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Acoustic and perceptual measures of SATB choir performances on two types of portable choral riser units in three singer-spacing conditions

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Abstract

Under controlled conditions, we assessed acoustically (long-term average spectra) and perceptually (singer survey, listener survey) six performances of an soprano, alto, tenor, and bass (SATB) choir ($N = 27$) as it sang the same musical excerpt on two portable riser units (standard riser step height, taller riser step height) with varied dimensions of largely horizontal space (close spacing, lateral spacing, circumambient spacing) between singers. Given previous research that suggested horizontally spread spacing between choristers contributes to chorister perceptions of more efficient vocal production and audience preferences for choral sound, we wondered: (1) if spectra analyses might point to a possible acoustical explanation for auditor preferences; and (2) if increasing the height of riser steps to add more vertical space between rows of singers would affect choir sound.

Statistical analyses of spectra data acquired from an audience position microphone found significant differences ($p < .001$) in mean signal amplitudes among the various performances. The taller riser unit appeared to enhance modestly the contributions of horizontally spread lateral and circumambient singer spacing. These effects were most robust (c.2–4dB) in diffusion of higher frequency partials in the 2.4–3.7kHz range in and around the 'singer's formant' frequency region on both riser units, and in 4.7–7.1kHz partials on the tall riser unit.

All choristers (100%) thought horizontal singer spacing influenced choir sound; 92.59% of singers described this perceived influence as 'moderate' or 'much.' Most choristers (96.29%) thought riser step height influenced choral sound, with 62.95% of singers perceiving this influence as 'moderate' or 'much.' Singers thought spread spacing contributed to most comfortable vocal production, better hearing of self and ensemble, and best overall choir sound.

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Listener (N = 21) survey results indicated significant preference for the overall sound of the spread singer conditions in close versus spread comparisons.

Keywords
choir risers, choral sound, long-term average spectra (LTAS), singer spacing

Music teacher Magnus Paysen (born 1875) filed an application with the United States Patent Office on 3 August 1930. Therein he described what would become one of the most commonly used pieces of equipment by school choirs in many parts of the world (see Figure 1). Paysen's application set forth the details of a collapsible chorus stand that could be 'easily carried about' and its 'plurality of shelves or platforms' folded to 'occupy the minimum of storage space when not in use' (Paysen, 1931). This riser unit, he suggested, afforded a portable, uniform means for choral ensembles, such as his own Hebron (Nebraska) Junior College A Cappella Choir, to be seen and heard while performing in a variety of venues.

'Paysen's Collapsible Chorus Stands' found a ready market after Paysen commenced their mass manufacture in Hebron around 1932. A 1934 advertisement claims sales 'in 28 states in two years,' with a picture of F. Melius Christiansen and the St. Olaf College Choir positioned on Paysen risers. 'You have made a very practical stand,' states Christiansen, 'I do not think there is anything in the country to compare with it' (Music Educators National Conference [MENC], 1934, p. 63). A newspaper account from the same year describes Paysen's 36-member choir 'making a summer tour in a big bus' (*The Ellsworth County Independent Reporter*, 1934). Amid rising interest in a cappella choral singing and choir touring in the United States (Kegerreis, 1970), such bus travel, along with daily performances in different school and church auditoria, likely contributed both to the perceived practicality of Paysen's invention and his marketing success.

Other manufacturers subsequently marketed portable choir risers. Over time, some construction features changed – for example aluminum rather than wooden or steel frames – and companies increasingly offered choices in the width of individual riser steps and the number of steps per riser unit. Paysen's advertising descriptors ['light, substantial, easily transported, small storage space, inexpensive'], though, succinctly captured the basic logistical appeal still used today in marketing portable choir risers (e.g., Wenger Corporation, 2010). Currently manufactured portable riser units (e.g., SICO Europe Ltd., 2010; Wenger Corporation, 2010) offer choices with respect to the width (e.g., 12 inches, 18 inches, 24 inches) and number (three, four, or five) of individual riser steps. However, the height (c.8 inches) between each riser step appears to have remained consistent, regardless of manufacturer, since Paysen's day (MENC, 1942, p. 71).

Paysen advertisements, moreover, asserted that his portable riser units could 'improve' a choir's 'singing-appearance-discipline' (MENC, 1936, p. 68) and 'make good choirs better' (MENC, 1942, p. 71; see Figure 2). This claim, that performing on portable risers may have desirable acoustical consequences, echoes still today in some advertisements (e.g., 'choral risers never sounded this good,' SICO, 2010).

One Paysen advertisement (MENC, 1943, p. 52) pictured businessmen standing shoulder-to-shoulder on his risers. With the weight of each man printed below, the apparent intent of this ad was to demonstrate the sturdiness of the units. At the same time, however, it also illustrated an early assumption of maximum occupancy that continues to inform the marketing and use of choir risers. Contemporary advertisements typically provide consumers with only two calculations of riser occupancy: one based on 'performers (standing) shoulder-to-shoulder,' and the other based on 'performers facing center, shoulders turned in' (SICO, 2010; Wenger Corporation, 2010).

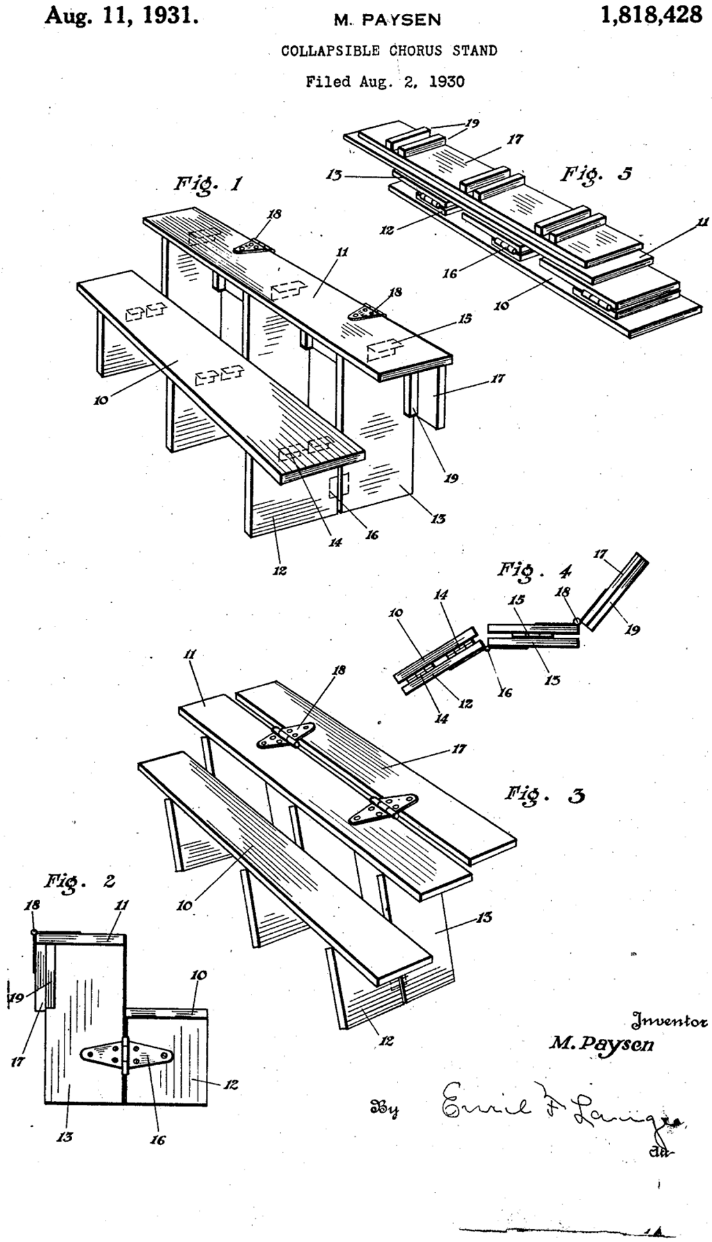

Figure 1. Payson patent application, 1930

Several lines of investigation have addressed possible effects of close proximity of choir singers to one another. Tonkinson (1994) examined the Lombard effect among singers in choir-like conditions. He found that singers, unless otherwise instructed, tended to raise their voices in the presence of loud sounds from neighboring singers. Ternström (1989, 1994, 1999) explored self-to-other (SOR) ratios among choir singers. Results from these studies indicated that choir singers exhibited defined

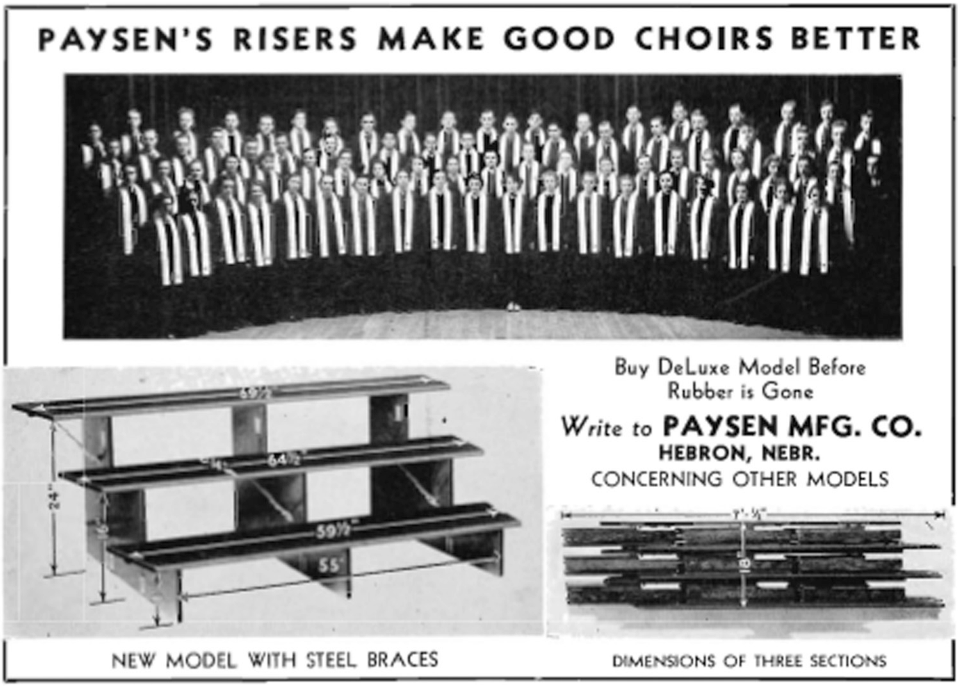

Figure 2. Paysen advertisement, *Music Educator's Journal*, 1942

preferences for balance between the feedback received from their own voices (self) and the sound received from the rest of the choir (other). Of the two factors, ability to hear one's own voice sufficiently appeared to be of primary importance.

Daugherty (1996, 1999, 2003) found that the amount of inter-singer space afforded choristers performing on portable risers affected singer and audience perceptions. Both choristers and auditors expressed significant preferences for spread singer spacing over close, shoulder-to-shoulder spacing, regardless of the particular standing formation (sectional or mixed) employed. Singers reported more efficient vocal production and better ability to hear their own voices with more spread spacing. In a subsequent study, Daugherty (2005) found that choir performances were significantly more in tune with spread singer spacing than with close spacing.

Some choral teacher-conductors have expressed concern that horizontal stage dimensions of their school auditoria cannot accommodate additional riser units needed for large ensembles to perform with laterally spread singer spacing (Daugherty, 1996). Whether increased height between riser steps, thereby providing more vertical space between rows of singers, might yield discernable choral sound differences is a question of practical interest for choral music educators.

Ford (2003) examined auditor ($N = 139$) preferences for choral sound with respect to anechoic chamber choir performances that included a fully resonate singer's formant and performances that used a weaker singer's formant resonance. Choir members viewed a running spectrogram as they sang to assist them in monitoring energy in the singer's formant region. Auditors significantly preferred the choral sound produced with the weaker singer's formant resonance. Mean amplitude differences between the fully and less-resonate singer's formant conditions were approximately 4dB.

Some studies have employed long-term average spectra (LTAS) data to assess acoustical differences between various choir sectional and mixed formations (Aspaas, McCrea, Morris, & Fowler, 2004; Morris, Mustafa, McCrea, Fowler, & Aspaas, 2007) and between different dynamic levels of choir singing (Morris, Ternström, LoVetri, & Berkun, 2010). No study to date, however, has used LTAS data to assess potential acoustical differences between uniform chorister spacing conditions. In light of previous studies (e.g., Daugherty, 1999, 2003) that found significant auditor preference for spread singer spacing over close singer spacing when listening to recordings obtained from an audience position, LTAS measures might assist to identify possible acoustical reasons for such auditor preference.

The purpose of this study was to assess acoustically and perceptually six performances of an SATB choir ($N = 27$) as it sang the same musical excerpt on two riser units (standard riser step height, taller riser step height) with varied dimensions of horizontal and vertical space (close spacing, lateral spacing, circumambient spacing) between singers. To that end, the following research questions guided this investigation:

1. What differences, if any, do long-term average spectra (LTAS) data acquired from an audience position microphone indicate about the overall sound of this choir during performances on two riser units with varying amounts of space among the singers?
2. What perceived differences, if any, do singers report after performing on two riser units (regular, taller) in three spacing conditions (close, lateral, circumambient)?
3. Do listeners ($N = 21$) hear any differences between audience position recordings?

Methods and procedures

All procedures for this study were approved following an institutional review board (IRB) process designed to ensure ethical treatment of participants, the integrity of participant recruitment, and the informed consent of all participants. With IRB approval, participants were informed beforehand of the general purpose of the study (to assess performer and listener preferences for choral sound). Participants were not informed beforehand of the specific variable of interest (chorister spacing).

Participants

A convenience choir of experienced choral singers ($N = 27$) from a midwestern university constituted the choral ensemble employed for this study. Participating singers included 14 females (eight sopranos, six altos) and 13 males (six tenors, seven basses). Singers ranged in age from 18 ($n = 1$) to 38 ($n = 1$) years, with a modal age of 20 years. Most ($n = 20$, 70.74%) were music majors. There were six graduate students and 21 undergraduate students in the ensemble.

A convenience sample of listeners ($N = 21$) also participated in the study. These auditors ranged in age from 20 to 36 years. Each listener was an undergraduate ($n = 17$) or graduate ($n = 4$) student majoring in music at the same university. No listener reported any known hearing problems. These listeners were selected – irrespective of their major or performing instruments – according to their availability at the scheduled time of the listening task, their having attended at least 10 choir concerts within the past year, and their willingness to participate in the study.

Musical excerpt and rehearsals

Singers rehearsed and performed ‘Ave Regina Coelorum’ by Anton Bruckner. We chose this motet because it was homophonic, lent itself to a moderate tempo, and was unfamiliar to the singers. We thought this initial lack of familiarity would afford singers a mutual learning experience, while controlling for any individual biases or associations potentially ensuing from prior experiences with singing this particular motet.

Singers rehearsed together on four occasions prior to a recording session. At their first rehearsal we randomly assigned singers positions in one of three rows in a block sectional choir formation. Choristers maintained these assignments throughout rehearsals and the recording session. To guard against possible novelty effects, singers spent equal amounts of rehearsal time in each of the spacing conditions that would be employed in the recording session. Two rehearsals occurred in a choir rehearsal room, while the final two rehearsals took place in the recital hall that would serve as the recording venue.

Recording session procedures and equipment

During a 25-minute recording session in a university recital hall, the choir sang the first verse of the strophic 'Ave Regina Coelorum' motet (duration: 64 seconds) in each of the following six conditions: (1) regular risers with close singer spacing; (2) regular risers with lateral singer spacing; (3) regular risers with circumambient singer spacing; (4) tall risers with circumambient singer spacing; (5) tall risers with lateral singer spacing; and (6) tall risers with close singer spacing. We used Wenger Tourmaster three-step risers as the regular riser unit for this study. 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. For the taller riser unit, we maintained other dimensions of the regular risers while adding an additional 4 inches to the height of each riser step. Thus the height between each riser step on the tall riser unit was 12 inches.

Singer spacing distances on the two riser units conformed to those used in previous studies (e.g., Daugherty, 1999, 2003). 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 inches lateral distance and, in addition, left vacant the equivalent of a riser step width (18 inches) 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 (see Figure 3).

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.

An Edirol R-109 digital sound recorder captured each performance at a sampling rate of 44.1kHz (16 bits) in .wav format. We positioned the recorder at a level commensurate with a sitting audience member's head at a location halfway back in the hall's center audience seating section, 32.5ft from the first row of the choir. Measured reverberation time of the unoccupied hall at that position was 1.5 seconds at mid frequencies. Volume and gain controls were set manually at the beginning of the recording session and remained the same throughout all recordings.

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

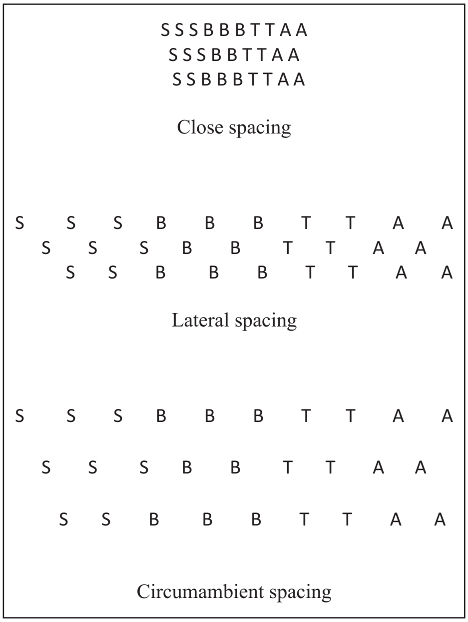

Figure 3. The three singer spacing conditions (close, lateral, circumambient) in the block sectional formation used for this study

Auditor recordings

In a quiet room auditor participants ($N = 21$) listened to two pairs (regular riser close vs. spread, tall riser close vs. spread) of the same recordings used for LTAS analyses. We manually transferred the acquired .wav recordings to a compact disc that was played on a Tascam CD-150 player connected to a PreSonus HP4 distribution amplifier. Auditors listened through AKG 240 headphones. Volume remained consistent. At no time was there compression of the electronic signal.

Previous studies (Daugherty 1996, 1999, 2003) examined preferences of large groups of auditors (overall $N = 368$) with respect to close and spread singer spacing. Because a primary focus of the present investigation was acoustical assessment, we employed a small group of experienced listeners ($N = 21$) for this study to gain a broad notion of whether any differences in LTAS would be detected by this particular array of human hearers. Auditors were informed that the purpose of this investigation was to assess preferences for choral sound. They were not informed of the specific variable (singer spacing) of interest; thus they were not aware which recordings pertained to which spacing condition.

Surveys

Singer survey. Choir members completed a short survey (see Figure 4) at the conclusion of the recording session. This researcher-designed survey sought to ascertain singers' perceptions after they performed on two riser units in three singer-spacing conditions. The survey consisted of seven questions based on variables identified by previous research (e.g., Daugherty, 2003): (1) perceived comfort/ease of individual vocal production; (2) perceived ability to hear self and others; (3) perceived effects of singer spacing and riser conditions on the sound of the choir; and (4) perceived best overall performance by the choir.

1. In which arrangement did you think the choir as a whole sounded best?

(Circle one): Regular riser unit | Taller riser unit

(Circle one): Close spacing | Lateral spacing | Circumambient spacing

2. I thought my own vocal production was most efficient/comfortable in configuration:

(Circle one): Regular riser unit | Taller riser unit

(Circle one): Close spacing | Lateral spacing | Circumambient spacing

3. I thought my own vocal production was least efficient/comfortable in configuration:

(Circle one): Regular riser unit | Taller riser unit

(Circle one): Close spacing | Lateral spacing | Circumambient spacing

4. In which arrangement were you generally able best to hear/monitor the sound of your own voice?

(Circle one): Regular riser unit | Taller riser unit

(Circle one): Close spacing | Lateral spacing | Circumambient spacing

5. In which arrangement were you generally able best to hear/monitor the sound of the rest of the choir?

(Circle one): Regular riser unit | Taller riser unit

(Circle one): Close spacing | Lateral spacing | Circumambient spacing

6. What effect, if any, do you think spacing between/among singers had on the sound of this choir?

(Circle one); Not sure | No effect | A little effect | A moderate Effect | Much Effect

7. What effect, if any, do you think taller riser steps had on the sound of this choir?

(Circle one); Not sure | No effect | A little effect | A moderate Effect | Much Effect

Figure 4. Singer survey items

Auditor survey. Auditors ($N = 21$) completed a two-item survey after each hearing of a recorded pair of choir performances. Survey phrasing replicated language used in previous studies (Daugherty, 1999, 2003). We first inquired whether listeners detected differences in the overall sound of the two recordings (comparing the overall sound of the choir in these two performances, I heard: no difference, a little difference, much difference, very much difference, not sure). We then asked about listener preferences (I preferred the overall sound of the: first performance, second performance, both sounded the same to me).

Results

Research question one: Long-term average spectra

Our first research question asked if long-term average spectra (LTAS) data would indicate acoustical differences between the choir's six performances. Transmitted human vocal sound is complex sound. That is, it includes an array or spectrum of simultaneous frequencies, each of which constitutes a part (or partial) of the complex whole. In addition to the perceived sung pitch (fundamental

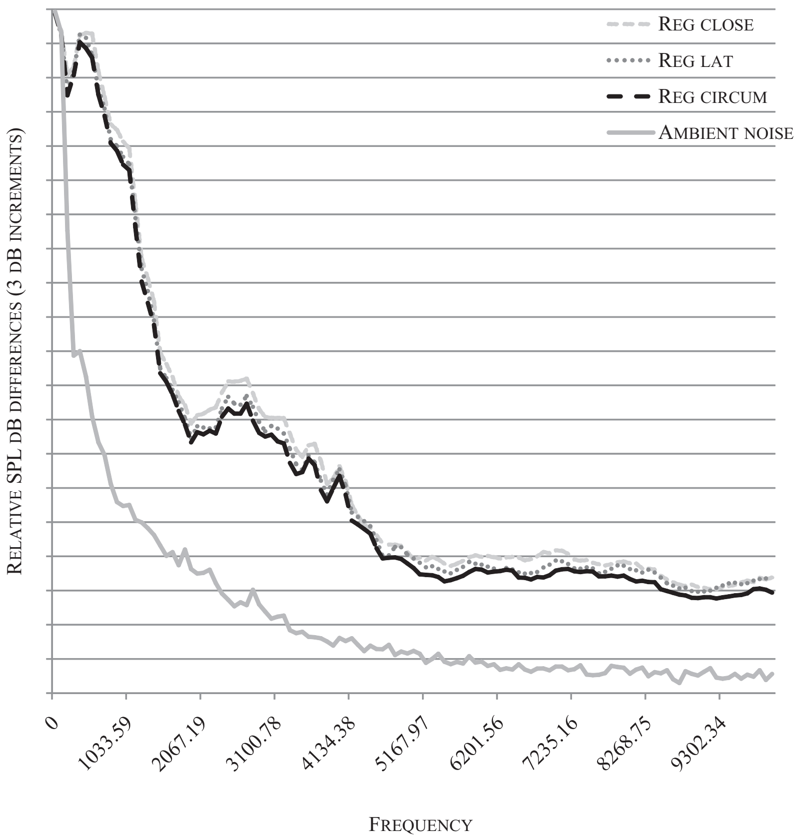

Figure 5. Audience position LTAS contours of performances with close, lateral, and circumambient singer spacing on the regular riser unit

frequency), there are numerous other simultaneous frequencies that inform the perceived timbre (color or quality) of the sound. Each spectral frequency, moreover, exhibits energy or power. Depending on context, some partials may be dampened (exhibit less energy) or amplified (exhibit more energy).

Long-term average spectra measurement provides information averaged over a period of time about timbre. This information includes both frequency and sound pressure density (amplitude intensity) across the spectrum of complex sound. More particularly, LTAS graphs present sound pressure power as a function of frequency. Sound pressure level amplitude is presented according to a decibel (dB) scale. Frequency is presented as Hertz (the number of sound cycles per second, abbreviated as Hz). Because higher frequency partials may entail thousands of sound cycles per second, kiloHertz (kHz) serves as a shorthand way of expressing cycles per second for these partials. In sum, LTAS data provide a quantifiable index of sound quality across a specified period of time. These data can be useful for detecting persistent spectral events.

Figures 3 and 4 present obtained LTAS contours according to the three singer-spacing conditions employed (close, lateral, circumambient) and type of riser unit (regular riser, taller riser). As evident from Figures 5 and 6, the ambient noise of the recital hall (primarily due to the hall's air conditioning system) did not appear to be a confounding factor for any of the recorded conditions.

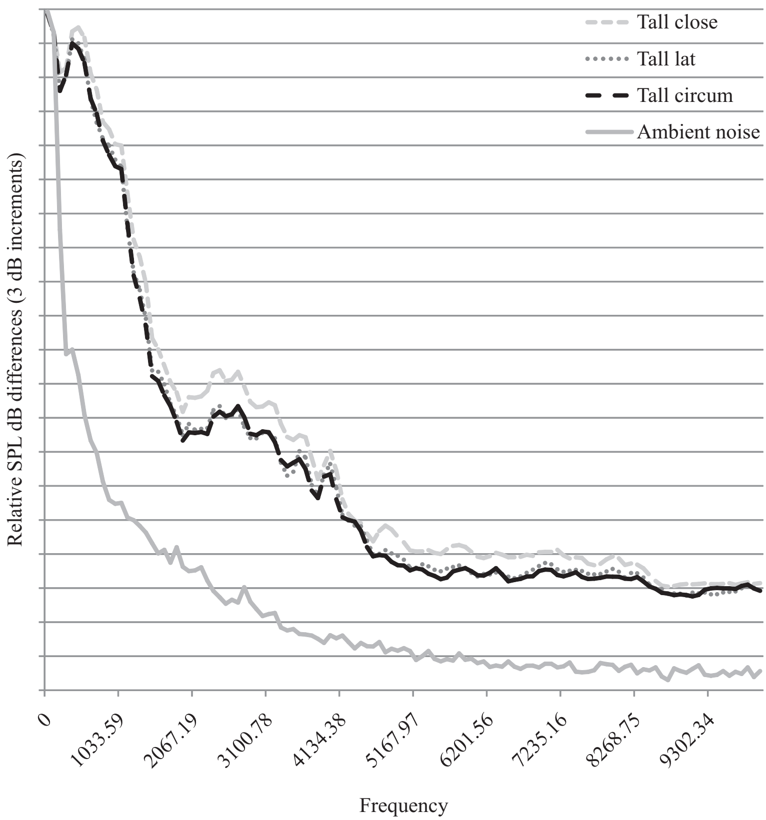

Figure 6. Audience position LTAS contours of performances with close, lateral, and circumambient singer spacing on the tall riser unit

Entire spectrum results. Comparisons ($N = 6$) of overall (0–10kHz) mean signal amplitude differences among the three singer-spacing conditions indicated that signal energy tended to decrease as largely horizontal space between and among singers increased, regardless of the riser unit employed: (1) regular riser close versus regular riser circumambient ($M = -1.42$dB); (2) regular riser close versus regular riser lateral ($M = -0.76$dB); (3) regular riser lateral versus regular riser circumambient ($M = -0.65$dB); (4) tall riser close versus tall riser circumambient ($M = -1.82$dB); (5) tall riser close versus tall riser lateral ($M = -1.61$dB); (6) tall riser lateral versus tall riser circumambient ($M = -0.22$ dB).

Overall mean amplitude comparisons ($N = 3$) according to riser unit indicated that signal amplitudes decreased with taller riser steps in regular riser lateral versus tall riser lateral ($M = -0.50$dB) and regular riser circumambient versus tall riser circumambient ($M = -0.65$dB) comparisons, but not in the regular riser close versus tall riser close comparison ($M = 0.34$dB).

A 2 × 3 repeated measures analysis of variance (ANOVA) found a significant interaction effect, $F(1,116) = 126.037$, $p < .001$. Nine follow-up paired *t*-tests (two-tailed) measured specific differences in the model with a Bonferroni adjustment of alpha levels to provide conservative tests of significance ($p = .05/9 = .0056$). *T*-test results indicated significant differences ($p < .001$) in all nine pairs compared, with decreased signal amplitudes in each spread singer-spacing condition and with decreased signal amplitudes in two of the three riser condition comparisons (regular lateral vs. tall lateral and regular circumambient vs. tall circumambient).

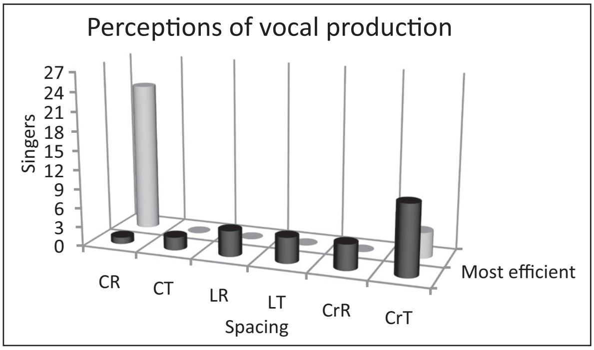

Figure 7. Singers' perceptions of their individual vocal production
Note: **CR** = close spacing/regular riser; CT = close spacing/tall riser; LR = lateral spacing/regular riser; LT = lateral spacing/tall riser; CrR = circumambient spacing/regular riser; CrT = circumambient spacing/tall riser.

Specific frequency region results. As indicated by Figures 5 and 6, spread singer spacing yielded more robust signal amplitude decreases on both riser units from 2.4–3.7kHz in and around the 'singer's formant' frequency region. This region also includes frequencies where the human ear is most sensitive (Fletcher & Munson, 1933). When comparing circumambient spacing and close, shoulder-to-shoulder conditions, these decreases in the 2.4–3.7kHz region ranged from −1.2 to −2.9dB ($M = -2.1$dB) on the regular riser unit, and from −2.1 to −3.8dB ($M = -3.0$dB) on the tall riser unit.

The tall riser unit, moreover, contributed to signal amplitude decreases in the 4.7 to 7.1kHz region. Comparison between close and circumambient singer spacing on the tall riser unit indicated a mean amplitude decrease of 2.3dB (range: −1.7 to −2.9dB) in 4.7–7.1kHz partials, while the same comparison on the regular riser unit yielded a mean decrease of 1.4dB (range: −0.8 to −1.9dB).

Research question two: Singer perceptions and preferences

Our second research question inquired about singer perceptions after performing on two riser units in three singer-spacing conditions. Results are presented according to: (1) perceived effects of taller risers and singer-spacing conditions; (2) perceptions of most efficient and least efficient individual vocal production; (3) hearing of self and others; and (4) perceived best overall sound of the choir.

Perceived effects of risers and singer spacing. Responses to survey item six ('What effect, if any, do you think spacing between/among singers had on the sound of this choir?') indicated that 100% of these choristers thought singer-spacing conditions had some effect on the choir's sound (no effect, $n = 0$; a little effect, $n = 2$, 7.41%; moderate effect, $n = 17$, 62.96%; much effect, $n = 8$, 29.63%; not sure, $n = 0$). Most participants (92.59%) described this perceived influence as 'moderate' or 'much.'

Responses to survey item seven ('What effect, if any, do you think taller riser steps had on the sound of this choir?') indicated that 96.29% ($N = 26$) of participants thought taller riser step heights had some effect on the choir's sound (no effect, $n = 1$; a little effect, $n = 9$, 33.33%; moderate effect, $n = 13$, 48.14%; much effect, $n = 4$, 14.81%; not sure, $n = 0$). While 62.95% of the singers described this perceived influence as 'moderate' or 'much,' no single descriptor received endorsement from a majority of participants, as was the case with singer spacing.

Least and most efficient vocal production. Figure 7 compares responses to survey item two ('Most efficient/comfortable' individual vocal production) and survey item three ('Least efficient/

comfortable' individual vocal production). Most participants thought the close spacing condition on the regular riser unit promoted their least efficient vocal production (*n* = 23, 85.19%), while one of the more spread spacing conditions, either horizontal or vertical, contributed to their most efficient vocal production (*n* = 25, 92.59%).

Hearing of self and others. Responses to survey item four ('In which arrangement were you generally able best to hear/monitor *the sound of your own voice*?') indicated that a majority of participants (*n* = 21, 77.78%) thought they best heard the sound of their own voices on the tall riser unit in circumambient spacing. Responses to survey item five ('In which arrangement were you generally able best to hear/monitor *the sound of the rest of the choir*?') indicated that a majority of participants (*n* = 20, 74.07%) thought they best heard the sound of the rest of the choir in one of the closer singer-spacing conditions (close spacing on the regular riser unit: *n* =11, 40.74%; close horizontal spacing on the tall riser unit: *n* = 9, 33.33%). Most participants (*n* = 16, 59.26%) thought the regular riser unit afforded best hearing of choir sound.

Perceptions of best choir sound. Responses to survey item 1 ('In which arrangement did you think *the choir as a whole* sounded best?') indicated nearly all singers (*n* = 26, 96.30%) thought the choir sounded best when singing in a more spread spacing condition, whether horizontal or vertical (tall riser close: *n* = 3, 11.11%; lateral: *n* = 9, 33.33%; circumambient: *n* = 14, 51.85%). Overall responses also indicated most of these singers (*n* = 18, 67.67%) perceived that the choir's best sound occurred while performing on the tall riser unit (tall riser close: *n* = 3, 11.11%; tall riser lateral: *n* = 5, 18.52%; tall riser circumambient: *n* = 10, 37.04%).

Research question three: Listener results

In order to assess whether particular listeners (*N* = 21) would report differences in the overall sound between close and spread choir configurations on both riser units, a convenience sample of auditors individually listened to two pairs of randomly ordered performances (regular riser close vs. lateral, tall riser close vs. lateral) from the same recordings used for LTAS analyses. For the regular riser comparison, 19 listeners (90.5%) reported hearing a difference: 'a little difference' (*n* = 13), 'much difference' (*n* = 2), very much difference' (*n* = 4). Of those 19 listeners who reported hearing a difference, 18 (85.7% of all listeners) preferred the excerpt with laterally spread spacing, *p* = .002, Fisher's exact probability test (two-tailed). For the tall riser comparison, all listeners (100%) reported hearing a difference: 'a little difference' (*n* = 12), 'much difference' (*n* = 4), 'very much difference' (*n* = 5). All but one (95.2%) of the listeners preferred the excerpt with laterally spread spacing, *p* = .00005, Fisher's exact probability test (two-tailed).

Discussion

This investigation yields three primary findings of interest to choir directors and researchers. First, LTAS data indicate that, regardless of riser unit, largely horizontal spread spacing (lateral, circumambient) of singers yields a consistent diffusion of certain higher frequency partials, notably in the 2.2–3.7kHz region. While sound pressure naturally decays with increased distance from its source, these signal amplitude reductions occur while measuring the choir's sound at a consistent audience location. There is thus some assurance that differences stem from the independent variables of singer spacing and riser step heights.

Second, choir members report that, when compared to close, shoulder-to-shoulder configurations, spread singer spacing is conducive to their most comfortable vocal production, better hearing of their own voices in relation to the sound of the rest of the choir, and better overall choir performance.

Such perceptions appear consistent with results obtained in previous studies (Daugherty, 1996, 1999, 2003) from choir singers performing on portable risers with 8 inches step heights.

Third, singer participants in this study, although by lesser majorities, think a taller riser step height (12 inches) contributes positively to individual vocal production, hearing, and the sound of the choir as a whole. LTAS trends appear to indicate some differences at an audience position attributable to the increased height between riser steps on the taller units. In particular, the taller riser unit appears to reduce by about 1dB more than the regular riser unit the signal amplitude of partials in the 2.2–3.7kHz region when singing with spread spacing, and also contributes to increased reductions of 4.7–7.1kHz partials.

Because all choirs are not the same and all performance venues are not the same, results from this study should not be generalized to other choirs and other concert halls. Taken together, however, these specific findings suggest that spread singer spacing (most prominently in the horizontal dimension, but also somewhat in the vertical dimension) assists the architecture of this particular auditorium to diffuse at an audience position certain higher frequency partials in this choir's singing, and that it does so non-intrusively – that is, without asking singers consciously to manipulate their vocal production.

In terms of choral pedagogy, the mean signal amplitude reductions (2.2–3.9dB) in the 2.2–3.7kHz region obtained here tend to compare favorably with the approximately 4dB-signal amplitude differences between fully and less-resonate singer's formant reported by Ford (2003), who found significant auditor preference for choral sound with less energy in the singer's formant region. This diffusion may contribute to audience perceptions of choir timbre and 'blend,' and thus ultimately contribute to an acoustical explanation of why auditors (e.g., Daugherty, 1996, 1999, 2003) have reported significant preference for choir performances with spread chorister spacing. Future studies might well explore this possibility in order to confirm or refute it with other choirs in other halls.

Some voice teachers argue that choir directors who request singers to alter their vocal tracts in order to achieve less resonance in higher frequency partials in the cause of a more 'blended,' less 'soloistic' choral timbre unnecessarily compromise the efficiency of individuals' vocal production. It may be that choir directors can achieve some reduction in higher partial energy for listeners simply by affording their singers more inter-singer room; that is, without requiring singers to dampen these partials by manipulating their vocal production.

Future studies might compare the acoustical effects of choir spacing by obtaining data from a conductor's position as well as various audience locations. A measure of individual choristers' amplitude within the soundscape of the choir, perhaps through use of phonation monitors, would also be instructive.

Howard and Angus (2006) suggest that differences of 1dB in the amplitude of complex sounds may constitute 'just noticeable differences' for human hearing, dependent on the nature of the sound and the hearing acuity of listeners. That factor lends some perspective to results obtained here. Mean signal reductions per each spacing and riser condition across the 0–10kHz spectrum ranged from 0.65dB to 1.42dB on the regular riser unit, and from 0.22dB to 1.82dB on the taller riser unit. Such amplitude differences may not be readily discernable to human hearers. However, the 2.2–3.9dB reductions (from 2.2dB to 2.9dB on the regular riser unit, and from 3.1 to 3.9dB on the taller riser unit) obtained in the 2.2–3.7kHz region might likely be audible, particularly when we consider that human hearing is more sensitive to amplitude changes in the 2–4kHz region than in other frequency regions (Fletcher & Munson, 1933).

Listening panel results provide some support for that contention. Most listeners report hearing differences between close versus lateral spacing condition comparisons on both riser units. Most listeners describe that difference as 'a little difference,' which is in keeping with findings from previous investigations (Daugherty, 1996, 1999, 2003). Significant listener preference for the overall choral sound of the more spaced conditions also conforms to results of previous studies.

Such factors suggest that chorister spacing may add a nuance, but nonetheless a detectable and desirable nuance, to choir sound as heard by audience members. LTAS results from the present study indicate that reduction of energy in higher partials in the 2.2–3.7kHz region may be primarily responsible for that subtle difference. Future research might focus particularly on the 2–4kHz region.

Singing on riser units with taller step heights also merits further investigation. LTAS trends appear to indicate some differences at an audience position attributable to the increased height between riser steps on the taller units. In particular, the taller riser unit appears to reduce by about 1dB more than the regular riser unit the signal amplitude of partials in the 2.2–3.7kHz region when singing with spread spacing, and also contribute to increased reductions of 4.7–7.1kHz partials. However, the taller riser unit used here had a vertical distance of 12 inches between singer platforms, while the consistent horizontal distance between singers in the lateral and circumambient conditions was twice that (24 inches) on the taller riser unit and three times as much on the regular risers, which had a vertical distance of 8 inches between singer platforms. It may be that a greater than 4 inches increase in riser step height might yield different results. The issue, in other words, may be the ratio of vertical spacing to horizontal spacing. In this respect, the circumambient spacing condition may confound examination of riser step height per se, because it combines 24 inches lateral singer spacing with a vacant middle row, thus adding some increased vertical distance as well. Future investigations might test only close versus lateral singer spacing on regular versus taller riser units.

Microphone calibration is not strictly necessary for obtaining LTAS comparisons at one consistent location. But future studies, particularly investigations that desire simultaneous data from multiple microphone locations (e.g., conductor position and various audience positions), will want to incorporate calibration procedures.

In sum, results of this investigation: (1) suggest that spread chorister spacing contributes primarily to choral sound at an audience position in this auditorium by diffusion of certain higher frequency partials; (2) indicate that increased riser step height may possibly boost this effect by about 1dB; and (3) confirm findings of previous studies with respect to singer and auditor preference for spread spacing.

Choir singing occurs worldwide in both formal and informal education contexts. Portable choir risers, because they are easily transported, assembled and dissembled, facilitate choir rehearsals and performances in many of these contexts by enabling larger groups of choristers to see and be seen in virtually any venue –from multi-purpose classrooms to gymnasia and cafeterias, and from community centers to social halls and shopping malls.

Teachers routinely make logistical decisions about how many riser units may be needed to accommodate singers and about who stands where. Such logistical choices, however, potentially entail acoustical and psycho-acoustical consequences. Scientific research of choir spacing phenomena, including examination of riser step dimensions and how singers might be positioned on risers for optimal vocal and acoustical efficiency in various venues, can assist music educators to make informed, vocally friendly decisions about these matters in their particular singing contexts.

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Abstracts

Mesures acoustiques et perceptifs des performances du chœur satb sur deux types d'unités portables de contramarche sous trois conditions d'espacement des chanteurs

Dans des conditions contrôlées, nous avons évalué six performances d'une chorale SATB ($N = 27$) du point de vue acoustique (Spectre Moyen à Long Terme) et perceptuel (Enquête Chanteur - Enquête Auditeur) en chantant le même extrait musical sur deux unités portables de contramarche (contramarche à la hauteur normale, contramarche en hauteur plus haut) avec des dimensions variées de l'espace horizontale (l'espacement proche, l'espacement latéral, l'espacement circumambient) entre les chanteurs. Compte tenu de recherches antérieures qui suggéraient que l'espacement horizontal entre les choristes contribue à la perception de choriste d'une production vocale plus efficace et à la préférences du public pour le son choral, nous nous sommes demandés (a) si les analyses des spectres peuvent pointer vers une explication possible des préférences acoustiques des auditeurs et (b) si l'augmentation de la hauteur de contremarches pour ajouter plus d'espace vertical entre les rangées de chanteurs aurait une incidence sur le son du chœur. Les analyses statistiques des données de spectres acquis à partir d'un microphone placé entre les spectateurs ont trouvé des différences significatives ($p < 0{,}001$) dans l'amplitude moyenne du signal parmi les divers spectacles. L'unité de contremarche en grande taille semblé augmenter légèrement la contribution de l'espacement horizontal latéral et circumambient des chanteurs. Ces effets ont été les plus robustes (2 v. - 4 dB) dans la diffusion des partiels de fréquence plus élevée dans la plage de 2,4 – 3,7 kHz dans et autour de la région de fréquence de «formant du chanteur» sur les deux unités de contremarche, et dans 4,7 à 7,1 kHz (partiels) sur la unité de contremarche plus haute. Tous les choristes (100%) pensent que l'espacement horizontal parmi les chanteurs a influencé le son du choeur; 92,59% des chanteurs ont décrit cette influence perçue comme «modérée» ou «beaucoup». La plupart des choristes (96,29%) ont trouvé que la hauteur de contremarche a influencé le son de la chorale, avec 62,95% des chanteurs percevant cette influence comme «modérée» ou «beaucoup». Les chanteurs ont pensé que l'espacement a contribué à une production vocale plus confortable, une meilleure audition de soi et de l' ensemble, et le meilleur son global du choeur. Des résultats de l'enquête ($N = 21$) ont indiqué préférence des auditeurs pour la qualité sonore globale dans des conditions avec d'espacement parmi les chanteurs en comparaison avec leurs positions plus proche.

Mediciones acústicas y perceptivas de interpretaciones corales a cuatro voces sobre dos tipos de tribunas móviles con tres modos de espaciamiento de los coristas

Bajo condiciones controladas, evaluamos acústica (espectros medios) y perceptivamente (encuesta a cantores y a oyentes) seis actuaciones de un grupo a cuatro voces mixtas ($N = 27$) mientras cantaban el mismo fragmento musical sobre dos tribunas portátiles (con contrahuella normalizada y de mayor altura, respectivamente) y con diferente espaciamiento horizontal entre los coristas (estrecho, lateral y circundante). A partir de investigaciones previas que sugerían que un espaciamiento horizontal entre coralistas contribuye a percepciones de los mismos de una producción vocal más eficiente y a una mayor predilección del público de la sonoridad del coro, nos preguntamos: a) si el análisis de los espectros podrían señalar una posible explicación acústica que explicara las preferencias del oyente; b) si el aumento de la contrahuella de los peldaños para añadir mayor espacio

vertical entre las filas de coristas afectaría la sonoridad del coro. Los análisis estadísticos de los espectros tomados desde un micrófono situados a la altura del público encontraron diferencias significativas ($p < 0'001$) en las amplitudes de la señal media recogidas entre las diferentes interpretaciones. La tribunal móvil más alta pareció mejorar discretamente las contribuciones del espaciamiento horizontal lateral y circundante. Estos efectos fueron más robustos (cerca de 2-4 dB) en la difusión de sobretonos parciales de alta frecuencia en la gama de los 2'4 y 3'7 kHz alrededor de la región de frecuencia del "formante del corista" en ambas escalinatas, y en el rango de entre 4'7 y 7'1 kHz para los parciales en la tribuna de mayor altura. Todos los coristas (100%) creían que su espaciamiento en horizontal influía en el sonido del coro; el 92'59% describieron la influencia de esta percepción como "moderada" o "alta". La mayoría (96'29%) pensaban que la influencia de los peldaños más elevados influían en el sonido coral, con un 62'95% valorando esta influencia como "moderada" o "alta". Los coristas también creían que el espaciado contribuía a una producción vocal más cómoda, mejor audición del propio sonido y del conjunto, y una mejor sonoridad coral de conjunto. Los resultados de la encuesta a los oyentes ($N = 21$) indicaron una preferencia clara por la sonoridad global con un espaciamiento estrecho de los corista frente a los más espaciosos.