AGE- AND GENDER-DEPENDENT ANALYSIS OF VOICE SOURCE CHARACTERISTICS

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ABSTRACT

The effects of age, gender, and vocal tract configurations on the glottal excitation signal are still only partially understood. In this paper we examine some of these effects, and show that the voice source parameters, such as fundamental frequency ($F_0$), open quotient (related to $H_1^n - H_2^n$), and spectral tilt (related to $H_1^n - A_3^n$), are not only affected by age and gender but are also intercorrelated. Recordings of 92 male and female speakers from three age groups (8, 15, 20-39) are analyzed. The main observations are: for low-pitched talkers $H_1^n - H_2^n$ (hence, the open quotient) is proportional to $F_0$, while for high-pitched talkers $H_1^n - H_2^n$ is proportional to $F_1$ (high to low vowels) for $F_1 < 700$ Hz. The parameter $H_1^n - A_3^n$ showed a strong dependence on $F_2$ and $F_3$ for all talkers and age groups; increasing $F_2$ or $F_3$ yielded an increase in $H_1^n - A_3^n$. Spectral tilt was seen to be vowel dependent and for male talkers, spectral tilt changed dramatically with age.

1. INTRODUCTION

The acoustic characteristics of the glottal excitation signal have been shown to be gender dependent [1] and are believed to change with age. A better understanding of these age- and gender-dependencies will help improve voice source estimation and analysis for a variety of speech processing and medical applications.

A study of the effects of age on speech acoustics was presented in [2]. Amongst other things, it analyzed the fundamental frequency ($F_0$) and formant frequencies for 10 monothong vowels from a relatively large database [3] with about 490 subjects in the age range of 5 - 50 years old. The study shows that children have higher $F_0$ and formant frequencies, and greater temporal and spectral variability than adults. These findings are attributed to vocal-tract anatomical differences and possible differences in the ability to control speech articulators.

Another study compares the effects of gender on voice source parameters for about 21 adult male and female talkers for the three vowels /eh/, /æ/, and /ah/ [1]. The main voice source parameters studied were open quotient (OQ) and spectral tilt (SL). The study shows that OQ and SL are generally higher for female than for male talkers.

The focus of this paper is on the analysis of voice source characteristics ($F_0$, OQ and SL). Age-, gender-, and vowel dependencies are evaluated on the CID database [3] with the 5 vowels /i/ / /b/ /b/ /eh/ /æ/, and /u/ / / /u/. The paper is organized as follows: Section 2 presents the statistics of the data in terms of the age and gender of the talkers. The voice source parameters and their estimation methods are described in Section 3. Results are then presented and discussed in Section 4. Section 5 concludes the paper.

2. SPEECH DATA

Speech signals recorded from 92 people (54 males, 38 females) in three age groups, ages 8, 15, and 20–39, from the CID database [3] were analyzed. The carrier sentence was “I say uh, bVt again”, where the vowel was /b/ /b/ /b/ (bet), /æ/ (bat), and /u/ /u/ (boot). ‘uh’ is used before the target word to maximize vocal tract neutrality. The corner vowel /i/ in ‘head’ was also analyzed. Most utterances were repeated twice by each speaker. No pronunciation instructions were given to the speakers beforehand. In total, 879 utterances were analyzed. The sampling frequency was 16 kHz. The distribution of analyzed talked (males/females) was: 25/11 (age 8), 11/11 (age 15), and 18/16 (ages 20–39).

3. ANALYSIS AND PARAMETER DESCRIPTION

The voice source parameters $F_0$, $H_1^n - H_2^n$, and $H_1^n - A_3^n$ were estimated. These parameters are of significant importance in the areas of voice perception and voice synthesis ([4] and [5]). $H_1^n - H_2^n$ is the difference between the spectral magnitudes of the first 2 source harmonics, is related to the open quotient (OQ) [5]. $H_1^n - H_3^n$, the difference between the spectral magnitudes of the first harmonic and the third formant peak, is related to the spectral tilt [5]. The asterisk denotes that the corresponding spectral magnitudes ($H_1$, $H_2$, $A_3$) have been corrected for the effect of the first and second formants ($F_1$ and $F_2$) with the formula described in [6]. This formula has no restrictions on formant locations. For comparison, $A_3$ additionally was normalized to a neutral vowel, as was done in [1]. The calculation of the three parameters requires the estimation of the first 3 formant frequencies ($F_1$, $F_2$, $F_3$), the bandwidths $B_1$ and $B_2$, and $F_0$. Formant frequencies $F_1$, $F_2$, and $F_3$, as well as $F_0$ were estimated using the “Snack Sound Toolkit” software [7] with these settings: the pre-emphasis coefficient was 0.9, the length of the analysis window was 25 ms, and the window shift was 10 ms. The amplitudes $H_1$, $H_2$ and $A_3$ were extracted from the signal spectrum using values of $F_0$ and $F_3$ as reported by Snack. Since the Snack bandwidth estimates were sometimes too high, bandwidths were calculated from their corresponding formant frequency applying the formula in [8]. This reduced the bandwidth variance and therefore the variance of results depending on bandwidth. Analysis segments were chosen at the steady-state part of the vowel, where the context-influence was small.

The estimates of $F_0$, $F_1$, $F_2$, and $F_3$ were manually checked for every utterance. The number of formant estimate corrections in per-
cent. for 8 year old children, was: 86% for /iy/, 44% for /ēh/, 32% for /ōh/, and 2% for /ου/. Most formant estimation errors occurred with children speech. With /iy/, Snack typically allocated 2 formants to the first spectral peak resulting in a much lower 2nd formant frequency. In addition to the mis-identification of F2, there were 3 utterances of /ου/ spoken by 8 year old females which needed an adjustment of F0. The formant values for the vowels are not listed in this paper as the results are similar to what was reported in [2].

4. RESULTS

In this section, we will refer to high-pitched talkers (age 8 both genders, females 15 and older, with usually F0 > 175 Hz) as “group 1” and to low-pitched talkers (males 15 and older, with usually F0 < 175 Hz) as “group 2”. The 3 source parameters, F0, H1* − H2* and H1* − A2* are evaluated as a function of age, gender, formant frequencies and vowel type.

4.1. F0

Table 1 shows the range of F0 values. Note that F0 changes significantly with age (by about 130 Hz) for male talkers, while the change is less dramatic for female talkers (about 50 Hz). This agrees with the results in [2]. We noticed that the very high F0 values (above 300 Hz) are due to high lexical stress on the target word. In those cases F0 was around 300 Hz for the rest of the sentence, but increased for the target word.

Table 1. Min/Max/Max of F0 (in Hz) per age group.

<table>
<thead>
<tr>
<th>Age</th>
<th>F0 males</th>
<th>F0 females</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>182/255/422 Hz</td>
<td>181/281/419 Hz</td>
</tr>
<tr>
<td>15</td>
<td>95/124/248 Hz</td>
<td>179/228/303 Hz</td>
</tr>
<tr>
<td>20–39</td>
<td>87/127/189 Hz</td>
<td>158/233/335 Hz</td>
</tr>
</tbody>
</table>

Average F0 values are highest for /ου/, and higher for /iy/ than for /ēh/ and /aːl/. The trend of increasing F0 as the tongue moves from a front to a back position and from open to closed vowels, has been described for German talkers in [9]. This trend can be seen for all ages and genders for the vowels in this study and may partly be explained by vowel-dependent intrinsic pitch [10]. Note that F0 was not normalized for lexical stress.

Fig. 1. Relation between F1 and F0 for 8 year old children, and females ages 15 and 20−39. The lines correspond to F1 = kF0 with k = 1, . . . , 4.

Fig. 1 shows F1 versus F0 for group 1. Interestingly, F1 is often close to an integer multiple of F0 (while it is not for group 2). This effect could be due to source-vocal tract interaction and has been shown in simulations [11] to be more enhanced with high pitched voices.

4.2. H1* − H2*

4.2.1. H1* − H2* vs. F0

The effects of age and gender on H1* − H2* are shown in Figs. 2–4.

Comparing the histogram distributions, it is interesting to observe that the H1* − H2* separation between genders is the clearest at age 15. The mean H1* − H2* value drops by about 3 dB for male talkers between ages 8 and 20−39, whereas for female talkers it remains relatively unchanged.

Fig. 2. Histogram of H1* − H2* values at age 8. The mean for males is at 4.3 dB and for females, it is at 3.7 dB.

Fig. 3. Histogram of H1* − H2* values at age 15. The mean for males is at -1.5 dB and for females, it is at 4.1 dB.

Fig. 4. Histogram of H1* − H2* values at 20−39. The mean value for males is at 1.5 dB, and for females it is at 3.5 dB. Compared with Fig. 3, there is a greater overlap between male and female talkers.
The difference between genders may be attributed to the fact that $F_0$ drops significantly between age 8 and 15 for males while it does not change as much for females [2].

Fig. 5. Relation between $H_1^* - H_2^*$ and $F_0$ for high-pitched (group 1) and low-pitched (group 2) talkers. A linear relationship for $F_0$ between 80 and 175 Hz is observed: see Eq. 1.

Fig. 6 shows the relationship between $H_1^* - H_2^*$ and $F_1$ for group 1 (high-pitched talkers). $H_1^* - H_2^*$ increases simultaneously with $F_1$ when $F_1$ is less than 700 Hz; the PPC is 0.61. As $F_1$ increases, related to shifting the tongue from a high to a low position, $H_1^* - H_2^*$ increases by about 10 to 15 dB. No such relationship can be seen for $F_1$ values above 700 Hz nor was it observed for group 2 speakers.

Fig. 7 depicts $H_1^* - H_2^*$ as a function of vowel for high-pitched talkers. 'F' and 'M' denote the values for female and male talkers respectively. Note the low values for the high front vowel /iy/ (compare to Fig. 6).

The mean $H_1^* - A_3^*$ value drops for male talkers by about 20 dB between ages 8 and 20–39, whereas for female talkers it drops by about 8 dB.

Table 2. Mean/standard deviation in dB for $H_1^* - A_3^*$ at ages 8, 15, and 20–39. For comparison, parameters from [1] are given in parentheses. Large differences from [1] are in bold.

<table>
<thead>
<tr>
<th>Gender</th>
<th>8</th>
<th>15</th>
<th>20–39</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>33.8/8.5</td>
<td>15.5/7.5</td>
<td>13.0(13.8)/8.5(4.8)</td>
</tr>
<tr>
<td>F</td>
<td>31.0/9.9</td>
<td>20.4/7.9</td>
<td>23.5(23.4)/9.1(6.6)</td>
</tr>
</tbody>
</table>

Compared to [1], for adults, our standard deviation for $H_1^* - A_3^*$ is significantly higher. This may be explained by the inclusion of five vowels in our analysis, while [1] studied three vowels. The PCC between $H_1^* - A_3^*$ and $F_0$ was very small for low-pitched talkers (0.22) and zero for high-pitched talkers. A similar relationship was observed with $F_1$.

A much stronger correlation was observed with $F_2$: PPC is 0.61. This is shown in Fig. 8 which shows $H_1^* - A_3^*$ gradually increasing for $F_2 > 1600\ Hz$.

In Fig. 9 $H_1^* - A_3^*$ is plotted as a function of $F_3$ for all talkers (PCC was 0.6). It shows that, with increasing $F_3$, $H_1^* - A_3^*$ increases monotonically until $F_3 > 3800\ Hz$ where the plot flattens out. An
5. SUMMARY AND CONCLUSIONS

In this paper, we examined three voice source parameters: fundamental frequency ($F_0$), $H_1^* - A_3^*$, and $H_3^* - A_3^*$ for their dependence on age, gender, and vocal tract configuration. For low-pitched talkers $H_1^* - H_2^*$ (hence, the open quotient) is proportional to $F_0$ while for high-pitched talkers, it is proportional to $F_1$ for $F_1 < 700$ Hz. The parameter $H_1^* - A_3^*$ (hence spectral tilt) showed a strong dependence on $F_3$ for all talkers and age groups: increasing $F_2$ or $F_3$ yielded an increase in $H_1^* - A_3^*$. Hence spectral tilt is vowel dependent. Future work will examine the effect of context and prosody on voice source parameter estimates.

6. REFERENCES