Developmental Change of Phoneme Duration in a Japanese Infant and Mother

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Abstract

To investigate the early stage of speech development, the phoneme duration in an infant’s utterances and in a mother’s infant-directed speech (IDS) was analyzed for an infant between the ages of 4 and 45 months. In infant utterances, the durations of vowels and special moras gradually decrease as a function of month in entire period, whereas consonants such as fricatives, plosives, and semivowels rapidly decrease before the onset of two-word utterances. Almost all the phonemes in infant utterances except for plosives are longer than those in adult-directed speech (ADS) in entire period. In mothers’ IDS, vowels and long vowels gradually decrease in duration as a function of month, but most consonants do not. Phonemes in IDS except for fricatives and plosives are longer than those in ADS. These results indicate that, in terms of duration, developmental change is different for different phonemes in infant utterances and mothers’ IDS.

1. Introduction

Developmental studies of speech production [1, 2, 3, 4] have found that the durations of speech segments, phonemes, syllables, and words are longer in children than in adults, and that they gradually become shorter as the child’s age increases. However, because previous studies have used only a few phonemes, it is not known whether the developmental change in duration differs among phonemes. In addition, because many previous studies focused on the developmental change in children at ages of about 3 to 13 years, it is unclear whether the phoneme duration decreases as the age increases between the ages of 0 to 3 years. This study seeks to clarify these points by analyzing the durations of many kinds of phonemes in the utterances of a very young infant.

Another issue dealt with by this study is phoneme duration in a mother’s infant-directed speech (IDS). It is well known that IDS has many special characteristics such as a higher fundamental frequency (F0) [5], a more exaggerated formant frequency [6], and a slower speaking rate [7] compared with adult-directed speech (ADS). It is possible that the phoneme duration in IDS is also special and different from that in ADS, but this has not been confirmed. In addition, the difference might vary among phonemes.

Our previous study [8] found that Japanese parents’ F0 is high in IDS before the onset of an infant’s two-word utterances but it gradually decreases and reaches almost the same value as in ADS after the onset of two-word utterances. This result suggests that other IDS characteristics such as phoneme duration are also different before and after the onset of two-word utterances. In addition, the phoneme duration in infant utterances might be also different before and after the onset, because an infant’s speech production ability improves greatly around the onset. Therefore, this study analyzes the phoneme duration in relation to the onset of two-word utterances.

More specifically, this study addresses the following questions with regard to phoneme duration both in the infant’s utterances and the mother’s IDS. 1) Does phoneme duration have any developmental change before or after the onset of two-word utterance? If so, which phonemes change? 2) Is the phoneme duration different from that of ADS? If so, which phonemes are different?

2. Analysis

2.1. Data

An infant speech database [9] is being developed from longitudinal recordings of five Japanese infants and their parents in natural situations in daily life over a period of five years from the infants’ birth. The utterances of Infant C and its mother were extracted from the database at 4, 6, 8, 10, 12, 14, 16, 18, 20, 25, 30, 35, 40 and 45 months of age. There are 5966, 3514, and 57 samples of infant utterances, mother’s IDS, and mother’s ADS, respectively.

According to the utterance transcriptions in the database, Infant C started one-word utterances at 10 months and two-word utterances at 16 months. Thus, the data at 4, 6, 8, 12, and 14 months were categorized as “before the onset of two-word utterances” and the rest were categorized as “after the onset of two-word utterances”.

One Japanese adult listened to the utterances and provided a phoneme label and a start and end time for every phonemic segment in the utterances. Another Japanese adult checked and corrected this information. The start time of the affricates and plosives was the onset of a burst portion in the speech waveforms. That is, any closure before the burst portion was not included in the phonemes.

2.2. Procedure

Phonemes are grouped into consonants, vowels, and special moras. The consonants consist of affricates (/ch/ and /ts/), a flap (/ɾ/), fricatives (/s/ and /ʃ/), nasals (/m/, /n/, and /ŋ/), plosives (/p/, /t/, /k/, /b/, /d/, and /ɡ/), and semivowels (/w/ and /y/). The vowels consist of /a/, /i/, /u/, /e/, and /o/. The special moras consist of long vowels (/aː/, /iː/, /uː/, /eː/, and /oː/). Phonemes that are not listed above were not used in the analysis.

The infant’s data before the onset of one-word utterances (i.e., 10 months of age for Infant C) were not used for analyzing the special moras. This is because the special moras are closely related to linguistic mora units and an infant most probably does not acquire mora units before it acquires words (i.e., the onset of one-word utterances).

Phoneme duration was calculated by subtracting the start...
time from the end time. The mean and standard deviation of the phoneme duration were obtained for each phoneme category for each month for the infant’s utterances and the mother’s IDS. The mean phoneme duration in mother’s ADS was calculated using the data for entire periods, because the number of utterances was too small to provide a reliable value for each month, and because it is reasonably assumed that phoneme duration is constant in mother’s ADS over months.

To examine the developmental change of the phoneme duration in infant utterances and mother’s IDS, regression analysis was conducted for the mean phoneme duration as a dependent variable (y) with the infant’s age in months as an independent variable (x) and employing the best linear unbiased estimation (BLUE) method. The regression analysis was conducted for the data before the onset of two-word utterances, after the onset of two-word utterances, and for the entire period.

To examine whether the phoneme duration in infant utterances and mother’s IDS is same as that in adult utterances, a t test was conducted for the difference from the mother’s ADS before the onset of two-word utterances, after the onset of two-word utterances, and for the entire period.

3. Results and Discussion

The mean phoneme durations in the infant utterances and the mother’s IDS are shown for the consonant, vowel, and special mora groups, respectively, in Figs. 1, 2, and 3 as a function of infant age in months. The mean phoneme duration of the mother’s ADS is also shown in each panel. Table 1 shows the results of regression analysis with the regression coefficient, and the results of the t test are shown with the differences in the durations as regards ADS for infant utterances and mother’s IDS.

3.1. Infant’s utterance

3.1.1. Developmental change

The regression analysis shows that a developmental change in duration is observed only in some phonemes, and that the period of the change is different for different phonemes. For example, a consonant such as a fricative, a plosive, or a semivowel decreases significantly in duration before the onset of two-word utterances, but other consonants, vowels, and special moras do not. Vowels and special moras decrease

**Figure 1:** Developmental change of consonant duration. The arrow indicates the onset of two-word utterances by the infant. The dotted line represents the consonant duration in the mother’s ADS in each consonant category. The bars represent the standard deviation.
significantly in duration after the onset of two-word utterances and over the entire period, but consonants do not.

Although the duration of affricates increases over the entire period, there may be certain problems related to phoneme labeling because background noise is easily mistaken for an affricate when the speech signal level is very low. A more precise analysis would be necessary as regards the developmental change of affricates.

The current results for vowels and special moras agree with the results of previous child utterance research [1, 2, 3, 4], which found that there is a decrease in speech segment duration as a function of age. However, the results for consonants do not agree. One possible reason for the discrepancy is that the observation period of this study is too short to detect the slight developmental change in phoneme duration in infant utterances.

Another possibility is that all utterance types such as word and nonword utterances were included in the current analysis, whereas the utterance types were limited in previous studies. For instance, by analyzing words and nonwords separately, Robb and Tyler [10] found a developmental change in duration only in words produced by infants in the 8 to 25 month age range. Therefore, if the phonemes in words are analyzed for the current data, a developmental decrease in phoneme duration might be clearly observed.

### 3.1.2. Difference from ADS

The t test shows that the durations of almost all the phonemes in infant utterances are significantly longer than ADS over the entire period. Plosives are the exception. Their duration is only longer before the onset of two-word utterances. This means that the duration of plosives in infant utterances becomes the same as that in ADS at a very early stage in an infant's speech production development. However, other phonemes take a much longer time to reach the same duration as that found with adults. Affricates might be another exception. However, because of the problems mentioned above, we cannot yet reach a conclusion about affricates.

### 3.2. Mother’s IDS

#### 3.2.1. Developmental change

The regression analysis shows that a change in duration is observed for only a few phonemes. A significant decrease in duration was observed in semivowels and a moraic nasal before the onset of two-word utterances, in long vowels after the onset of two-word utterances, and in vowels and long vowels over the entire period.

It seems that there are no distinct changes in phoneme duration in the mother's IDS either before or after the onset of two-word utterances. That is, the phoneme duration is almost constant in the mother's IDS. However, the vowels and long vowels are exceptions. They gradually decrease in duration as a function of the infant’s age in months.

#### 3.2.2. Difference from ADS

The t test shows that the durations of almost all the phonemes in the mother's IDS are significantly longer than in her ADS over the entire period. However, fricatives and plosives are exceptions. These phonemes in the mother's IDS have the same duration as in her ADS. This means that fricatives and plosives do not contribute to the slow speaking rate of the mother's IDS [9] but other phonemes do.

There are no clear differences between the phoneme

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**Figure 2**: Developmental change of vowel duration. The arrow indicates the onset of two-word utterances. The dotted line represents the vowel duration in the mother’s ADS. The bars represent the standard deviation.

**Figure 3**: Developmental change of special mora duration. The arrow indicates the onset of two-word utterances. The dotted line represents the special mora duration in mother’s ADS in each special mora category. The bars represent the standard deviation.
durations in the mother’s IDS before and after the onset of two-word utterances. This is completely different from the F0 characteristics of IDS. That is, the F0 in IDS is higher than in ADS before the onset of two-word utterances and it becomes the same as that in ADS after the onset of two-word utterances [8]. The current result of this study indicates that not all IDS characteristics disappear after the onset of two-word utterances.

4. Conclusions

Phoneme duration was analyzed in an infant’s utterances and in the mother’s IDS for an infant between the ages of 4 and 45 months. As regards infant utterances, the analyses revealed that there is a developmental change in phoneme duration. Vowels and special moras gradually decrease in duration as a function of month during the observation period, whereas fricatives, plosives, and semivowels decrease before the onset of two-word utterances. Almost all the phonemes in infant utterances except for plosives are longer than those in ADS in entire period. As for the mother’s IDS, there is also a developmental change in phoneme duration. Vowels and long vowels gradually decrease in duration as a function of month, but most consonants do not. With the exception of fricatives and plosives, phonemes in IDS are longer than those in ADS. These results indicate that there is a discrepancy among phonemes in developmental change of their duration.

5. Acknowledgements

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6. References


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<th>Phoneme Category</th>
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Note. Single and double asterisks respectively represent 5% and 1% significance levels (two-tailed). Non-significant results are not shown.