of the production was released for the adult group and 70% was released for the child group. The unreleased tokens were replaced by the mean voiced or voiceless closure duration of that speaker and were submitted to analysis. The consonant closure duration was compared to the preceding vowel duration in both voiced and voiceless conditions for normalization.

3.5 Statistical Analyses

The analyses include both absolute and relative measures of duration. First, to compare the inherent duration of the monosyllabic words, adult and child groups were examined using ANOVAs. The dependent variables for all comparisons were vowel duration and the independent variables were vowel (11) and group (2). The vowels were conducted with repeated measures. In case of a significant group and vowel interaction, 11 ANOVAs was conducted to examine the effect of group on each vowel.

Next, mean consonant closure duration and the normalized vowel-to-consonant closure duration ratios for voiced and voiceless coda words were analyzed and compared between the two groups using a repeated-measures analysis of variance (ANOVA). For the stressed vowel duration in polysyllabic words, the effects of group and syllable number ((2), 2 syllables and 3, 4 syllables) on stressed vowel durations and first vowel-to-word duration ratios were assessed. Partial eta squared values (η_p^2) are provided for all analyses to estimate the effect size.

4. Results

4.1 Inherent vowel duration of monosyllabic words

An ANOVA on mean duration of English vowels produced by adult and child groups returned no significant effect of group [$F(1,18) = 0.526$, $p = .478$, $\eta_p^2 = 0.028$], but a significant group by vowel interaction [$F(10,9) = 3.461$, $p = .038$, $\eta_p^2 = 0.798$]. When a group comparison on each vowel was conducted, two vowels were produced significantly longer by the child group: ‘bait’ /eɪ/ [$F(1,18) = 4.852$, $p = .036$, $\eta_p^2 = 0.693$], ‘bout’ /ɑʊ/ [$F(1,18) = 4.258$, $p = .041$, $\eta_p^2 = 0.634$]. Other vowels were all not significant between the two groups. Figure 1 shows the durational difference for the two words, *bait* and *bout*.

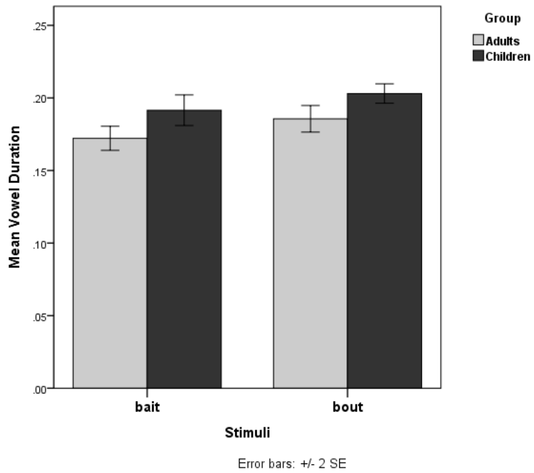


Figure 1. Vowel durations of two English vowels, bait and bout, produced by 20 native English-speaking adults and children are shown.

When the normalized word-to-vowel duration ratio was submitted, however, there was no significant effect of group [$F(1,18) = 0.997$, $p = .331$, $\eta_p^2 = 0.052$] or the vowel and age interaction [$F(10,9) = 1.387$, $p = .320$, $\eta_p^2 = 0.605$]. Post-hoc analyses on diphthongs showed no significant difference across the adults and children groups. The overall results indicate that the two diphthongs were produced significantly longer by children in absolute duration but not in relative duration.

4.2 Coda voicing on consonant closure duration

An ANOVA on mean consonant closure duration of the English monosyllabic words produced by the adult and child groups revealed a significant effect of group [$F(1,36) = 37.129$, $p = .000$, $\eta_p^2 = 0.508$], coda voicing [$F(1,36) = 153.899$, $p = .000$, $\eta_p^2 = 0.810$], as well as a significant interaction between the two [$F(1,18) = 9.203$, $p = .034$, $\eta_p^2 = 0.329$]. When the group difference on each coda type was examined, the adult group differed from the child group for both voiced [$F(1,18) = 12.261$, $p = .003$, $\eta_p^2 = 0.405$] and voiceless coda words [$F(1,18) = 25.021$, $p = .000$, $\eta_p^2 = 0.582$]. As shown in Figure 2, consonant closure duration was produced longer by the child group in both coda types.

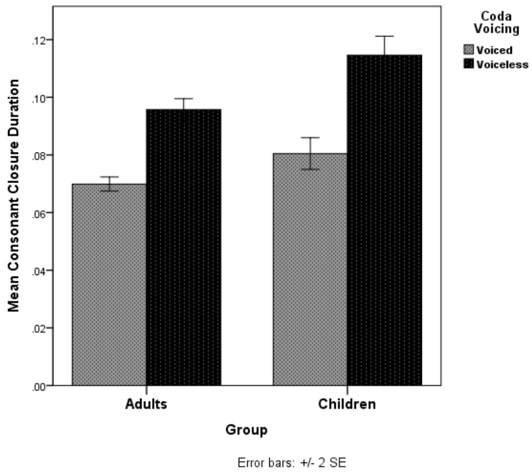


Figure 2. Mean consonant closure durations of 8 English voiced and voiceless coda words produced by 20 native English-speaking adults and children are shown.

As raw duration can vary across different speaking rates, the effect of group on the normalized vowel-to-consonant duration ratios in voiced and voiceless coda conditions were explored. As shown in Figure 3, the ratios showed no significant effect of group in either voiced [$F(1,18) = 0.583$, $p = .455$, $\eta_p^2 = 0.031$] or voiceless [$F(1,18) = 2.526$, $p = .129$, $\eta_p^2 = 0.123$] condition, indicating that the magnitude of the voicing effect on both vowel and consonant closure duration did not statistically differ between the two groups. Although not significant, vowel duration was produced overall longer than consonant closure duration in adults' than in children's productions.

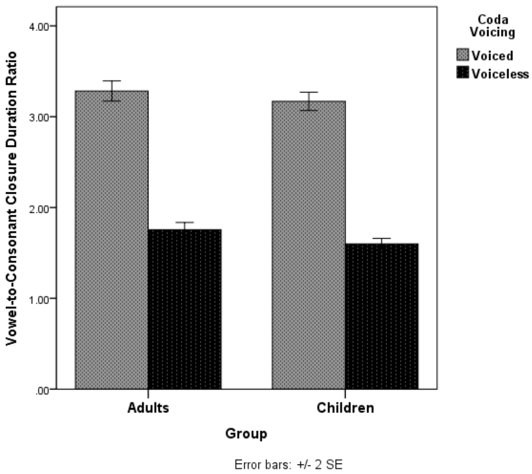
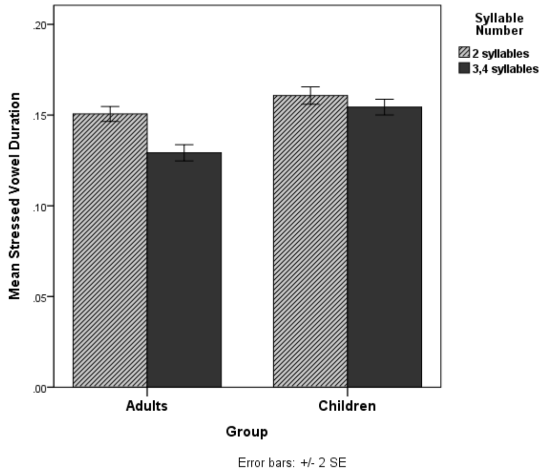


Figure 3. Vowel-to-consonant closure duration ratios of 8 English voiced and voiceless coda words produced by 20 native English-speaking adults and children are shown.

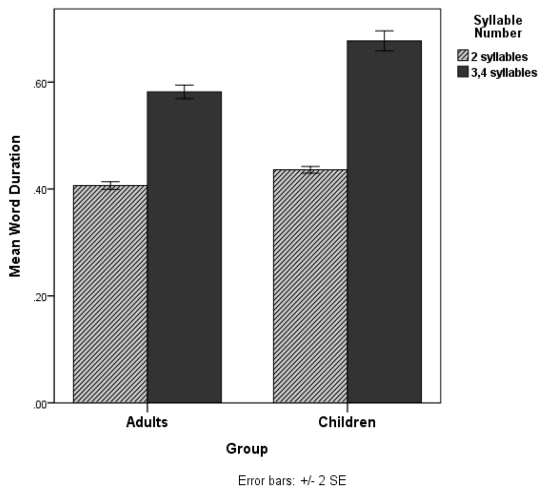
4.3 Stressed vowel duration of polysyllabic words

An ANOVA on mean stressed vowel duration for adult and child groups showed a significant effect of age [$F(1,36) = 14.697$, $p = .000$, $\eta_p^2 = 0.290$] and the number of syllables [$F(1,36) = 9.098$, $p = .005$, $\eta_p^2 = 0.202$] but no significant interaction between the two [$F(1,36) = 2.662$, $p = .111$, $\eta_p^2 = 0.069$]. When each word type was examined, the 3,4-syllable words, but not 2-syllable words, were significantly different between adult and child groups [$F(1,18) = 24.654$, $p = .000$, $\eta_p^2 = 0.578$]. As shown in Figure 4, the ANOVA on the child group confirmed that there was no durational difference between 2- and 3,4-syllable words [$F(1,36) = 0.818$, $p = .378$, $\eta_p^2 = 0.043$] while there was a significant effect of the number of syllables in adult group productions [$F(1,18) = 14.047$, $p = .002$, $\eta_p^2 = 0.420$].

When the whole word duration was examined separately, there was the effects of age [$F(1,36) = 19.087$, $p = .000$, $\eta_p^2 = 0.346$], the number of syllables [$F(1,36) = 213.193$, $p = .000$, $\eta_p^2 = 0.856$] as well as the interaction between the two variables [$F(1,36) = 5.310$, $p = .027$, $\eta_p^2 = 0.129$]. The overall results for the child group indicate that the number of syllables influenced the whole word duration but not the stressed vowel duration.



(a)



(b)

Figure 4. Stressed vowel duration (a) and word duration (b) of 8 English multisyllabic words produced by 20 native English-speaking adults and children are shown.

When the whole word duration was considered together with the stressed vowel duration, either the effect of age [$F(1,36) = 0.037$, $p = .848$, $\eta_p^2 = 0.001$] or the interaction between the age and the number of syllables [$F(1,36) = 0.276$, $p = .603$, $\eta_p^2 = 0.008$] was not significant. Only the number of syllables influenced the durational ratios in that both groups produced the stressed vowels of the 2-syllable words significantly longer [$F(1,36) = 193.647$, $p = .000$, $\eta_p^2 = 0.843$] compared to the those of the 3,4-syllable words. As shown in Figure 5, the durational differences between the stressed vowel and the whole word are invariable between the two groups.

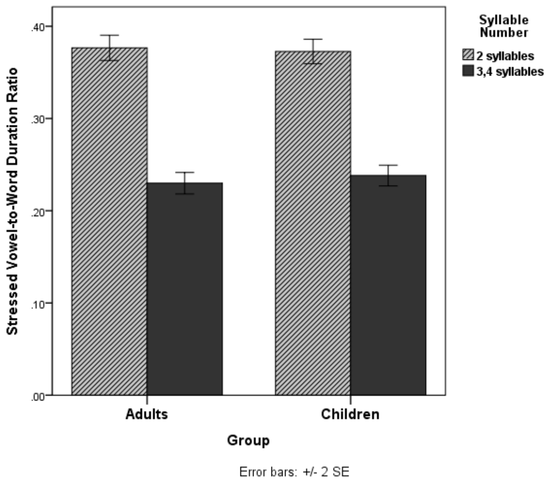


Figure 5. Stressed vowel-to-word duration ratios of 8 English multisyllabic words produced by 20 native English-speaking adults and children are shown.

5. Discussion

The current study was conducted to provide additional information about the nature of children's durational patterns. The priori predictions were that children would demonstrate overall longer segmental duration than adults. As well, it was suggested that children would show greater accuracy in distinguishing different vowel qualities in comparison to other durational parameters such as coda voicing and syllable structure. With regard to these predictions, the current study exhibited the following results: Children were able to distinguish different vowels with duration as adults except for two diphthongs, *bait* and *bout*. The gliding movement of diphthongs demands greater movement of the articulators than monophthongs and children's immature control over the movements of the articulators may have led to longer vowel duration. Additionally, these diphthongs may have been produced longer due to their comparatively low word frequency. As word duration typically decrease with word frequency (Wright 1979) it is likely that the children found these monosyllabic words less familiar, resulting in longer segmental duration.

As for the results of the absolute duration, not only the inherent vowel duration but also the consonant closure duration was produced longer in both voiced and voiceless final consonant conditions. Also, stressed vowel durations as well as the word durations were produced longer by children regardless of the syllable number. The result of prolonged segmental duration in school-aged children speech is in line with previous findings on the role of motoric development in the acquisition of segmental duration (Naeser 1970, Kent and Forner 1980, Lee et al. 1999). Namely, the significantly longer absolute duration suggests that children in the current study have not yet achieved adult-like speech motor control.

Of particular interest is the adult-like relative durational pattern in children's productions. The relative durations of vowels, consonants, and stressed syllables in multisyllabic words were not significantly different between the two groups. Namely, children's performance was far more adult-like in proportional terms. Unlike the adults, for example, the children produced similar stressed vowel duration for both disyllabic and multisyllabic words. The durational difference between disyllabic and multisyllabic words, however, was significantly larger in children's production. That is, children produced multisyllabic substantially longer than disyllabic words. Taken together, children were unable to shorten the stressed vowel duration as a function of syllable number but they were able to control the proportional duration of the stressed vowels in comparison to the following segments (see Figure 4).

The adult-like ratios of stressed vowel durations to word durations show children's ability to match the duration patterning frequently observed in adult speech. The significant relationship between the relative timing of vowels and word length was also shown in apraxic speakers (Strauss and Klich 2001). They examined the effect of word duration on the timing of lip electromyographic (EMG) activity in normal and apraxic speakers. The results showed that the relative vowel duration in apraxic speakers was similar to that in normal speech. The absolute vowel and word durations, however, were significantly longer in apraxia of speech. Strauss and Klich (2001) argued that the normal pattern of the relative vowel duration suggests that the phonological knowledge used in normal speech production may be intact while the longer absolute duration reflects some constraints in the oral motor system.

Furthermore, the acquisition of relative timing of sequential segments may be discussed in line with the development of rhythmic patterns (Vihman et al. 2006). Vihman and colleagues examined the segmental duration of infant's babbling at two different developmental points (i.e., 4 words and 25 words) to investigate their ability to produce words and phrases with adult-like rhythm. The purpose of the study was to understand the rhythmic characteristics of infant disyllabic vocalizations through the patterns of the segmental duration. The comparison of the proportionate vowel and consonant durations of (C)VCV (non)words produced by infants and adults with different native languages (English, French, Welsh) showed that infants conformed closely to the adult norm by the later developmental point regardless of their native language. In a different study, the first-to-second vowel duration ratios for French infants showed stable and adult-like productions (Vihman et al. 1998). Vihman and colleagues note that "to achieve the native language pattern in production the child must be able to match both the overall melody and the rhythmic pattern of individual word" (Vihman et al. 2006: 363). The overall patterns of relative durations in the current study suggest that children appear to have acquired a sense of the rhythmic patterning in English.

Lastly, the subsequent study of development of timing control might include second language learners with different English proficiency to investigate the effect of phonological knowledge on durational patterns. Another interesting issue that might be explored is the universal phonetic pressures towards vowel duration differences as a function of syllable structure and final consonant voicing. Data on second language learners of English would clarify what the language-specific contributions are to the timing patterns.

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