Vocal characteristics of 5-year-old children: Proposed normative values based on a French-speaking population

Running headline: Vocal characteristics of 5-year-old children

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Abstract

Purpose: Previous research proposed normative data on gender- and age-specific voice acoustics for adults. Such reference values are lacking for children, particularly under the age of 6. This study was intended (1) to collect reliable normative data for the acoustic parameters of 5-year-old children's voices, and (2) to investigate potential gender-specific differences.

Study: Prospective and cross-sectional.

Methods: Acoustic analyses were done on the voices of 53 normophonic children (26 girls; 27 boys) aged 5;0 to 5;11 years, using Praat software. The fundamental frequency, local jitter, local shimmer, and noise-to-harmonics ratio (NHR) were measured on the sustained vowels [a], [i], and [u]. The highest frequency, lowest frequency, and frequency range were measured using ascending and descending glissandi on the vowel [a].

Results: For the three sustained vowels, the mean fundamental frequency ranged from 255 Hz to 277 Hz, mean jitter ranged from 0.394% to 0.591%, mean shimmer ranged from 2.571% to 5.824%, and mean NHR ranged from 0.009 to 0.034. The frequency range was from 190 Hz to 750 Hz, which corresponds to 23.7 semitones. No gender difference was found, except for NHR on the vowel [a].

Conclusions: The lack of gender differences – other than for NHR on the vowel [a] – led us to propose mixed norms for 5-year-old boys and girls combined.

Implications: These normative data will allow clinicians to compare children's voice assessments to specific references in order to enhance diagnostic accuracy and measure therapy outcomes.

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Introduction

According to the European Laryngological Society [1], voice assessment is based on a multidimensional set of basic measurements including perceptual assessment by the clinician, laryngeal examination, acoustics, aerodynamics, and subjective ratings by the patient. Acoustic parameters provide objective, noninvasive, and inexpensive measures of vocal function [1]. Now that free software such as Praat is available, acoustic measures are an integral part of voice assessment. In order to interpret each patient's results and to detect the presence of dysphonia, clinicians need gender- and age-specific normative data. Such norms exist for adults but are less common for children, and particularly the youngest ones.

In addition to diagnosing dysphonia, acoustic analysis of children's voices can help to identify such pathologies as attention deficit disorder with or without hyperactivity (ADHD) [2,3]. Among deaf children, improved vocal acoustic parameters also constitute an early indicator of the benefits of a cochlear implant [4]. For diagnosis and monitoring treatment outcomes, reliable normative data are indispensable bases for comparison.

Among acoustic parameters, fundamental frequency (F0) is the most studied in children. F0 gradually decreases with age until it reaches adult values at puberty [5–10]. This decline reflects the growth of the laryngeal structures: the increase in the mass and length of the vocal folds, the enlargement of the membranous portion of the vocal cord in relation to the cartilaginous portion, and the descent of the larynx in the neck [11–13].

In the first months of life, a baby's cries range from 400 Hz to 600 Hz [14–17]. The larynx changes substantially by age three, which is why F0 declines rapidly. It is approximately 300 Hz at age four [12]; after that, the decline slows down, only to speed up again, although less significantly, between the ages of seven and nine years [18,19]. This time is called the premutation period [20]. The last noteworthy acceleration starts around 11 or 12 years, when the child enters puberty and the mutation period [20].

At present, the difference in F0 based on children's gender is still subject to debate. Although some authors have found a lower F0 in boys [6,10,21–23], most studies agree that there is no significant gender difference before puberty [8,9,17–19,24–26]. Berger et al. [5] showed that gender-specific values of F0 measured on 2,626 children's speaking voices are comparable between 5.5 and 10.5 years. The major changes in F0 occur between 13 and 14 years in boys, while females show a continuous decrease [5]. Hacki and Heitmüller [20] point out that the premutation period starts about one year earlier in girls, around age seven or eight. It is commonly accepted that the drop in F0 occurs more slowly and regularly in girls, whereas, in boys, it occurs later but faster [5,7,20]. In addition to age and gender, F0 also varies based on the nature of the vocal task [25,27–30], the child's environment [31], and the language spoken [25].

As an indirect measure of the "biomechanical and physiological limits of the respiratory and phonatory systems" [32, p. 429], frequency range can help to assess the tone-generating capacity of the larynx and the extent of laryngeal adjustment during voice production [33]. Usually measured using a phonetogram or a voice range profile, frequency range can be elicited by tasks such as the discrete-steps, steps, and glissando procedures [33]. In children, the discrete-steps procedure yields smaller frequency ranges than steps or glissandi [32]. Like F0, frequency range changes with the growth of the larynx. The descent of the larynx allows for greater mobility and thus also for greater frequency variations. Frequency range expands gradually into the lower frequencies. It is estimated at between 5 and 9 semitones at the age of two months, 12 semitones at six months, 24 semitones at two years, and 36 semitones at six years [12–14]. When investigating the effect of repeated trials on frequency range in 6- to 11-year-old girls, Ma and Li

[34] found ranges of 36 semitones at the first trial and 42 semitones at the tenth trial. In children aged 8 to 12 years, the frequency range measured with the steps procedure was larger for girls (32 semitones) than for boys (28 semitones) [32]. Using the glissando procedure, a range of 30 semitones was reported for girls and 27 semitones for boys [32]. Reference data are needed for younger children.

Perturbation measures such as jitter and shimmer depict the voice's stability. According to Kreiman and Sidtis [35], an increase in perturbation measures can have different physiological causes: unstable or asymmetric muscle tension in the vocal folds, fluctuating subglottal pressure or randomness in airflow through the glottis, perturbations in muscular innervation, mucus on the vocal folds, or changes in local blood flow during the cardiac cycle. Several studies have examined jitter and shimmer in normophonic children. Some have shown that these parameters are not correlated with age, from four years to puberty [6,9,10,36]. Others found a decline in jitter and shimmer between four and six years old, which is interpreted as indicating gradual neurological and anatomical maturation [21,37]. As for the influence of gender on jitter, some studies observed no difference between boys and girls [6,10,21,36]. Regarding shimmer in 5- to 11-year-old children, Glaze et al. [6] reported higher values in females than in males. In children aged 4 to 8, the overall mean jitter and shimmer were lower for girls than for boys [7]. According to McAllister et al. [38], children's voices present higher perturbation values for running speech than for isolated vowels.

The noise-to-harmonics ratio (NHR) represents the voice's harmonicity, that is, its degree of acoustic periodicity [39]. Ranging from 0 to 1, the NHR can be used as a measure for voice quality: the higher its value, the greater the noise or inharmonic content in the voice spectrum. Reference values for NHR in children and how it changes with age are rare in the literature. The harmonic content of voice increases significantly as of the second month of life, probably due to improved control over subglottal pressure. This increase remains significant throughout the first year, particularly in moans and discomfort cries [40]. After that, NHR appears to stabilize: no significant difference is described between 5 and 12 years [9,21,34]. Mean NHR values for 5- to 12-year-old children range from 0.11 to 0.18, with no significant difference between boys and girls [7,9,21,37]. In a study by Glaze et al. [6], the signal-to-noise ratio and shimmer of 5- to 11-year-old children fell within a range that would be considered pathological for adults. According to the authors, these abnormal values may reflect the continually changing anatomy and morphology of vocal fold structures [6].

The literature review shows that reference values for acoustic parameters have been established for the voices of children speaking different languages. At first, the age range between 6 and 12 years was studied. In the last ten years, younger children's voices have also been examined. Some authors have gradually lowered the floor age of their samples to 5 years [6,18,24,25,27,29–31,41] or even 4 years [7,9,20,21,26,28,37,42,43]. Others have tracked a developmental progression, starting with babies [14,15,16,17,40,44]. At present, the age range between 3 and 6 has not been extensively described. In addition, the acoustic parameters for French-speaking children remain under-investigated.

The small number of studies addressing the acoustic characteristics of young children is partially due to the difficulty of describing the tasks to children and their ability to follow the instructions. Given their influence on the acoustic parameters, task instructions and data collection methods need to be controlled.

Although children are usually considered as a homogeneous group regarding voice acoustics, it would be worthwhile to clarify whether gender differences exist for some parameters. Consequently, the objectives of this study are (1) to collect reliable normative data for the acoustic parameters of French-speaking 5-year-old children, and (2) to investigate potential gender-specific differences.

Methods

Participants

Fifty-three normophonic children (26 girls and 27 boys), aged 5;0 to 5;11 years old at the time of the voice recordings, participated in this study. Inclusion criteria: children who were born in 2001, were attending the highest level of kindergarten at a French-speaking school in Belgium, were monolingual speakers with French as their mother tongue, had never had hearing or voice problems, had not been diagnosed with a neurodevelopmental disorder (e.g., autism spectrum disorder or ADHD), had no respiratory or ENT problems at the time of the study, and had a normal voice at the time of the study. The normal character of the voice was established on the basis of a detailed questionnaire completed by the parents and a perceptual evaluation carried out by the first, second, and third authors. The purpose of the perceptual evaluation was to state whether the voice was normal or abnormal, based on recordings of sustained vowels, ascending and descending glissandi, and running speech (object naming and story telling using pictures).

Procedure

This study follows the principles of the Declaration of Helsinki.

Each child met the researcher individually two or three times, in weekly sessions. The vocal samples used to construct norms were recorded in the last session. All samples were recorded in the morning to control for the impact of time of day. The session(s) preceding the recording were intended to familiarize the children with the researcher, the materials and the tasks to be done. The objective was to create a condition in which children would execute the tasks without a model, to avoid imitation of the experimenter's voice.

Material

Voice productions were recorded using a portable digital stereo recorder (Zoom H1) and a headset cardioid microphone (Shure WH20) placed 3 cm from the mouth. The recorder input level was standardized across all the participants. The audio signal was recorded in .wav format, with a sampling frequency of 44.1 kHz and 16 bits. The "lo cut" filter, which is a high-pass filter, was turned on to attenuate low frequencies corresponding to the background noise. The recordings were made in a quiet room at school (background noise < 40 dB).

Tasks, extracted data, and acoustic analyses

Task instructions were integrated into a story to motivate the children and hold their attention. The characters of the story were used to put the tasks into context. Each task was performed based on a visual support and was accompanied by a motor action of the finger. Voice examples were provided during the session(s) preceding the recording. These examples were progressively reduced and were absent during the task recording sessions.

Each child produced the sustained vowels [a], [i], and [u] at a comfortable pitch and intensity, for about 5 seconds. Each vowel was repeated three times. The child was asked to follow a line with the finger during the vowel production. Acoustic analyses were performed on a 1-second stable midvowel portion, as in [22]. The following parameters were derived for each sample: mean F0 (in Hz) measured using an autocorrelation method; local jitter (in %); local shimmer (in %); and NHR (in dB). The mean values of these parameters over the three repetitions were considered separately for the vowels [a], [i], and [u].

The highest frequency (F0 high) and the lowest frequency (F0 low) were measured on glissandi on the vowel [a], produced with normal voice quality. The glissando procedure is easier for children to produce and helps them to achieve larger frequency ranges than the discrete-scale procedure [32]. Participants were asked to produce ascending glissandi from their usual pitch to the highest possible note, and then descending glissandi from their usual pitch to the lowest possible note. Each glissando was accompanied by a finger motion on a picture representing an animal. For the ascending glissandi, the child moved the finger on a line starting from him/herself (representing his/her own F0) toward a mouse (representing the highest possible F0). The descending glissandi were accompanied by a finger motion on a line running from the child toward a bear (representing the lowest possible F0). For each participant, the following measures were taken into account: the highest F0 of three upward glissandi; the lowest F0 of three downward glissandi; and the frequency range (F0 high – F0 low) in semitones. In the results section, mean F0 low, mean F0 high, and mean frequency range are presented across participants.

Acoustic analysis was done using the freeware Praat, version 6.0.05.

Analysis and statistics

Statistical processing was performed with SPSS Statistics for Windows (Version 24.0. Armonk, NY: IBM Corp.). For each parameter, box plots show the results for girls (n = 26), for boys (n = 27), and for both groups (n = 53). Table 1 presents the descriptive analysis of the data.

To determine whether there was a difference due to gender, the values for girls and boys were compared for each acoustic parameter. Given that the data were not all normally distributed, the Wilcoxon non-parametric test was applied to assess the significance of the differences observed between girls' and boys' results. The significance threshold was set at $\alpha = 0.05$.

Results

F0

For boys and girls together (n = 53), the mean F0 for the sustained vowel [a] was 255 Hz, the mean F0 for [i] was 271 Hz, and the mean F0 for [u] was 277 Hz.

As for gender differences, mean F0 was higher for girls than for boys for all three vowels, but the Wilcoxon test did not reveal any significant difference. Mean F0 for [a] was 260 Hz for girls and 251 Hz for boys ($Z = -1.57$, $p = 0.117$). For [i], mean F0 was 275 Hz for girls and 268 Hz for boys ($Z = -0.80$, $p = 0.423$). And for [u], mean F0 was 282 Hz for girls and 272 Hz for boys ($Z = -1.03$, $p = 0.302$). Figure 1 illustrates the data for each of the three vowels.

Local jitter

For boys and girls together, mean jitter for [a] was 0.591%. For [i], it was 0.457%. For [u], it was 0.394%.

Regarding the results according to gender, figure 2 shows that mean jitter was higher for boys than for girls for each of the three vowels. However, the Wilcoxon test revealed no significant difference. Mean jitter for [a] was 0.540% for girls and 0.641% for boys ($Z = -1.65$, $p = 0.100$). For [i], mean jitter was 0.451% for girls and 0.463% for boys ($Z = -0.81$, $p = 0.418$). And for [u], mean jitter was 0.378% for girls and 0.409% for boys ($Z = -0.94$, $p = 0.346$).

Local shimmer

For both genders combined, mean shimmer for [a] was 5.824%. For [i], mean shimmer was 2.645%. For [u], mean shimmer was 2.571%.

As for the results according to gender, figure 3 shows that mean shimmer was higher for boys than for girls for all three vowels, but the Wilcoxon test did not show any significant difference. Mean shimmer for [a] was 5.289% for girls and 6.338% for boys ($Z = -1.71$, $p =$

0.088). For [i], mean shimmer was 2.437% for girls and 2.846% for boys ($Z = –1.55$, $p = 0.122$). And for [u], mean shimmer was 2.351% for girls and 2.784% for boys ($Z = –1.82$, $p = 0.068$).

Noise-to-harmonics ratio (NHR)

For boys and girls together, mean NHR for [a] was 0.034. For [i], mean NHR was 0.009. For [u], mean NHR was 0.004.

Concerning the results according to gender, figure 4 shows that mean NHR for [a] was 0.027 for girls and 0.041 for boys. For [i], mean NHR was 0.008 for girls and 0.010 for boys. And for [u], mean NHR was 0.003 for girls and 0.004 for boys. The standard deviation indicates that the change in NHR is greater for [a] than for the other vowels, particularly in boys. The Wilcoxon test showed a significant gender difference for [a] ($Z = –1.99$, $p = 0.046$) but not for the other vowels ([i]: $Z = –1.66$, $p = 0.098$; [u]: $Z = –1.82$, $p = 0.069$).

F0 low and F0 high

For boys and girls combined, the mean F0 low was 190 Hz and mean F0 high was 750 Hz.

As shown in figure 5, girls had a lower mean F0 low (182.4 Hz) than boys (197.5 Hz). However, the Wilcoxon test revealed no significant gender difference ($Z = –1.17$, $p = 0.240$). Figure 6 shows that girls had a higher mean F0 high (761.6 Hz) than boys (738.1 Hz) but the difference is not statistically significant ($Z = –0.78$, $p = 0.434$).

Frequency range

A mean frequency range of 23.7 semitones was measured for boys and girls together.

As figure 7 indicates, the mean frequency range for girls was 24.7 semitones and the mean frequency range for boys was 22.7 semitones. The Wilcoxon test showed no significant gender difference ($Z = –1.60$, $p = 0.109$) between the two groups.

Discussion

This study fills a gap in the literature concerning voice acoustic data for young children. The objectives were, first, to collect reliable normative data for the voices of 5-year-old French-speaking children, and second, to identify potential gender differences. For sustained phonation, the phonetic material comprised the vowel [a], as recommended by the European Laryngological Society [1], and the vowels [i] and [u] corresponding to the other vertices of the vowel triangle. Frequency range was elicited using glissandi on the vowel [a].

Among the inherent difficulties of creating norms in young children are ensuring that (1) the instructions are fully understood, (2) the tasks are performed properly, and (3) the voice parameters measured are not influenced by the experimenter's voice. To avoid these biases, the tasks were (1) integrated into a story, (2) elicited using pictures and movements of the child's finger, and (3) performed upon direction and not in imitation. The researchers met each child once or twice before recording the sample to ensure that the child would be able to execute each task without following a vocal example, given the level of understanding of 5-year-old children.

Proposed normative data

The mean F0 for boys and girls combined (n=53) was 255 Hz for the sustained vowel [a], 271 Hz for [i] and 277 Hz for [u]. These results are in accordance with Brazilian [37] and American data [7] measured on the sustained vowel [a]. These studies showed that (1) Portuguese-speaking children aged 5;0 to 5;11 had an F0 of 253 Hz (σ = 29) [37]; (2) English-speaking children aged 5 had an F0 of 263 (σ =24) for girls and 266 (σ = 28) for boys [7]; and (3) an F0 higher than 250 Hz constitutes the norm until 12 years [9]. For comparison, analyses on the sustained vowel [a] in larger age groups showed that the mean F0 was 270 Hz (σ = 45) in children aged 5 to 9 [24] and 232 Hz (σ = 23) in 5- to 11-year-old children [6].

For each of the three vowels, girls had a slightly higher mean F0 than boys. In addition, the standard deviation revealed more variable data among girls than boys. Nevertheless, the Wilcoxon test revealed no gender-based difference. Similar findings are reported in other studies that used the vowel [a]. In German-speaking children aged 5 to 9 years old, Brockmann-Bauser et al. [24] obtained a mean F0 of 277 Hz ($\sigma = 51$) for girls and 261 Hz ($\sigma = 34$) for boys. In Arabic-speaking children aged 4 to 6 years, Abo-Ras et al. [21] found a mean F0 of 289 Hz ($\sigma = 42$) for girls and 277 Hz ($\sigma = 34$) for boys. Lower F0 values were reported for American children aged 5 to 11 years: 238 Hz ($\sigma = 24$) for girls and 226 Hz ($\sigma = 20$) for boys [6]. Before puberty, girls and boys do not differ in the size of their larynges or the overall length of their vocal tract [35]. Previous findings suggest that the slight differences in F0 are more likely to be explained by sociolinguistic than physiological factors: during the premutation phase, children copy the vocal patterns of adults of the same gender [19]. Thus, girls may speak with a higher pitch to imitate women's voices while boys may use a lower pitch to sound "more male."

Among the various existing perturbation measures, this study proposes norms for local jitter (%) and local shimmer (%), since these parameters are frequently used in clinical settings. In addition, local jitter is needed to calculate the Dysphonia Severity Index [45].

The results for the whole sample show that mean jitter ranged between 0.394% for [u] and 0.591% for [a]. Cappellari and Cielo [37] measured jitter of 0.96% for [a] in 11 Portuguese-speaking children aged 5;0 to 5;11 years. Maturo et al. [7] reported higher jitter values: 1.18% and 1.9% for American 5-year-old girls and boys, respectively. Other researchers point out that jitter higher than 1% is not abnormal in children [9,21].

Mean shimmer for the 53 French-speaking children ranged from 2.57% for the sustained vowel [u] to 5.82% for [a]. In children of the same age sustaining the vowel [a], Cappellari and

Cielo [37] measured shimmer of 5.51% and Maturo et al. [7] obtained 3.43% for boys and 3.11% for girls. In German-speaking children aged 5 to 9 years, Brockmann-Bauser et al. [24] found shimmer higher than 9% on the sustained vowel [a]. In summary, relatively substantial differences were reported among studies. Such comparisons require careful interpretation given the different material and algorithms used across studies.

Our comparisons based on gender showed that jitter and shimmer were slightly higher in boys than girls for all three vowels. The standard deviations showed that data were more variable in girls than boys. Nevertheless, the lack of any significant gender difference means that the mixed norms can be used for 5-year-old children.

The mean NHR measured in the 53 French-speaking children ranged from 0.004 for the sustained vowel [u] to 0.034 for [a]. These near-zero values suggest great voice harmonicity. These values are lower than the mean NHR of 0.17 obtained by Cappellari and Cielo [37] and 0.11 obtained by Maturo et al. [7].

For all three vowels, mean NHR is slightly higher in boys than in girls. This difference is significant for the sustained vowel [a] (girls' mean = 0.027; boys' mean = 0.041). For purposes of comparison, in Brazilian children 4 to 5 years old, Mendes Tavares et al. [9] obtained a mean NHR of 0.132 for boys and 0.135 for girls, suggesting more inharmonic content than in the present study.

Some caution is needed regarding interpretation and comparison of perturbation measures across studies. The clinical relevance of jitter, shimmer, and NHR has been questioned as they are influenced by the nature of the task, the methodology and equipment used for the acoustic analysis, background noise, time of day, and voice pitch and intensity [41,45,46]. In our study, the children produced the vowels at a comfortable intensity. Perturbation indices are influenced by voice intensity: an increase in voice intensity implies increased vocal cord tension, which makes it possible to stabilize the vocal cords and reduce the variability from one vibratory cycle to another. Thus, the higher the intensity of the voice, the lower jitter and shimmer will be [47]. NHR is also influenced by voice intensity: the louder the subject speaks, the less noise there is in the voice and thus the lower NHR will be [47].

For the French-speaking children in this study, boys and girls combined, the voice ranged from 190 Hz to 750 Hz, which corresponds to a mean frequency range of 23.7 semitones or 2 octaves. Although girls presented a lower F0 low, a higher F0 high, and consequently a broader frequency range than boys, the statistical analyses did not reveal any gender difference. Using a glissando procedure in children aged 8 to 12 years, Reich et al. [32] obtained F0 range data of 30 semitones for girls (F0 low = 179 Hz; F0 high = 1014 Hz) and 27 semitones for boys (F0 low = 179 Hz; F0 high = 888 Hz). With ascending and descending glissandi, Ma and Li [34] obtained a frequency range of up to 45 semitones after three trials in girls aged 6 to 11 years. This extended range is due to a considerably greater F0 high than we obtained: after three trials, the 6- to 11-year-old girls reached 1519 Hz [34], whereas the 5-year-old girls in this study had a mean F0 high of 762 Hz. The lowest frequency was similar in the three studies: 179 Hz for 8- to 12-year-old girls [32], 184 Hz for 6- to 11-year-old girls [34], and 182 Hz for 5-year-old girls. The lower frequency range in the present study compared to others [32,34] may be explained by our methodology: only modal and falsetto registers were taken into account for the F0 measurements, while glottal fry, shouts, and whispers were excluded.

Gender differences

The second objective of this study was to investigate potential gender differences. The only significant difference between girls and boys concerns NHR for the sustained vowel [a].

Note that the p-value ($p = 0.046$) was only slightly lower than the significance threshold (5%). For all the other parameters, none of the differences between girls and boys was significant.

These results confirm those reported in the literature. It is generally admitted that, before puberty and the anatomical changes it triggers, the acoustic parameters of the voice do not differ based on gender. In particular, this has been shown to be the case for fundamental frequency, jitter, shimmer and NHR [6,8–10,17–19,21,24–26,36,37]. Our study complements these data by showing that frequency range does not differ based on gender in 5-year-old children either.

Perspectives

Given the lack of normative voice data for young children, this work aimed to provide reliable acoustic norms. We addressed the 5-year-old age bracket. Younger ages remain to be investigated in future research.

Task type is known to influence the determination of children's acoustic parameters [27-29,32]. Regarding the fundamental frequency of a 5-year-old boy, Hunter [29] found lower values on sustained vowels than in routine daily activities. Structured elicited tasks such as sustaining vowels, repeating sentences or counting may not accurately represent F0 in spontaneous speech [29]. Nevertheless, acoustic measures on sustained vowels are part of the European Laryngological Society's procedure for voice assessment [1] and remain widely used in clinical settings. In addition to sustained vowels, future research should also characterize the acoustic parameters of children's voice based on spontaneous speech. Finally, interlanguage comparisons seems worthwhile to determine the influence of the spoken language on the acoustic parameters of the voice. Such studies will make it possible to determine whether it is advisable to compare a subject to acoustic norms established for a population that speaks a different language.

Conclusion

This study proposes reference values for the acoustic parameters of French-speaking 5-year-olds, based on the production of sustained vowels [a; i; u] and glissandi on the vowel [a]. No gender difference appears, except for the NHR of the vowel [a], which was slightly higher in boys. Apart from this exception, our results support the common finding in the literature that there is no gender difference in young children. Consequently, we suggest using mixed norms for 5-year-old children. The data presented here can help clinicians diagnose vocal dysfunctions and monitor therapy outcomes.

Declaration of interest statement

The authors report no conflicts of interest.

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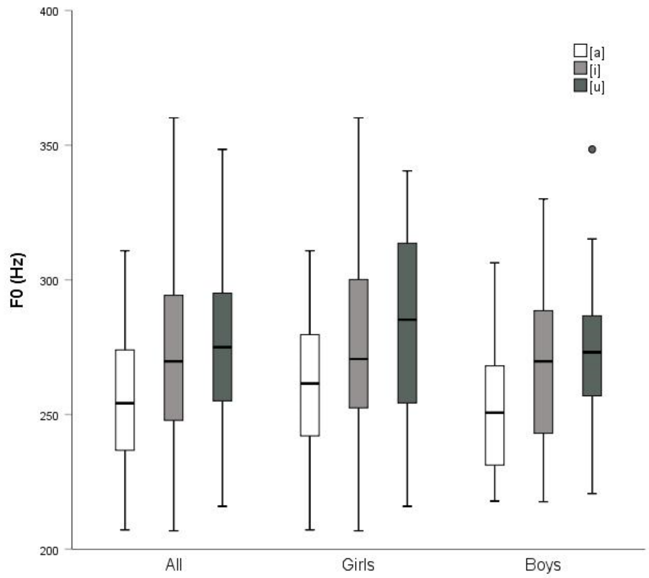

Figure 1. Box plot of F0 by vowel for all children, for girls, and for boys.

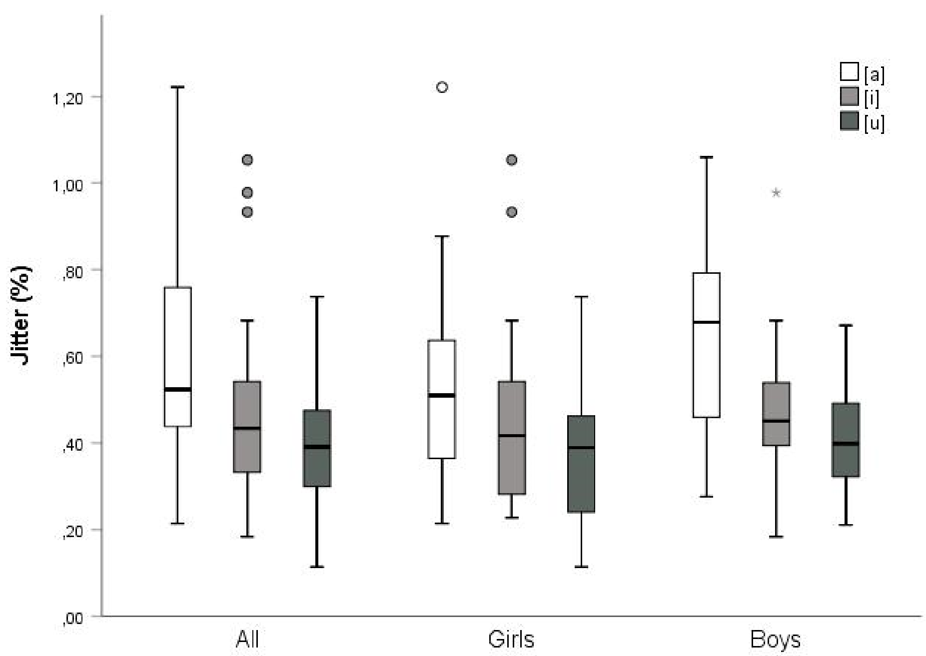

Figure 2. Box plot of jitter by vowel for all children, for girls, and for boys.

Remacle, A., Genel, Y., Segers, M., & de Bodt, M. (In press). Vocal characteristics of 5-year-old children: proposed normative values based on a French-speaking population. *Logopedics, Phoniatrics, Vocology*.

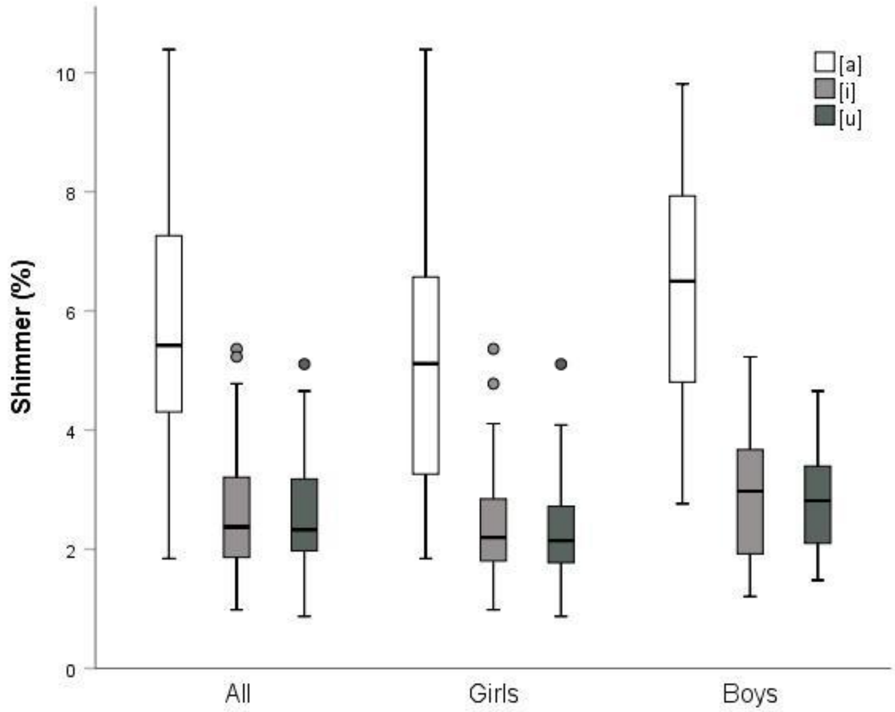

Figure 3. Box plot of shimmer by vowel for all children, for girls, and for boys.

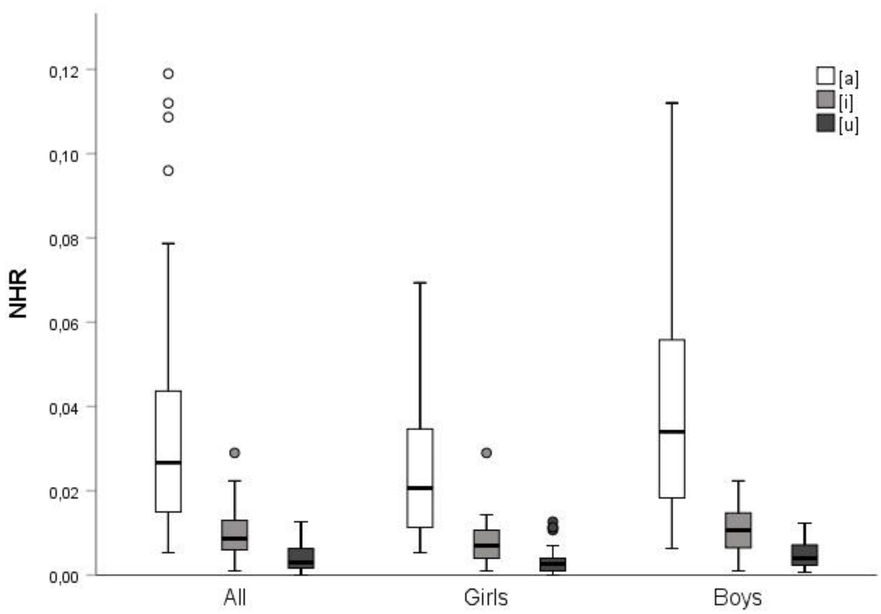

Figure 4. Box plot of NHR by vowel for all children, for girls, and for boys.

Remacle, A., Genel, Y., Segers, M., & de Bodt, M. (In press). Vocal characteristics of 5-year-old children: proposed normative values based on a French-speaking population. *Logopedics, Phoniatrics, Vocology*.

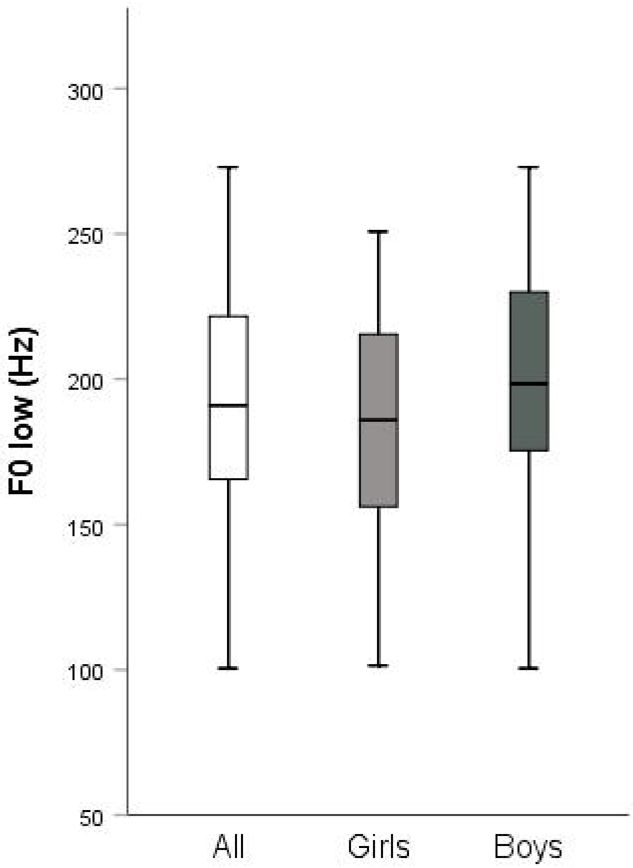

Figure 5. Box plot of F0 low by vowel for all children, for girls, and for boys.

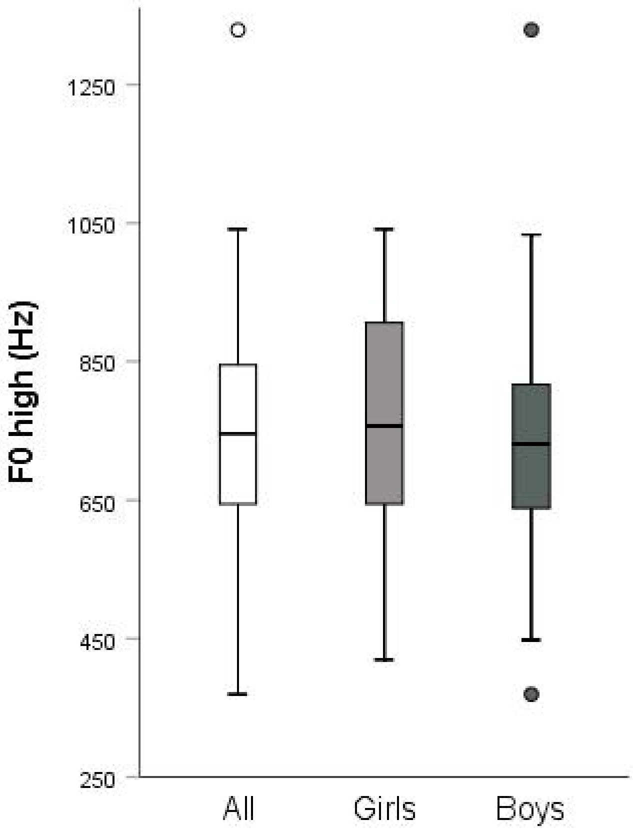

Figure 6. Box plot of F0 high by vowel for all children, for girls, and for boys.

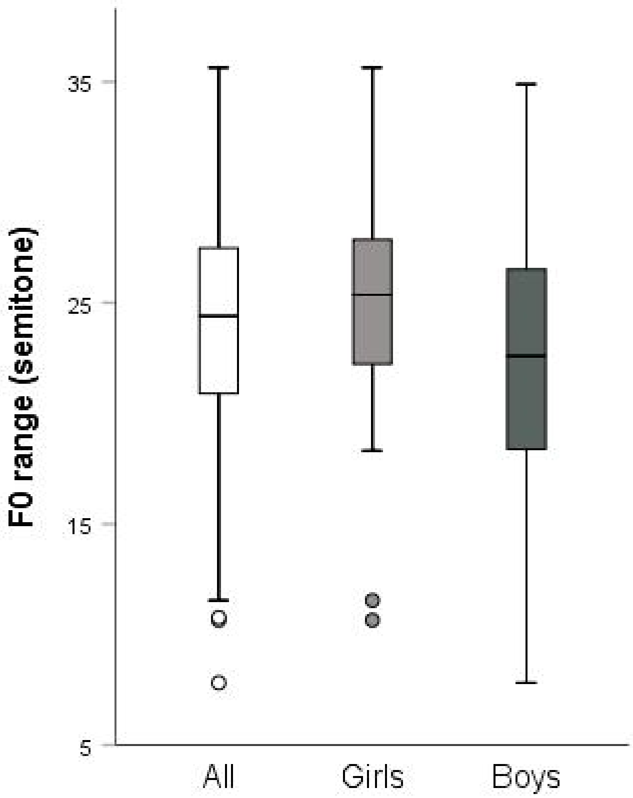

Figure 7. Box plot of frequency range by vowel for all children, for girls, and for boys.

Remacle, A., Genel, Y., Segers, M., & de Bodt, M. (In press). Vocal characteristics of 5-year-old children: proposed normative values based on a French-speaking population. *Logopedics, Phoniatrics, Vocology*.

Table 1. Descriptive analysis of the data

Variable	Vowel	Gender	N	Mean	Standard deviation	95% confidence interval	Median	Minimum	Maximum
F0 (Hz)	[a]	Girls	26	259.91	25.19	249.73 – 270.08	261.49	207.13	310.79
		Boys	27	250.51	24.07	240.98 – 260.03	250.66	217.83	306.31
		All	53	255.12	24.85	248.27 – 261.97	254.16	207.13	310.79
Jitter (%)	[a]	Girls	26	0.540	0.230	0.447 – 0.633	0.510	0.214	1.222
		Boys	27	0.641	0.219	0.554 – 0.728	0.678	0.276	1.060
		All	53	0.591	0.228	0.528 – 0.654	0.523	0.214	1.222
Shimmer (%)	[a]	Girls	26	5.289	2.304	4.359 – 6.220	5.114	1.842	10.387
		Boys	27	6.338	2.054	5.525 – 7.151	6.500	2.765	9.812
		All	53	5.824	2.223	5.211 – 6.436	5.422	1.842	10.387
NHR	[a]	Girls	26	0.027	0.024	0.017 – 0.037	0.020	0.005	0.119
		Boys	27	0.041	0.030	0.029 – 0.053	0.034	0.006	0.112
		All	53	0.034	0.028	0.026 – 0.042	0.026	0.005	0.119
F0 (Hz)	[i]	Girls	26	274.89	34.48	260.96 – 288.82	270.61	206.82	360.12
		Boys	27	267.72	29.35	256.11 – 279.33	269.76	217.60	330.07
		All	53	271.24	31.86	262.45 – 280.02	269.76	206.82	360.12
Jitter (%)	[i]	Girls	26	0.451	0.208	0.366 – 0.535	0.416	0.227	1.053
		Boys	27	0.463	0.159	0.400 – 0.526	0.451	0.183	0.978
		All	53	0.457	0.183	0.406 – 0.508	0.433	0.183	1.053
Shimmer (%)	[i]	Girls	26	2.437	1.017	2.026 – 2.848	2.196	0.984	5.362
		Boys	27	2.846	1.044	2.433 – 3.259	2.974	1.206	5.230
		All	53	2.645	1.042	2.358 – 2.933	2.374	0.984	5.362
NHR	[i]	Girls	26	0.008	0.005	0.005 – 0.010	0.007	0.001	0.029
		Boys	27	0.010	0.005	0.008 – 0.012	0.010	0.001	0.022
		All	53	0.009	0.005	0.007 – 0.011	0.008	0.001	0.029
F0 (Hz)	[u]	Girls	26	282.44	35.65	268.04 - 296.84	285.21	215.90	340.46
		Boys	27	272.45	26.27	262.06 - 282.85	273.12	220.65	348.44
		All	53	277.35	31.33	268.72 - 285.99	274.99	215.90	348.44

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Jitter (%)	[u]	Girls	26	0.378	0.155	0.315 - 0.441	0.389	0.113	0.737
		Boys	27	0.409	0.126	0.359 - 0.459	0.398	0.210	0.671
		All	53	0.394	0.141	0.355 - 0.433	0.391	0.113	0.737
Shimmer (%)	[u]	Girls	26	2.351	0.962	1.962 - 2.739	2.143	0.872	5.107
		Boys	27	2.784	0.913	2.422 - 3.145	2.815	1.478	4.654
		All	53	2.571	0.954	2.308 - 2.834	2.326	0.872	5.107
NHR	[u]	Girls	26	0.003	0.003	0.002 - 0.005	0.002	0.000	0.013
		Boys	27	0.004	0.003	0.003 - 0.006	0.004	0.001	0.012
		All	53	0.004	0.003	0.003 - 0.005	0.003	0.000	0.013
F0 low (Hz)	[a]	Girls	26	182.39	42.46	165.24 - 199.55	185.86	101.43	250.79
		Boys	27	197.53	44.02	180.12 - 214.95	198.36	100.54	272.96
		All	53	190.11	43.52	178.11 - 202.11	190.83	100.54	272.96
F0 high (Hz)	[a]	Girls	26	761.64	182.65	687.87 - 835.42	757.21	419.61	1041.04
		Boys	27	738.11	191.05	662.53 - 813.68	731.46	369.53	1329.17
		All	53	749.65	185.55	698.51 - 800.80	746.12	369.53	1329.17
Frequency range (semitone)	[a]	Girls	26	24.74	5.46	22.53 - 26.94	25.36	10.65	35.64
		Boys	27	22.73	6.50	20.16 - 25.31	22.58	7.82	34.89
		All	53	23.72	6.04	22.05 - 25.38	24.40	7.82	35.64

Remacle, A., Genel, Y., Segers, M., & de Bodt, M. (In press). Vocal characteristics of 5-year-old children: proposed normative values based on a French-speaking population. *Logopedics, Phoniatrics, Vocology*.