



Select Acoustic and Perceptual Measures of Choral Formation

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Abstract

The purposes of this study were (1) to acoustically compare three contrasting choral formations (block sectional, mixed, and sectional in columns) in performance of two contrasting pieces of choral literature (homophonic and polyphonic) by a university graduate choir (N=30), and (2) to compare singers' perceptions of and preferences for the contrasting choral formations across vocal part and gender. Both long-term average spectrums (LTAS) and perceptual chorister ratings were examined for differences. Acoustic results demonstrated no differences between the formations. However, LTAS differences attributable to the homophonic and polyphonic literature selections were observed. Chorister ratings indicated significant gender differences across many of the perception and preference items surveyed, particularly with respect to the sectional in columns formation.

Choral music educators have long sought the means to create a blended sound within their ensembles. Knutson (1987) defines this blend as "...a product of sound where each element becomes unified or homogenized," as determined by the conductor. In an article comparing the acoustical properties of choral and solo singing, Goodwin (1980) stated, "Achieving choral blend is often a fundamental objective in ensemble singing, but there exists a diversity of concepts concerning how the phenomenon occurs, resulting in a profusion of

pedagogical techniques." Researchers have examined a variety of possible influences, including choral formation, in an effort to identify or better understand the elements of choral blend.

Many conductors believe that the formation or arrangement of singers greatly influences the blend of the ensemble. One of the earliest experiments in this area was conducted by Lambson (1961), who placed members of an intact choral ensemble in several contrasting formations (block sectional, quartets/sextets, scrambled, and random distribution) and had the choir perform homophonic and polyphonic works. Ten judges were directed to listen to the choruses live and via audiotape. The judges were directed to determine the choral formations for each example and to rank each formation in order of preference. Judges had difficulty identifying the formations from the sound of the live and recorded performances for both homophonic and polyphonic selections. Moreover, they exhibited mixed preferences for the choral arrangements. In fact, Lambson (1961) concluded that the formation of the choir did not result in clearly perceived differences. He stated that other, practical factors should be used in selecting choral arrangements.

The Lambson (1961) study also exhibited certain methodological problems. First, there was no mention of how long all of the examples took to perform, and whether or not there was any consideration of fatigue for either performers or judges. Second, judges indicated that both

the lack of familiarity with the process of identifying choral formation from sound alone and the requirement of written comments between examples hampered their ability to focus their attention on the task at hand. In spite of these issues, however, the judges did agree with the findings of the study in a post-experiment questionnaire. It would have been interesting if Lambson (1961) had examined the choristers' perceptions of the different arrangements to compliment the perceptions of judges listening to the choruses.

Tocheff (1990) compared how mixed and sectional formations may have influenced listener perception for a variety of perceptual aspects of singing, including intonation and overall blend. The sectional formation was rated higher than the mixed for intonation and for choral blend. In addition, Tocheff (1990) examined the effect of "acoustic placement" of singers on overall choral performance of homophonic and polyphonic selections. The placement of voices by choral conductors, also known as voice matching, is a highly subjective procedure that uses pitch, intensity, timbre, vowel formation, and vibrato rate to place singers of the same voice part next to other singers throughout their section (Giardiniere, 1991). In contrast to Lambson's (1961) findings, Tocheff's (1990) results suggested that the acoustical placement of voices had a great influence on the dependent variables of overall blend, intonation, and achievement of a choral ensemble. Again, however, this study demonstrated some methodological problems, as more than thirty performances were judged and fatigue may have been an influence.

In his 1996, 1999, and 2003 studies, Daugherty examined the effects of choral formation and spacing on the perceptions of choristers and listeners. Daugherty (1999) placed an intact ensemble of high school students ($N=46$) in one of two formations, sectional blocks or mixed, as well as three different levels of spacing; close, lateral (more space side to side), and circumambient (both increased lateral and front-to-back space). Both the auditors ($N=160$) and the choristers preferred the sound produced with wider chorister spacing. In addition, although auditors expressed no clear formation preference, the singers preferred the mixed formation over the block sectional formation. One of the most interesting points about this research was that 95.6% of the choristers reported that they felt spacing influenced choral sound. Such

measures of chorister preferences may help us understand the effects of differences related to choral formations. Hence, further study of chorister preferences and perception is warranted.

Moreover, previous research regarding the effects of formation on choral blend has been based upon perceptual measures of sound. Examination of the acoustical signal produced by a chorus may provide researchers with valuable information regarding how to arrange an ensemble to generate the best choral blend. For example, spectrograms have been used to measure both individual voices (Hunt, 1970) and an ensemble demonstrating high- and low-formant modes of singing (Ford, 2003). In an early spectrographic inspection of choral singers, Hunt (1970) examined "good" and "bad" examples of singing by individuals in the choir. He discovered that the examples rated by judges as "good" contained formant frequencies that were tuned to the natural overtone series for the given fundamental frequency. Conversely, "bad" examples were found to contain formant frequencies that were misaligned, implying that hearing and tuning vowel formant frequencies between singers may be an important part of the blending process. One may infer from this research that measurements of well-blended choral ensemble singing may have more clearly aligned and reinforced formant frequencies, whereas less blended examples would contain a different and more scattered spectrographic signature.

The single instance of correlating spectrographic analysis of a choral ensemble with perceptual measures was performed by Ford (2003). He examined auditor preferences for either strong or weak presence of a singer's formant across mode of singing. Clear differences between the spectrograms emerged, with auditors preferring the weak singer's formant examples of singing. This difference in spectrograms demonstrated this tool's potential efficacy for measuring different modes of singing within ensembles. Unfortunately, the singers were moved between examples to allow for more evenly biased recordings for the auditors' perceptual evaluation. These changes in the distance from the microphone to the singers between the singing modes could alter the spectrographic results. In addition, it should be noted that Ford (2003) reported that the alteration of singing modes affected pitch accuracy and vibrato rate. These factors may

have influenced auditor preference for the weak singer's formant examples.

The studies cited above have not provided acoustic information that compares a chorus across different choral arrangements for a variety of musical selections. Although some previous studies indicate that different choral arrangements and different musical selections may affect listeners' perceptions of the quality of the choral sound, there are little data on chorister perception of formation, with the exception of Tocheff (1990) and Daugherty (1996; 1999; 2003). Such information could assist conductors in their use of different techniques of choral arrangement and singer placement. This study was designed to make such acoustic comparisons and to assess the perceptions of the choristers concerning different choral arrangements.

Thus, the first purpose of the present study was to acoustically compare three contrasting choral formations: block sectional, mixed, and sectional in columns. It was hypothesized that a mode of singing more close to the solo mode would be present in the mixed formation in comparison to the block sectional and sectional by columns formations. The expected soloistic mode for the mixed formation would be evident as a relative increase of acoustic energy between 2500 and 3000 Hz when comparing pieces sung at similar dynamic levels (i.e., *pp*, *mf*, *ff*). This frequency region of increased energy has been reported as a common acoustic feature of solo singers (Sundberg, 1973; 1974; 1977; Schutte & Miller, 1983).

The second purpose of this study was to compare the choristers' perceptions of and preferences among the contrasting choral formations. Previous research has shown that choristers exhibit a preference for singing in mixed or synergistic formation over a block formation (Daugherty, 1999; 2003). However, Daugherty (2003) also suggested that choristers may simply prefer the formation that they are most accustomed to. A chorister's preferences may influence an individual member's quality of singing (Ford, 2003), which could alter the acoustic silhouette of the ensemble sound. Based on Daugherty's (1999) finding, it was hypothesized that the choristers would prefer the mixed formation over the two block formations.

METHOD

Participants

The participants for this study included an intact, functioning choir of 30 choristers, consisting of 18 female and 12 male singers, ranging in age from 21-53 years ($M=32.5$ years). The choir was divided into four singing parts, which included sopranos ($N=8$), altos ($N=10$), basses ($N=7$), and tenors ($N=5$). All participants were trained singers who reported an average of 11.5 years of solo vocal training; the reported years of training ranged from 5 to 15 years. All participants reported being in good general health with no vocal difficulties at the time of recording.

Equipment

Recordings of the choir were completed in a concert hall with a seating capacity of 480 occupants. Room reverberation for this study was determined using a Goldline GL-60 Reverb Time Meter. A sound source was introduced and reverberation was measured using the -0 dB SPL reference point at 2000 Hz. A stable reverberation measurement was achieved at this setting, allowing other frequencies to be reliably measured. All measurements were obtained with the meter directly under the position of the microphone used for the recordings and the sound source produced at the position of the chorus on the stage. Repeatable reverberation measurements were made at the following frequencies and levels: 1.3 second at 125 Hz, 1.85 second at 250 Hz, 2.4 second at 500 Hz, 2.5 seconds at 1000 Hz, 2.3 seconds at 2000 Hz, and 2.4 seconds at 4000 Hz. The volume (V) of the hall was calculated to be 1844 cubic meters and the average reverberation time (T) was measured at 2.4 seconds. Using the equation $r_r = .056 \sqrt[3]{V/T}$, the reverberation radius (r_r) was 1.55 m.

The choir was digitally recorded using two Schoeps CMC-5 omni condenser microphones suspended from the ceiling of the concert hall approximately 4 meters above the floor and 10 meters in front of the chorus. The choir's productions were recorded on an Ampex 467 (R-60) DAT recorder through a Soundcraft 220-B mixing board. The DAT recordings were then digitized to a Dell Optiplex GX1P computer via a CSL 4300B (Kay Elemetrics) at a sampling frequency of 44.1 KHz. The files were stored

and acoustically analyzed using the CSL 4300B computer hardware/software system.

PROCEDURE

The chorus was recorded when singing the following choral selections: *Jubilate Deo* by Orlando di Lasso (Theodore Presser #352-0080) in its entirety, and rehearsal numbers six to eight of *Gloria* by Lars Edlund (Walton Music Corporation WH-103). These compositions were selected because they were familiar to the choir and they represented two contrasting textures: the polyphonic selection, *Jubilate Deo*, because of the independent lines of music for each section and the homophonic, *Gloria*, for the homophonic singing by all parts together.

The musical selections were sung a *cappella* with the choristers on stage facing the seats and standing on five sections of portable Wenger standing risers, which were 18 inches wide and four feet long. The choristers stood in three different choral formations: blocked sectional, mixed, and sectional in columns (see Figure 1). These formations are commonly utilized by choral directors and have been the focus of previous research dealing with the perceptual effects of choral formation (Daughtery, 1999; Lambson, 1961; Tocheff, 1990). The block sectional formation involved placing the singers in three rows. The front two rows consisted of sopranos to the left of the conductor and altos to the right. The back row consisted of basses placed behind the sopranos and tenors behind the altos. The mixed formation also involved placing the singers in three rows; however, unlike the block sectional formation the singers were grouped together in quartets, each containing one soprano, bass, tenor, and alto. Because of the unequal number of choristers in each part, only five of the seven quartets included all four voice parts. The remaining singers were asked to stand next to someone of a different voice part. The sectional in column formation involved grouping the singers into two or three rows, depending on the number of singers in each category. Then, according to voice part, the groups were organized so that each vocal part was next to each other, with no section behind another. The sopranos and basses were to the left of the conductor, and the tenors and altos were to the right of the conductor.

		B		T	
Block Sectional		S		A	
		S		A	
Mixed		SATB	SATB	SATB	SATB
		BTAS	BTAS	BTAS	BTAS
		SATB	SATB	SATB	SATB
Sectional in Columns		S	B	T	A
		S	B	T	A
		S	B	T	A

Figure 1. Three formations according to voice part.

The choristers sang both of the musical selections three times, once in each formation. The order of the pieces in each formation was randomized. At the end of the hour-long recording session, the choristers took approximately 10-15 minutes to complete a five-item questionnaire utilizing an anchored 10-cm scale designed to determine the choristers' perception of the various formations. Below each item were the anchor words and three lines marked 'A', 'B', and 'C' for the three choral formations, block, mixed and column, respectively (See Figure 2). The perceptual items were designed to determine the chorister's rating of the particular choral arrangement. The five perceptual items and their anchor words were as follows. The first item was "In which choir formation did you find it easiest for you to sing your part?" with anchor words 'Difficult' and 'Easy.' The second item was "How would you rate the sound of each choir formation?" with anchor words 'Worst' and 'Best'. The third item was "How would you rate each choir formation regarding the ease of hearing/blending with your

section?" with anchor words 'Worst' and 'Best'. The fourth item was "How would you rate the choir formations regarding the ease of hearing other sections?" with anchor words 'Worst' and 'Best'. The fifth item was "Which choir formation did you prefer singing in?" with anchor words 'Worst' and 'Best'. The choristers were instructed to mark an 'X' on the anchored lines to rate each of the formations across each of the questions.

1. In which choir formation did you find it easiest for you to sing your part?

Difficult Easy

A |-----|

B |-----|

C |-----|

Figure 2. Example question from the chorister survey.

Data Analyses

For acoustic data, the long term average spectra (LTAS) for each choral formation and musical selection were visually inspected to determine any differences in energy pattern. Specifically, energy peaks at the fundamental frequency, first formant, and 2-3 kHz were visually examined for differences among the three formations. Any noticeable differences in LTAS pattern underwent significance testing using a one-way analysis of variance (ANOVA).

The length of the samples for LTAS analysis varied slightly across formation and musical selection. For example, the *Gloria* excerpt length was 76.79 seconds for the block arrangement, 75.69 seconds for the mixed formation, and 74.07 seconds for the sectional by column formation. On the other hand, the lengths of the *Jubilate Deo* selection were 87.44 seconds in the block formation, 84.54 seconds in the mixed formation, and 83.73 seconds in the sectional by column formation. For the perceptual data a Chi-squared analysis of variance by ranks (χ^2) was performed to determine whether or not the singers' perceptions significantly differed among

the choral formations by vocal part (Siegel & Castellan, 1988).

Reliability

To minimize conductor variability, an experienced conductor was asked to conduct in the same manner over all six experimental conditions. His performance was videotaped. Three experienced choral conductors viewed the videotape and completed the Conductor Consistency Observation Form (Madsen and Yarbrough; 1980). Several items on this form were adapted so that the focus of the evaluation was on conductor constancy across conditions.

Results from the conductor consistency tests showed an overall average of 87% interrater agreement (SD=0.07). These results are similar to those of Ekholm (2000), who adapted this method to assess choir conductor reliability. Agreement among the raters was high across all of the categories, including 100% agreement for magnitude and expressiveness of conducting gestures, eye contact, and facial expression.

RESULTS

Acoustic Findings

The LTAS for each of the choral formations exhibited strong agreement in their distribution of power across the frequency band. As shown in Figures 3 and 4, the slopes of the three lines are almost identical. Each formation showed maximum energy in the bandwidth range of 500-600 Hz, followed by a decline in energy until the 2-3 kHz bandwidth range where an approximately 5 dB increase of energy was observed. These findings are consistent with previous acoustical analyses associated examining the LTAS patterns during choral singing (Rossing et al., 1986, 1987; Ternström, 1991). The greater energy in the 2-3 kHz region was not great enough to be considered a singer's formant.

Further visual inspection of the LTAS revealed differences in the energy distribution across frequency bands between the homophonic and polyphonic selections used in this study. Figure 5 depicts the two separate LTAS of the homophonic and polyphonic selections. The LTAS of the homophonic selections displayed higher energy levels than the polyphonic selections for the frequencies below 650 Hz and lower energy levels for the

frequencies above 650 Hz. For example, the LTAS for the polyphonic selection displayed maximum energy in the frequency band centered at approximately 517 Hz, followed by a steep decrease in energy, while the homophonic

selection's peak energy was centered at approximately 603 Hz. In addition, the LTAS for the homophonic selection displayed less energy in the singer's formant region of 2-3 kHz range than the LTAS for the polyphonic selection.

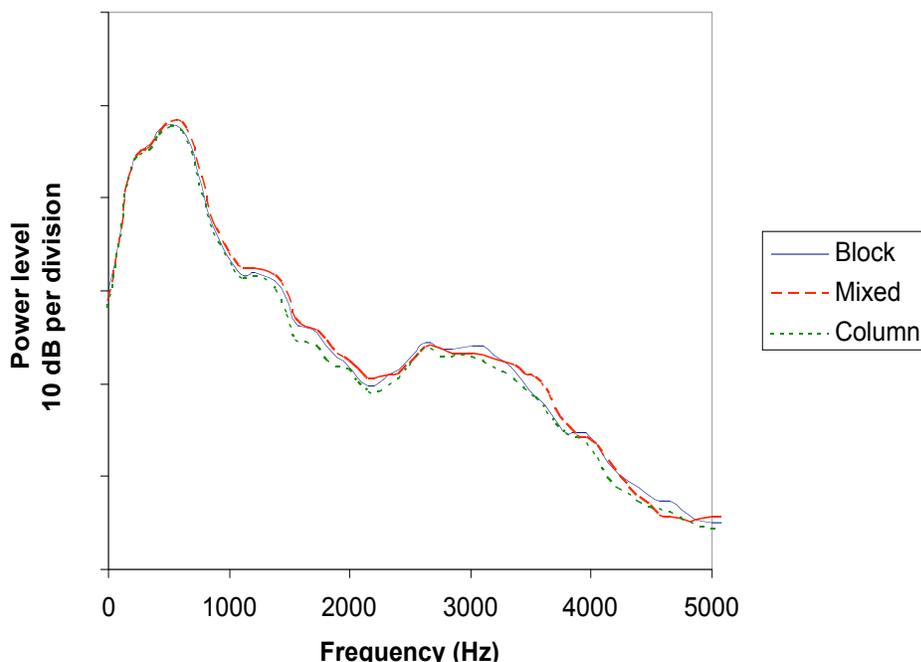


Figure 3. Long-term average spectre (LTAS) of the block sectional, mixed and sectional in columns formations for the monophonic selection, *Gloria*

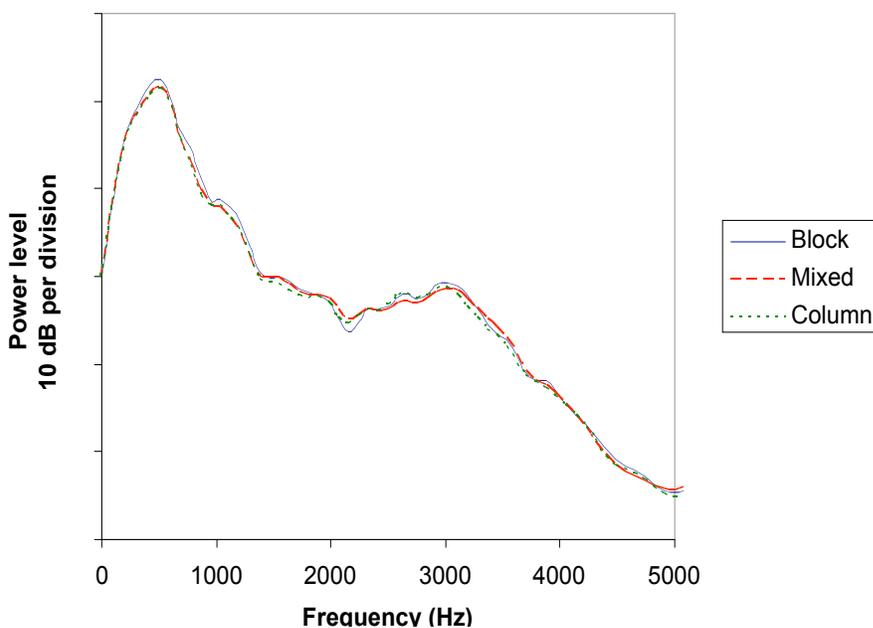


Figure 4. Long-term average spectre (LTAS) of the block sectional, mixed and sectional in columns formations for the polyphonic selection, *Jubilate Deo*

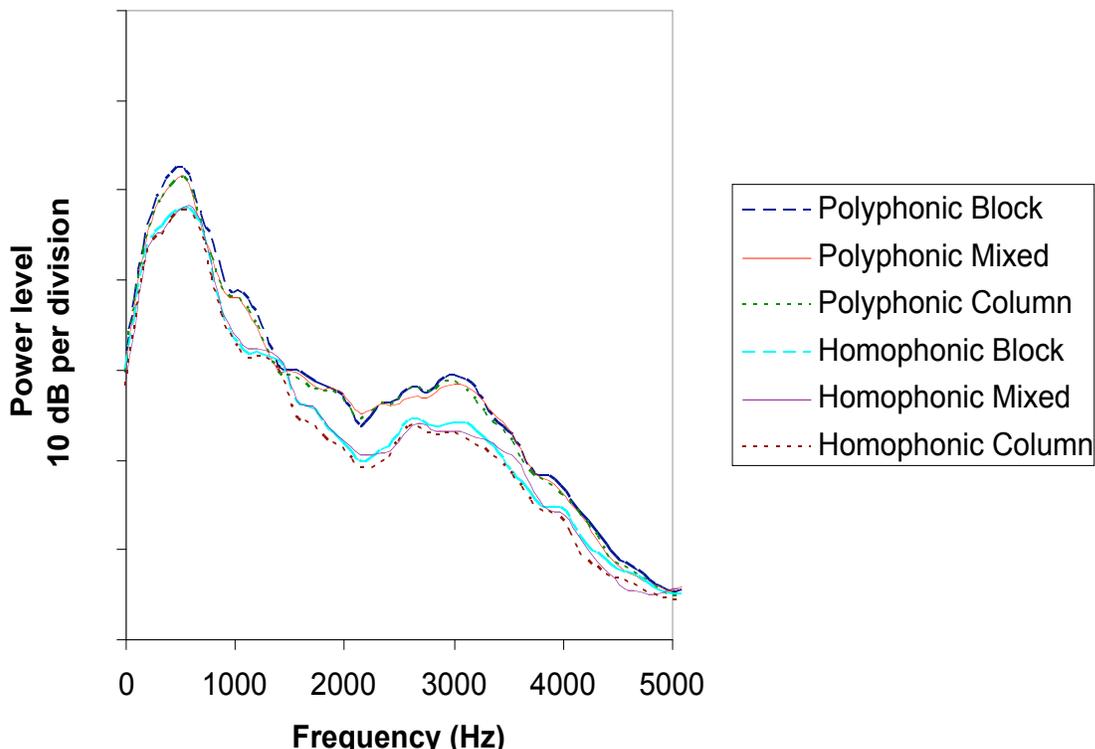


Figure 5. Long-term average spectre (LTAS) of the block sectional, mixed and sectional in columns formations for both the homophonic and polyphonic selections.

Perceptual Findings

In general, all choristers gave fairly high ratings for all of the items, with average scores within the vocal parts above 5.0 (See Table 1). Exceptions to that trend were the sopranos rating of the sectional by columns formation for sound of the choir ($M=4.08$), ease of hearing others ($M=2.39$), and preferred formation for singing ($M=3.73$). In addition, the altos rating of the sectional by columns formation for ease of hearing other vocal parts ($M=4.80$, and preferred formation for singing ($M=4.55$), were also below average. Finally, the basses' rating of the mixed formation for ease of blending within section was below average with a score of 2.82.

A trend observed across the perceptual items occurred for the sectional by columns formation. Analysis of these data revealed that the

chorister ratings for this formation varied systematically across vocal part. These differences in average ratings of sectional by columns formation were significant across the vocal parts ($\chi^2(3)=35.18$; $p < .001$). Vocal part differences for the perceptual items across formation are displayed in Figure 6. The sopranos gave the lowest average rating of 4.56 (SD=1.74) for the sectional by columns formation, accompanied by the altos with an average rating of 5.95 (SD=1.36). The tenors, on the other hand, rated the sectional by columns formation rather favorably at 7.53 (SD=1.09), followed by the basses, who gave the highest average rating of 8.47 (SD=1.43).

Table 1

Choristers' mean preference ratings and standard deviations for perceptual questions by choral formation and vocal part.

Choral Formation	Vocal Part (N)	Ease of Production	Sound of Choir	Ease of Blending With Section	Ease of Hearing Others	Prefer Singing
Block	Soprano (8)	8.07 (2.10)	7.08 (1.61)	6.76 (3.04)	5.78 (2.61)	5.89 (2.18)
	Alto (10)	8.13 (1.83)	7.10 (1.88)	8.39 (1.71)	5.75 (2.30)	6.20 (2.76)
	Tenor (5)	8.77 (1.06)	6.05 (2.88)	6.71 (3.45)	5.23 (4.16)	6.22 (3.56)
	Bass (7)	7.99 (1.42)	6.80 (1.70)	7.62 (1.62)	5.83 (1.83)	6.63 (1.55)
Mixed	Soprano (8)	5.28 (2.60)	7.69 (2.22)	6.00 (2.89)	7.10 (3.52)	7.21 (3.35)
	Alto (10)	7.23 (2.55)	6.80 (2.34)	6.20 (2.93)	9.20 (0.73)	8.68 (1.60)
	Tenor (5)	6.42 (3.52)	6.51 (3.64)	6.05 (3.34)	8.13 (3.88)	7.09 (3.77)
	Bass (7)	5.01 (1.94)	6.26 (3.38)	2.82 (2.58)	8.63 (1.60)	6.94 (3.43)
Column	Soprano (8)	6.81 (2.99)	4.08 (2.13)	5.78 (3.40)	2.39 (2.20)	3.73 (3.88)
	Alto (10)	7.56 (2.38)	5.68 (1.69)	7.18 (2.18)	4.80 (2.78)	4.55 (2.61)
	Tenor (5)	8.38 (1.6)	7.81 (1.96)	8.68 (2.33)	6.22 (3.21)	6.57 (3.91)
	Bass (7)	9.64 (0.23)	8.66 (1.62)	9.36 (0.75)	6.04 (2.74)	8.66 (0.97)

Note. Standard deviations are enclosed in parentheses.

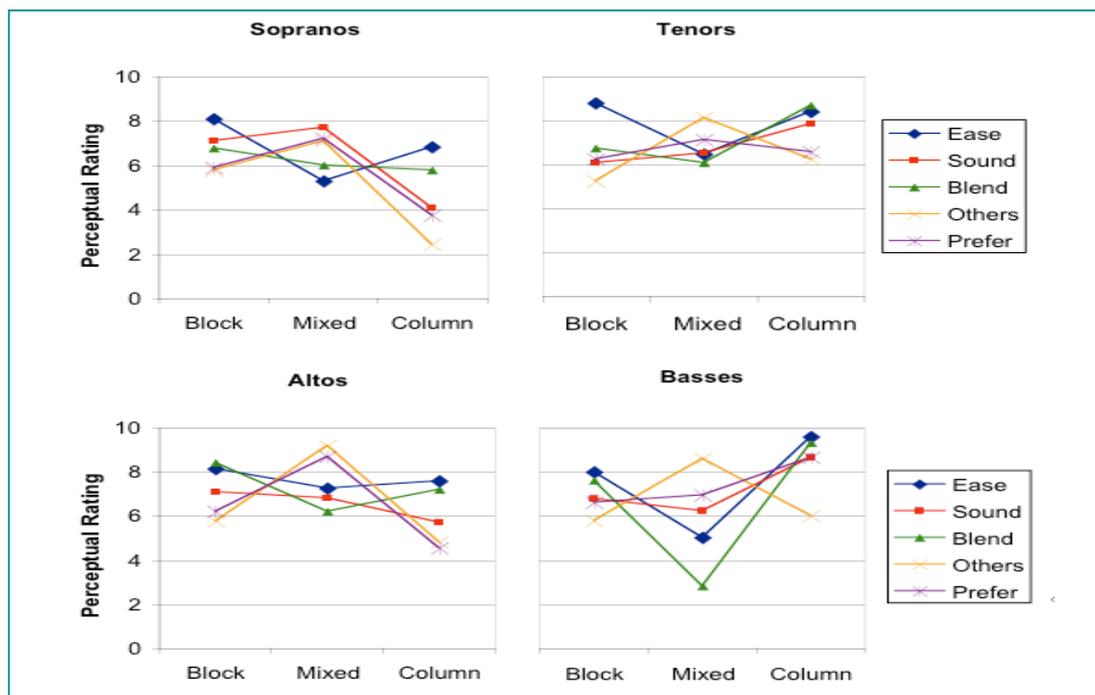


Figure 6. Choristers' average ratings of choral formations across perceptual questions by vocal section.

As indicated by Figure 6, soprano and alto mean responses displayed similar patterns across formations, with higher responses for the block sectional and mixed formations compared to the sectional in column formation. The sopranos average rating across questions for the block sectional formation was 6.72 (SD=0.94) and 6.66 (SD=0.99) for the mixed formation, whereas the average rating for the sectional in columns formation was 4.56 (SD=1.74). Likewise, the altos average ratings across questions were 7.11 (SD=1.16) for the block sectional, 7.62 (SD=1.27) for the mixed formation, and 5.95 (SD=1.36) for the sectional in columns formation.

The tenor and bass mean responses displayed a pattern that differed from that of the female vocal parts across the formations. Male choristers rated the sectional in columns formation higher than the other formations at 8.47 (SD=1.43). The tenors' average ratings across questions were 6.60 (SD=1.33) for the block sectional, 6.84 (SD=0.81) for the mixed and 7.53 (SD=1.09) for the sectional in columns formation. Similarly, the basses' average ratings across questions were 6.97 (SD=0.85) for the block sectional, 5.93 (2.17) for the mixed and 8.47 (SD=1.43) for the sectional in columns formation.

Given the differences in ratings for the sectional by columns formation across vocal parts, further analysis was conducted to determine if the differences reported across vocal part displayed any trends. Overall reference ratings across voice part were similar for the block sectional and mixed formations, but differed along gender lines with respect to the sectional in column formation. As reported in Table 2, the sopranos and altos rated the sectional in columns formation significantly lower than basses and tenors ($\chi^2(1)=30.93$; $p < .001$). No significant gender differences were observed

for the mixed ($p > .05$) or block formations ($p > .05$).

In terms of average ratings for each item, the first question related to "ease of production" was rated fairly high for the block sectional formation across all of the vocal parts. Responses ranged from 7.99 for the basses to 8.77 for the tenors (See Table 1). The lowest mean ratings for "ease of production" occurred for the mixed formation. Scores ranged from 5.01 for the basses to 7.23 for the altos. The mean ratings for the sectional by columns formation across the 'ease of production' item were fairly high, from 6.81 for the sopranos to 9.64 for the basses.

As depicted in Figure 7a, the male and female choristers rated the block sectional and mixed formations similarly, but the sectional by columns formation differently. Although the male choristers favored the sectional by columns formation more than the females, no significant gender differences were observed here ($p > .05$) (See Table 2).

Next the "sound of the choir" was rated. The vocal part means were more similar across the formations. For the block sectional formation the means varied from 6.05 for the tenors to 7.10 for the altos (See Table 1). For the mixed formation they varied from 6.26 for the basses to 7.69 for the sopranos. For the sectional in columns formation means varied from 4.08 for the sopranos to 8.66 for the basses.

A gender based difference for "sound of the choir" again occurred for the sectional in columns formation ($\chi^2(1)=12.06$; $p=.001$). Figure 7b displays that the males rated the sectional by columns formation higher than the females, whereas the females rated the block and mixed slightly higher than then males (See Table 2).

Table 2

Choristers' mean preference ratings and standard deviations for perceptual questions by choral formation and gender.

Choral Formation	Gender (N)	Ease of Production	Sound of Choir	Ease of Blending With Section	Ease of Hearing Others	Prefer Singing
Block						
	Male(12)	8.31 (1.29)	6.49 (2.18)	7.24 (2.44)	5.58 (2.87)	6.46 (2.44)
	Female(18)	8.10 (1.89)	7.09 (1.71)	7.66 (2.46)	5.76 (2.37)	6.06 (2.45)
Mixed						
	Male(12)	5.60 (2.66)	6.36 (3.33)	4.17 (3.23)	8.42 (2.63)	7.00 (3.40)
	Female(18)	6.36 (2.68)	7.20 (2.27)	6.11 (2.83)	8.26 (2.56)	8.02 (2.56)
Column						
	Male(12)	9.11 (1.18)	8.31 (1.74)	9.08 (1.55)	6.11 (2.80)	7.79 (2.69)
	Female(18)	7.23 (2.61)	4.97 (2.01)	6.56 (2.79)	3.73 (2.75)	4.19 (3.16)

Note. Standard deviations are enclosed in parentheses

For the “ease of hearing/blending with their own vocal section” item, gender based differences occurred for both the mixed and sectional by columns formations ($\chi^2 (1)=7.82$; $p=.005$). As shown in Figure 7c, the average female chorister ratings were fairly consistent at 7.58 for the block sectional, 6.10 for the mixed, and 6.48 for the sectional in columns formation. In contrast, the average male chorister ratings varied more widely among the formations from 7.17 for the block sectional to 4.44 for the mixed to 9.07 for the sectional in columns formation (See Table 2). The low rating for the mixed formation was strongly based on the low responses of the basses at 2.82. The other vocal sections exhibited similar ratings of 6.00 for the sopranos, 6.20 for the altos, and 6.05 for the tenors. The average ratings of the block sectional varied from 6.71 for the tenors to 7.62 for the basses. For the sectional in columns ratings the range was from 5.78 for the sopranos to 9.36 for the basses.

The trend for responses to the “ease of hearing other sections” item differed from those observed for the other items reported thus far. The average responses for both males and females to this question showed that the highest average ratings occurred for the mixed formation (male=8.38, female=8.15) and the lowest average ratings occurred for the sectional in columns formation (male=6.13, female=3.59) (See Table 2). As can be seen in Figure 7d, the gender differences for the ratings of the sectional in columns formation were significant ($\chi^2 (1)=4.22$; $p < .040$). Furthermore, the average ratings of the “ease of hearing other sections” item for the different choral formations were from 5.23 among the tenors to 5.83 among the basses for the block sectional formation, from 7.10 among the sopranos to 9.20 among the altos for the mixed formation, and from 2.39 among the sopranos to 6.04 among the basses for the sectional in columns formation.

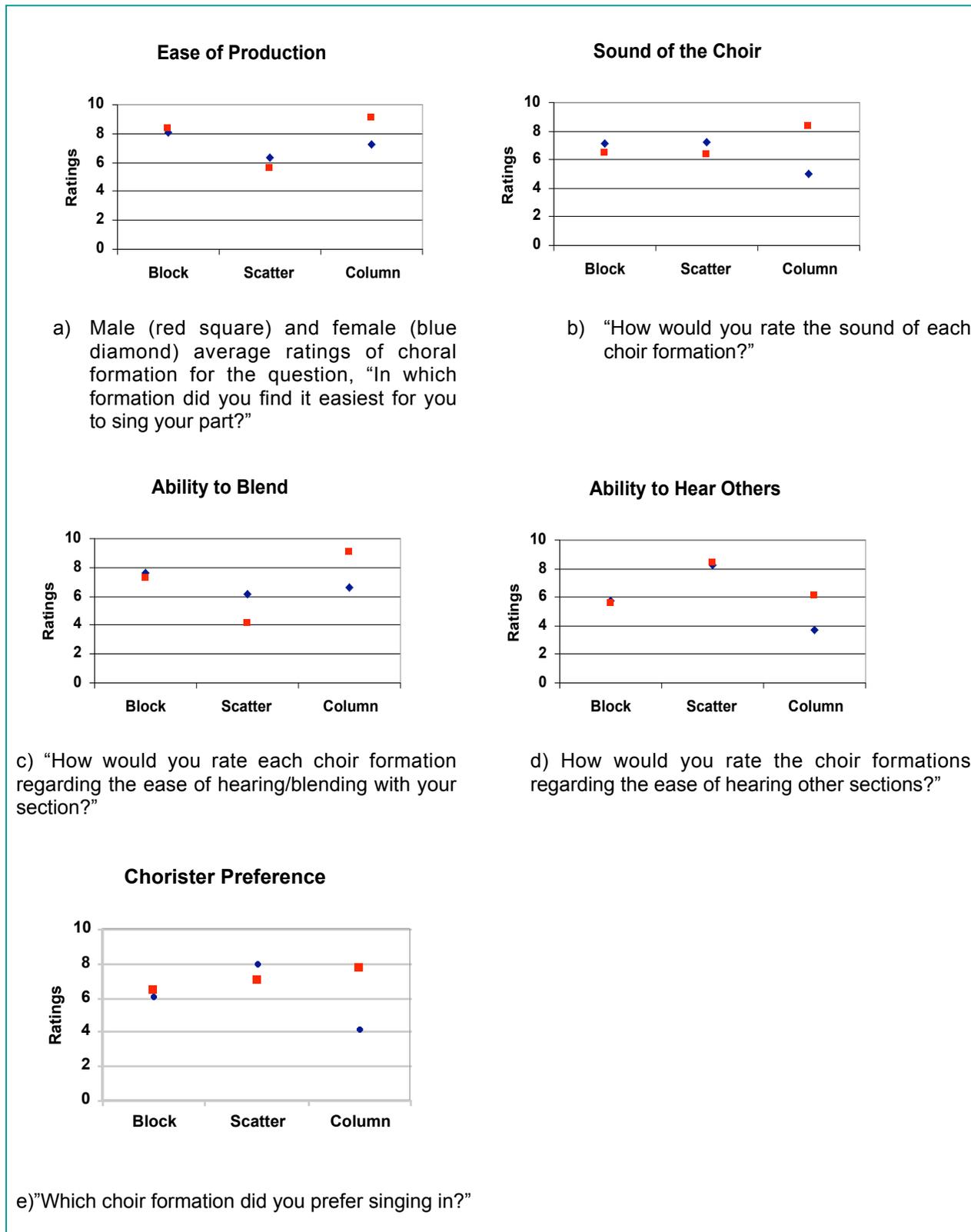


Figure 7a-7e Choristers' average rating of choral formations across perceptual questions by gender.

Finally, the responses to the 'preferred formation for singing' followed a pattern similar to most of the other questions with similar responses by the male and female choristers for the block sectional and mixed formations, but significant differences by gender for the sectional in columns formation ($\chi^2(1)=6.68$; $p=.01$) (See Table 2 & Figure 7e). The ratings of the block sectional formation ranged from 5.89 among the sopranos to 6.63 among the basses. For the mixed formation the ratings ranged from 6.94 among the basses to 8.68 among the altos, and for the sectional in columns formation the ratings ranged from 3.73 among the sopranos to 8.66 among the basses.

DISCUSSION

The purpose of this experiment was to compare LTAS data and chorister perceptions across different choral formations. Choral conductors place a great deal of emphasis on the selection of choral formation, often switching between several formations during one concert. Hence, the acoustic and perceptual data from this study could indicate the nature of any differences among the formations.

The acoustic data from this study did not reveal spectral differences among the block sectional, mixed and sectional in columns formations. It appears that choral formation does not significantly affect the LTAS of choral sound when recorded in the diffuse field out in the auditorium. Apparently, the blend of the singers' voices maintained a similar pattern across the different formations. This result was contrary to the hypothesized result of the mixed formation producing different spectral patterns than the other two formations. Recording the voices from microphones located near the singers or at the position of the conductor may result in different LTAS patterns.

Recording from this position might provide acoustic data that also reinforce the different perceptions of the choral formations between the male and female singers. Visual inspection of the LTAS for each piece demonstrated that no spectral differences were evident in the source or resonance spectra by altering formation. The distribution of energy across the frequency bands is similar to data reported from previous research examining the LTAS during choral singing, in which most of the energy was seen in the fundamental frequency and first formant, and

another increase in energy around 3 kHz (Rossing et al., 1986, 1987; Ternström, 1991).

However, the increase in energy at 3 kHz was much less noticeable in the current results than in previous studies, even for the choristers. This reduction in energy may indicate that the choristers were attempting to produce a more "choral" sound (Goodwin, 1980), which displays a concentration of energy at the fundamental and first formant frequencies, in contrast to the solo mode of singing which displays more energy around the singer's formant or 3 kHz (Rossing et al., 1986; 1987).

The difference in energy increase at 3 kHz between the present study and previous studies (Rossing et al., 1986; 1987) could also be related to the room's diffuse sound field. Whereas Rossing et al. (1986; 1987) analyzed recordings from an anechoic chamber, the present recordings were measured in a large auditorium with the microphone a good distance away from the choir. The diffuse field of the room may have dampened or smoothed out the directivity of the acoustic signal; resulting in the relatively low values observed presently.

The LTAS results did demonstrate differences between the musical selections. Overall, the polyphonic selection was more intense than the homophonic selection for frequencies above 650 Hz. This difference was particularly noticeable at the singer's formant, where a difference of nearly 6 dB is shown between the selections. A more "soloistic" mode of singing may have been used by the choristers because in polyphonic music each section contains its own independent line of musical material (Goodwin, 1980). Were this the case, however, one might then expect differences between the formations, especially for the mixed formation where singers are separated from members of their own section. Another possibility is that differences in pitch range and durations between the selections resulted in the differing LTAS spectra.

In future research, the same selection, a canon or round that can be sung both homophonically in unison and polyphonically in any number of parts without changing the pitch set, should be used for all tests in order to control for variability and duration of pitches. Also, future researchers may want to examine the auditory processing of the choral signal for differences, given formation. For example, Bregman and Pinker (1978) examined the effects of auditory streaming and the building of

timbre which revealed possible auditory effects on the processing of sound.

However, the LTAS did successfully demonstrate differences between the musical examples and will be an important part of future research. Measurement of source and resonance spectra provides valuable information regarding the type and intensity of production. Unfortunately, it accounts neither for instances of individual noticeable voices (Tocheff, 1990), nor for the tuning of formant frequencies (Hunt, 1970), which are considered important factors in determining blend.

It is also possible that formation affects variables that are not measured by LTAS, but rather may affect variables in the auditory or cognitive pathways that are time dependent rather than pitch or loudness dependent. In that vein, perceivable differences among the choral formations may relate to the listener's ability to extract streams of auditory information (Bregman, 1990). For example, when hearing choral singing the listener may follow the pitch related stream of each vocal part while simultaneously appreciating the auditory scene created by the blend of the four vocal parts. Variations in the separation of the four streams may create perceptible variations in the auditory scenes. This combination of perceived auditory streams across time with the perceived changing momentary auditory scenes cannot be captured by acoustic equipment that measures either the acoustic changes over time or the acoustic scene at one moment.

In addition to the acoustical analyses, perceptual data were collected and analyzed to determine differences in preference across the three formations. The major perceptual finding of the present investigation was a strong gender difference in preferences and perceptions of singing in the three choral formations. The male singers clearly preferred the sectional in columns formation. They rated it highly in terms of ease of production, desirability of choral sounds, and the ability to blend with others in the section, and generally favored it more than the block sectional and mixed formations. In contrast, the female singers varied their highest perceptual ratings between the mixed and block formations, and indicated a strong dislike for the sectional in columns formation.

The male preference for the sectional in columns formation may have been secondary to the novel acoustic experience of singing at the front of the choir. The choristers in this study routinely sang in the classical block sectional

formation illustrated in Fig. 1. In the sectional in columns formation, most male singers had members of their vocal section standing directly behind them, which appears to have enhanced their self-reported ability to blend with others in their section. The reception of vocal input from behind appeared to impact the bass and tenor singer's perceptions of ease of production and their overall impressions regarding the sound of the choir.

Most of the female singers in this particular choir were accustomed to receiving vocal input from at least two other vocal sections behind them, and in some cases, three vocal sections by virtue of routinely singing in the block sectional formation. Their marked dislike for the sectional in columns formation may be attributed to a perceived decrease in vocal input from the other vocal sections. Interestingly, female singers also indicated their ability to blend with singers in their own section remained relatively stable across all three choral formations. This effect could be directly attributable to the larger number of female singers in the choir and the consistency of having people singing their vocal part behind them in all the configurations.

A possible factor in the choral arrangement preference differences between the males and females might be the typical differences in acoustic output power between them. Ternström (1994) reported that soprano singers in *forte* typically produce stronger signals than do bass singers in *forte*. He stated that this effect was related to the increase in sound pressure level of the voice with increases in fundamental frequency (Ternström 1994; 1999). In two studies Ternström (1994; 1999) discussed the Self-to-Other Ratio, a measure of choristers' experience of their own sound in comparison to that of other singers. He indicated that the relative strength of a chorister's sound in comparison with those around him or her is an important factor in choral singing. He found this ratio to be typically lowest for basses and highest for sopranos.

Quite possibly, when the bass singers go to a mixed formation, they will be standing closer to singers that are louder than themselves, and so the ratio of their sound in comparison to the singers around them drops even lower, making it harder for them to hear their own voice. In contrast, when sopranos go to a mixed formation, they get to stand closer to singers with softer voices, and so their ability to hear others increases.

This concept relates to the perceptual data depicted in Figure 6. The preference of bass singers for the overall sound and blend of the column formation and dislike of the mixed formation for overall sound and preference contrasts with the sopranos ratings of these formations. The basses were better able to hear the singing of the other basses and thus could better appreciate the blend of the entire chorus. The sound of the sopranos would still be heard because of the greater signal strength coming from them. In contrast, the sopranos could not hear the other, weaker vocal parts, so they could not hear the overall choral sound as well.

Inherent in the above discussion is the implication that singers' voices send a directional signal such that the signal projected laterally has less of an effect on chorister ability to hear other singers than the signal going forward to these choristers in front of each singer. Further evidence to support this assertion is the fact that all of the singers, divided into vocal sections, rated the sectional in columns formation as being the least effective in allowing them to hear singers in the other vocal sections. In the column formation, many of the singers were standing directly next to one singer from a different vocal section, and were two spaces away from another vocal section on their alternate side, yet this proximity did not increase the ability to hear these other parts.

This finding is consistent with the fact that greatest energy in sound waves emanating from the vocal tracts of singers are in front of the singer (Kent, 1997; Kent & Read, 1996). The head will dampen the projection of the sound in directions other than directly in front of the mouth. Consequently, singers in this study appeared to hear other sections better when they were standing directly in front of singers from those sections.

Finally, the singers in this study indicated that being able to hear the singers from different vocal sections is an important variable contributing to overall improved choral blend. They also indicated that the mixed formation best provided that acoustic atmosphere, which is consistent with the earlier findings of Daugherty (1999). When in this configuration, singers were receiving both lateral and posterior vocal input from other vocal sections, which appeared to influence the ease of hearing the other parts. Additionally, because all of the music was performed *a cappella*, there was greater reliance on listening to the other parts while singing than when singing with instrumental accompaniment.

This increased ability to hear the other sections, however, did not significantly influence the chorister's perceptual rating of the overall sound of the choir. Male singers continued to display a strong preference for the sectional in columns formation, whereas female singers gave a lower rating for this formation. As noted above, this finding indicates that the experience of being able to hear other singers in their section and to hear the other vocal sections varied among the vocal parts. The weaker sound of the sections made the column formation more desirable as they could hear both their own section and the other sections well. However, the perception of the column formation was opposite for the stronger sound of the female sections.

The primary limitation to the data concerning the overall sound of this choir was the lack of using outside auditors to rate the sound. However, when it is considered that the singer's ratings on this question across the three formations were generally in the range of 6 to 8 on a 10 point scale, these perceptions support the lack of significant findings on the LTAS. The apparent agreement between the acoustic and perceptual findings of this study suggest that the pitch and loudness features essential to establishing a balanced choral blend result in similar LTAS. Perceived chorister differences among the choral arrangements may be more inherent in the time based aspects of the sound of the filtering functions of the human ear, rather than resulting from differences in the intensity by frequency aspect of the acoustic signal. Other limitations that may have impacted these findings were that only one choir was included, the relative small size of that choir, and the unequal balance of members in each vocal section.

Alternately, it can be argued that LTAS is simply not a sensitive enough measure to detect differences in the acoustic signals produced by these different formations. For instance, because the LTAS averages frequency energy over time produced by both the vocal source and vocal tract, it would not measure instances of noticeable individual voices, i.e. instances when an individual singer's voice could be heard above the rest of the choir. Tocheff (1990), reported that critics of mixed choral formations cite noticeable individual voices as being a common problem, however no such increased incidence was detected by the LTAS in this study due to the averaging effect of the procedure. LTAS also does not account for the tuning of formant frequencies (Hunt, 1970),

which is considered another important facet of blend. Even so, the LTAS did successfully demonstrate a difference between musical literature examples, and will be an important part of future research in this area.

Choristers reported that differences in sound occurred for the three formations; however, these differences were not seen acoustically in this experiment. It is possible that the acoustic filtering of the auditory system and/or the cognitive processing of the signal may be responsible for these differences. Future research should include auditory filtering of the acoustic data before measurement in order to observe any differences. Also, additional controls for the musical selection should be performed as mentioned above, as should the spacing of the ensemble (Daugherty, 1999; 2003), which was approximated but not specifically controlled in this study. Finally, the use of a videotaped conductor would ensure a constant pace and increase the reliability of future research.

Perceptual measures can be effective in describing a subjective art as such choral singing. Even so, the discovery and development of acoustic measures of choral blend would be advantageous to the choral music community, if only to better understand how each unique voice works with others to create a blended sound.

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