A study of the effects of vocal intensity variation on children's voices using long-term average spectrum (LTAS) analysis[1]

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Studies of adult voices have shown that, as vocal intensity is increased, the partials at higher frequencies gain more than those at lower frequencies. Investigations involving children's normal productions are uncommon, however, and there is, consequently, little knowledge of how children's vocal function differs from that of adults. Using LTAS analysis, this study investigates the effects of vocal intensity variation on the voices of 10-year-old schoolchildren singing in soft, mid and loud voice. A frequency-dependent gain factor was calculated which showed the increase in level to have been greater for partials at higher than at lower frequencies for these children. Also, gain within frequency bands was often different between boys and girls, although this was not demonstrated statistically.

Key words: children, sex differences, intensity variation, LTAS.

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INTRODUCTION

It has been well documented in studies of adults that as vocal intensity increases there is a greater increase in the amplitude of higher partials compared to lower ones (2-4, 17). Fant (2) found that, for adults, a 10 dB increase in sound pressure level (SPL) resulted in an increase of around 3 dB per octave up to 3 kHz. There has been some research relating to children's perceptually normal speech at varying vocal intensities. Stathopoulos and Sapienza (16), for example, investigated the aerodynamic, acoustic and kinematic differences in respiratory and laryngeal measures of children who were asked to vocalize at three loudness levels: soft, mid and loud (at a target level of ±5 dB from each subject's mid loudness production). The subjects, adults and children in age groups ranging from 4 to 14 years, produced syllable repetitions of [pa:] and from these measures, mean acoustic intensities were calculated for each of the loudness conditions. The results were presented by age group and by sex. One of the main findings was that men and 14-year-old boys function differently from women and all other groups of children.

The only other variable tested was pitch, the results of which showed that the children's fundamental frequency (F_0) increased as loudness increased. This finding was in agreement with

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previously published data showing SPL to increase by around 8 or 9 dB per octave of F_0 (20). Stathopoulos and Sapienza (16) concluded that the laryngeal and respiratory mechanisms used to increase SPL differed across age groups and were not easily predicted from an adult model.

Glaze *et al*. (5) took four acoustic measures (F_0, jitter, shimmer and signal-to-noise ratio) for two vowels produced by 97 children aged between 5 and 11 years. They too found F_0 to increase as a function of increased SPL. The subjects were asked to phonate using “regular”, “quiet” and “as loud as you can” voice types. The results were presented with girls’ and boys’ data combined as the investigators found no significant sex-based differences in any of the measures. They did, however, discover significant SPL differences between vowels.

Long-term average spectrum (LTAS) analysis has been applied in a number of studies as a measure of pathological voice or dysphonia (7, 8), or of voice quality in speech (1, 9-13, 21) and singing (14, 18, 19).

LTAS analysis provides spectral information averaged over a period of time and thus highlights the more long-term aspects of speech or singing voice production. The method is particularly useful when persistent spectral features are under investigation, features that might not be apparent in shorter samples or single speech sounds. Also, when the sample is long (upwards of 20 sec) the resulting spectrum is not greatly affected by differences in speech material (11). This increases confidence in comparisons between speakers and between studies.

Ternström (18) conducted an LTAS investigation of three choirs: adult, youth (i.e. adolescent boys and girls) and boys singing in different environments. The study evaluated the effects on the spectrum of a choral sound of several variables (room acoustics, musical material, choir type) as well as those of vocal effort, and produced results on dynamic range (softest and loudest productions) and overall power for each of the choirs. Ternström also introduced the dimension of a frequency-dependent gain factor applied to the data which provided further detailed descriptions of the LTAS slopes. Given an increase in the overall spectrum level the amount of gain per frequency band could be calculated.

All three choirs in Ternström’s study demonstrated a gain factor of around 1.0 at 800 Hz and around 2.0 at 3 kHz. This finding predicted that a gain of 10 dB in overall intensity would result in a 10 dB increase at 800 Hz and a 20 dB increase at 3 kHz for these choirs. However, the amount of gain within each frequency band differed significantly between choirs. Ternström’s results provided evidence that higher frequency gain is greater than lower frequency gain in children as well as adults but that differences in voice production exist between age groups. These data are limited, however, to an analysis of a choral sound. From an extensive review of the research literature it appears that no data have as yet been published of the systematic inter- and intra-subject effects of loudness variation on the spectra of individual children’s singing or speaking voices using LTAS analysis.

Aim

The present experiment has sought to establish the effects of changes in vocal loudness on the LTAS of children’s voices. The results will have implications for the control of loudness of production when investigating children’s voices.

The experiment, therefore, aimed to:

(a) show the systematic effects on the LTAS of increasing or decreasing vocal loudness;
(b) identify those LTAS frequency bands showing the greatest gain (i.e. peaks) in amplitude as vocal loudness increases;
(c) compare results for boys’ and girls’ groups;
(d) compare the results with the findings of studies with adults.

METHOD AND MATERIALS

The subjects were drawn from two schools in southwest London. The girls were from an independent day school that has a reputation for good music practice, and the boys were pupils of a state primary school with an enthusiastic choir. The music specialist of each school was asked to select six or seven pupils aged around 10 years who were considered to have relatively good singing skills and experience.

Singing training produces a systematised behaviour and experienced singers are less likely to confuse pitch and loudness. Thus, the instructions to the music specialist were to ensure that the subjects should be able to sing mid, soft and loud versions of a pre-learned song (see Fig. 1) without their pitching ability being significantly affected. Fifteen subjects, seven girls and eight boys, attended on the day of recording and all were included in the study. Of the 15 subjects, 11 were aged 10 years, three were aged 11 years and one was aged 9 years. The average age was 10 years. At the time of recording, a subjective evaluation by the author of singing competence suggested that the abilities of the subjects were adequate for the task (given the specific demands of the research design) but were also somewhat varied, particularly amongst the boys. This subject age-range was chosen to ensure the children were old enough to understand and complete the tasks but without having reached puberty and the vocal changes associated with it. The vocal task required each subject to sing the same practised song as this allowed some control over such variables as pitch and vowel content as well as temporal aspects of production.

The subjects were brought to the television studios of Roehampton Institute London for the recording sessions (one session per school). The studio floor-space was approximately 400 sq m and had a relatively short reverberation time. A small 4 sq m recording area was fashioned in the studio by positioning soft-cloth sound-absorbing partition boards to form a three-sided cubicle. Carpeting was also placed on the floor.

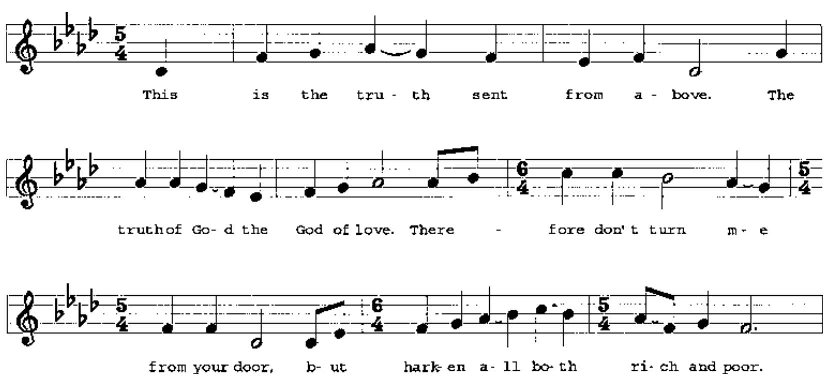

Fig. 1. Score for “This is the truth”.

Calibration was achieved as follows. The microphone of an A-weighted sound level meter was positioned next to the recording microphone that was in turn connected to a Casio DA-7 digital audio tape (DAT) recorder. This “tie-clip” microphone was used for all subsequent subject recordings. The vowel [ɑː] was produced and recorded on the DAT by the investigator at an F_0 of approximately 262 Hz (C_4) and at an SPL of 73 dB as determined from the sound level meter.

It was noted that, during rehearsal, the music specialists used phrases such as “sing like you would sing in the classroom” to describe the mid loudness condition, “as we would sing in a big hall or church” for loud and “like singing a lullaby to a baby” for soft.

The microphone was attached to each subject's clothing in turn at a distance of 15 cm below the mouth, and the signal input to one channel of the DAT recorder[3]. Subjects were asked to sing the song under the three conditions and were given a starting note from an electronic keyboard for each performance of the song. The song was sung in the key of F-minor, the notes ranging from C_4 (262 Hz) to C_5 (523 Hz). The 45 samples (15 subjects x 3 conditions) and the calibration sound were captured at a sample rate of 16 kHz to the PC-based CSL (Kay Elemetrics, Computerised Speech Lab) speech analysis system. All children completed the tasks satisfactorily.

It was necessary to equate the level of the calibration sound with the dB measure provided by the CSL. An LTAS analysis was performed, therefore, of a 1-sec steady-state portion of the calibration vowel using a filter bandwidth of 250 Hz. A transform size of 64 points provided 32 frames for analysis, each 250 Hz wide (i.e. at 250 Hz, 500 Hz, 750 Hz, 1000 Hz,…, 8000 Hz). In a sustained vowel LTAS reveals a spectrum SPL approximately equal to the level of the strongest partials (6, 20). SPL was, therefore, estimated as being the level of the highest peak within the 0-8 kHz frequency range and is henceforth referred to as the overall sound level (L_{os})[4]. According to the CSL analysis the L_{os} for the calibration sound was 28 dB. By adding 45 dB to the levels in each of the 32 frequency bands, the maximum level became 73 dB thereby approximating its known SPL at the time of recording.

The 45 subject data files were analyzed using the same LTAS procedure as for the reference sound. However, instead of a vowel, the subjects sang a 25-sec song containing voiced and voiceless components. It is preferable that the LTAS analysis be of voiced sounds only as it is vocal fold function that is of interest rather than voiceless sounds such as fricatives or intakes of breath. For this purpose, a subroutine was written into the LTAS analysis program that could detect periodicity within analysis frames and discard any unwanted data. In this way, only voiced data were included in the analysis.[5]

RESULTS

Harmonic information generally did not occur above 6 kHz. Also, the lowest F_0 used by the subjects was 262 Hz (C_4) and so calculation of the results was restricted to the range 250 Hz to 6 kHz.

L_{os} was determined for each subject and condition, and the level in each frequency band (L_{fb}) compared between and within subjects and between loud, mid and soft productions. Also, comparison with the calibration sound allowed for comparison of L_{os} values in the recorded output of each subject.

Mean intensity level

The level in each frequency band for each of the three conditions was averaged across subjects to produce a mean LTAS contour. Fig. 2 (a-c) shows such mean contours for the female and male subjects for each loudness condition separately. By and large, the contours were similar between male and female data, showing three clear energy peaks for both groups. These peaks are related to formants but cannot be labelled as such. Therefore, they are referred to in this text as peak 1, peak 2 and peak 3 (or as the abbreviations p_1, p_2 and p_3) numbered consecutively from low to high frequency.

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[3] The 'off-axis' position of the microphone introduced a high-frequency loss to the signal. This does not affect the results, however, which are relative rather than absolute.
[4] This method of measurement is an approximation only to SPL. For reasons of accuracy, therefore, the term overall sound level or L_{os}, and not SPL, is used throughout this article.
[5] Speech Technology Research Ltd, Victoria, British Columbia, Canada.

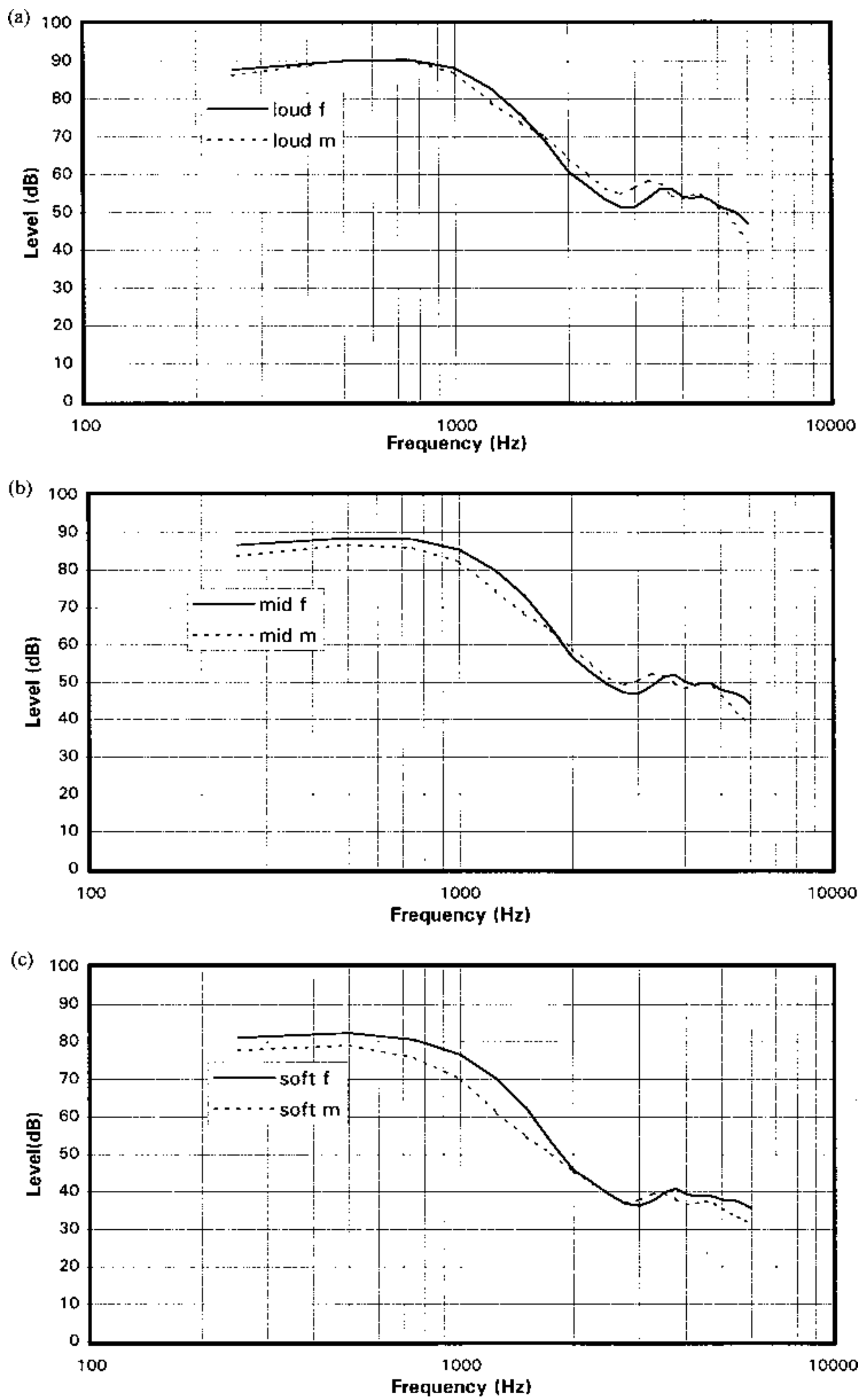

Fig. 2. Mean of actual dB levels across all subjects for (a) loud, (b) mid and (c) soft conditions.

A broad peak (p_1) centred around the 750 Hz frequency band was present in the loud condition, and around the 500 Hz frequency band in the other two conditions, in both the female and the male data. The level of p_1 was comparable between the girls' and the boys' groups for both the loud (L_{os}=90.5 dB for both groups) and mid conditions (girls' L_{os}=88.5 dB; boys' L_{os}=86.7 dB). There was a slight sex difference in the soft condition (girls' L_{os}=82.3 dB; boys' L_{os}=79.0 dB) but analysis of variance (ANOVA) proved non-significant.

Table 1. *Mean L_{os} (and SDs) across groups and across all subjects for the loud, mid and soft loudness conditions. Mouth-to-microphone distance =15 cm*

	Los (dB)			
	N	Loud	Mid	Soft
Girls	7	90.8 (15.0)	88.8 (15.7)	82.3 (16.8)
Boys	8	91.0 (15.0)	86.9 (15.3)	79.1 (15.4)
All	15	90.9 (15.0)	87.8 (15.5)	80.6 (16.0)

As Table 1 shows, there was a shift in Los for the whole group of +3.1 dB from the mid to the loud production of the song. The boys' group, however, increased their Los by 4.1 dB, compared to the girls' group whose increase was only 2.0 dB. Between the mid and soft productions of the song there was an overall shift of -7.2 dB for the group, with the equivalent shift for the boys' and girls' groups being -7.8 dB and -6.5 dB, respectively (see Fig. 3).

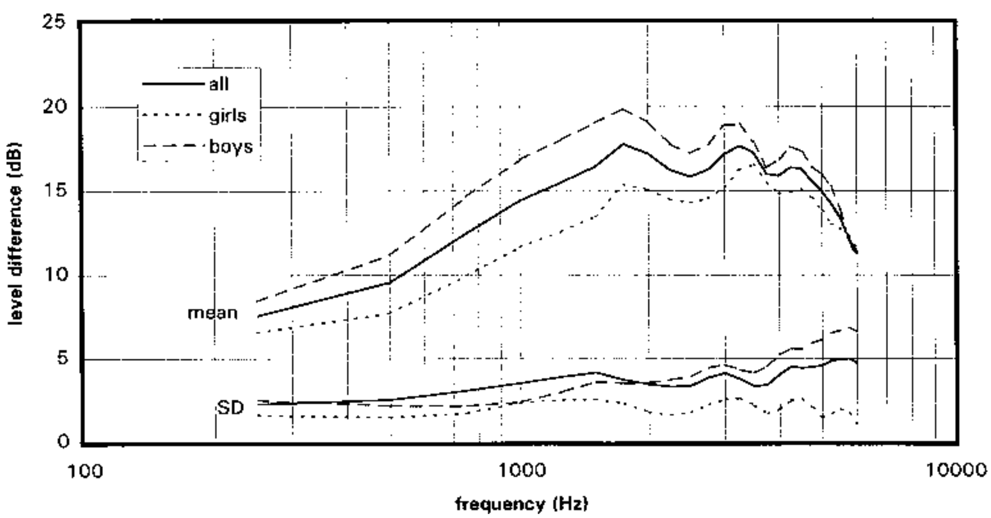

Fig. 3. Means and SDs of spectral dynamic ranges across all 15 subjects and by sex.

A peak in the region of F_2 was not clearly discernible. This was to be expected due to the relatively high variability of F_2 frequency locations, compared to other formants, between vowels. However, the LTAS contour in the region 1-2 kHz was evidently different between sexes, being slightly convex for females, and concave for males. As a finer analysis of the present data, a one-way ANOVA was performed in which the girls and boys were compared with regard to the sound level in each of the 24 frequency bands in each of the three degrees of loudness. Only four bands yielded statistically significant (p <0.05) differences, which all occurred in the soft condition only. These frequency bands were 750 Hz, 1 kHz, 1.25 kHz, and 1.5 kHz. This substantiates the differences in the curvature in this 1-2 kHz region at least in soft voice production.

As mentioned above, broad peaks were apparent at higher frequencies also, at around 3.5 kHz (p2) and 4.5 kHz (p3) for all conditions. These peaks represent means of vowel formants F3 and F4, respectively. The p2 peaks were higher in frequency for females (mean=3.75 kHz for all conditions) than for males (mean=3.25 kHz for mid and loud, 3.5 kHz for soft). Compared to males, the levels of p_2 and p_3 in the females were lower in the loud condition, nearly identical in the mid condition, and higher in the soft condition. Also, p_2 was lower in level in proportion to p_1 in the female data compared to the male data, also suggesting a greater spectral tilt in females.

Dynamic range

The intensity variation within each frequency band, henceforth referred to as spectral dynamic range (DR_s), was calculated as the difference between the soft and the loud productions of the song for each subject. Fig. 3 shows the mean DR_s and standard deviation (SD), as calculated for the whole group and for the girls' and boys' groups separately.

In the lower frequency range, up to 1.75 kHz for boys and 3.5 kHz for girls, DRs tended to increase with frequency. For higher frequencies the opposite was true so that DRs generally decreased as frequency increased. Both groups had evidence of peaks in DRs at 1.75 kHz, between 3 and 3.5 kHz and between 4 and 4.5 kHz, meaning the difference between loud and soft productions was greater in these frequency bands as compared to other frequency bands.

The mean DR_s and SDs for the boys' group were often higher than the comparable values for the girls' group. The DR_s for the boys' group was wider than that for the girls' group in all frequency bands up to and including 5.5 kHz. The greatest difference in DR_s between the two groups was 5.5 dB in the range 1250-1500 Hz.

The differences in SD between the two groups were greatest at 4 kHz and above where the mean SD for the boys was always more than 5 dB. The SD for the boys also tended to increase steadily as frequency increased, whereas the SD curve for the girls was relatively flat.

Gain

Ternström, in his article detailing the LTAS characteristics of choirs (18), used a dimensionless, frequency-dependent gain factor to describe and predict the change in level per frequency band (L_{fb}) as compared to the change in overall sound level (L_{os}). This description was reliant on a generally linear trend existing between L_{fb} and L_{os}. For Ternström's data on a boys' choir, the correlation for yielding straight lines was better than r =0.9, and better than r =0.97 for the youth and adult choirs (a good fit between the data and a straight line would produce a correlation of 1.0). Linearity also appeared to exist in the present data. On statistical analysis, correlations for all subjects were indeed better than r =0.9 (Pearson's correlation coefficient) across all frequency bands.

Linear regression analysis provided slope and intercept values for each subject for the 24 frequency bands between 250 Hz and 6 kHz for the three loudness levels. The slopes for the 15 subjects were averaged to produce a gain factor (GF) for the group and for the girls' and boys' groups separately. Fig. 4 (a) shows the resulting curves (mean ±one SD) for the whole group. The same calculations for the girls' and boys' groups can be seen in Fig. 4 (b) and (c).

There were three clear peaks in the curve for the whole group at 1.75 kHz, 3.25 kHz and 4.5 kHz. The three GF peaks occurred at 1.75 kHz, 3.25 kHz and 4.25 kHz for the boys and, for the girls the peaks were located at 1.75 kHz, 3.5 kHz and 4.5 kHz. Also, the GF for all three peaks was greater in magnitude for the girls.

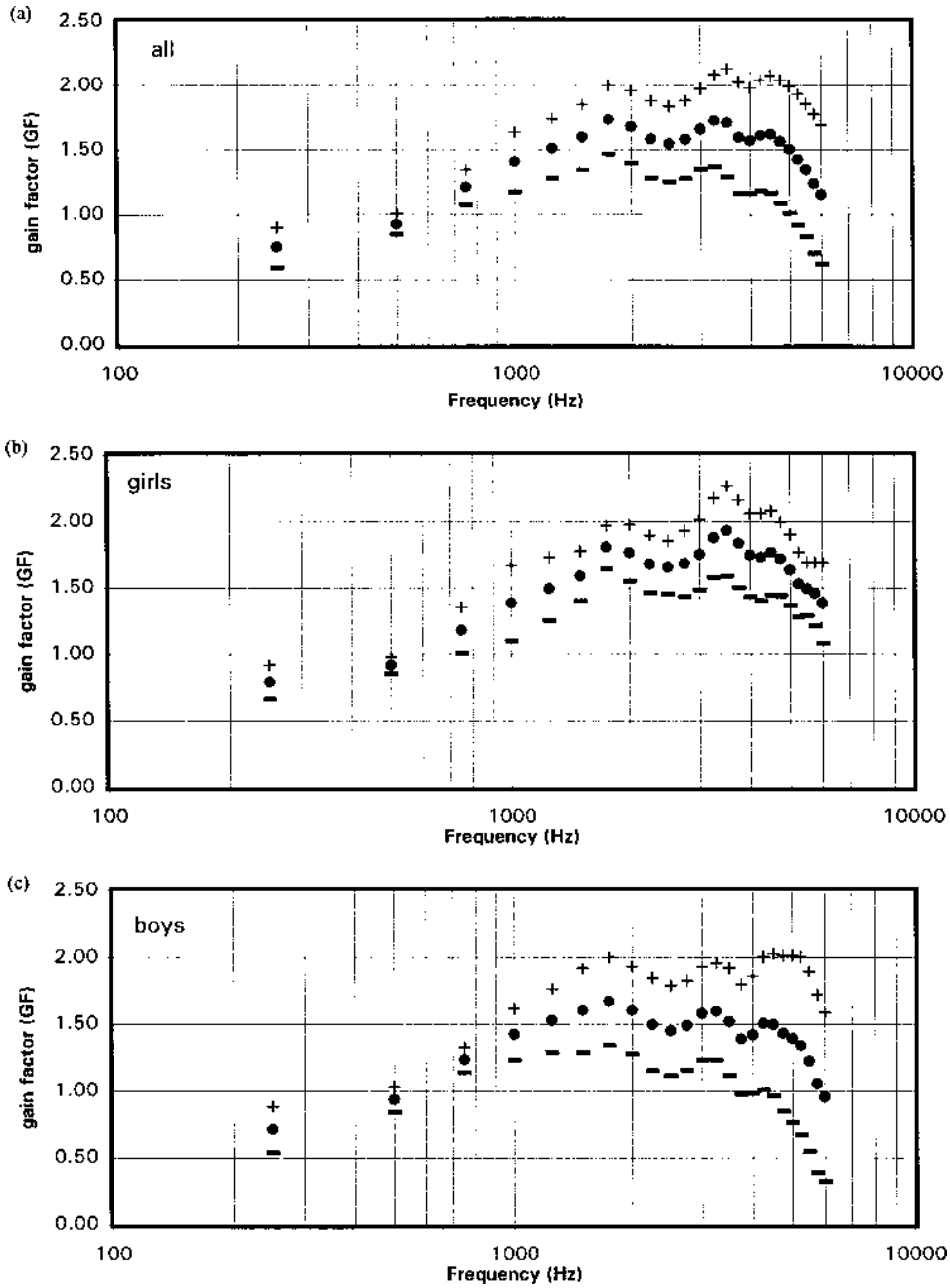

Fig. 4. Mean gain factor (GF) contour (±SD) across (a) all 15 subjects, (b) seven female subjects and (c) eight male subjects.

Fig. 5 (a) shows a comparison of the gain factor curves for the two groups as well as for all subjects. To 1.5 kHz, GF was almost identical for the girls' and boys' groups. Above 1.5 kHz, the gain between the two groups showed some differences, being of greater magnitude for the girls in all frequency bands between 1.75 and 6 kHz. Another noticeable sex difference was that the first gain peak (1.75 kHz) was of greater magnitude in relation to the second gain peak in the boys but the opposite was true for the girls. This meant that not only was the overall gain in the higher frequency bands greater for the girls than the boys but that the gain was also of greatest magnitude in a part of the frequency spectrum which differed quite substantially from that of the boys.

The SDs for the boys' group were greater overall than those for the girls' group. The SD in GF was greatest (0.7 dB) for the boys between 5.25 and 5.75 kHz whereas, for the girls the SD was greatest (0.3 dB) at 3.5 kHz.

The standard errors (SEs) were generally much higher for the boys than the girls, the maximum mean error being 2.2 GF at 2.75 and 3 kHz (Fig. 5 (b)). This indicated the gain across 9conditions was typically more linear for the girls than for the boys. The boys presented errors of >1.0 GF for nearly all frequency bands above 1 kHz. The girls had a maximum error of 1.2 GF at 1.75 kHz, but otherwise the error was relatively low at <1.0 GF across frequency bands.

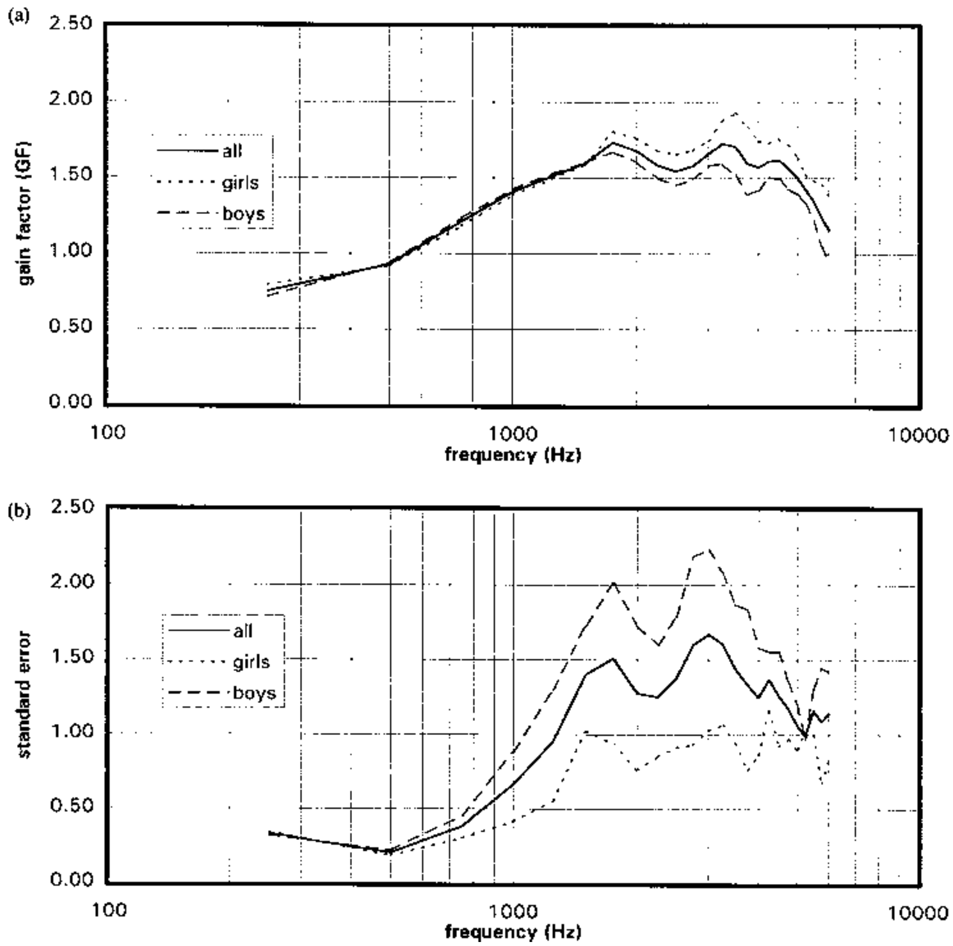

Fig. 5. (a) Gain factor contour and (b) SEs across all 15 subjects and by sex.

Spectral tilt

As mentioned above, it appeared from the present data that sex differences might exist in the area of 3-3.5 kHz, but that it was the male subjects who showed greater relative energy in the higher frequencies. It was also apparent that there was a male– female difference in the spectrum between 1 and 2 kHz. To establish if the spectral tilts differed between sexes, a number of high frequency to low frequency energy ratios were calculated, using different dividing frequencies and disregarding frequencies higher than 5 kHz. The dividing frequencies chosen were 1, 1.25, 1.5, 1.75, 2, 2.25, 2.5, 2.75 and 3 kHz[6]. In addition, spectral energy in the region 0-1 kHz was compared to that in the 1-2 kHz region and to that in the 3-4 kHz region. All ratios were analyzed using a single-factor ANOVA and ratio calculations were repeated to include all three conditions. The results showed that, although spectral tilt became steeper with decreasing loudness of phonation, there were no statistical differences demonstrable between girls and boys in any of the three conditions.

DISCUSSION

Mean intensity level

In the present study, the girls showed slightly higher L_{os} values than boys in the soft and mid condition whilst the reverse was true for the loud condition. Using SPL, Stathopoulos and Sapienza (15) made similar observations in their study of 8-year-old children's spoken vocalizations. It was not possible to compare absolute values for the soft and loud conditions between the two studies as the Stathopoulos and Sapienza subjects were asked to produce loudness levels which were relative (±5 dB) to the comfortable loudness measurement. At the comfortable level, however, the 8-year-olds displayed lower intensities (81.1 dB for girls, 80.8 dB for boys) than the 10-year-olds in the present study (88.1 dB and 86.9 dB, respectively).

Glaze *et al*. (5) found SPL in three loudness conditions (soft, medium, loud) to elicit, for the vowel /a/, a mean of 64 dB, 70 dB and 86 dB, and for the vowel /i/, 66 dB, 73 dB and 83 dB, respectively, in 97 children aged between 5 and 11 years. This finding indicates the variation between vowels and supports the use of LTAS analysis for these kinds of investigations.

The present downward shift in the frequency of P_1 as loudness decreased was probably the result of a change in the relative levels of the fundamental and F_1. As overall vocal loudness decreases, the amplitude of the voice source fundamental increases in relation to F_1 (2, 3, 6). Also, the fact that the subjects placed their mid production closer to loud than to soft compares well with Ternström's LTAS data on a boys' choir (18).

Dynamic range and gain

It is interesting that, for dynamic range measurements in the present study, the greatest difference in dB between soft and loud for boys occurred within the 1.75 kHz frequency band, whereas for girls the greatest level difference was at 3.5 kHz. This sex difference can also be seen in the gain factor data.

The wider SDs seen in the dynamic ranges of the boys' group may be due to the relative inexperience of the boys compared to the girls who also gave more uniform responses. The SEs produced in calculating the regression statistics were relatively high, particularly for the boys' group, probably as a factor of the variability between individual voices and the closeness in level between mid and loud productions made by some subjects. The relatively large SDs for the male subjects (see Fig. 4 (c)), particularly in the higher frequencies, probably reflects the greater variation in performance of the song in each condition between the male subjects.

Ternström's data (18) for three choirs (adult, youth and boys) did not show an obvious peak in gain at or around 1.75 kHz for any of the choirs, but demonstrated peaks in GF at around 3 kHz and 4.5 kHz. The peak in the present boys' data at 3.25 kHz (1.6 GF) compared favourably with Ternström's results for the boys' choir (approximately 3 kHz and 1.6 GF). The present data for the

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[6] Ratios were calculated as per the following example: ratio of 0-1 to 1-5 kHz compared energy in the four frequency bands 250, 500, 750 and 1000 Hz with energy in all frequency bands from and including 1.25-5 kHz.

girl singers showed frequency locations and GF values which, interestingly, appeared similar to those of Ternström's youth choir (i.e. GF in 3 kHz region=2.0 approximately).

The present results show that a shift in loudness will affect significantly the spectral characteristics of children's voices. This too has implications for spectral analysis.

Spectral tilt

The girls' data showed a greater level difference between p_1 and p_2 than the boys' data across conditions but it was not possible to demonstrate this statistically. Löfqvist and Mandersson (11) successfully used the energy ratio in the 0-1 kHz and the 1-5 kHz bands as a means of differentiating adult voice qualities. Also using energy ratios, Mendoza *et al*. (13) showed spectral energy above 1.6 kHz was greater in adult females than in adult males. The present investigation of children's voices revealed no corresponding statistically significant sex difference. It appears, however, that traditional spectrum energy ratio calculations are not detailed enough to fully describe the differences illustrated in these mean LTAS contours.

CONCLUSIONS

A frequency-dependent gain factor was calculated which showed, similar to studies of adults, the increase in level was greater for partials at higher than at lower frequencies for these children. The gain in the higher frequency bands (above 1.5 kHz) was, however, greater for the female group than for the male group. Also, although peaks in gain were found at similar frequency locations for both males and females, the relative magnitude of these peaks differed substantially between sexes.

Even though there were clear differences in the energy distribution between boys' and girls' data, the present LTAS results showed no significant dividing frequency when comparing high and low relative energy. The failure to demonstrate this sex difference statistically was probably because an upper and lower frequency ratio is too coarse a method of analysis.

The choice of skilled singer subjects successfully helped to avoid any extremes of pitch variation during soft or loud voice production that might have influenced the results. In other words, it was possible to be confident that variations observed in the spectrum envelope between conditions were due to intensity variation and not to pitch differences which are likely to accompany differences in vocal loudness in non-singers. The subjects appeared to find the singing task relatively simple which suggests the same could be achieved by children with little singing experience and across a wide age-range.

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REFERENCES

1. Dejonckere PH. Recognition of hoarseness by means of LTAS. Int J Rehabil Res - brief research reports 1983; 6 (3): 343-5.
2. Fant G. Acoustic analysis and synthesis of speech with applications to Swedish. Ericsson Technics 1959, No 1, 27-30.
3. Gauffin J, Sundberg J. Data on the glottal voice source behaviour in vowel production. STL-QPSR 1980, KTH, Stockholm, 2-3, 61-70.
4. Gauffin J, Sundberg J. Spectral correlates of glottal voice source waveform characteristics. J

Speech Hear Res 1989; 32: 556-65.

5. Glaze LE, Bless DM, Susser RD. Acoustic analysis of vowel and loudness differences in children's voice. J Voice 1990; 4 (1): 37-44.
6. Gramming P, Sundberg J. Spectrum factors relevant to phonetogram measurement. J Acoust Soc Am 1988; 83 (6): 2352-60.
7. Hammarberg B, Fritzell J, Schiratzki H. Teflon injection in 16 patients with paralytic dysphonia: perceptual and acoustic evaluations. J Speech Hear Dis 1984; 49: 72-82.
8. Izdebski K. Overpressure and breathiness in spastic dysphonia: an acoustic (LTAS) and perceptual study. Acta Otolaryngol (Stockh) 1984; 97: 373-8.
9. Kitzing P. LTAS criteria pertinent to the measurement of voice quality. J Phon 1986; 14: 477-82.
10. Kitzing P, Åkerlund L. Long-time average spectrograms of dysphonic voices before and after therapy. Folia Phoniatr 1993; 45: 53-61.
11. Löfqvist A, Mandersson B. Long-time average spectrum of speech and voice analysis. Folia Phoniatr 1987; 39: 221–9.
12. Mendoza E, Muñoz J, Valencia Naranjo N. The longterm average spectrum as a measure of voice stability. Folia Phoniatr 1996; 48: 57-64.
13. Mendoza E, Valencia N, Muñoz J, Trujillo H. Differences in voice quality between men and women: use of the long-term average spectrum (LTAS). J Voice 1996; 10 (1): 59-66.
14. Rossing TD, Sundberg J, Ternström S. Acoustic comparison of voice use in solo and choir singing. J Acoust Soc Am 1986; 79 (6): 1975-81.
15. Stathopoulos ET, Sapienza C. Respiratory and laryngeal measures of children during vocal intensity variation. J Acoust Soc Am 1993; 94 (5): 2531-43.
16. Stathopoulos ET, Sapienza MC. Developmental changes in laryngeal and respiratory function with variations in sound pressure level. J Speech Lang Hear Res 1997; 40 (3): 595-614.
17. Sundberg J, Ternström S, Perkins WH, Gramming P. Long-term average spectrum analysis of phonatory effects of noise and filtered auditory feedback. J Phon 1988; 16: 203-19.
18. Ternström S. Long-time average spectrum characteristics of different choirs in different rooms. Voice 1993; 2 (2): 55-77.
19. Ternström S, Sundberg J. Formant frequencies of choir singers. J Acoust Soc Am 1989; 86 (2): 517-22.
20. Titze IR. On the relation between subglottal pressure and fundamental frequency in phonation. J Acoust Soc Am 1989; 85 (2): 901-6.
21. Wendler J, Rauhut A, Krüger H. Classification of voice qualities. J Phon 1986; 14: 483-8.

SAMMANFATTNING

En studie av röststyrkevariationers effekter pa barnröster med anvandande av LTAS analys

Studier av vuxenröster har visat att ökad röststyrka medför större nivå ökning hos deltoner i det högre frekvensområdet än i det lägre. I denna artikel redovisas motsvarande data för 10-åriga pojkar och flickor. Barnen sjöng en 25 sekunder lång sång med svag, medelstark och stark röst. Långtidsmedelvärdesspektrum (LTAS) för de tre röststyrkorna var likartade, men vissa spektrala skillnader mellan pojkar och flickor fanns i alla tre röststyrkorna (Fig. 2). Den spektrala lutningen var större hos flickorna, dock ej signifikant. Samtliga försökspersoner visade ett positivt, linjärt samband mellan generell ljudnivå och nivån i vart och ett av 24 stycken 250 Hz breda band i området mellan 250 Hz och 6 kHz. En frekvensberoende skalfaktor beräknades (Fig. 4 och 5), som visade att nivåändringen var större för höga frekvenser än för låga hos dessa barn. Ändringen i de högre frekvensbanden (över 1,5 kHz) var dock större för flickorna än för pojkarna. Vidare återfanns toppar i skalfaktorn vid samma frekvenser för pojkar och flickor, men storleken på topparna visade stora skillnader mellan könen; pojkarnas största topp låg vid 1,75 kHz medan flickornas låg vid 3,5 kHz. Skalfaktorn för frekvenser lägre än 1,75 kHz var mycket lika mellan grupperna.

YHTEENVETO

Lasten äänenvoimakkuuden vaihtelun vaikutukset pitkäaikaisspektriin (LTAS)

Aikuisten ääniä tutkittaessa on havaittu, että äänenvoimakkuuden kasvattaminen korostaa korkeampia osasäveliä spektrissä. Tutkimuksessa selviteltiin vastaavaa asiaa kymmenvuotiaiden tyttöjen ja poikien äänissä. Lapset lauloivat n. 25 s mittaisen laulun hiljaa, keskivoimakkaasti ja kovaa. LTAS analyysissä todettiin tyttöjen ja poiken spektrien eroavan toisistaan, vaikka sinänsä eri voimakkuuksien välillä piirteet olivat yhteneväiset. Tyttöjen äänen spektri laski jyrkemmin (Kuva 2). Äänen voimakkuuden kasvattaminen lisäsi aina osasävelten voimakkuutta alueella 250 Hz-6 kHz 250 Hz kaistaleveydellä. Muodostettiin faktori (kauvat 4 ja 5), jonka avulla voitiin todeta korkeiden osasävelten voimistuvan alempia enemmän. Korkeampien taajuuskaistojen (yli 1,5 kHz) tasot olivat korkeammat tytöillä. Spektrissä esiintyi energiahuippuja samoilla alueilla, mutta pojilla 1,75 kHz alueella oli voimakkain huippu ja tytöillä 3,5 kHz. Alle 1,75 kHz alueella tasot eivät poikenneet tyttöjen ja poikien välillä toisistaan.