Formant Frequencies of Malay Vowels Produced by Malay Children Aged Between 7 and 12 Years


Summary: The formant frequencies of Malaysian Malay children have not been well studied. This article investigates the first four formant frequencies of sustained vowels in 360 Malay children aged between 7 and 12 years using acoustical analysis. Generally, Malay female children had higher formant frequencies than those of their male counterparts. However, no significant differences in all four formant frequencies were observed between the Malay male and female children in most of the vowels and age groups. Significant differences in all formant frequencies were found across the Malay vowels in both Malay male and female children for all age groups except for F4 in female children aged 12 years. Generally, the Malaysian Malay children showed a nonsystematic decrement in formant frequencies with age. Low levels of significant differences in formant frequencies were observed across the age groups in most of the vowels for F1, F3, and F4 in Malay male children and F1 and F4 in Malay female children.

Key Words: Formant frequency–Malay children–Normal voice–Sustained vowels.

INTRODUCTION

Formant frequencies have been studied in children and adults across different languages such as American English by Peterson and Barney1 and Hillenbrand et al,2 Japanese by Homma,3 Chinese by Andrianopoulos et al4 and Chen,5 Polish by Majewski and Hollien,6 and Russian by Purcell.7 Fundamental frequency (F0) and perturbation measures of Malaysian Chinese and Malay young adults have been well studied by Ting et al.8,9 but formant frequency data especially for Malay children in different age groups have not been well established so far. Thus, there is a need to look into the formant frequencies of Malay children.

Peterson and Barney1 studied the F0 and the first three formant frequencies of 10 American English vowels in 33 men, 28 women, and 15 children. They found that children had the highest formant frequencies, whereas men had the lowest formant frequencies. The study was extended by Hillenbrand et al5 in 45 men, 48 women, and 46 children to include the fourth formant frequency and two more American English vowels. They found numerous differences in terms of average frequencies of F1 and F2 compared with the study by Peterson and Barney. But in both of these studies, the age and sex of children were not specified.

Peterson and Barney,1 Hillenbrand et al,2 and Bennett10 reported that females had higher formant frequencies than males. These studies, however, did not determine the significant differences in formant frequencies across the genders. Busby and Plant11 found that there were gender differences in F2 for almost 11 Australian English vowels and in F1 for low vowels. In another study of Swedish children aged 11 years, White12 reported that female children had significantly higher F1 and F2 than male children. However, the gender differences for formant frequencies among Malaysian Malay children are yet to be known.

A few studies have investigated formant frequencies in multiple vowels.1–7,10 In general, they reported that low vowels had higher F1 than that of high vowels. However, most of these studies did not report the significant differences in formant frequencies across different vowels. White12 reported that highly significant differences were observed across the vowels for F1 and F2 in Swedish children. On the other hand, some researchers suggested that F1 and F2 were sufficient to be used for vowel classification, so F0 or upper formants such as F3 could add no additional advantage.1–7,10 Potamianos and Narayanan14 reported that because of the combination of a large acoustic parameter range and increased acoustic variability, the performance of vowel identification and classification seriously degraded in children compared with that in adults.

Eguchi and Hirsh15 measured the F0 and first two formant frequencies of vowels in 84 children aged between 3 and 13 years. Their results showed that the formant frequency values decreased with age. Busby and Plant11 also reported that, in general, the F1, F2, and F3 values decreased with age. In another study of vowel development in English and Korean, Lee and Iverson16 showed that the F1 and F2 of children aged 10 years were lower than those of children aged 5 years. In Italian language, a nonsystematic decrease in formants was also reported by Gerosa et al.17 This trend of decrement in formant frequencies with age has not been reported. Besides that, the significant differences in formant frequencies across the age groups among the Malaysian Malay children are still unknown.

The aim of this study was to determine the first four formant frequencies of sustained Malay vowels in Malaysian Malay children aged between 7 and 12 years. The study also investigates the effects of gender, vowel, and age on the formant frequencies among the Malaysian Malay children.

METHODS

Subjects

Three hundred sixty normal Malaysian Malay children aged between 7 and 12 years were selected from primary schools...
around Petaling Jaya and Kuala Lumpur, Malaysia, for the study. Each age group consisted of 30 males and 30 females. None of the subjects selected had vocal pathology or voice disorders, symptoms of cold and flu, allergies, history of smoking, neurological disease, and respiratory dysfunctions.

**Equipment and procedure**

The subjects were shown the list of the vowels, and they were asked to pronounce sustained vowels of /a/, /e/, /ə/, /i/, /o/, and /u/ for 5 seconds each, at a comfortable pitch and loudness level. The recording was done using Shure SM58 microphone (Shure Brothers Inc., Agua Prieta, Mexico) in a normal room environment. The mouth-to-microphone distance was fixed at 2–3 cm. The speech sounds were digitally recorded by GoldWave (St. John’s, Newfoundland, Canada) digital audio editor at a sampling rate of 20 kHz with 16-bit resolution.

A discrimination test was carried out to check the pronunciation of the vowels by the children. The listeners were asked to identify the vowels based on the six Malay vowels. The pronunciation of the vowels was considered correct if seven of the 10 listeners identified them correctly. The Praat (Boersma and Weenink, University of Amsterdam, The Netherlands) software was used to determine the average values of the first four formant frequencies of the sustained vowels. Standard formant settings were used: 5500 Hz for maximum formant frequency, five numbers of formants, 25 milliseconds for the duration of the vowels.

**TABLE 1. Mean Value of Formant Frequencies and Standard Deviation (Hz) of Malay Children in Different Age Groups**

<table>
<thead>
<tr>
<th>Age (y)</th>
<th>Vowel</th>
<th>F1 (Hz)</th>
<th>F2 (Hz)</th>
<th>F3 (Hz)</th>
<th>F4 (Hz)</th>
<th>F1 (Hz)</th>
<th>F2 (Hz)</th>
<th>F3 (Hz)</th>
<th>F4 (Hz)</th>
<th>F1 (Hz)</th>
<th>F2 (Hz)</th>
<th>F3 (Hz)</th>
<th>F4 (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>/a/</td>
<td>815 ± 153</td>
<td>818 ± 193</td>
<td>1473 ± 127</td>
<td>1576 ± 164</td>
<td>3303 ± 340</td>
<td>3252 ± 456</td>
<td>4492 ± 291</td>
<td>4436 ± 320</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>/e/</td>
<td>613 ± 152</td>
<td>611 ± 138</td>
<td>2343 ± 495</td>
<td>2192 ± 609</td>
<td>3184 ± 507</td>
<td>3244 ± 499</td>
<td>4518 ± 424</td>
<td>4688 ± 350</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>/ə/</td>
<td>559 ± 115</td>
<td>626 ± 93</td>
<td>1612 ± 185</td>
<td>1659 ± 256</td>
<td>3618 ± 273</td>
<td>3683 ± 280</td>
<td>4745 ± 337</td>
<td>4560 ± 255</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>/i/</td>
<td>368 ± 62</td>
<td>404 ± 62</td>
<td>2517 ± 628</td>
<td>2543 ± 651</td>
<td>3618 ± 273</td>
<td>3683 ± 280</td>
<td>4745 ± 337</td>
<td>4560 ± 255</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>/o/</td>
<td>529 ± 95</td>
<td>582 ± 118</td>
<td>1044 ± 178</td>
<td>1114 ± 183</td>
<td>3179 ± 400</td>
<td>3133 ± 632</td>
<td>4343 ± 299</td>
<td>4372 ± 349</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>/u/</td>
<td>419 ± 79</td>
<td>463 ± 51</td>
<td>987 ± 387</td>
<td>986 ± 244</td>
<td>2998 ± 316</td>
<td>2969 ± 514</td>
<td>4286 ± 357</td>
<td>4211 ± 378</td>
<td></td>
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</tr>
</tbody>
</table>

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- **F1**: First formant frequency
- **F2**: Second formant frequency
- **F3**: Third formant frequency
- **F4**: Fourth formant frequency

*TABLE 1.* Mean Value of Formant Frequencies and Standard Deviation (Hz) of Malay Children in Different Age Groups

**Note:** The values represent the average of the mean ± standard deviation for each age group and vowel. The table includes the formant frequencies for /a/, /e/, /ə/, /i/, /o/, and /u/ at different age levels (7, 8, 9, 10, 11, and 12) for both genders (Male and Female).
window length, and a dynamic range of 30 dB. The average value of all the first three formant frequencies could be obtained in every vowel. However, in some vowels, the fourth formant frequency was undefined at certain segments of time. Nevertheless, the average fourth formant frequency value was still calculated based on the available fourth formant frequency values in the vowel.

Statistical analysis was carried out using SPSS Statistics 17.0 (SPSS, Inc., Chicago, IL) to determine the significant differences in formant frequencies across the vowels, genders, and age groups. Independent sample t tests were used to determine the group mean differences in formant frequencies between genders for every individual vowel. One-way analysis of variance (ANOVA) with Tukey post hoc analysis was used to determine the groups’ mean differences in formant frequency across the vowels and age groups. The significant level for independent sample t test, ANOVA, and Tukey post hoc test was set at $\alpha = .05$.

RESULTS

Formant frequencies
Table 1 shows the mean formant frequencies of Malaysian Malay children aged between 7 and 12 years in six Malay vowels. The overall means of F1–F4 were $510 \pm 88$, $1665 \pm 269$, $3240 \pm 272$, and $4380 \pm 299$ Hz, respectively, for males and $536 \pm 92$, $1670 \pm 317$, $3254 \pm 320$, and $4405 \pm 310$ Hz, respectively, for females. The highest F1 was observed for /a/, whereas the lowest F1 was observed for /i/. On the other hand, /u/ had the lowest F2 in all the age groups and /i/ had the highest F2, except females aged 8 and 11 years. In F3, /i/ had the highest value in males and females and /u/ had the lowest value except in females aged 7 years. The mean and standard deviation of the formant frequencies by vowels and age groups are shown in Table 2. The effect of the age group and vowel on the formants for both Malay male and female children is illustrated in Figures 1 and 2, respectively.

Significant differences across genders
In general, formant frequencies of Malaysian Malay female children were higher than those in males except in certain vowels in some age groups. Table 3 shows the significant levels in formant frequencies across the genders in different vowels
and age groups using independent sample $t$ test analysis. Generally, no significant difference between the genders were observed in most of the vowels in all age groups except F1 in the age groups of 7 and 12 years, F2 and F3 in the age group of 12 years, and F4 in the age group of 10 years. Significant gender difference was observed in more vowels in Malay children aged 12 years than those in other age groups.

**Significant differences across vowels**
Significant differences in all formant frequencies were observed across the Malay vowels in both Malay males and females for all age groups except F4 in female children aged 12 years. F1 and F2 had stronger significant differences across the vowels than F3 and F4. The post hoc test analysis showed that significant differences in formant frequencies were observed between the vowel pairs, mostly for F1 and F2 compared with F3 and F4, for both genders in each age group.

**Significant differences across age groups**
Table 4 shows the $F$ number and significant level in formant frequencies across the age groups for six Malay vowels. Significant differences in formant frequencies across the age groups were observed in most of the vowels for F1, F3, and F4 in Malay male children and for F1 and F4 in Malay female children. However, the significance was not strong because the $F$ numbers were less than 10. The post hoc test analysis showed that significant differences in formant frequencies across the age groups were found in some vowel pairs in certain age groups only.

**DISCUSSIONS**
Malaysian Malay female children had higher formant frequencies than male children, in general. This result is in agreement with the studies of Peterson and Barney, Hillenbrand et al., Busby and Plant, and White. Based on the independent sample $t$ test, there were no significant differences in all four
formant frequencies between males and females. But some significant gender differences in certain vowels and formants were observed in each age group. This observation was also similar to the previous studies.

Statistical analyses showed that there were significant differences in formant frequencies across the Malay vowels in most of the Malaysian Malay children. The significant differences were stronger in F1 and F2 compared with those in F3 and F4. White\textsuperscript{12} also reported that there were strong significant differences in the first two formants across the vowels among the Swedish children. The study also suggested that the use of F1 and F2 was enough for vowel identification or classification.

Generally, the Malaysian Malay children experienced a decrement in all formant frequencies with age. The result was in agreement with most of the studies of Busby and Plant,\textsuperscript{11} Eguchi and Hirsh,\textsuperscript{15} and Gerosa et al.\textsuperscript{17} However, the decrement in formant frequencies was not systematic, with some of the formant frequencies being higher between the ages of 7 and 12 years.

Fant\textsuperscript{21} used the formant scale factors of K-factors to describe the relationship between the formant frequency values of males and females. Figures 3 and 4 show the formant scale factors

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|c|c|c|c|}
\hline
Vowel & F1 & F2 & F3 & F4 & P & Number & Value & P & Number & Value \hline
/a/ & 4.728 & 0.000 & 2.210 & 0.055 & 6.845 & 0.000 & 5.996 & 0.005 & 3.374 & 3.733 \hline
/e/ & 4.293 & 0.001 & 2.210 & 0.055 & 6.845 & 0.000 & 5.996 & 0.005 & 3.374 & 3.733 \hline
/ə/ & 5.018 & 0.000 & 2.210 & 0.055 & 6.845 & 0.000 & 5.996 & 0.005 & 3.374 & 3.733 \hline
/i/ & 1.171 & 0.325 & 2.210 & 0.055 & 6.845 & 0.000 & 5.996 & 0.005 & 3.374 & 3.733 \hline
/o/ & 4.429 & 0.001 & 2.210 & 0.055 & 6.845 & 0.000 & 5.996 & 0.005 & 3.374 & 3.733 \hline
/u/ & 2.313 & 0.046 & 2.210 & 0.055 & 6.845 & 0.000 & 5.996 & 0.005 & 3.374 & 3.733 \hline
\hline
\end{tabular}
\caption{F Numbers and P Values in Formants Across the Age Groups for Six Malay Vowels}
\end{table}

The bold values indicate that the P values are less than 0.05 which indicates the significant gender and age differences.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure3}
\caption{Ratio of female-to-male formant frequencies (K-factors, in percent) across the age groups.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure4}
\caption{Ratio of female-to-male formant frequencies (K-factors, in percent) across the Malay vowels.}
\end{figure}
across the Malay vowels and the age groups, respectively. Generally, the four K-factors for each vowel and each age group were less than 9% for Malaysian Malay children. The reported percentages were much lower than those in the studies of Bennett, White, and Eguchi and Hirsh. The previous studies reported all positive values for the K-factors; however, some of the Malay male children had higher formant frequencies than females, which resulted in negative values for some K-factors. This was very obvious in /i/ for F2.

CONCLUSIONS
The study investigated the first four formant frequencies of sustained vowels in normal Malaysian Malay children aged between 7 and 12 years. The results showed that, generally, Malay female children had higher formant frequencies than their male counterparts. However, no significant differences in all four formant frequencies were observed between the Malay male and female children in most of the vowels and age groups. Significant differences in all formant frequencies were found across the Malay vowels in both Malay male and female children for all age groups except for F4 in female children aged 12 years. Generally, the Malaysian Malay children showed a nonsystematic decrement in formant frequencies with age. Low levels of significant differences in formant frequencies were observed across the age groups in most of the vowels for F1, F3, and F4 in Malay male children and for F1 and F4 in Malay female children.

Acknowledgments
The authors thank the Ministry of Science, Technology and Innovation, Malaysia, for supporting this research under the Science Fund project (06-01-03-SF0516).

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