The Effects of Choir Formation and Singer Spacing on the Tone Quality of a TTBB Male Chorus

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Abstract

Against the standard of a 1 dB SPL mean difference, I tested the effects of 2 choir formations (block sectional, mixed) and 3 inter-singer spacing conditions (close, lateral, circumambient) on long-term average spectra (LTAS) acquired at 2 microphone locations (conductor position, audience position) from a TTBB men's chorus as it sang from memory a 4-part a cappella song under the direction of a videotaped conductor. Results from both microphone locations indicated that grand mean spectral energy differences attributable to inter-singer spacing exceeded 1 dB SPL (conductor location: 2.13 dB SPL, audience location: 1.87 dB SPL), while differences attributable to choir formation did not meet the 1 dB SPL standard (conductor location: 0.25 dB SPL, audience location: 0.23 dB SPL). This male ensemble exhibited greater mean signal energy differences between close and lateral spacing conditions than between lateral and circumambient conditions. There were greater mean signal amplitude differences between formations in circumambient spacing than between formations in close and lateral spacing.

Keywords: choir formation, choir spacing, choral sound, nonverbal choral pedagogy

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TTBB Male Chorus

Modern choral methods books commonly recommend placing singers in various choir formations according to the scored voice parts they sing (e.g., Soprano, Alto, Tenor, Bass) as a strategy to modify choir sound. Figure 1 illustrates the longevity of this continuing perspective.

Christiansen (1916)

Willetts (2000)

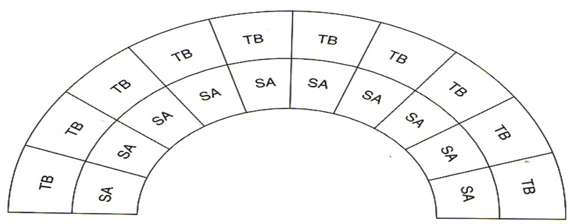

Figure 3.16

Brinson and Demorest (2014)

Figure 1. Examples of choir formation diagrams from choral methods books.

Representative acoustical claims that accompany choir formation diagrams include such statements as: "The sound heard will be noticeably different in each of these formations" (Kohut & Grant, 1991, p 125); "The balance, blend, and even the tone will likely change as different placements are used" (Lamb, 1977, p 16).

Numerous studies have examined these claims through perceptual measures. In the earliest published investigation of the matter, Lambson (1961) concluded, "Acoustical differences among various seating plans are not nearly as pronounced as generally believed" (p 53). Perceptual investigations since Lambson (e.g., Atkinson, 2006; Daugherty, 1996; Eckholm, 2002; Tocheff, 1990; Wang, 2007) have yielded varied results, sometimes finding significant preferences for one or more of a variety of particular sectional or mixed formations, and sometimes not, depending upon the participants, the literature sung, and the controls instituted.

Daugherty (1999, 2003, 2005) found that inter-singer spacing, that is, the distance between and among choir singers, influenced singer and auditor perceptions of choir sound more than the particular formation of the choir, and that spread singer spacing elicited significantly more in tune singing regardless of formation. Subsequent acoustical studies (Daugherty, Manternach & Brunkan, 2011; Daugherty, Manternach, Coffeen & Brunkan, 2012; Daugherty, Grady & Coffeen, 2013) found significant long-term average spectra (LTAS) differences between choral sound produced with close, shoulder-to-shoulder singer positioning and choral sound produced when the choir stood with more distance between and among singers.

A series of acoustical investigations of choir formation (Aspass, McRae, Morris & Fowler, 2004; Mustafa, 2005; Morris, Musftafa, McCrae, Fowler & Aspass, 2007) found no significant LTAS differences among a variety of mixed choir formations. Morris, et al. (2007), however, speculated that although some 3 - 5 dB differences in individual harmonics obtained at a singer-position microphone dissipated as the choir's sound reached an audience position, the conductor might hear those differences and consider them when making decisions about choir formations.

No acoustical study to date has assessed choir formation and inter-singer spacing simultaneously with the same choir. Moreover, no acoustical study to date has assessed either choir formation or inter-singer spacing with an ensemble comprised entirely of men's voices.

Foot (1965) and Tonkinson (1990) observed that vocalists sang with increased intensity in proportion to decreases in the intensity of auditory feedback from direct and reflected sound pressure waves to their external ears. A series of studies by Ternström (1989, 1994,1999) examined self-to-other Ratios (SOR) among choir singers. SOR denotes the difference in dB sound pressure levels between the airborne feedback received from a singer's own voice and the sound reaching a singer's ears from surrounding choristers. Of these two factors, ability to hear and thus monitor one's own voice in choral contexts appears to be of primary importance. Ternström found that male singers, perhaps because of the length of the sound waves emitted at lower frequencies, required a lesser ratio of self to other sound than did female singers. Daugherty (2003) found that male singers optimally preferred a lesser amount of spread singer spacing than female singers. Thus, one might hypothesize that a chorus of male voices presents a particularly interesting case for exploring acoustically and simultaneously the potential effects of inter-singer spacing and choir formation on choral sound.

The purpose of this study was to test the effects of two choir formations (block sectional, mixed) and three inter-singer spacing conditions (close, lateral, circumambient) on long-term average spectra (LTAS) acquired at two microphone locations (conductor position, audience position) from a TTBB men's chorus as it sang from memory an a cappella gospel song under the direction of a videotaped conductor. The following research questions guided this investigation:

1. Will LTAS data acquired from a conductor location microphone exhibit mean spectral energy differences of 1 dB SPL or greater according to either the choir's formation (block sectional, mixed) or the choir's inter-singer spacing (close, lateral, circumambient)?

2. Will LTAS data acquired from an audience location microphone exhibit mean spectral energy differences of 1 dB SPL or greater according to either the choir's formation (block sectional, mixed) or the choir's inter-singer spacing (close, lateral, circumambient)?

Method

Participants

Members ($N = 24$) of the men's chorus participating in this study ranged in age from 20 to 50 years (modal age = 31 years). Each chorister sang as a member of various regional barbershop quartets. They came together weekly to rehearse and perform in a larger men's chorus that sang a variety of a cappella literature and competed regularly in national and international festival events (Figure 2).

Figure 2. Participants following a public performance.

With Institutional Review Board (IRB) approval, I informed choristers that the purpose of the study was to explore positioning singers on choir risers. I did not apprise participants beforehand of the specific independent variables of interest (choir formation, singer spacing).

Rehearsal Room Venue

This investigation occurred in the choir's accustomed rehearsal area, a basement room of a local church building. The rectangular room was 31 ft wide by 41 ft long with a 9 ft ceiling. It featured a hard tile floor, semi-absorbent ceiling panels, and wood paneled walls. Two sets of support columns divided the room lengthwise at intervals of approximately 13.5 ft. As was their custom, the men stood while singing on three-step Wenger Tourmaster choir riser units. Risers conjoined to form a modest semi-circular curve. The width of each riser step was 18 inches. The height between each riser step was 8 inches. The risers, situated approximately 6 ft from the wall at one end of the venue, faced into the hall lengthwise.

Sung Musical Excerpt

For this study, the chorus performed from memory an 87-s excerpt from "O Love That Will Not Let Me Go," a largely homophonic, four-part gospel song arrangement by David Phelps. The selected excerpt featured contrasting dynamics and tessiturae, and the men could sing it from memory, having recently performed this literature in a public concert.

Recording Session Procedures

The choir sang the musical excerpt in two formations (block sectional and mixed) with three inter-singer spacing conditions (close, lateral, circumambient) in each formation, yielding a total of six sung trials: (a) mixed formation with close singer spacing, (b) mixed formation with lateral singer spacing, (c) mixed formation with circumambient singer spacing, (d) sectional formation with close singer spacing, (e) sectional formation with lateral singer spacing, and (f) sectional formation with circumambient singer spacing. This ensemble typically rehearsed and performed in a conductor-devised mixed formation (see Figure 3).

B2 T1 B1 T2 B2 T1 B1 B2
T1 B2 T2 B1 T2 T1 B2 T2 B1
B1 T2 B2 T1 B1 T2 T1

Figure 3. TTBB mixed formation. T1 = tenor, T2 = lead, B1 = baritone, B2 = bass.

The choir retained this particular configuration as the mixed formation condition for this study. To control for possible confounding variables that might result from singers shifting from row to row, choristers remained on the same row for the block sectional formation, simply moving to stand by a singer of the same voice part on the same row to form a three row Tenor-Lead-Baritone-Bass sectional formation (see Figure 4).

T1 T1 T2 T2 B1 B1 B2 B2
T1 T1 T2 T2 T2 B1 B1 B2 B2
T1 T1 T2 T2 B1 B1 B2

Figure 4. TTBB block sectional formation. T1 = tenor, T2 = lead, B1 = baritone, B2 = bass.

Inter-singer spacing conditions conformed to those used in previous studies (e.g., Daugherty, 1999, 2003; Daugherty, Manternach & Brunkan, 2012). For close spacing, singers stood in a comfortable shoulder-to-shoulder stance with less than 1 inch between the upper arms of contiguous singers. A consistent horizontal distance of 24 inches between each singer, measured with dowel rods prior to each performance, constituted the lateral spacing condition. For circumambient spacing, singers retained the 24 in. lateral distance and, in addition, left vacant the equivalent of a riser step width (18 in.) between each of the three rows of singers. This configuration was accomplished by having the first row of singers remain in place while moving the riser unit back 18 inches. Thus the second row of the choir stood on the first riser step and the third row stood on the third riser step. At no point, however, did the location of the first row of singers change, thus ensuring a consistent distance between the first row of the choir and the microphones in all sung trials. Figure 5 illustrates the three inter-singing spacing conditions using the block sectional formation.

Close Spacing

T1T1T2T2B1B1B2B2
T1T1T2T2T2B1B1B2B2
T1T1T2T2B1B1B2

Lateral Spacing

T1 T1 T2 T2 B1 B1 B2 B2
T1 T1 T2 T2 T2 B1 B1 B2 B2
T1 T1 T2 T2 B1 B1 B2

Circumambient Spacing

T1 T1 T2 T2 B1 B1 B2 B2

T1 T1 T2 T2 T2 B1 B1 B2 B2

T1 T1 T2 T2 B1 B1 B2

Figure 5. The three inter-singer spacing conditions (close, lateral, circumambient) in the block sectional formation used for this study. T1 = tenor, T2 = lead, B1 = baritone, B2 = bass.

Videotaped conducting ensured that singers responded to exactly the same conducting stimuli in each performance. It thus served to control for possible confounding variables due to any changes between performances in conductor gesture, facial expression, and tempo that might occur had the conductor led the six performances live. The choir's regular conductor was videotaped as he led the choir once in singing the musical excerpt. For each sung trial, that recording was projected on a screen placed at the back wall of the venue. Just prior to each replaying of the conductor video, singers heard the keynote of the musical excerpt played on a pitch pipe.

Recording Equipment

Two factory calibrated, omni-directional Edirol R-09 digital sound recorders captured each of the choir's performances at a sampling rate of 44.1kHz (16 bits) in .wav format. Volume and gain controls were set manually to the same positions on both recorders at the beginning of the recording session and remained the same throughout all recordings.

I positioned the first recorder (conductor position microphone) where the conductor typically stood when rehearsing the ensemble, that is, 11 ft 8 in. from the front row center of the choir at a height of 5'1" or the approximate ear height of the choir's conductor. I placed the second recorder (audience position microphone) at a height commensurate with a sitting audience member's ear (3 ft 10 in) at a location approximately two-thirds back in the center of the room, 28 ft 4 in. from the first row of the choir and 6 ft 6 in. from the rear wall of the hall.

LTAS Data

Long-term average spectra (LTAS) measurement provides information averaged over a period of time about timbre or tone quality. LTAS data include both frequency and sound pressure density (amplitude intensity) across a spectrum of complex sound. More particularly, LTAS graphs present sound pressure power as a function of frequency. In sum, LTAS data provide a quantifiable index of sound quality across a specified period of time. These data can be useful for detecting persisting spectral events.

I used KayPentax Computerized Speech Lab (CSL) Model 4500 software to examine recordings of the choir's performances. To acquire LTAS data, I analyzed each recording using a window size of 512 points with no pre-emphasis or smoothing, a bandwidth of 86.13Hz, and a Blackman window. I used data from one channel of the Edirol recordings, because differences between the two channels were negligible.

According to Howard and Angus (2006), a change of 1 dB SPL constitutes the just noticeable difference (JND) in the signal amplitude of complex sound, depending on the sound source and the hearing of particular listeners. Arguably, it is more important for choral pedagogy that human ears potentially be able to hear any changes in the spectra of choir sound than whether sound spectra may exhibit differences not likely to be heard. Therefore, I employed a 1 dB SPL JND standard by which to assess mean LTAS differences among the independent variables of this investigation.

Results

Research Question One: Conductor Location Formation versus Spacing

The first research question asked if there would be mean conductor location LTAS differences of at least 1 dB SPL attributable to the choir's formation (block sectional, mixed) or the choir's inter-singer spacing (close, lateral, circumambient). Figure 5 presents conductor location overall mean LTAS contours (0 - 10 kHz) of all sung performances according to choir formation.

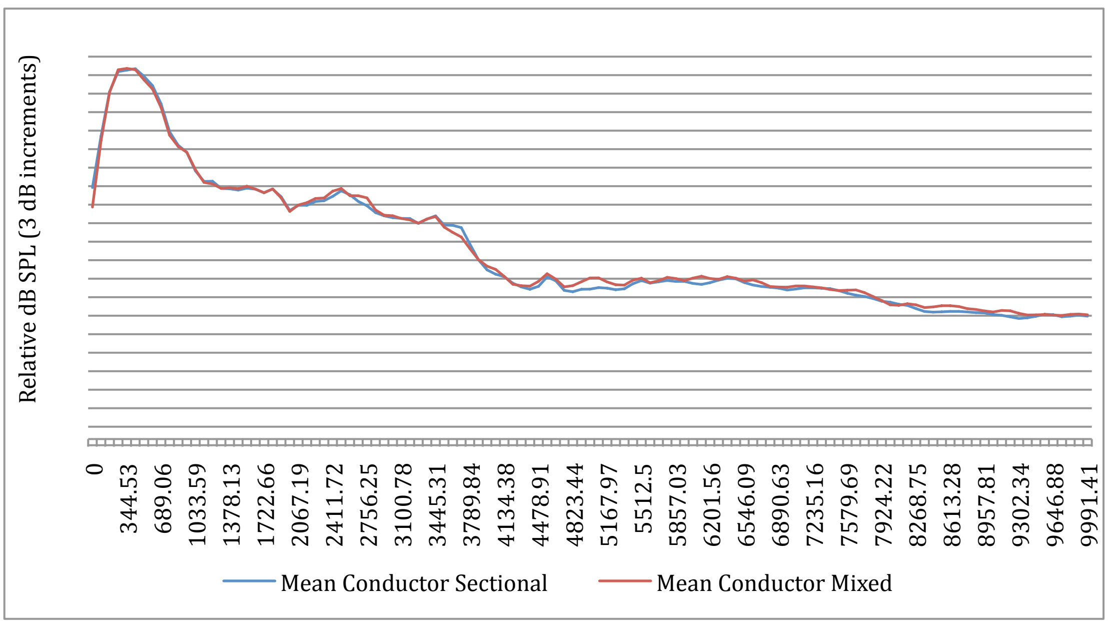

Figure 5. Conductor location grand mean LTAS contours of all performances sung with block sectional and mixed choir formations.

At the conductor location, the overall mean signal energy difference between sectional and mixed formation performances was 0.25 dB SPL, less than the 1 dB SPL JND standard set for this investigation. The choir performed three iterations each of the two formations, one at each level of inter-singer spacing: (a) close sectional vs. close mixed (*M* difference = 0.09 dB SPL, range: 0.00 - 1.57 dB SPL); (b) lateral sectional vs. mixed (*M* difference = 0.12 dB SPL, range: 0.01 - 2.25 dB SPL); and (c) circumambient sectional vs. mixed (*M* difference = 0.54 dB SPL, range: 0.01 - 2.57 dB SPL). All conductor-location performance pairs according to formation exhibited mean signal energy differences below the 1 dB SPL JND standard.

Figure 6 presents overall mean LTAS contours according to the choir's inter-singer spacing.

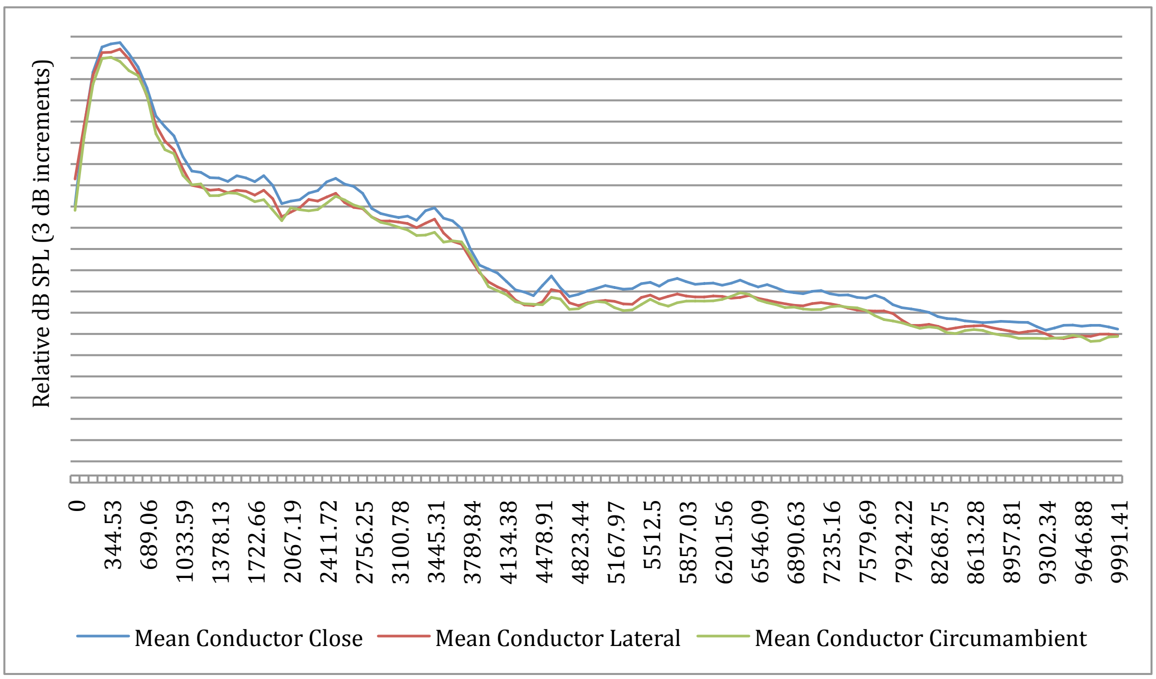

Figure 6. Conductor location grand mean LTAS contours of all performances sung with close, lateral, and circumambient spacing.

The overall mean signal energy difference between performances at the conductor location with close (shoulder-to-shoulder) and circumambient (most spread) inter-singer spacing was 2.13 dB SPL, which exceeded the 1 dB SPL JND standard set for this investigation. The choir performed two iterations each of the three inter-singer spacing conditions, one for each formation.

Contrasting performance pairs according to spacing included: (a) sectional close vs. sectional lateral (*M* difference = 1.56 dB SPL, range: 0.06 - 7.79 dB SPL); (b) sectional lateral vs. sectional circumambient (*M* difference = 0.80 dB SPL, range: 0.04 - 8.19 dB SPL); (c) mixed close vs. mixed lateral (*M* difference = 1.53 dB SPL, range: 0.03 - 3.42 dB SPL); and (d) mixed lateral vs. mixed circumambient (*M* difference = 0.38 dB SPL, range: 0.04 - 1.76 dB SPL).

Obtained differences between close (shoulder-to-shoulder) and circumambient (most spread inter-singer spacing) were: (a) close sectional vs. circumambient sectional (*M* difference = 2.34 dB SPL, range: 0.06 - 4.05 dB SPL); and (b) mixed sectional vs. mixed circumambient (*M* difference = 1.91 dB SPL, range: 0.03 - 4.01 dB SPL). All conductor location performance pairs contrasting close inter-singer spacing with lateral inter-singer spacing exhibited mean signal energy differences in excess of the 1 dB SPL JND standard. Performance pairs contrasting lateral with circumambient inter-singer spacing at the conductor location did not exceed the 1 dB SPL JND standard. That is, the transition from close to lateral spacing appeared to influence the overall spectral energy produced by this men's choir more than did the transition from lateral to circumambient inter-singer spacing.

Figure 7 illustrates the interaction between spacing and formation at the conductor microphone location.

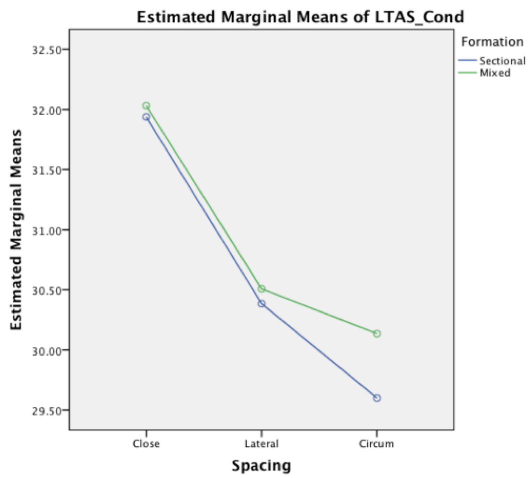

Figure 7. Interaction between spacing and formation at the conductor location.

As indicated by Figure 7, the more spread the inter-singer spacing, the greater the reduction in mean signal energy, regardless of formation. Spectral energy differences were greater between close and lateral spacing than between lateral and circumambient spacing. In the sectional and mixed formation performances with circumambient (most spread) inter-singer spacing, the mixed formation performance exhibited slightly greater mean amplitude (M = 0.54 dB) than the sectional formation performance. That is, the greatest mean energy differences in formation occurred with the greatest increase in inter-singer spacing; conversely, the least mean energy differences in formation occurred with the least amount of inter-singer spacing.

Research Question Two: Audience Location Formation versus Spacing

The second research question inquired about mean audience location LTAS differences of at least 1 dB SPL attributable to the choir's formation (block sectional, mixed) or inter-singer spacing (close, lateral, circumambient). Figures 8 presents audience location overall mean LTAS contours (0 - 10 kHz) of all sung performances according to choir formation.

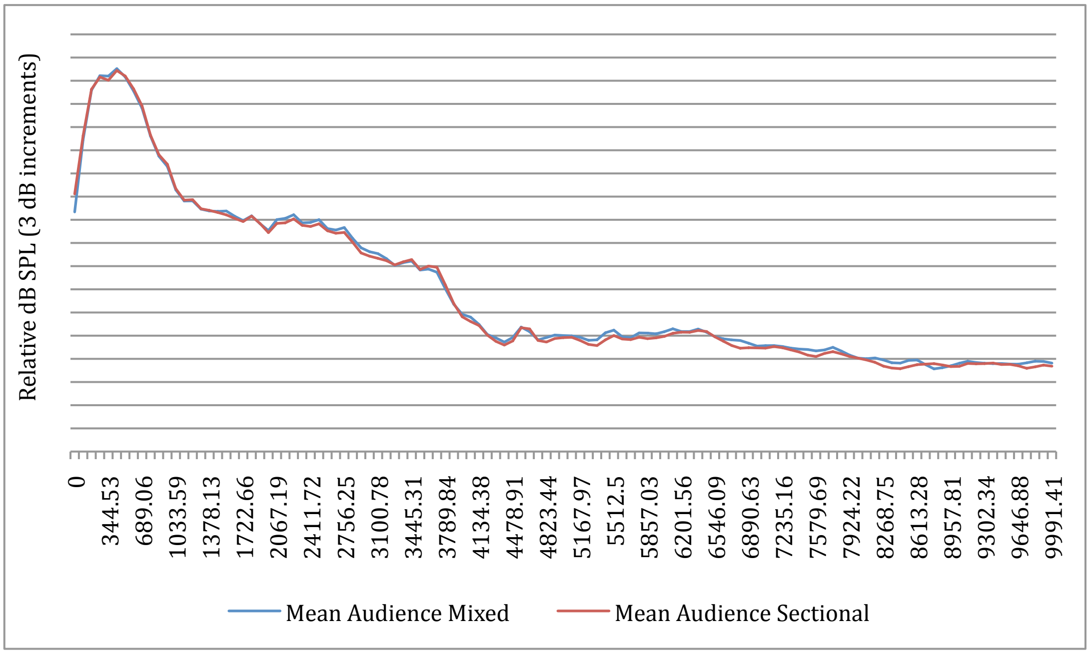

Figure 8. Audience location grand mean LTAS contours of all performances sung with block sectional and mixed choir formations.

At the audience location, the overall mean signal energy difference between sectional and mixed formation performances was 0.23 dB SPL, less than the 1 dB SPL JND standard set for this investigation. The choir performed three iterations each of the two formations, one at each level of inter-singer spacing: (a) close sectional vs. close mixed (*M* difference = 0.01 dB SPL, range: 0.00 - 1.04 dB SPL); (b) lateral sectional vs. mixed (*M* difference = 0.09 dB SPL, range: 0.02 - 1.56 dB SPL); and (c) circumambient sectional vs. mixed (*M* difference = 0.60 dB SPL, range: 0.01 - 2.17 dB SPL). All conductor-location performance pairs according to formation exhibited mean signal energy differences below the 1 dB SPL JND standard.

Figure 9 presents overall mean LTAS contours according to the choir's inter-singer spacing.

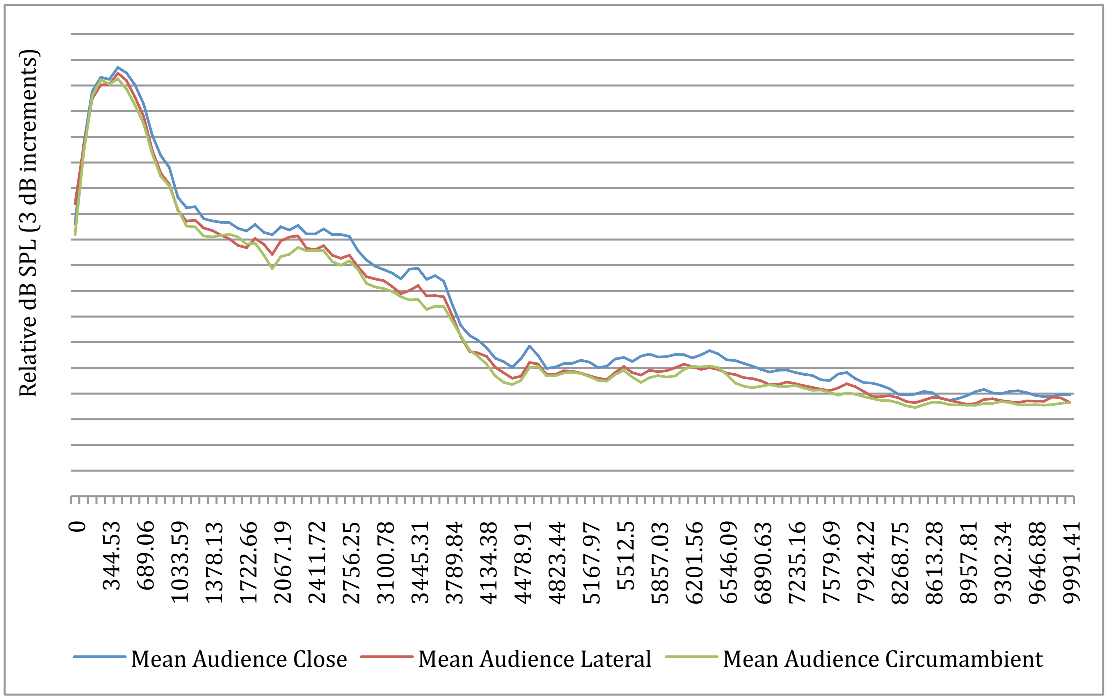

Figure 9. Audience location grand mean LTAS contours of all performances sung with close, lateral, and circumambient spacing.

The overall mean signal energy difference between performances at the audience location with close (shoulder-to-shoulder) and circumambient (most spread) inter-singer spacing was 1.87 dB SPL, which exceeded the 1 dB SPL JND standard set for this investigation. The choir performed two iterations each of the three inter-singer spacing conditions, one for each formation. Contrasting performance pairs according to spacing included: (a) sectional close vs. sectional lateral (*M* difference = 1.37 dB SPL, range: 0.30 - 6.10 dB SPL); (b) sectional lateral vs. sectional circumambient (*M* difference = 1.00 dB SPL, range: 0.10 - 7.24 dB SPL); (c) mixed close vs. mixed lateral (*M* difference = 1.30 dB SPL, range: 0.31 - 2.40 dB SPL); and (d) mixed lateral vs. mixed circumambient (*M* difference = 0.50 dB SPL, range: 0.10 - 1.24 dB SPL). Obtained differences between close (shoulder-to-shoulder) and circumambient (most spread inter-singer spacing) were: (a) close sectional vs. circumambient sectional (*M* difference = 2.17 dB SPL, range: 0.06 - 4.95 dB SPL); and (b) mixed sectional vs. mixed circumambient

(*M* difference = 1.60 dB SPL, range: 0.06 - 3.50 dB SPL). All audience location performance pairs contrasting inter-singer spacing conditions exhibited mean signal energy differences at or in excess of the 1 dB SPL JND standard. As was the case at the conductor location, the transition from close to lateral spacing appeared to influence the overall spectral energy produced by this men's choir more than the transition from lateral to circumambient inter-singer spacing.

Figure 10 depicts the interaction between spacing and formation at the audience microphone location.

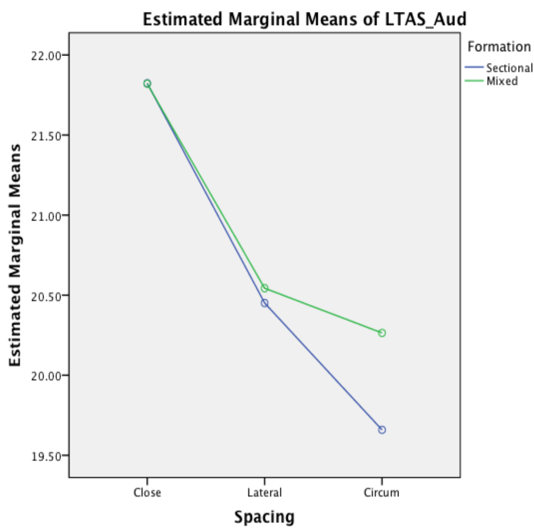

Figure 10. Interaction between spacing and formation at the audience location.

As was the case at the conductor location, the more spread the inter-singer spacing, the greater the reduction in mean signal energy, regardless of formation, at the audience location microphone. Again, spectral energy differences were greater between close and lateral spacing than between lateral and circumambient spacing. In the sectional and mixed formation performances with circumambient (most spread) inter-singer spacing, the mixed formation performance exhibited slightly greater mean amplitude (*M* = 0.60 dB) than the sectional formation performance. The general pattern observed at the conductor location remained largely consistent at the audience location: the greatest mean energy differences in formation occurred with the greatest increase in inter-singer spacing; conversely, the least mean energy differences in formation occurred with the least amount of inter-singer spacing.

Discussion

The major finding of this investigation is that inter-singer spacing appears to affect the overall tone quality of the participating male chorus to a greater extent than this choir's formation. Mean inter-singer spacing differences, moreover, exceed a 1 dB SPL JND while mean formation differences do not. This finding is limited to the particular participants, venue, and procedures of this study. Nonetheless, it raises matters that merit further research and ongoing professional dialogue.

Data indicate that the transition from close to lateral inter-singer spacing affects the overall tone quality of this men's choir more than a transition from lateral to circumambient singer spacing. This outcome appears to align conceptually with some previous studies (Daugherty, 2003; Ternström, 1999), which suggest that male singers may prefer a lesser SOR and less spread inter-singer spacing than female singers. Future inter-singer spacing studies might well include female only ensembles, as well as other male and mixed choirs, in order to confirm or refute this finding. Subject to further research, this factor potentially could have practical consequences for mixed voice choirs with limited riser or stage real estate. It may be possible, for instance, to employ non-uniform chorister spacing (i.e., spacing that affords more distance between female singers and somewhat less distance between changed-voice male singers) without sacrificing and perhaps even enhancing characteristics of choir tone presently associated with uniform chorister spacing. In this regard, a mixed choir study that contrasts uniform and non-uniform inter-singer spacing conditions might yield interesting results.

In this study, the spectral differences in mean signal energy according to inter-singer spacing reflect overall reductions in amplitude, rather than increased energy. This finding mirrors results of previous studies (e.g., Daugherty, Manternach & Brunkan, 2011; Daugherty, Manternach, Coffeen & Brunkan, 2012; Daugherty, Grady & Coffeen, 2013) with mixed choirs. Thus, even though data from this study suggest that this male ensemble exhibits greater mean signal energy differences between close and lateral inter-singer spacing conditions than between lateral and circumambient conditions, the primary outcome of transitioning from a close, shoulder-to-shoulder stance aligns with results from previous studies using mixed choirs.

Various reasons potentially inform this phenomenon. Ternström and Sundberg (1987) suggest that reducing the singer's formant in choristers may abet a more blended choir sound. To date, LTAS studies (e.g., Daugherty, Manternach & Brunkan, 2011) of inter-singer spacing with mixed choirs indicate that such may be the case. Results of those studies show that significant reduction (2 - 4 dB SPL) of spectral energy in the 2 - 4 kHz region (in and around the singer's formant area) accompanies more spread inter-singer spacing. Although in the present study with male choristers there are slightly more robust spectral energy reductions in the 2 - 4 kHz region, the reduction appears more consistently distributed across the 0 - 10 kHz spectrum than clustered primarily in specific regions. Future research with male choirs can examine whether or not this finding is peculiar to this particular male ensemble with its background in barbershop quartet singing, or is perhaps due to the characteristics of the rehearsal venue used for this study.

Another reason why slight reductions in mean signal energy might be desirable is SOR, or the ability of choral singers to hear their own voices optimally when singing with others. When standing shoulder-to-shoulder, singers may experience a Lombard Effect (cf. Foot, 1965; Tonkinson, 1990) and thus tend to over-sing in a compensatory effort to hear sufficient feedback from their own voices. More spread inter-singer spacing may evoke more efficient singing through a better balance between self-sound and the sound of the rest of the choir without verbally directing singers to alter their vocal production.

To be clear, this study and previous investigations find that mean reductions in spectral energy attributable to some degree of spread inter-singer spacing tend to be modest reductions on the order of 1.5 - 3.5 dB SPL. That is, they constitute a nuance in choral sound. Yet results of previous studies (e.g., Daugherty, 1999; Daugherty, et al., 2013) indicate that singers and audience members alike readily perceive and significantly prefer this sound. I did not formally survey the ensemble in this study. However, its conductor reports anecdotally that following the recording session these singers requested spread spacing and they have employed it ever since in both rehearsals and public performances.

The finding that choir formation (sectional block vs. mixed) does not appear to influence appreciably the choral tone of this men's ensemble confirms results of previous acoustical investigations using mixed choirs (Aspass, McRae, Morris & Fowler, 2004; Mustafa, 2005; Morris, Musftafa, McCrae, Fowler & Aspass, 2007) and some previous perceptual studies (e.g., Atkinson, 2006; Daugherty, 1999, 2003; Lambson, 1961) with mixed choirs. In that light, writers of choral methods and choral conducting textbooks may wish to reconsider perpetuation of the acoustically oriented choir formation diagrams that regularly populate such books. Choir formations serve various useful purposes, including administrative and social ones. It appears, however, that they may not function well per se as a strategy to modify choir sound.

Contrary to the speculation of Morris, et al. (2007), results of this investigation do not indicate that, in the main, the overall contours of choir formation spectra differ noticeably as the sound of the choir travels into the venue. For the most part, LTAS contours acquired at conductor location and audience location microphones exhibit remarkable similarity. However, because the participants, literature, and venues vary between this study and Morris' investigation, further investigation of this matter is advisable.

Although still below the standard of a mean 1 dB SPL JND, a puzzling aspect of this study is the greater exhibited difference in mean spectral energy between sectional and mixed formations in circumambient spacing. It could be argued that a mixed formation in itself constitutes a modest inter-singer spacing phenomenon. For instance, singers in mixed formation do not stand contiguously by persons singing the same vocal line. Even when standing shoulder-to shoulder in mixed formation, a degree of lateral spacing exists between individual singers performing the same vocal line. Because data from this study show a negligible mean difference between formations in close spacing and given that these men exhibit less mean signal energy reduction between lateral and circumambient spacing conditions than between close and lateral conditions, it is possible that with male voices there exists a limit or boundary beyond which more spread inter-singer spacing begins to encourage slightly more energetic, soloistic singing. Were that the case, then mixed formation with circumambient spacing (which in one sense may be conceived as a circumambient-plus condition) may exacerbate or push that boundary still more by making it somewhat more difficult to hear other persons singing the same vocal line. Similarly, it is also possible that because this ensemble typically sang in mixed formation, the circumambient spacing condition confounded these singers' expectations of mixed formation hearing and they sought to compensate by singing with more volume. This matter warrants further research.

Room environments partner with choristers in determining the overall quality of a choir's sound (Ternström, 1989). For example, the same choir singing the same literature may exhibit significantly different LTAS contours when it transitions from a rehearsal room to a performance hall (Hom, 2014). Although for this study the choir remained in the same venue, the particular characteristics of this venue likely contributed to the findings of this investigation. Unfortunately, this venue exemplifies a reality encountered by many choirs as they sing in less than ideal environments.

Nonverbal, nuanced modification of choir sound appeals to choral conductor-teachers because such approaches may be time efficient and singer friendly. Results of the present study, the first acoustical investigation to compare variables of choir spacing and choir formation with the same ensemble, indicate that with a choir of male singers the ensemble's inter-singer spacing contributes more to differences in the choir's tone quality than does its particular choir formation.