The development of monophthongal vowels in Korean: Age and sex differences

Soyoung Lee
University of Wisconsin–Milwaukee
Department of Communication Sciences and Disorders

Gregory K. Iverson
University of Maryland
Center for Advanced Study of Language

Address Correspondence to:
Soyoung Lee, Ph.D.
Department of Communication Sciences and Disorders
The University of Wisconsin–Milwaukee
Milwaukee, WI  53201-0413
Email: lees59@uwm.edu
Telephone: 414-229-2838
Fax: 414-229-2620
Abstract

The purpose of this study was to examine acoustically the developmental characteristics of fundamental ($f_0$) and formant frequencies ($F_1$ and $F_2$) in vowels produced by Korean male and female children in two age ranges (5 and 10 years of age). The study also compared formant frequency values among Korean children with those from existing English data (Lee et al., 1999). Results revealed that $f_0$ and $F_1$ and $F_2$ decrease as age increases. The $f_0$ was similar, but formant frequencies were found to differ between male and female children. In particular, $F_1$ and $F_2$ values differed for the low-central vowel /a/ among the four Korean groups, similar to English-speaking children, but, unlike English, $F_2$ values of front vowels were not different between age groups in Korean. The results of this study provide a base of information for establishing the normal pattern of development in Korean children, and bear on the exploration of cross-linguistic similarities and differences in vowel development between English and Korean.
Introduction

Acoustic investigation of the vowel production of children has been of increasing interest because it opens an avenue to explaining anatomical growth of the vocal folds and vocal tract as well as the development of speech motor control. Vorperian and Kent (2007) recently reviewed existing acoustic and anatomical studies of children’s vowel production. In this comprehensive summary, they reported the results of 21 acoustic vowel studies from various age ranges. Most acoustic studies which examine development of $f_0$ and formant frequencies, however, have focused on English language. There is a paucity of information about $f_0$ and vowel formant frequency characteristics of children in general and, in particular, about age and sex differences among prepubertal children who speak languages other than English. Examination of $f_0$ and spectral formant frequency values of children speaking other languages can answer the question of whether there is anatomical generalization during the prepubertal period. This can also be expected to provide further insights into the underlying development of speech organs and speech motor control, and, it is hoped, eventually to lead to an accurate model of the developing vocal tract. The present study, accordingly, examines the vowels of Korean, which, as is well-known, occupy vowel spaces different from English (Yang, 1996). This study then seeks specifically to provide additional information relative to common and language-particular features of fundamental frequency and formant frequencies among young children.

The results of the study are also valuable in multi-cultural countries, such as the United States, where it is estimated that in 2004, 10 million children aged 5 to 17 years spoke a language other than English at home (U.S. Bureau of the Census, 2005).
Approximately 63% of these children were categorized as Asian, of whom 15% were reported to have difficulty speaking English. Korean-born individuals comprise one of the largest immigrant groups in the United States: almost 1 million Americans speak Korean at home (U.S. Bureau of the Census, 2005). In order for English as a Second Language (ESL) teachers and/or speech-language pathologists (SLP) to help children from Korean families to learn English pronunciation, they need to understand the basic phonetic characteristics of the first language. In providing fundamental information on Korean vowels, this study can contribute guidance in teaching English vowel pronunciation to children from Korean families living in the United States.

Previous studies of children’s English vowels

Eguchi and Hirsh (1969) examined \( f_0 \) and formant frequencies in eighty-four children, ranging from 3 to 13 years of age. Children older than 10 years were divided into two groups according to sex. Each group consisted of 5 or 6 children. Six English vowels /æ, ɛ, ɪ, ɔ, u, ə/ were elicited in two sentences. Starting from about 300 Hz at 3 years, \( f_0 \) was seen to decrease with age, with children at 10 years of age showing 262 Hz. Moreover, a gradual but marked decrease in \( F2 \) was found, as contrasted with the more stable \( F1 \). The sharpest drop in formant frequencies occurred between 3 and 5 years of age. One interesting observation was that the \( F1 \) of /a/ was independent of age and relatively stable across ages although its \( F2 \) value decreased as age increased. Eguchi and Hirsh (1969) did not test whether there was difference as a function of sex. However, no clear sex difference in the children’s vowel productions is apparent based on the data they provided. For example, for the vowel /a/, at 11 years of age, \( F1 \) of male was lower (884Hz) than female students (1005Hz). However, at 12 years of age, the pattern was not
consistent in that $F_1$ of male students (915Hz) was higher than that of female students (895Hz).

While Eguchi and Hirsh (1969) did not find sex differences in children’s resonant frequencies, Bennett (1981) did. She analyzed the formant frequencies of forty-two children ranging from 7-8 years of age. Six vowels, /i, ɪ, æ, u, ʌ/, were elicited in a word frame of /dVd/ construction embedded in a carrier phrase. Bennett found clear sexual dimorphism in vocal tract resonance characteristics, with formants of 5 of the 6 vowels consistently lower in male children than in female children. In particular, a greater difference in $F_1$ occurred in the low vowel /æ/ than in the high vowel /i/. These results were consistent with Fant (1973), who developed formant scale factors to establish male and female differences in resonant frequencies. According to Fant, male and female differences were largest for $F_2$ of the high/mid-front vowels /i, e/ and $F_1$ for low-front and low-central vowels /æ, ə/, based on both English and Swedish data. On the other hand, the differences were minimal for $F_1$ and $F_2$ of back vowels. Fant (1975) reported that this phenomenon also existed in vowels for different languages. Following the formant scale factor developed by Fant (1973), Bennett concluded that the pattern of sex difference for children’s vowels was similar to that of adults, but the magnitude of the difference is considerably less distinct for children.

Busby and Plant (1995) also measured $f_0$ and formant frequency values of vowels produced by a total of forty Australian English-speaking boys and girls who were 5, 7, 9, and 11 years of age. Eleven monosyllabic words were produced to elicit English vowels: sheep /ɪ/, ship /ʃ/, bed /ɛ/, cat /æ/, cart /ɑ/, cut /ʌ/, four /ɹ/, dog /ɑ/, shoe /ʌ/, book /ɔ/, and bird /ɹ/. The formant frequency values decreased with increases in age for the
majority of vowels, except for the two vowels /i, a/. This pattern was especially clear in girls rather than in boys. Busby and Plant found that the largest changes in $F_1$ values related to age were for the low vowels /æ, a/ which were not consistent with what Eguchi and Hirsh (1969) found. The $F_1$ for 5 non-high vowels /æ, a, ə, ɔ, ʌ/ and $F_2$ values for all vowels except for /ʊ/ were higher in girls than in boys for all ages. They concluded that their findings were consistent with those of Bennett (1981).

Lee, Potanianos, and Narayana (1999) examined temporal and acoustic parameters of four hundred and thirty-six English-speaking children (aged from 5 to 18 years) and fifty-six adults. Ten vowels, /i, i, ɪ, æ, u, ʊ, ɔ, a, ʌ, ə/, were elicited in a word frame of /pVC/ construction such as bead and bit. Lee et al. found that $f_0$, $F_1$, $F_2$, and $F_3$ values decreased as age increased. The $f_0$ and formant frequency patterns began to differ around age 11 as a function of sex, and were fully established around age 15; however, they did not reach the adult range within this time period. More specifically, pubertal pitch change in male children starts between age 12 and 13; however, a large between-subject variation is also observed at ages 13 and 14. For female children, pitch drops from age 7 to 12, but $f_0$ change is more gradual than for male children. In terms of formant frequencies, a liner trend is clear in male children, suggesting that formant values change linearly as a function of age in male speakers, consistent with Kent’s notion (1976) of uniform axial growth of the vocal tract. However, such a linear trend did not emerge in female children. Lee et al. analyzed a large number of children in various age ranges, but without direct comparisons of formant frequencies between age groups and between sex groups it is difficult to interpret whether such difference in formant values is statistically significant.
Whiteside and Hodgson (2000) examined \( f_0 \) and formant frequency of 6, 8, and 10 year-old male and female children using the vowel /a/ in bar, jar, and car. They found significant age and sex differences for both \( f_0 \) and formant frequencies. A general decrease in \( f_0 \) and formant values was found with age, with lower \( f_0 \) and formant values for males as compared to females, but \( f_0 \) was different for all age and sex comparisons except between 6- and 8-year-olds; \( F_1 \) and \( F_2 \) values were different for all group comparisons. Thus, Whiteside and Hodgson concluded that sexual dimorphism of the vocal tract begins to emerge at around 8 years of age.

Perry, Ohde and Ashmead (2001) examined \( f_0 \) and formant frequencies of 10 girls and 10 boys at 4, 8, 12, and 16 years of age using 7 nondiphthongal American English vowels, /i, í, æ, e, a, ò, u/. Gender differences between the \( f_0 \) values of girls and boys were found only in the 16 year-old age group. \( F_1 \) and \( F_2 \) values for the boys were significantly lower than those for the girls at 8, 12, and 16 years of age, but not for 4 years of age.

A few studies reviewed only fundamental frequency. Bennett (1983) examined \( f_0 \) longitudinally for 15 boys and 10 girls from 8 to 11 years of age and found a significant age effect, but no difference related to sex. On the other hand, Hasek, Singh, and Murray (1980) examined 180 children, 15 boys and 15 girls for each year of age between 5 and 10 years, and reported lower \( f_0 \) for boys than girls at 7-10 years of age but no difference in \( f_0 \) for children at 5-6 years of age. In the same vein, Whiteside and Hodgson (1998) examined \( f_0 \) for English boys and girls who were 6, 8, and 10 years of age, with significant age differences showing that \( f_0 \) decreases as age increases. In particular, there was a strong similarity in \( f_0 \) between boys and girls at age 6 years; however, the similarity
disappeared between the ages of 8 and 10 years. The rate of $f_0$ development for boys, of course, speeds up during preadolescence as the onset of puberty approaches.

The findings of acoustic studies in English-speaking children have been verified by anatomical studies of the child vocal tract. Recent reports point toward relational growth of the vocal tract length with development (Fitch & Giedd, 1999; Vorperian, Kent, Lindstrom, Kalina, Gentry, & Yandell, 2005). Fitch and Giedd examined midsagittal vocal tract length, shape, and proportions for subjects aged 2-25 years, using magnetic resonance imaging (MRI). They found clear differences in the male and female vocal tract, including overall length and the relative proportion of the oral and pharyngeal cavity. The sex differences are not evident in prepubertal children (younger than 10.3 years of age), but substantial changes in vocal tract morphology occur at puberty. Specifically, peripubertal children (10.3-14.5 years of age) showed a small but significant sex difference with a 7.5mm longer vocal tract in male than in female children, while postpubertal children (older than 14.7 years of age) showed a highly significant sex difference with a 12.9 mm longer vocal tract in male than in female children. Fitch and Giedd suggested that acoustic characteristics of sex difference in prepubertal childhood are primarily due to behavioral, not anatomical differences.

In summary, several acoustic studies have been conducted to examine $f_0$ and formant frequency values as functions of age and sex. Although these studies commonly reported developmental characteristics in that $f_0$ and formant frequency values decrease as age increases, they found different onsets of sexual dimorphism. Bennett (1981), Busby and Plant (1995) and Whiteside and Hodgson (2000) found that children as young as five years of age already showed different $f_0$ and/or formant frequencies between the
two sexes, while Eguchi and Hirsh (1969), Bennett (1983), Lee et al. (1999) and Perry et al. (2001) reported that sexual dimorphism did not appear until 11 years of age or later. Recent anatomical studies reported no differences of vocal tract between male and female children until ten years of age and suggested that formant frequencies would result from behavioral modification, though it is still not certain whether such different patterns in formant frequencies between sexes are due to anatomical or behavioral characteristics. In addition, these studies only examined English-speaking children, so it is not clear whether such developmental patterns and sexual dimorphism would appear in children who speak languages other than English. Thus, further studies of children’s vowels in various language environments are needed.

The purpose of the study reported on here, accordingly, was to examine acoustically the $f_0$ and formant frequencies in vowels produced by Korean children in order to establish the normal pattern of development in this language and provide a base of information for investigation of typically developing as well as disordered vowel production in Korean. This study also compared formant values of Korean children with those from existing English data (Lee et al., 1999) in order to explore whether cross-linguistic similarities and differences of vowel production observed in adult speech between English and Korean also appear in child speech.

Korean vowel studies

Only a few acoustic studies of children’s vowels are available for Korean. Choi and Kim (1995) examined 31 five-year old Korean boys and girls, measuring the formant frequencies of the eight Korean monophthongal vowels, /i, e, e, a, u, o, ı/. Later, Lee, Lee and Ock (2001) conducted a developmental study in children at 3, 4, and 5 years of age.
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age, but the number of children per group was very limited (five children each) and they measured only the three peripheral vowels, /i a u/. In this study on Korean vowels, formant frequency values did not reflect the pattern previously observed for English, where formant frequencies decrease as age increases. As the studies to date of Korean vowel development have not provided comprehensive and reliable data, further investigation should be conducted to examine whether the vowel development pattern of Korean children is similar to that of English-speaking children.

In order to identify the cross-linguistic characteristics of children’s vowels, it is necessary to understand the acoustic characteristics of the target vowel systems. A few studies are currently available to examine adult vowels in English and Korean. Yang (1996) conducted a comparative study of English and Korean vowels produced by 10 male and 10 female speakers. The $f_0$ and formant frequencies of 10 Korean /i, e, e, i, a, u, o, a, y, o/ and 13 English /i, i, e, æ, a, u, o, o, e, a, λ/ vowels were measured, although the last two Korean vowels were often considered as diphthongs in Korean. Yang found similar $f_0$ but different vocal tract length between English- and Korean-speaking adults: English-speaking adults showed longer vocal tract length for both males and females. Korean vowel space appears to be wedge-shaped, with /i, a, u/ at the corners. Among the seven shared vowels between the two languages (i.e., /i, e, e, a, a, u, o, λ/), $F1$ for male speakers significantly differed in three vowels, /i, u, o/, while $F2$ differed in all 7 vowels. $F1$ for female speakers, on the other hand, differed in four vowels, /i, e, a, u/, and $F2$ values in all vowels except for /i, e/ were significantly different between English and Korean speakers. The greatest cross-language difference
was found in the vowel /u/. English /u/ was centralized so that F2 of /u/ was similar to that of the Korean high-central vowel /i/.  

Methods

Participants

A total of 60 Korean children living in Seoul, Korea participated in this study. Thirty children were 10 years of age and the other 30 were 5 years of age. Half of the children were boys, half were girls. All participating children had no history of speech or hearing impairment and were from families where standard Korean was spoken at home. Any children who had extensive experience in English use were eliminated. The 10 year-old children had learned English at school for two to three hours per week, but not in any way were not identified as bilingual language learners. The children were recruited from two preschools and two elementary schools in Seoul, Korea.

Data Collection & Speech materials

Speech production recordings were made at the school in a quiet room. A digital flash recorder (Marantz Model PMD670) was connected to a stand-mounted omnidirectional dynamic microphone (Electro-Voice 635A/B) positioned on a table. Speech was recorded at a sampling rate of 44 kHz. The children sat at the table and spoke the test items. The distance between the subject and microphone was around 20 cm. Because some 5 year-old children do not read, eight picture cards without written letters were shown in a random order to elicit Korean vowels. The eight pictures included  

- kicha ‘train’ for /i/;
- key ‘crab’ for /e/;
- kay ‘dog’ for /e/;
- kuney ‘swing’ for /i/;
- kemi ‘spider’ for /e/;
- kabang ‘bag’ for /a/;
- kwu ‘Nine’ for /u/;
- kong ‘ball’ for /o/. As Korean is not a stress language, each syllable in the disyllabic words was produced similarly in pitch,
loudness, and duration. No modeling was necessary because these words were easy enough for 5 year-old children. The children were asked to repeat each test item 3 times. The best 2 out of the 3 productions of each vowel for each subject were chosen for the average data set because some children in the younger group tended to produce the third repetition either weakly or with excessive loudness. This reduced the data to 960 values for each formant frequency: 8 vowels *2 ages *2 sexes *2 repetitions *15 subjects.

Data Analysis

Computerized Speech Lab (CSL, model 4300, Kay Elemetrics) software was used to analyze the recordings, all of which were down-sampled to 11.025 KHz. A spectrogram of each word was made using a 256 point discrete Fourier transform analysis with a 20 ms Hamming window. This gives the equivalent bandwidth of 43.07 Hz for spectrogram analysis. $f_0$ and formant frequency measures were taken one-third into the vowel, following Yang (1996). Most spectrograms showed steady states between vowel onset and offset points. The vowel onset and offset were used to determine total vowel duration. The vowel onset was determined at the end of formant transition and the vowel offset was identified at the beginning of formant transition. In order to estimate $f_0$, the first harmonic was measured from the FFT display and verified as the inverse of the time between glottal impulse markers in a waveform. Formant values were computed automatically by LPC (linear predictive coding) analysis and visually verified using the spectrographic display. The order of the LPC analysis was adjusted from 10 to 14 to match the number of expected formants. If the LPC-derived formants were not visually identified, formant values were obtained from the spectrographic display. For reliability, measurements of selected tokens (20%) were independently made by another
phonetician; there was less than 5% disagreement. Any systematic errors were immediately corrected after discussion.

Results

Fundamental frequency

The means and standard deviations of $f_0$ of each vowel for sex and age groups are shown in Table 1. A multivariate analysis of variance (MANOVA) indicates no significant main effect for sex ($F(8, 49) = .929, p = .502$) as well as no significant interaction between age and sex ($F(8, 49) = .614, p = .762$) on $f_0$ for all 8 vowels. However, a significant main effect for age was found for all vowels ($F(8, 49) = 12.44, p < .001$). As can be seen in Table 2, $f_0$ values of the older groups were significantly lower than those of the younger groups for all comparisons.

Vowel formant frequency

The means and standard deviations for the $F1$ and $F2$ of each vowel for sex and age groups are shown in Table 1. The $F1$ and $F2$ values for each group were plotted to form vowel spaces in Figure 1. In general, each vowel category for the four groups was established on the basis of $F1$ and $F2$ measures. Within each vowel category, older children’s productions were easily distinguished from younger children’s vocalizations. $F1$ and $F2$ values of the older group were lower for all vowels than for those of the younger group. The formant frequency values were similar between boys and girls in both groups for most vowels. However, production of the low-central vowel /a/ among the four groups was spread out. Older boys produced the vowel with the most high-back tongue position while younger girls produced it with the most low-front tongue position.
A MANOVA indicated no significant interaction between age and sex on F1 and F2 for all comparisons ($F_{(16, 41)} = 1.043, p = .436$). However, there was a significant age effect ($F_{(16, 41)} = 12.06, p < .001$). Most vowel formant values were significantly different between old and young except for F2 of the high-front /i/ and the two mid-front vowels /e, e/ (see Table 2). Only the F2 values of these vowels were not significantly different between the older and younger children. MANOVA also revealed sex differences ($F_{(16, 41)} = 2.97, p = .002$) for F1 and F2 in the low-central vowel /a/ and mid-front vowels /e, e/. Girls produced significantly higher F1 for /a/, and higher F2 for /a, e, e/. However, no sex differences were found in the other Korean vowels (see Table 2).

Previous data on English-speaking children (Lee et al., 1999) were adapted to be plotted together with Korean data in order to examine cross-linguistic similarities and differences between the two languages. Figures 2 through 5 depict the Korean and English vowel spaces per age and sex group. The F1 and F2 of the two peripheral vowels /i/ and /a or α/ were similar between the two languages. Although Korean /a/ is often categorized as low-central vowel while English /a/ is categorized as a low-back vowel, productions of the English variant range between these two vowels, depending on the speaker, which in any case have similar F1 and F2 and hence are considered together for purposes of the present study. However, a noticeable difference in the vowel systems is that the F2 of English /u/ was higher than that of Korean, so that English /u/ was similar to the Korean high-central vowel /i/ for all groups. In addition, the Korean vowels /e, e/, which are merged for most speakers, were similar to English /e/ and Korean vowel /α/ was closer to English /α/. Since Lee et al. did not report formant frequency values for /o/, a comparison was not made for that vowel between the two languages.
This study found significant age and sex difference for Korean /a/ among the four groups of Korean children. In order to examine whether the difference in formant frequency values of /a/ among the four groups is a language-specific characteristic, $F1$ and $F2$ values of the English /a/ vowel from previous studies of English (Busby and Plant, 1995; Lee et al., 1999) were plotted in Figure 6. Instead of 10 year-old children, formant values of 11 year-old children were plotted from Busby and Plant due to the lack of a 10 year-old age group in that study. As can be seen in Figure 1, a similar pattern of gradual changes in formant values among the four groups was found in English (see Figure 6). Figure 7 also gives $F1$ and $F2$ plots of English /æ/ taken from the previous studies. A similar gradual change also appeared in the low-front vowel in English, although this was not as linear as in the vowel /a/.

Discussion

The primary interest in this study was to investigate whether there was any systematic difference in $f_0$ and vowel formant frequencies in terms of age and sex groups in order to characterize developmental patterns in Korean children. We found significant differences in $f_0$ between older and younger groups of children, consistent with the previous data on English (Busby & Plant, 1995; Eguchi & Hirsh, 1969; Hasek et al., 1980; Lee et al., 1999; Whiteside & Hodgson, 1998). As expected, the older group of children showed a significantly lower $f_0$ than the younger group for all vowels, reflecting the morphological development of vocal folds of children. The present study found that $f_0$ was not significantly different between the two sexes, consistent with previous findings of no sex difference with respect to $f_0$ in children younger than 12 years of age (e.g., Bennett, 1983; Lee et al., 1999). However, this result was different from those of Hasek
et al. (1980) and Whiteside & Hodgson (2005) that $f_0$ differences begin to emerge by age seven or earlier, respectively. Hasek et al. and Whiteside & Hodgson found $f_0$ differences between sexes when they examined only the /a/ vowel, while other studies examined $f_0$ by combining all vowel productions. Research studies reported that $f_0$ intrinsically differed in terms of tongue height (Whalen & Levitt, 1995): in general, $f_0$ of high vowels is higher than that of low vowels. Diehl and Kluender (1989) have claimed that $f_0$ is an enhancement of the speech signal, and perception of vowel height is claimed to be influenced by the difference between $f_0$ and $F1$. As we will discuss later in this section, if sex differences in formant frequency values are more distinguishable in low vowels than in high vowels, different $f_0$ also may play a role. Future studies need to examine $f_0$ between sexes for each vowel separately in order to obtain more accurate findings of the effect of sex on $f_0$.

We found significant age and sex effects on vowel formant frequencies, also consistent with previous studies (Bennett, 1981; Lee et al., 1999). In terms of age, $F1$ and $F2$ for all vowels were significantly different between older and younger groups, except for the $F2$ of front vowels. As expected, formant frequencies of older children were significantly lower than those of younger children, reflecting the growth of the vocal tract between 5 and 10 years of age. The age effect did not appear in $F2$ of the high-front and the two mid-front vowels in Korean, which contrasts with previous studies of English (Busby & Plant, 1995; Eguchi & Hirsh, 1969), in which $F2$ showed a marked decrease while $F1$ was more stable. But for Korean, a marked change in formant values between the two age groups was found in the low-central vowel /a/.
The sex effect appeared mostly in non-high and non-back vowels. Girls produced significantly higher $F_1$ for the low-central vowel and higher $F_2$ for the low-central and mid-front vowels. This result is consistent with Busby and Plant (1995) and Bennett (1981) in that sex distinctions were small for high vowels, but large for lower vowels. In particular, the difference in $F_1$ value of /a/ productions between Korean-speaking boys and girls was the greatest among vowels, similar to Bennett’s finding that the difference in $F_1$ value of the English low-front vowel /æ/ was largest. Bennett did not examine the English vowel /æ/, however.

As can be seen in Figure 1, Korean /a/ showed gradual but marked changes among the four groups. When formant values of English /a/ and /æ/ for the similar age ranges were plotted from Busby & Plant (1995) and Lee et al. (1999), similar patterns were found in English-speaking children. Thus, this study revealed that this is not a unique characteristic of Korean, rather it is an apparently universal developmental pattern in vowel production. Sex and age differences appeared more clearly among low vowels than non-low vowels. However, this result is different from that of Eguchi & Hirsh (1969), who concluded that the $F_1$ of English /a/ was independent of age.

Bennett (1981) discussed why the sex distinctions were small for high-front vowels, but large for the low-front vowel in English, in terms of vocal tract characteristics. Because low vowels are typically produced with a relatively unconstricted vocal tract and a large mouth opening (Stevens & House, 1955), the acoustic output would reflect the dimensions of the entire tube, and as a result, provide for maximum distinction between the two sexes on the basis of vocal tract size. The different formant values between boys and girls could also indicate different articulatory
gestures between the two sexes. The degree of mouth opening may be a good index for
displaying a sex-dependent articulatory gesture. Girls may tend to open their mouth more
widely which results in a higher $F_1$. In addition, girls may tend to advance their tongues
to a more anterior position than boys, especially for mid and low non-back vowels.

In short, this study revealed that most developmental vowel patterns were similar
between English and Korean. One aspect which differed from English is that age
difference was not significant with respect to $F_2$ of front vowels. It is not certain whether
this is a language-specific characteristic in Korean, however. Since developmental
studies of Korean vowels are very limited, further investigation will be necessary to
confirm the findings presented here.

This study partially supports Fitch & Giedd (1999)’s argument that differences in
acoustic vowel characteristics between the sexes are attributed to behavioral, not
anatomical differences. Given that the vocal tract length is the same between prepubertal
boys and girls, according to Fitch & Giedd, our finding that 5 year-old Korean children
produced /a/ and /e, e/ differently according to two sex points toward the behavioral
element in vowel production even in young children. Although the present study found
evidence of anatomical similarity between boys and girls at 10 years of age in that $f_0$ was
the same between the sexes, it is not certain whether the vocal tract length of Korean
children is also the same between the sexes because Fitch & Giedd found a small but
significant sex difference in peripubertal children at 10 years of age. Thus, it is still open
to investigation whether sex-correlated vowel formant frequency differences in Korean
10 year-old children are solely behavioral or due to anatomical differences.
This study has provided a preliminary comparison of developmental vowel space between Korean and English. In previous work, Yang (1996) found that Korean male speakers produced higher $F_1$ and lower $F_2$ for /i/, higher $F_2$ and similar $F_1$ for /a/, and higher $F_1$ and lower $F_2$ for /u/ than English male speakers. Korean female speakers produced lower $F_1$ and similar $F_2$ for /i/, higher $F_1$ and $F_2$ for /a/, and similar $F_1$ but lower $F_2$ for /u/ than English female speakers. One noticeable finding was that English speakers produced the high back vowel similar to the Korean high-central vowel in terms of $F_2$ values, a characteristic that was more obvious in older children than in younger children. Compared to the English formant values obtained from Lee et al. (1999), both Korean and English-speaking children produced similar $F_1$ and $F_2$ vowels in the /a/ category. The high-front vowel /i/ is also similar between the two languages, but the younger group showed closer values than the older group between Korean and English. Thus, the different adult patterns in vowel production between the two languages were not reflected in child productions yet in terms of /i/ and /a/.

Two things worth noting are that, parallel to Yang’s (1996) comparisons of English and Korean adults, the two Korean non-high front vowels were identical in pronunciation (i.e., formant frequencies were similar to each other). Therefore, it is not surprising that they are no longer discriminated in children’s speech. Furthermore, these two vowels were similar to English /e/, not to /æ/. Thus, in both adult and child productions, the vowel in the Korean word key ‘crab’, transcribed as /e/, and that in kay ‘dog’, traditionally phonemicized as /æ/, are now merged as /e/, i.e., into a single (lower) mid-front vowel.
These findings provide some suggestion for English vowel pronunciation of children whose first language is Korean. While Korean has 7 monophthongal vowels, English has 11. The main difference between the vowels of the two languages is that English has a tense-lax distinction while Korean does not. Thus, ESL teachers and/or SLPs likely need to focus on the tense-lax distinction in English when they teach children from Korean families. When Korean children learn an English word like *boots*, they may not need to place the tongue as far back as they do for a Korean word like *bok*, ‘drum’. Further, when they pronounce an English word like *ball*, the tongue position may be similar to what they have in producing a Korean word like *umma*, ‘Mommy’, but the lips need to be slightly protruded and rounded. Finally, for producing an English word like *bat*, they need to open the mouth to lower the tongue to the level of /æ/ so as to distinguish this vowel from the /e/ in *bet*.

To conclude, the study reported on here found both similar and different patterns with respect to $f_0$ and formant frequencies among Korean children compared to English-speaking children. The results of the study provide a base of information for establishing the normal pattern of development in Korean children, and are also useful for exploring cross-linguistic patterns of similarity and difference as well as in structuring guidance for teaching Korean children the pronunciation of English vowels.¹
REFERENCES


ACKNOWLEDGMENTS

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Footnotes

1 This study made indirect comparisons between Korean and English children in that consonant contexts were not considered when the vowels were compared. Vowel space variation could be due to this context difference as well as to dialectal differences among the speaker populations of the studies (Lee et al., 1999). Further study should collect child speech in the same consonant contexts in order to obtain more precise measurements of vowel formant values between Korean and English.
Table 1 Mean (M) and Standard deviation (SD) of Korean vowels

<table>
<thead>
<tr>
<th>Vowels</th>
<th>Values</th>
<th>10yrs Boys M (SD)</th>
<th>10yrs Girls M (SD)</th>
<th>5yrs Boys M (SD)</th>
<th>5yrs Girls M (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>/i/</td>
<td>$f_0$</td>
<td>223 (14)</td>
<td>239 (20)</td>
<td>265 (31)</td>
<td>260 (14)</td>
</tr>
<tr>
<td></td>
<td>$F1$</td>
<td>309 (68)</td>
<td>321 (63)</td>
<td>409 (120)</td>
<td>417 (105)</td>
</tr>
<tr>
<td></td>
<td>$F2$</td>
<td>3072 (326)</td>
<td>3174 (157)</td>
<td>3156 (391)</td>
<td>3096 (420)</td>
</tr>
<tr>
<td>/e/</td>
<td>$f_0$</td>
<td>202 (14)</td>
<td>220 (22)</td>
<td>258 (36)</td>
<td>258 (47)</td>
</tr>
<tr>
<td></td>
<td>$F1$</td>
<td>591 (157)</td>
<td>561 (117)</td>
<td>702 (102)</td>
<td>772 (52)</td>
</tr>
<tr>
<td></td>
<td>$F2$</td>
<td>2448 (293)</td>
<td>2648 (179)</td>
<td>2566 (167)</td>
<td>2639 (164)</td>
</tr>
<tr>
<td>/e/</td>
<td>$f_0$</td>
<td>203 (12)</td>
<td>219 (15)</td>
<td>252 (25)</td>
<td>260 (40)</td>
</tr>
<tr>
<td></td>
<td>$F1$</td>
<td>614 (112)</td>
<td>565 (142)</td>
<td>744 (79)</td>
<td>780 (71)</td>
</tr>
<tr>
<td></td>
<td>$F2$</td>
<td>2413 (289)</td>
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<td>2560 (221)</td>
<td>2571 (162)</td>
</tr>
<tr>
<td>/a/</td>
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<td>223 (11)</td>
<td>238 (18)</td>
<td>270 (30)</td>
<td>275 (32)</td>
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<tr>
<td></td>
<td>$F1$</td>
<td>529 (89)</td>
<td>488 (59)</td>
<td>584 (63)</td>
<td>554 (99)</td>
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<tr>
<td></td>
<td>$F2$</td>
<td>1660 (177)</td>
<td>1636 (184)</td>
<td>1857 (224)</td>
<td>1838 (224)</td>
</tr>
<tr>
<td>/æ/</td>
<td>$f_0$</td>
<td>213 (12)</td>
<td>231 (23)</td>
<td>262 (27)</td>
<td>262 (20)</td>
</tr>
<tr>
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<td>$F1$</td>
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<td></td>
<td>$F2$</td>
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<td>1159 (101)</td>
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</tr>
<tr>
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<td>254 (22)</td>
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<td>1077 (125)</td>
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<td>1553 (94)</td>
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<td>273 (27)</td>
</tr>
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<td>978 (128)</td>
<td>1041 (165)</td>
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<td>$f_0$</td>
<td>223 (15)</td>
<td>237 (22)</td>
<td>258 (25)</td>
<td>260 (18)</td>
</tr>
<tr>
<td></td>
<td>$F1$</td>
<td>445 (30)</td>
<td>493 (65)</td>
<td>501 (74)</td>
<td>548 (53)</td>
</tr>
<tr>
<td></td>
<td>$F2$</td>
<td>819 (85)</td>
<td>827 (113)</td>
<td>982 (153)</td>
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Table 2. F values of the test of between subject effects

<table>
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<th></th>
<th>$f_0$ Age</th>
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<th>$F_1$ Sex</th>
<th>$F_2$ Age</th>
<th>$F_2$ Sex</th>
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<td>16.55***</td>
<td>.16</td>
<td>.00</td>
<td>.58</td>
</tr>
<tr>
<td>ey / e/</td>
<td>30.45***</td>
<td>30.01***</td>
<td>.47</td>
<td>1.01</td>
<td>6.45**</td>
</tr>
<tr>
<td>ay / ε/</td>
<td>44.81***</td>
<td>40.03***</td>
<td>.05</td>
<td>.51</td>
<td>4.41**</td>
</tr>
<tr>
<td>u / ü /</td>
<td>43.73***</td>
<td>8.64**</td>
<td>2.93</td>
<td>14.30***</td>
<td>.17</td>
</tr>
<tr>
<td>e / η /</td>
<td>47.05***</td>
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<td>3.46</td>
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<td>.194</td>
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<td>a / a /</td>
<td>66.28***</td>
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<td>113.97***</td>
<td>18.81***</td>
</tr>
<tr>
<td>wu / u /</td>
<td>83.77***</td>
<td>14.74***</td>
<td>1.88</td>
<td>14.34***</td>
<td>3.31</td>
</tr>
<tr>
<td>o / o /</td>
<td>31.03***</td>
<td>13.66***</td>
<td>2.55</td>
<td>23.11***</td>
<td>.01</td>
</tr>
</tbody>
</table>

** $p < .01$, *** $p < .001$, dF = (1, 56)
Figures

**Figure 1**: Vowel space of Korean children: Age & Sex

**Figure 2**: Vowel space of 10-year old Korean- and English-speaking boys

**Figure 3**: Vowel space of 10-year old Korean- and English-speaking girls

**Figure 4**: Vowel space of 5-year old Korean- and English-speaking boys

**Figure 5**: Vowel space of 5-year old Korean- and English-speaking girls

**Figure 6**: F1 and F2 of English /a/ from Busby and Plant (1995) and Lee et al. (1999)

**Figure 7**: F1 and F2 of English /æ/ from Busby and Plant (1995) and Lee et al. (1999)
Vowel development in Korean children
Note. Black-Busby & Plant (1995) and White-Lee et al. (1999)
Note. Black-Busby & Plant (1995) and White-Lee et al. (1999)