Long-Term Average Spectra From a Youth Choir Singing in Three Vocal Registers and Two Dynamic Levels

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Summary: Objectives/Hypothesis. Few studies have reported the acoustic characteristics of youth choirs. In addition, scant data are available on youth choruses making the adjustments needed to sing at different dynamic levels in different registers. Therefore, the purpose of this study was to acoustically analyze the singing of a youth chorus to observe the evidence of the adjustments that they made to sing at two dynamic levels in three singing registers.
Study Design. Single-group observational study.
Methods. The participants were 47 members of the Brooklyn Youth Chorus who sang the same song sample in head, mixed, and chest voice at piano and forte dynamic levels. The song samples were recorded and analyzed using long-term average spectra and related spectral measures.
Results. The spectra revealed different patterns among the registers. These differences imply that the singers were making glottal adjustments to sing the different register and dynamic level versions of the song. The duration of the closed phase, as estimated from the amplitudes of the first two harmonics, differed between the chest and head register singing at both dynamic levels. In addition, the spectral slopes differed among all three registers at both dynamic levels.
Conclusions. These choristers were able to change registers and dynamic levels quickly and with minimal prompting. Also, these acoustic measures may be a useful tool for evaluating some singing skills of young choristers.
Key Words: Youth singing–LTAS–Vocal registers–Dynamic levels.

INTRODUCTION

Most of the existing acoustic studies of choral singing have used adult singers as the participants. These studies have focused on differences between choral singing and classical solo singing[1–4]; singing attributes of choral singers[5]; and on the effects of choral formation, choral size, acoustic quality of rooms, song selection, and blend.[6–15] In contrast, few studies have evaluated the acoustics of youth choirs.

Howard et al[16] evaluated listeners' abilities to discriminate between boys and girls singing the same vocal part. They found that trained listeners could not distinguish between the singing of boys and girls younger than 11 years. A subsequent study reinforced this finding in which the authors reported almost identical spoken pitch and vocal ranges for boy and girl singers in this age range.[17] In contrast, White[18] reported that the long-term average spectra (LTAS) curves from boys had a spectrum peak around 5000 Hz, whereas the girls' LTAS had a relatively flat spectrum in the area of 5000 Hz. From this difference, she concluded that the peak at 5000 Hz indicates a "boy-like" sound. This indicates that the timbre difference in the higher harmonics has a greater effect on the perception of the "boy-like" sound than does the fundamental frequency.

Vocal training allows children to sing with greater pitch and dynamic ranges. Schneider et al[19] reported that children from singing or musically encouraging schools had an average fundamental frequency range of 32 semitones, and those from other schools had an average fundamental frequency range of 27 semitones. The former range was similar to previously reported ranges for children with vocal training,[20,21] and the latter range was similar to previously reported ranges for untrained children.[22–24] In addition, youth with vocal training exhibit spectral differences that imply the use of different laryngeal and vocal tract gestures when singing in a classical style as opposed to a music theater one.[25]

Whether youths should sing in different vocal registers has been discussed as an aspect of healthy singing practices. For example, singing in head and mixed registers has been considered the healthier and better training method for them.[26,27] The muscle adjustments in the larynx and vocal tract that allow us to change registers result in observable acoustic changes in the vocal and resonance components of sung vowels.[28,29] As noted by Andrews,[30] when these adjustments are inappropriate, they can result in vocal problems among untrained or poorly trained young singers.

In addition to the choristers, acoustic studies of choruses must consider room acoustics. Ternström[13] recorded three choirs in each of three different rooms to determine the possible effects of the room acoustics on LTAS. He found that singers in an adult choir, but not those in either a child or a youth choir, adapted their vocal effort level ostensibly to accommodate differences in room absorption.

Ternström[13] also reported that changes in a choir's sound level resulted in nearly linearly proportional level changes in each frequency band of an LTAS analysis and introduced a frequency-dependent gain factor $g(f)$ to account for the

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spectral effect of sound pressure level (SPL) changes on the LTAS. This frequency-dependent gain factor can be computed for speech also. Nordenberg and Sundberg[31] found that the *g(f)* changes for different amplitude levels of speech were nearly the same as those reported by Ternström[13] for different levels of choral singing. White[32] reported that *g*(*f*)-corrected LTAS revealed that the girls in her study sang at slightly higher mean intensity levels in the piano and mezzoforte conditions, whereas the boys had higher mean intensity levels in the forte condition. Thus, the *g*(*f*)-corrected LTAS can be used to provide information concerning the choral singing of children.

Therefore, *g*(*f*)-corrected LTAS may indicate physiological adjustments made by the members of a youth chorus when the chorus sings in different registers and at different dynamic levels. The purpose of the present study was to acoustically analyze the singing of a youth chorus to observe the evidence of the adjustments that they made to sing at two dynamic levels in three singing registers. The selected choir has been trained to sing in a variety of singing styles, including traditional youth choral, classical, belting, gospel, and musical theater styles.

METHOD

Participants

The participants were the 41 girls and six boys who comprised the Concert Chorus of The Brooklyn Youth Choir Academy (BYC). The BYC was selected on the basis of national recognition and the training of the choristers in a variety of musical styles. In contrast to some youth choirs who are trained to use head voice only, the members of the BYC are trained to use head and chest registers and styles that include belting and gospel. The girls in the choir ranged in age from 11 to 18 years (mean age = 14.2 years). The boys in the choir ranged in age from 11 to 14 years (mean age = 12.2 years). All members of the BYC participated in vocal training for at least 9 months. The time of vocal training in the BYC for the children ranged from one to eight school years. The BYC rehearses twice weekly for 2 hours. All children self-reported that they were of good general health at the time of the recording, and none exhibited observable symptoms of upper respiratory infections or nasal congestion on the day of recording.

Procedures

The choristers sang two repetitions of *Happy Birthday*, providing at least 30 seconds of sound. The song was sung using the nasal /n/ for all consonants and the vowels /a/ and /i/ for all vowels in syllables strings of /nananini/ and /nininana/. These phonemes were used to reduce the complicating effects of sibilants on the long-term spectra from the singing sample. Although the /n/ phonemes are characterized by lowered energy in the spectrum, the effect of these phonemes on the overall spectrum was minimal because of their low amplitude and short duration. The vowels were selected to provide the widest range of first- and second-formant values. The two vowels occurred the same number of times in the song. The small number of vowels in the song made the replacement lyrics easy for the choristers to learn.

The choristers sang the musical selection three times at each of the two dynamic levels: piano and forte. They completed these tasks in three vocal registers: head, chest, and mixed, resulting in 18 productions of the song. All productions were sung in unison in the key of E major beginning on the note B_3 at a tempo of 96 beats per minute.

All singing tasks were recorded via an Audio Technica Model AT3032 (AudioTechnica US, Inc., Stow, OH) omnidirectional condenser microphone connected via a Marantz Model 670 (Marantz America, Inc., Mahwah, NJ) solid-state recorder. Each recording was digitized in the recorder at a rate of 44, 100 samples per second and saved as a separate .wav file. The microphone was positioned 3 m from the nearest choristers to be in the diffuse field, outside the reverberation radius of the room. The reverberation radius was calculated from measures obtained using a Gold Line Model GL60 (Gold Line, West Redding, CT) reverberation time meter. The reverberation time of a brief noise was repeatedly measured at a range of octave intervals from 125 to 4000 Hz. The volume of the room was divided by each of the reverberation times. The square root of this dividend was multiplied by 0.056 to provide the reverberation radius at each frequency. These were averaged, and the average was determined to be 2.6 m. The microphone was placed farther from the chorus to record the choral sound heard by the audience.

Choral singing.

The choir stood in a semicircle around the microphone. For each production of the song, the choral director instructed the choristers as to the vocal register and dynamic level to use. The choral director then played an B_3 on a piano to cue the chorus to the note. The chorus then sang the piece *a cappella*. After each singing task, the choral director told the chorus on the next vocal register and dynamic level to use. Then she cued the choristers as to the pitch, and the choir began singing. The dynamic level and register combinations were sung in a random order. Thus, the choristers changed the register and/or the dynamic level for each production of the song. They made these adjustments without instruction.

Data analysis

The files were analyzed using a KayPentax Computerized Speech Lab Model 4500 (KayPENTAX, Lincoln Park, NJ) hardware-software analysis system. The song segments were analyzed using the LTAS function. Settings for the LTAS included a fast Fourier transform (FFT) window size of 256 points with no pre-emphasis or smoothing, a bandwidth of 172 Hz, and a Hamming window. The six LTAS for each register displayed on a single figure to compare the uniformity of the repetitions and any differences that may have occurred between the two dynamic levels (Figures 1−3).

L_{eq} differences and gain factor corrections

Because the spectrum slope changes with vocal loudness, the LTAS was adjusted to account for SPL difference.[13,31,32] The *g*(*f*) indicates the extent of spectrum level changes at each frequency *f* for an overall SPL change of 1 dB. Computing the *g*(*f*) required the following steps. For each production, the