ARCHIVES OF ACOUSTICS
13, 1-2, 55-65 (1988)

TIMBRE DIFFERENCES OF AN INDIVIDUAL VOICE IN SOLO AND IN CHORAL SINGING

TOMASZ ŁĘTOWSKI, LIDIA ZIMAK, HALINA CIOŁKOSZ-ŁUPINOWA

Sound Recording Department Chopin Academy of Music (00-368 Warszawa, Okólnik 2)

The object of the study was to analyze differences between solo and choral production of the same singer. Six female and six male chorus singers sang the same musical material solo, in vocal groups, and as a choir. Choral productions of the individual singers were obtained by recording their solo productions made under playback of the choir sound. Spectral analysis and listening tests were used to analyze differences between recorded samples. The results showed highly significant differences between both types of vocal production. The difference increased with the increasing degree of vocal training of the performer.

Celem niniejszej pracy było porównanie widma głosu śpiewaka solisty z widmem głosu tego samego śpiewaka śpiewającego w chórze. W ramach pracy dokonano szeregu nagrań produkcji solowej grupy śpiewaków, nagrań tej samej grupy osób występujących jako chór oraz nagrań wyizolowanych głosów pojedynczych chórzystów. Wyizolowania głosów pojedynczych chórzystów dokonano metodą opartą o technikę playbacku. W rezultacie przeprowadzonych porównań słuchowych oraz analiz widmowych próbek głosów stwierdzono istnienie znaczących różnic pomiędzy barwą głosu tego samego wykonawcy podczas śpiewu solowego i śpiewu w chórze. Wielkość tych różnic uzależniona jest od stopnia wyszkolenia wokalnego śpiewaka.

1. Introduction

A choir is a group of people simultaneously singing the same musical piece. Choral singing involves blending the voices of several singers together and, therefore, presents different requirements for performers than solo singing. The timbral quality of a choral production depends on the spectral characteristcs of the individual voices and their mutual compatibility. The extremely rich timbre of choral singing is the result of a phenomenon known as the chorus effect. This effect consists of the constant differences in spectral timbre, loudness, and pitch of the same note as performed at the same time by a number of performers. The rich, full timbre of large choirs is quite unique and is not matched by any other type of music ensembles. The chorus effect is not merely a mixture of various voices. Choral singing needs to be a smooth, well-blended production of a group of co-performing singers rather than a cluster of individual artistic performances. Therefore, it is important to know the type of spectral characteristics of solo voices which contribute most to high quality choir production. The present study approaches this question by investigating the timbre and spectral characteristics of both the choir as a whole and individual performers singing solo and in the choir (choral voice).

Although the term "sound quality" with respect to choral production is widely used, there has almost been no attempt to study this phenomenon from the acoustic point of view or to determine the influence of an elementary choir unit – a single voice – on the timbre of the whole ensemble. Previous studies of the human voice were concerned primarily with various aspects of speech production and perception and with the quality of a solo performance by highly trained professional singers. There have been only a few studies addressing the problem of choral singing and no attempt at all to relate the quality of an individual voice to the quality of the choir performance as a whole.

There is a general agreement among voice teachers that the quality of voice production depends on a large number of acoustical and artistic factors, e.g., the character of the produced vibrato, the relation between loudness and pitch over the entire voice scale, and the spectral character of the vocal sounds. In the case of vocally trained singers the formant regions of sung vowels are distinctly different from those of the spoken vowels [5]. Moreover, the spectra of sung vowels indicate the existence of a substantial concentration of energy in the region 2500–3000 Hz. This concentration is especially strong in the case of male operatic voices.

In 1934 BARTHOLOMEW [1] was the first to show the dependence of high-quality vocal production on the presence of additional acoustic energy in the region of 2800 Hz in the spectrum of sung vowels. This concentration of energy is commonly called the "singer's formant" [4] and is relatively independent of a sung vowel and its pitch. As a rule, it falls between the third and the fourth formant of a spoken vowel, making the singer's voice full and glamorous. SUNDBERG [7, 8] related the existence of the singer's formant to a lower position of the larynx in singing which, together with the widened pharynx, creates an additional resonating space with a resonant frequency of 2500–3000 Hz. The lowered larynx position also favors a darker voice timbre appreciated by most singers. In the case of untrained voices the singer's formant does not normally occur. On the contrary, there appears a tendency to elevate the larynx position in direct proportion to the pitch of the sound being sung [5] which makes higher notes sounding tinnier.

Although the presence of a strong singer's formant is not a necessary condition for good voice quality, e.g., in the case of soprano voice [1, 2, 3], it enables a voice to stand out from the background of the orchestra or that of the accompanying choir [8]. The prominence of one voice against the sound of the whole choir is not, however, a desirable feature in choral singing. On the contrary, in choral singing it is necessary to blend a single voice with the sound of the whole choir.

It has been observed that the same people sing differently while performing solo or in choir. So far, however, only two studies have addressed this issue. GOODWIN [4] studied soprano singers performing in various ensembles and found that soprano voices are notably weaker when performing in choir than solo. Notably, the energies of the second and the third formant were reduced while no substantial shifts in formant frequencies were observed. ROSSING *et al.* [6] studied bass\baritone voices and reported that solo and choir singing showed differences in both articulation and phonation. In particular, they found that solo in comparison with choir singing yielded a more prominent "singer's formant" and substantially reduced energy of the fundamental.

The purpose of the present study was to compare spectral and timbral differences between solo and choral production of the same person and to relate the overall timbre of the whole choir to that of an individual performer. The success in carrying out this task depends primarily on the method which is applied to isolate a single choral voice from the group production. It should be kept in mind that a necessary condition of a good choral production is that all voices fuse with one another. To satisfy this requirement each of the performers must hear, in natural proportions, the production of the other members of the choir. Therefore, in order to record only a single choral voice the studied voice must be isolated in such a way that the singer can still hear the sound of the choir just as he would normally hear it in the course of collective music making. To satisfy these conditions a method of recording a single, isolated choral voice has been developed by recording the voice of a single chorus singer singing under the playback of the choir performance.

2. Verification of the method used for recording of the isolated choral voices

To verify the desired character of the isolated choral voices a pilot study was performed which involved comparison of a natural choir sound with that made by the mixing of two separate recordings. A group of five sopranos from the chamber vocal ensemble "Warsaw Madrigal Singers" took part in the experiment. The music material was the first eight bars from the soprano part of Jan Maklakiewicz's song "A Lullaby". Instead of the lyrics, the singers sang the vowel (a). The voices of individual singers and various group of singers were recorded by the single-microphone technique using an AKG C-12 microphone set on the axis of the sound source at the height of the performers' heads. The block diagram of the recording equipment is shown in Fig. 1. Rather than placing microphone among the choir ensemble the above recording technique was applied to assure a good blend of all chorus voices in the recordings. The recording session included five steps:

(a) recording of the whole soprano group (recording I),
(b) recordings of the solo productions,
(c) recordings of the whole soprano group minus one person,
(d) recording of the whole soprano group (recording II),

(e) recordings of the single performer singing under the respective recording made in step (c).

Recordings made in steps (b), (c), and (e) were repeated for each of the five sopranos as an isolated voice. The sound intensity level of the original production was kept approximately constant at 75–80 dB. The recordings were made in Studio S-1 of the Chopin Academy of Music in Warsaw. To warm-up singers and to assure reliable singing each musical example was sung with repetition with only the repetition being used for the purpose of this study. The playback was provided with Beyer DT-48 earphones.

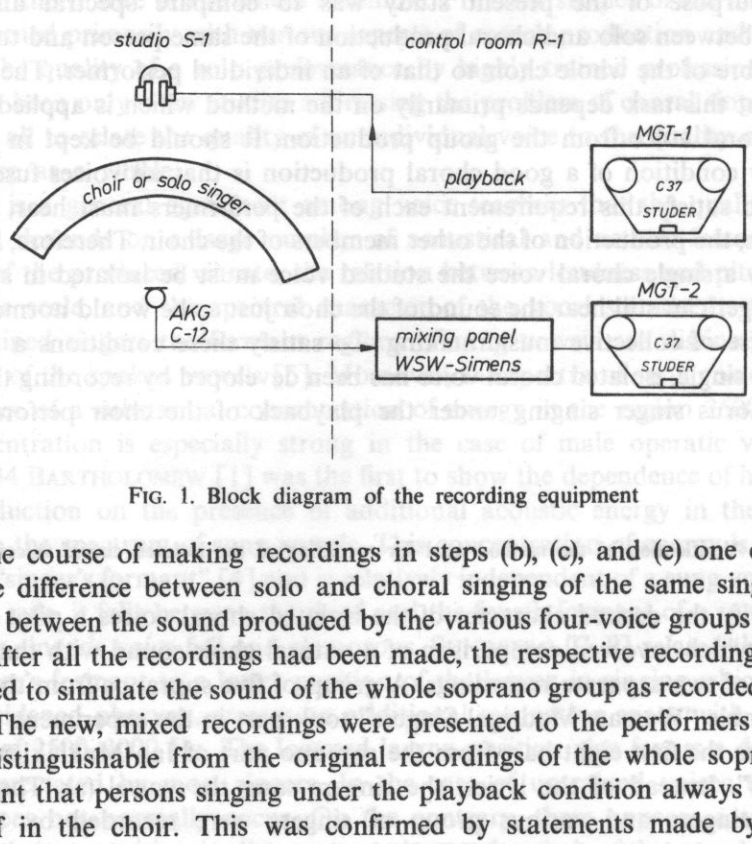

FIG. 1. Block diagram of the recording equipment

In the course of making recordings in steps (b), (c), and (e) one could easily notice the difference between solo and choral singing of the same singer and the difference between the sound produced by the various four-voice groups recorded in step (c). After all the recordings had been made, the respective recordings (c) and (e) were mixed to simulate the sound of the whole soprano group as recorded in steps (a) and (d). The new, mixed recordings were presented to the performers who found them indistinguishable from the original recordings of the whole soprano group. That meant that persons singing under the playback condition always managed to sing as if in the choir. This was confirmed by statements made by all of the performers that sound of playback heard through the earphones gave them the awareness of a "close" contact with the rest of the group. This made it possible to match individual voice production tô that of the other part of the ensemble.

The formal listening test employed three alternative forced choice (3-AFC) procedure. Each test trial included recordings I and II of the whole ensemble, and one of the recordings made during the mixing session. The test consisted of 15 triads incorporating all permutations of the tested stimuli. The order of trials in the test were randomized. The listening group consisted of ten experienced listeners and included five sound engineers and five conductor-choirmasters. Each listener was asked to indicate in each of the triads the stimulus which sounded most different from two others. The sounds were reproduced by Tannoy-Lockwood loudspeakers with sound intensity level equal to that of the original sound. The listeners listened individually to a single presentation of the test during which each listener's responses were collected.

The individual listener's responses appeared to be randomly distributed with the number of responses indicating a mixed recording not exceeding 40%. This result indicates that the recordings achieved by the mixing technique were not different to the listeners from those of the whole ensemble. Therefore, it may be concluded that for the individual choral voice the recordings made with the described method were perceptually equivalent to those of the same person singing directly in the ensemble.

3. Procedure and results

The whole, 17-person choir (ten women and seven men) "Warsaw Madrigal Singers" participated in the main experiment. The choir consisted of five soprano, four alto, five tenor, and three basso voices. The recordings were made with singers positioned in two rows (with men standing in the second row on the platform). The recording technique was the same as described in Section 2. The music material was an excerpt from the first movement of Johann Sebastian Bach's chorale "St. Matthew Passion" – "Befiehl du deine Wege". This four-bar fragment was sung with repetition. Similarly, as in the pilot experiment, the first four bars ensured that the singers had warmed-up properly while the recording consisted only of the repetition itself. The recording session included the following steps:

(a) recording of the whole choir,
(b) recordings of the individual voice groups (sopranos, altos, tenors, and bassos),
(c) recordings of the solo productions (for technical reasons they were made only for 12 performers: three of each voice group),
(d) as (c) but under the playback of the recording made by the whole ensemble,
(e) as (c) but under the playback of the recording made by the respective voice group.

For each of the twelve selected performers three sample recordings were obtained: solo production, voice isolated from the whole choir, and voice isolated from the voice group. Those recordings provided material for later comparative study in which comparisons between the voice of the same person singing solo and under various forms of playback were carried out. The respective recordings have been labeled from 1 to 12 according to the following scheme:

sopranos – from 1 to 3,
altos – from 4 to 6,
tenors – from 7 to 9,
bassos – from 10 to 12.

Each recording has also been labeled by the letter "*a*", "*b*", or "*c*" indicating solo singing, singing under the playback of the whole choir, and singing under the playback of the given voice group, respectively. The recording of the whole choir was denoted by the symbol "*ch*" while the recordings of the main vocal groups were denoted as indexed "*g*".

To make comparisons between the physical properties of the voice sample „*a*", "*b*", and "*c*", the average spectrum for each of the samples was calculated. Each of the recorded samples was analyzed with a set of one-third octave filters (B-K 1612). The analysis was limited for practical reasons to 100–6300 Hz. For each filter the time-amplitude envelope was recorded on the B-K 2305 graphic level recorder. Subsequently, the plots of spectrum levels for all the center frequencies were calculated at five arbitrarily chosen time prints t_i approximately equally distributed along the time axis. The points t_i were chosen in terms of the particular sound produced at these points. The spectra for all five time points were subsequently averaged with a Wang 600-12 computer. As a result 41 different voice spectra were obtained (36 spectra for single voices and 5 spectra for group performances). Examples of some characteristic spectra are shown in Fig. 2.

The sound spectra such as those presented in Fig. 2 were used later to calculate

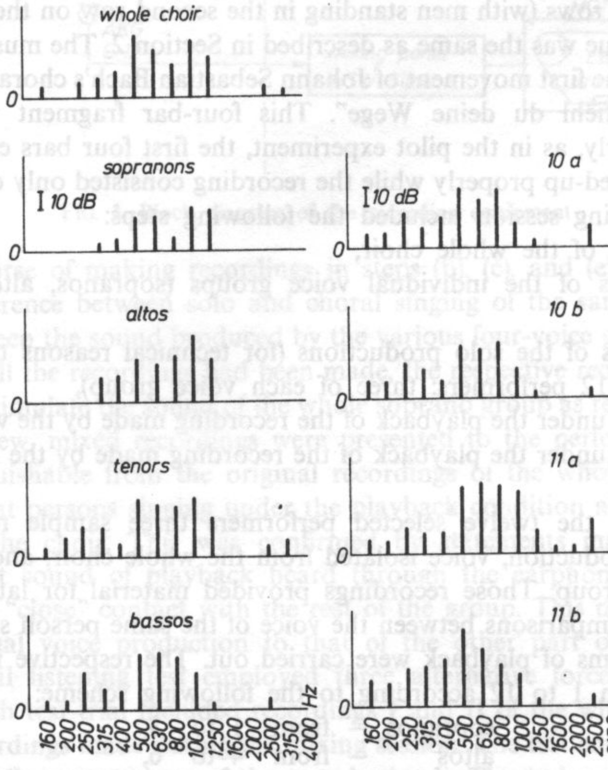

FIG. 2. One-third octave average spectra of vocal recordings made for the choir and four separate voice groups (sopranos, altos, tenors, and bassos). On the left side of the diagram there are four examples of the individual spectra obtained for two bass singers (voices 10 and 11) performing (a) solo and (b) under the playback of choir sound

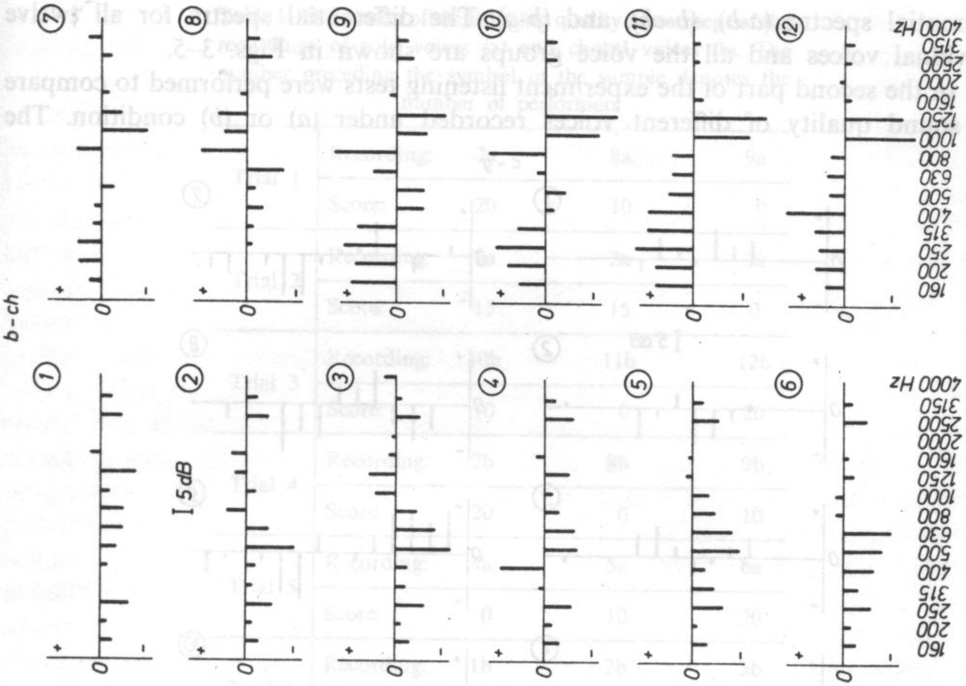

FIG. 4. Differential spectra "b–ch"

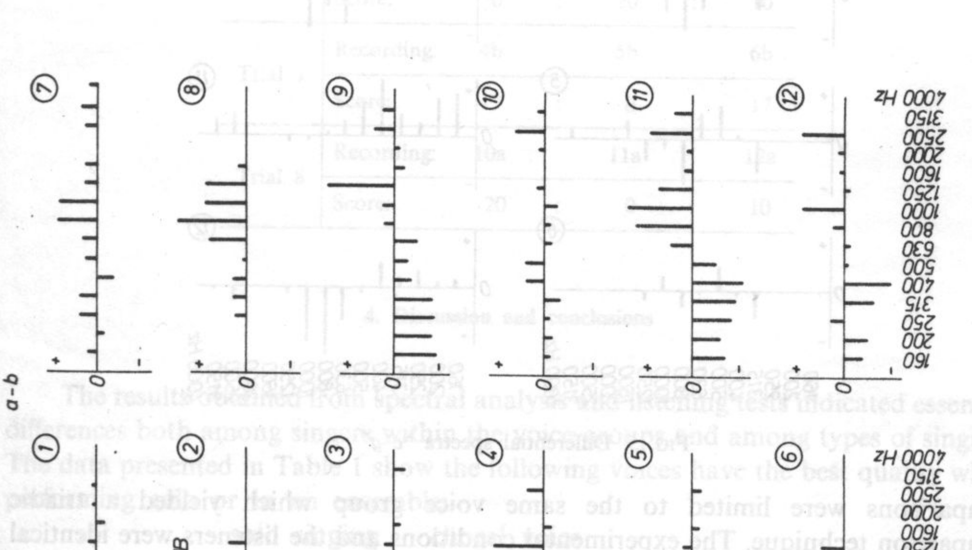

FIG. 3. Differential spectra "a–b"

differential spectra (*a-b*), (*b-ch*), and (*b-g*). The differential spectra for all twelve individual voices and all the voice groups are shown in Figs. 3–5.

In the second part of the experiment listening tests were performed to compare the sound quality of different voices recorded under (*a*) or (*b*) condition. The

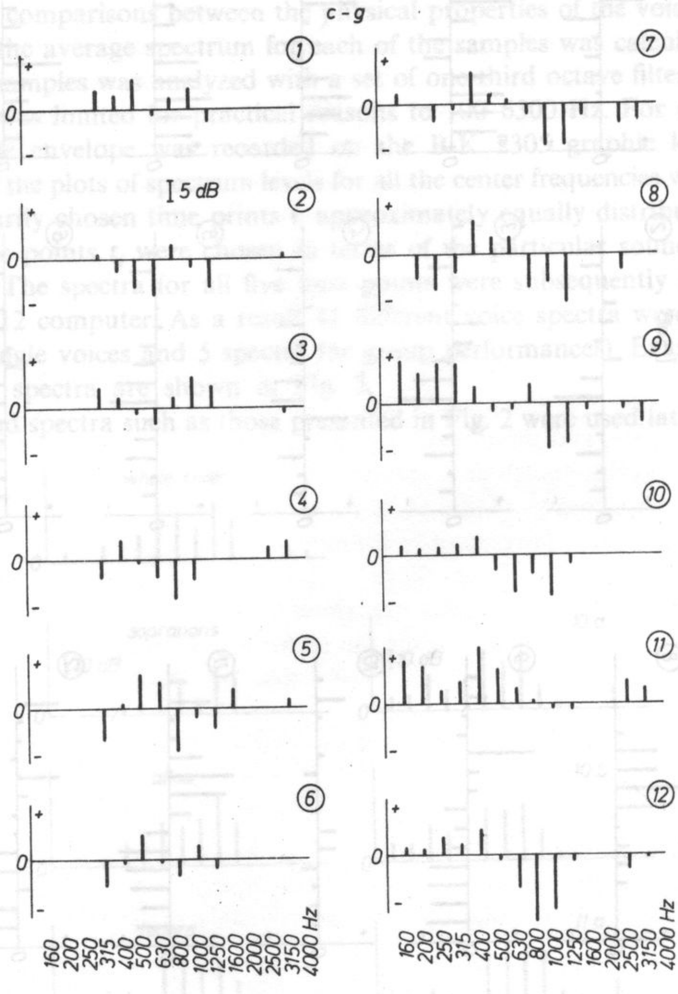

FIG. 5. Differential spectra "*c–g*"

comparisons were limited to the same voice group which yielded a triadic comparison technique. The experimental conditions and the listeners were identical with those described in Section 2. Each of the ten listeners was asked to order each three voice samples in a triad along a quality (pleasantness) scale from the most to the least pleasant. The most pleasant, the middle, and the least pleasant voice samples were given 2, 1, and 0 points, respectively. The numerical data were subsequently summed across all the listeners. The final scores are presented in Table 1. All the differences (with the exception of pair 4b-6b) were statistically significant at the level 0.05.

Table 1. The results of the listening quality assessment of the recordings of solo voices (a) and choral voices (b). The number preceding the symbol of the sample denotes the number of performers

Trial 1	Recording:	7a	8a	9a
	Score:	20 :	10 :	0
Trial 2	Recording:	1a	2a	3a
	Score:	15 :	15 :	0
Trial 3	Recording:	10b	11b	12b
	Score:	10 :	0 :	20
Trial 4	Recording:	7b	8b	9b
	Score:	20 :	0 :	10
Trial 5	Recording:	4a	5a	6a
	Score:	0 :	10 :	20
Trial 6	Recording:	1b	2b	3b
	Score:	0 :	20 :	10
Trial 7	Recording:	4b	5b	6b
	Score:	13 :	0 :	17
Trial 8	Recording:	10a	11a	12a
	Score:	20 :	0 :	10

4. Discussion and conclusions

The results obtained from spectral analysis and listening tests indicated essential differences both among singers within the voice groups and among types of singing. The data presented in Table 1 show the following voices have the best quality while performing solo or in an ensemble:

	solo singing	choral voice
sopranos	1 and 2	2
altos	6	4 and 6
tenors	7	7
bassos	10	12

The data presented in Figs. 3–5 show that all choral voices judged the most pleasant (voices 2, 4, 6, 7, and 12) exhibited large spectral differences between solo and choral modes of singing.

The fact that all the female singers participating in the experiment had no previous vocal training whereas four male singers (voices 7, 8, 10 and 11) had been vocally trained affected to a large extent the specific spectra of individual voices and the voice groups (Fig. 2.) Within the 50 dB dynamic range, the spectra of the female voices seldom extended beyond 1600 Hz, whereas the male voices showed components up to 4000 Hz.

The differential spectra show that among soprano voices the voice 2 was the most elastic, i.e., the most different in recordings "*a*", "*b*", and "*c*". For this voice the most favorable situation was singing along with the whole ensemble. This was expressed by considerable enrichment of the respective spectrum "*b*" in comparison to the other spectra of the same voice. In the case of two other soprano voices, voices 1 and 3, no such tendency was observed.

In the alto group, the most pleasant voice was voice 4. This was the only female voice to show the existence of the singer's formant in solo singing mode. A characteristic nasal timbre was observed in that voice during solo production. Such timbre is observed in cases when a spectrum which is basically limited to low frequencies includes one or two components at much higher frequencies. In turn, the lack of hoarseness and nasality in choral performance reflected the great flexibility of the voice and good matching to singing in the mixed ensemble. It may be hypothesized that it was the presence of low male voices in the ensemble which induced this voice to make the timbre darker (softer, more mellow).

Among the tenor group, voices 7 and 9 did not show any large differences between the spectra of samples "*a*", "*b*", and "*c*". Vocally trained voice 8 exhibited a rich spectrum in solo singing but it appeared to be much thinner as a choral voice. Probably, the singer tried to adapt as much as he could to the sound of the choir, causing a weakening of the higher components of the sound.

In the basso group voice 11 appeared to be the most different among all analyzed voices. Perhaps of importance was the fact that this person had been vocally trained and also had been with the choir for a relatively short time. Therefore, the singer could not blend the timbre of his voice to that of the choir and tried to dominate his vocal group. Voices 10 and 12 sounded especially thin in the case of the recording made under the playback of the voice group. Most probably, this resulted from their attempt to produce a uniform sound with voice 11 which was unflexible and not susceptible to changes in the conditions of singing.

The results of this study confirm the differences in the behavior of singers with trained and untrained voices. While singing in the ensemble, untrained voices were characterized by strengthening the extreme components of the voice spectrum compared with the spectrum of solo singing samples. In choral production these voices sounded brighter, more stable, and more colorful. On the other hand, the vocally trained singers sounded usually darker and poorer while performing in choir than in solo singing. It may be hypothesized that choral performance is a mobilizing factor for untrained voices. The trained singers, however, are forced to adapt their natural, rich sound to the timbre of the ensemble. This unfavorably affects the timbre and quality of their voices.

In the case of solo singing, persons with vocally untrained voices usually sang faster and more nervously than those with trained voices. These singers were unable to remember the tempo of the previously recorded sample of the whole choir, or to sustain longer notes to their end. Persons with trained voices had no trouble in maintaining the same tempo in solo production as it had been in the recording of the whole ensemble.

In summary, (a) the possibility exists for recording isolated choral voice by a method of singing under playback of the other part of the ensemble; (b) solo (group) singing made under playback of other voices is quite natural for choir singers which makes possible the application of such a method for recording choir performances by multitrack techniques; (c) vocally untrained singers tend to operate with a richer (brighter) voice while singing in the ensemble than in solo mode: (d) sharp (bright) voices, not able to maintain the timbre uniform with the rest of the ensemble, exert a considerable effect on the behaviour of the other voices making them sound much thinner than they might; and (e) the voices of vocally trained persons sound richer (more powerful) in solo singing than in choral performances, where the singer's formant is frequently totally missing, but nevertheless the presence of such voices on the ensemble is often an essential factor mobilizing the other performers.

References

[1] W. T. Bartholomew, *A physical description of "good voice quality"*, J. Acoust. Soc. Am., **6**, 25–33 (1934).

[2] G. Bloothooft, *Spectrum and timbre of sung vowels*, Doctoral Dissertation, University of Amsterdam, 1985.

[3] G. Bloothooft, R. Plomp, *The sound level of the singer's formant in professional singing*, J. Acoust. Soc. Am., **79**, 2028–2033 (1986).

[4] A. Goodwin, *Acoustic study of individual voices in choral blend*, J. of Research in Singing, **3**, 25–36. (1980).

[5] T. Rossing, *The science of sound*, Addison-Wesley, Reading, MA, 1982.

[6] T. Rossing, J. Sundberg, S. Ternström, *Acoustical comparison of voice use in solo and choir singing*, J. Acoust. Soc. Am., **79**, 1975–1981 (1986).

[7] J. Sundberg, *Articulatory interpretation of the "singing formant"*, J. Acoustic. Soc. Am., **55**, 838–844 (1974).

[8] J. Sundberg, *The acoustics of the singing voice*, Scientific American, **236**, 3 (1977).

Received on January 12, 1987.