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Voice characteristics of children aged between 6 and 13 years:
Impact of age, gender, and vocal training

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Abstract

Objective. To determine impact of age, gender, and vocal training on voice characteristics of children aged 6–13 years.

Methods. Voice acoustic and phonetogram parameters were determined for the group of 44 singing and 31 non-singing children. Results. No impact of gender and/or age on phonetogram, acoustic voice parameters, and maximum phonation time was detected. Voice ranges of all children represented a pre-pubertal soprano type with a voice range of 22 semitones for non-singing and of 26 semitones for singing individuals. The mean maximum voice intensity was 81 dB. Vocal training had a positive impact on voice intensity parameters in girls. Conclusion. The presented data on average voice characteristics may be applicable in the clinical practice and provide relevant support for voice assessment.

Key words: Children’s voice parameters, vocal training, voice type

Introduction

An interest in investigation of capabilities and acoustic parameters of children’s voice has already appeared at the beginning of the twentieth century (1). However, only development of objective methods of voice assessment (acoustic analysis, phonetography) allowed examining peculiarities of children’s voice more deeply and precisely.

Some data reflecting the relation between parameters of children’s voice and the age, gender, weight, and level of sex hormones of investigated individuals have been reported in the literature (2–6). Some studies are devoted to assessment of the impact of vocal training (7–9). Various studies have been conducted for studying children’s voices to establish normal levels of various acoustic and phonetogram parameters (2,7,9–13). However, very few papers represented the normalized data on children’s maximum phonation time (MPT) (7,14,15).

A rather significant diversity of the voice parameters in the literature may be determined by different methods and software used for the acquisition of the data as well as children’s age-groups.

According to Hacki and Heitmüller (1999) an evolution of boys’ voices may be divided into pre-mutation, mutation, and post-mutation phases (16). However, for most of the authors there is no difference in similar phases of girls’ voices. Signs of voice pre-mutation can be fixed at the age of 7–8 years for girls, and for boys between 8 and 9 years of age. Lowering of the habitual pitch or speaking voice, restriction of minimum vocal intensity of the speaking voice as well as of the singing voice, and decrease of the maximum speech intensity and shouting voice are the most common signs of the pre-mutation (16).

Most of these preschool or early school-age children typically begin their vocal training. It is important for music teachers to understand the physiological aspects of children voices and the signs of voice change during this period. Therefore, the establishment of a voice profile at this age is important for vocal teachers and singers as a guiding tool for the development of the child’s voice. This would suggest the optimum tessitura and would encourage teachers/trainers to select songs in suitable ranges for children to perform at this age. Recent studies have revealed the importance of regular singing lessons already in primary schools. Schneider et al. (2010) showed differences in children’s voice range subject to various schools (9). Pupils of vocally/musically encouraged
schools had wider voice ranges (average 32 semitones) than children from schools without vocal/musical encouragement (voice range on average 27 semitones) (9). However, as revealed by surveys, many music teachers/trainers do not even know the ranges of children’s voices and speaking fundamental frequencies (17). Adelmann (1999) stated that teachers and choirmasters sing at too-high frequency levels causing vocal over-use and voice problems (18).

The aim of the study was to establish voice characteristics of 6–13-year-old children, detecting the acoustic voice peculiarities, MPT, and vocal range, and to evaluate a possible impact of age, gender, and vocal training.

Material and methods

Voices of 75 healthy children aged 6–13 years were recorded and analyzed at the Department of Otolaryngology, Lithuanian University of Health Sciences, Kaunas, Lithuania. The youngest age of 6 years was chosen, because the ages of 5 and 6 years may be considered as the moment of maturation of the phonatory structures (14,19). To avoid the impact of puberty on voice parameters and referring to results of the previous studies, 13 years of age was considered as the upper age limit in our study (2,7,10,12,16). Nevertheless, individuals at the age of 12–13 years were included into the study if there were no basic signs of their puberty (6,7,11,20).

The children examined had no complaints of their voice and no history of chronic laryngeal diseases, nor any other long-lasting voice disorders, and they had never seen an otolaryngologist concerning the voice and/or hearing problems. No pathological changes in the larynx were revealed during video-laryngostroboscopy Kay Elemetrics RLS 9100 (Kay Elemetrics Corporation, Lincoln Park, NJ) device with 70° rigid telescope). The hearing of the study group children was within the normal limits.

The children in this study were divided into two groups: singing and non-singing, following the criteria for establishing a classification of singing activity (KLASAK) reported recently by Fuchs et al. (2008) (21). Thirty-one children (11 boys and 20 girls, mean age 10.7 years, SD 2.1 years) were included into the non-singing group. The singing group consisted of 44 children (18 boys and 26 girls, mean age 11.7 years, SD 1.9 years). Both groups were equal in respect of gender and age ($P < 0.05$).

All singing children represented choir singers and were recruited from two Kaunas musical schools. The average time of vocal training in that group was 4.0 (SD 2.1) years. The mean duration of vocal training in the singing boys subgroup was on average 4.8 (SD 2.4) years, in the singing girls subgroup 3.5 (SD 1.9) years ($P = 0.04$). It should be noted that there were only two children of 6 years old and two children of 7 years old with vocal training duration of 2 and 3 years in the Children’s Musical and Esthetical Education School, respectively.

Following the KLASAK classification, most of the singing children in our series ($n = 38; 86.4\%$) were classified as group C2: regular organized singing with concerts in large groups, average weekly time of rehearsals plus the total time of concerts per year of less than 6 hours. Another 6 children (13.6\%) had more individual voice training and corresponded to the group B2: occasional organized singing, and/or frequent singing in familiar milieu, and/or occasional public singing in a large group (21).

The voice test battery used in the study included: 1) acoustic voice analysis, 2) phonetography, and 3) measurement of MPT.

Acoustic analysis

Segments of 2 seconds’ duration of the sustained phonation using habitual pitch and loudness of vowel /a:/ were recorded in a sound-proof 2.5 × 1.5 m room through the D60S Dynamics Vocal (AKG Acoustics) microphone placed at 10.0 cm distance from the mouth and coupled to a digitized Sony Mini Disc Recorder MDS-101. Three separate voice samples were analyzed using Tiger Electronics Dr Speech software (Voice Assessment, Version 3.0). Acoustic voice signal parameters measured included mean fundamental frequency ($F_0$, Hz), perturbation of frequency (percent of jitter) and amplitude (percent of shimmer), and turbulent noise as normalized noise energy (NNE, dB) at 44,100 Hz sampling frequency. A mean of three consistent measurements was calculated for each of the parameters (22).

Phonetogram

Phonetogram (PG) was recorded according to the recommendations of the Union of European Phoniatrians: 1) noise-treated rooms with noise level less than 40 dB; 2) standing position of the subject; and 3) mouth-to-microphone distance 30 cm (23). Tiger Electronics Dr Speech software (Phonetogram 4.0) and multi-directional microphone D60S Dynamic Vocal (AKG Acoustics) were employed for the registration and assessment of the PG. Seven parameters of singing voice range profile were evaluated: 1) pitch range (PR) in semitones; 2) maximum frequency (F-max) in Hz; 3) minimum frequency (F-min) in Hz; 4) intensity range (IR) in dB (A); 5) maximum intensity (I-max) in dB (A); 6) minimum intensity (I-min) in dB (A); and 7) PG area in dB(A) × semitones (22).
Measurement of MPT

MPT as the simplest aerodynamic parameter of phonation was measured in seconds (s) for the longest period for phonation of vowel /a:/ selected from at least three trials with previous demonstration (24,25).

Statistics

Statistical analysis was performed using SPSS 13.0 (2006, SPSS) for Windows. Significance level of 0.05 was chosen for testing statistical hypotheses. Mann–Whitney U test was used to compare unpaired quantitative samples (voice parameters). Correlations between the voice parameters were tested using Spearman’s and Pearson’s correlation coefficients ($r$).

Results

Impact of gender and age on the voice parameters of the non-singing children

Generally, no statistically significant correlations among gender and/or age and acoustic voice parameters, PG parameters, and MPT were revealed. However, a statistically significant negative moderate correlation between the mean of fundamental frequency ($F_0$) and age ($r = -0.64$) was found in the subgroup of non-singing boys. No statistically significant correlation between age and $F_0$ was revealed in the subgroup of non-singing girls.

However, analyzing subgroups of boys and girls separately, a statistically significant strong negative correlation ($r = -0.71$) between age and lowest frequency (F-min) was found in the subgroup of non-singing boys. On the other hand, there was no age impact on the lowest or highest frequencies in the subgroup of non-singing girls.

Following the mathematical statistical analysis, the linear dependence between age and F-min was detected in the subgroup of non-singing boys (Figure 1). That statistical linear dependence allows expressing F-min proportionate to the boy’s age as:

$$F_{\text{MIN}} (\text{Hz}) = 293.1 - 9.44 \times \text{age (years)} \quad (\text{Eq. 1})$$

In the subgroup of non-singing boys the mean lowering of F-min during the age period from 6 to 13 years was in average 8 semitones ($P = 0.04$), i.e. from $c^1$ (262 Hz, SD 4.8 Hz) to $e$ (165 Hz, SD 7.6 Hz). In the subgroup of non-singing girls there was no statistically significant difference ($P = 0.75$) comparing F-min of 6- and 13-year-old girls (190.5 Hz, SD 7.8 Hz and 185.8 Hz, SD 17.6 Hz, respectively).

Impact of vocal training on voice parameters

Comparison of PG parameters between non-singing and singing children revealed statistically significant differences of the means of four PG parameters (PR, maximum and minimum frequency, and PG area), with singing children having better results (Table I). However, no statistically significant differences were found comparing means of MPT and acoustic voice parameters (jitter and shimmer), except the means of NNE, which remained within the limits of normal range (22).

The mean PR (21.9 semitones, SD 5.8) of non-singing children was statistically significantly lower compared with the mean PR (25.5 semitones, SD 5.1) of singing children. The difference was approximately 4 semitones: from $g$ (196 Hz) to $f^2$ (696.5 Hz) for non-singing children and from $f$ (174 Hz) to $g^2$ (784 Hz) for singing children. However, all the voices of the non-singing and singing children fitted the pre-pubertal soprano voice type (Figure 2) (26).

The statistical analysis revealed no significant difference of voice parameters considering singing activities and vocal training (KLASK groups). Positive impact of duration of voice training was revealed only in the subgroup of singing girls. Statistically significant moderate correlations among duration of vocal training and the following PG parameters were detected: intensity range ($r = 0.39$), maximum intensity ($r = 0.46$), minimum intensity ($r = 0.41$), PG area ($r = 0.39$), and MPT ($r = 0.44$). However, no statistically significant correlation between duration of vocal training and acoustic voice parameters or MPT was found in the subgroup of singing boys, except PG area ($r = 0.50$).

Discussion

The vocal capabilities of a child’s voice grow with advancing age but not continuously. During the
Table I. The means of acoustic and phonetogram parameters (Tiger Electronics Dr Speech Voice Assessment 3.0 and Phone-togram 4.0) and MPT of singing and non-singing children aged 6–13 years.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Non-singing n = 31</th>
<th>Singing n = 44</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td></td>
</tr>
<tr>
<td>Jitter (%)</td>
<td>0.24 (0.07)</td>
<td>0.22 (0.05)</td>
<td>0.14</td>
</tr>
<tr>
<td>Shimmer (%)</td>
<td>1.61 (0.67)</td>
<td>1.63 (0.55)</td>
<td>0.88</td>
</tr>
<tr>
<td>NNE (dB)</td>
<td>−16.3 (2.3)</td>
<td>−14.9 (2.3)</td>
<td>0.01*</td>
</tr>
<tr>
<td>F0 (Hz) boys</td>
<td>268.7 (29.1)</td>
<td>256.7 (28.7)</td>
<td>0.29</td>
</tr>
<tr>
<td>F0 (Hz) girls</td>
<td>288.8 (39.8)</td>
<td>281.8 (42.0)</td>
<td>0.57</td>
</tr>
<tr>
<td>PR (semitones)</td>
<td>21.9 (5.8)</td>
<td>25.5 (5.1)</td>
<td>0.01*</td>
</tr>
<tr>
<td>F-max (Hz)</td>
<td>734.4 (116.8)</td>
<td>796.9 (166.8)</td>
<td>0.04*</td>
</tr>
<tr>
<td>F-min (Hz)</td>
<td>199.2 (19.2)</td>
<td>178.8 (26.5)</td>
<td>0.00*</td>
</tr>
<tr>
<td>IR (dB(A))</td>
<td>35.2 (14.1)</td>
<td>33.7 (6.5)</td>
<td>0.52</td>
</tr>
<tr>
<td>I-max (dB(A))</td>
<td>81.1 (7.2)</td>
<td>81.8 (6.9)</td>
<td>0.68</td>
</tr>
<tr>
<td>I-min (dB(A))</td>
<td>48.2 (1.4)</td>
<td>48.1 (1.4)</td>
<td>0.94</td>
</tr>
<tr>
<td>S into PG area (dB(A)</td>
<td>349.7 (133.9)</td>
<td>409.9 (108.2)</td>
<td>0.03*</td>
</tr>
<tr>
<td>(semitones)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MPT (seconds)</td>
<td>15.9 (3.7)</td>
<td>15.4 (3.4)</td>
<td>0.55</td>
</tr>
</tbody>
</table>

*P < 0.05.

maturation process of vocal folds and development of neuromuscular control, the values of some acoustic voice parameters are changing as well. As a result, a lowering of the habitual pitch of the speaking voice as well as the entire pitch range occurs for boys between the ages 8 and 9 years, and for girls between 7 and 8 years (16). Nicollas et al. (2008) revealed that F0 decreases with age and is lower in boys than in girls even before mutation (2). According to Lee et al. (1999) differentiation of male and female F0 and formant frequency patterns begins at around the age of 11 years (27). On the other hand, Campisi et al. (2002) demonstrated that the acoustic voice profile of children was uniform across all girls and boys younger than 12 years (12).

According to our data, there was no gender or age impact on acoustic voice parameters (jitter, shimmer, NNE), MPT, and PG parameters in the healthy non-singing children aged 6–13 years. However, a tendency for different impact of age on voice lowering associated with decreasing of F0 and F-min in non-singing boys compared with girls was revealed in this study. A statistically significant negative moderate to strong correlation between the mean F0 and age (r = −0.64) as well as between F-min and age (r = −0.71) was found in the subgroup of non-singing boys. Furthermore, a linear dependence between age and F-min was established in the subgroup of non-singing boys (Figure 1). Therefore the consequent formula (F-min (Hz) = 293.1 – 9.44 × age (years)) may have some clinical application serving as a simple and practical tool for speech–language pathologists and musical teachers.

In the subgroup of non-singing boys during the age period from 6 to 13 years, F-min was lowered an average of 8 semitones, i.e. from c1 (262 Hz) to e (165 Hz), while voice lowering in the subgroup of non-singing girls was slight and reached approximately 1 semitone. Generally, the results of our study correspond to the data published in the literature by Wuys et al. (2003), who defined that age has a different effect in girls than in boys regarding vocal performance. Therefore, for the healthy boys two age periods of voice lowering can be identified: one below and one above 8 years of age. However, most of the voice characteristics for the healthy girls change gradually over the period from 6 to 11 years (5).

Data of the present study determined that boys and girls prior to puberty had an equivalent vocal range and timbre, which satisfies a pre-pubertal soprano range. Most of them have an approximate

Figure 2. Comparison of the mean pitch range of singing and non-singing children’s voices.
range from $a$ (220 Hz) to the $f$ (698 Hz) (25). All non-singing children in our study had a pre-pubertal soprano voice type, i.e. voice range from $g$ (196 Hz) to $f^2$ (698.5 Hz) was detected. Singing children also fitted the pre-pubertal soprano voice type; however, their voice range was wider: from $f$ (174 Hz) to $g^2$ (784 Hz) (Figure 2). The lowest frequency of children’s voices established in our study is close to the data published by Schneider et al. (9). Assessing voices of 186 children aged 7–10 years (mean 9.1 years, SD 0.7 years) they revealed that the value of the lower voice range limit is $g$ (196 Hz) in 75% of children. However, they found higher values of the upper voice range limit compared to our data. Half of the children showed the upper voice range limit at $b^2$ (932 Hz); consequently only 25% of children’s voices in that study were in concordance with our data in this respect (the highest frequency was $g^2$ (784 Hz)) (9). The mean pitch ranges of both non-singing children (21.9 semitones, SD 5.8) and singing children (25.5 semitones, SD 5.1) were revealed in our study. Generally, these data corresponded to those presented by Fuchs (2006) in a group of children aged 11–13 years, namely the mean pitch range was 18.9 semitones for vocally untrained boys, 22.3 semitones for girls, and 26.5 semitones for vocally trained children (7). However, the mean maximum voice intensity in our study (81.8 dB, SD 7.2 dB for non-singing and 81.1 dB, SD 6.9 dB for singing children) was slightly lower compared to the data (88 dB) presented by G. Böhme and G. Stuchlik (10). On the other hand, only 50% of children were able to sing up to 90 dB in the study performed by Schneider et al. (9).

MPT represents an easily measured parameter, which may reflect the neuromuscular and aerodynamic control of phonation and is therefore commonly used by otorhinolaryngologists and singing teachers. Optimum MPT performance can be enhanced by using repeated trials and by providing visual feedback and encouragement regarding depth of inhalation and verbal instructions (15). Some authors stated that normal school-age children should generally be capable of sustaining a vowel /a:/ for about 10 seconds (14). Finnegan (1984) investigated 3–11-year-old healthy children and revealed that a definite monotonic increase in length of sustained phonation was not apparent across all age levels (15). On the other hand Cielo and Cappellari (2008) assessed MPT in 23 children aged 4–6 years and determined that MPT increased significantly as age increased (14). Rather surprisingly, no statistically significant correlations among age, gender, and MPT were found in our study. The mean MPT of children aged 6–13 years was 15.9 seconds (SD 3.7 s) (non-singing group) and 15.4 seconds (SD 3.4 s) (singing group).

Regular training of the singing voice results in a positive effect on voice parameters in children as well as adolescents (7,8). In our study a statistically significant difference among the means of pitch range, maximum and minimum frequency, as well as PG area was established comparing singing and non-singing children’s voices. For example, the mean pitch range in the non-singing children’s group was 22 semitones, compared with 26 semitones in the singing children’s group. Similar data were published by Fuchs et al. (2006) who found significantly higher dynamic ranges and upper borders of the frequency range in singing children compared with non-singing children (7). However, the study by Schneider et al. (2010) did not find any significant differences in voice range profile among children from the different KLASAK groups with various singing and voice training peculiarities (9). These data are in concordance with the results of our study, which did not reveal significant differences of voice parameters comparing KLASAK C2 and B2 groups.

It is worth noting that a positive impact of duration of voice training on PG parameters was found only in the girls’ subgroup, despite the fact that the mean duration of vocal training in that subgroup was statistically significantly shorter than in boys’ subgroup (3.5 years, SD 1.9 years versus 4.8 years, SD 2.4 years). However, longer duration of vocal training improved parameters mainly reflecting voice intensity and aerodynamic capabilities: maximum and minimum intensity, PG area, and MPT.

Conclusions

The presented voice characteristics of children aged between 6 and 13 years bear potential for application for the clinicians and speech–language pathologists assessing voice disorders and monitoring children who are receiving speech therapy or singing voice training; however, further studies with higher numbers of subjects are advocated. To some extent, established voice characteristics could be beneficial in predicting a child’s voice capabilities for future voice-related activities.

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