The Effects of Musician's Earplugs on Acoustic and Perceptual Measures of Choral and Solo Sound

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Summary: Objectives. The purpose of this investigation was to assess the effects of earplugs on acoustical and perceptual measures of choral and solo sound.

Methods. The researcher tested the effects of musician's earplugs on choral and solo timbre and singer perceptions. Members of an intact women's university choir recorded *Dona Nobis Pacem* under two conditions, no earplugs and with earplugs over time. Approximately half of the choir members also participated as soloists, recording *Over the Rainbow* under the same two conditions. All recordings were analyzed using long-term average spectra (LTAS). After participating in each recording session, the participants responded to a questionnaire about ability to hear self (solo and choral context) and ability to hear others (choral context) under two conditions, no earplugs and with earplugs.

Results. LTAS results revealed that wearing earplugs in a choral setting caused decreased mean signal energy (>1 dB), resulting in less resonant singing. LTAS results also indicated that wearing earplugs in a solo setting had less effect on mean signal energy, resulting in a mean difference <1 dB in 3 of the 4 weeks studied. Singer questionnaire responses showed that wearing earplugs had a greater effect on participants' ability to hear others than it did on their ability to hear themselves.

Conclusions. In the context of this study, it seems that wearing earplugs had more effect on timbre and the ability to receive sufficient auditory feedback in a choral setting than it did in a solo setting. Findings from this study could provide important information when structuring hearing conservation strategies.

Key Words: Musician's earplugs–Hearing protection devices–Hearing loss–Sound dose–Noise-induced hearing loss.

REVIEW OF LITERATURE

The vocational demands of musicians require an acute sense of hearing, probably more so than in any other profession. Vocalists, in particular, face specific challenges inherent to the uniqueness of their instrument.[1] Singers employ a built-in neurobiological instrument to make music, the tuning of which is internal and requires an accurate perception of pitch. This perception of pitch includes the fundamental frequency, the timbre or harmonics of that sound, as well as the intensity of the sound.[2] A choral singer must be able to accurately hear themselves as well as the rest of the choir and make pitch and dynamic adjustments based on that aural feedback. Even a mild hearing loss could cause out of tune or excessively loud playing or singing, severely affecting a musician's ability to adequately perform his or her job.[3]

Singers are exposed to a variety of sound sources, often singing in both solo and choral contexts and relying on their hearing to produce accurate and in-tune sounds. There are, however, inherent differences between the two types of singing, and vocalists adjust their singing depending on whether they are singing in a solo or choral setting. Soloists, particularly those singing with orchestral accompaniment, work to produce a sound that has a certain "ringing quality" that will carry over the orchestra. Male singers and altos develop the singer's formant, an emphasis of the upper formants, typically around 2400–3000 Hz, enabling them to sing above the orchestra, which is usually around 500 Hz. Soprano soloists' ability to sing over the orchestra is produced by emphasizing the first formant.[4] The emphasis of the upper partials in solo singing is opposite that found in choral singing.

In a choral context where the goal is to produce a harmonious and unified blending of voices, it appears that singers adjust their articulation and phonation to accentuate the fundamental tone while simultaneously dampening the upper partials.[5,6] To achieve this, choir members constantly adjust their own sound (Self) to that of the rest of the choir (Other). The ability to hear oneself in an ensemble is often determined by the difference in sound pressure levels (SPLs) between "self" sound and "other" sound. In choral singing, Self-to-Other ratio (SOR) describes this difference in SPLs between oneself and other choristers, expressed in decibels. Ideally, the feedback from Self should be greater than the sound of Other, with sopranos typically having a higher SOR than the other voice parts.[7] The inability to hear one's own voice can result in pitch and timbre errors.[8] Whether in a choral setting where a singer must hear and tune to others or in a solo situation, precise hearing is vital to a vocalist's success.

It appears that by the very nature of their vocation, singers and instrumentalists may be at risk of developing occupational hearing loss due to repeated exposure to high sound levels. Occupational hearing loss in an industrial setting is termed noise-induced hearing loss (NIHL), a condition that is irreparable but also avoidable.[9] NIHL usually presents as hearing loss (an audiometric or noise notch) in the 3–6 kHz range and is symmetrical between the worker's ears.[10] Morata[11] described music-induced hearing loss (MIHL) as hearing loss due to overexposure to loud music, characterized by a "noise notch" or hearing loss in the 4–6 kHz region. Both types of hearing loss (MIHL and NIHL) are gradual and cumulative, often going unnoticed until after the

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damage has already occurred. For musicians, hearing loss in the upper frequencies could occasion an inability to correctly match pitch or correctly respond to dynamic changes, resulting in oversinging or overplaying. Early diagnosis is crucial, before the hearing loss widens into the 2–3 kHz range where speech comprehension is affected.[12]

Although there is no cure for noise-induced hearing disorders, hearing loss due to sound exposure is entirely preventable by reducing the exposure and maintaining safe exposure limits. In the United States to date, there have been no set standards that govern exposure to loud music in the music industry or in schools of music. In the absence of specific music sound level regulations, music researchers adopted the National Institute for Occupational Safety and Health (NIOSH) recommendations of an 8-hour time-weighted average of 85 dBA and a 3 dBA exchange rate.[13] The exchange rate is significant because a 3 dBA increase in SPL equals a doubling in loudness and cuts the allowable exposure time in half. Additionally, the National Association of Schools of Music (NASM) and the Performing Arts Medicine Association (PAMA) recommended 85 dBA as a safe hearing threshold for music students.[14]

Numerous studies indicate that musicians, particularly instrumentalists, are regularly exposed to sound levels that exceed the NIOSH and NASM/PAMA 8-hour recommendation of 85 dBA over an 8-hour time period.[15–22] There have been fewer studies that investigated noise doses among singers. However, several studies revealed that singers are also exposed to potentially dangerous sound doses.

SPL measurements taken among members of the Finnish National Opera personnel revealed that sound doses exceeded the Finnish national action level of 85 dBA averaged over an 8-hour period. Furthermore, within voice parts, soprano choristers received the highest noise dose with mean sound exposure levels of 94 dBA. Altos, tenors, and basses all recorded noise doses of 92 dBA. The results of this study lead to the establishment of a Hearing Conservation Programme for all opera personnel, providing all personnel with hearing protection devices (HPDs) of each member's choice with instructions on appropriate use and information on hearing risks.[23]

In another study, researchers measured vocalists' (N = 4) sound doses during various choir and combined choir-orchestra performances. The results indicated that in one or more of the 1-hour time periods studied, three of the four participants acquired sound doses in excess of the NIOSH recommended daily 8-hour noise exposure.[24]

Hearing loss among singers has not yet been widely studied but there are several studies that suggest singers may be at risk of loss of hearing. Researchers measured hearing thresholds of professional opera chorus members (N = 62) of the Vienna State Opera and compared them with thresholds from a normative population distribution. The results revealed noise notches in the lower frequencies, atypical of MIHL, of a significant number of study participants.[25] These results, however, are controversial due to unmatched control groups and possible ambient noise in the screening environment.

Two more recent studies indicated that singers might have a higher risk of developing NIHL than the average population. A chart review of 172 singers revealed a 17.5% incidence of hearing loss, which was not significant when compared with age and gender controls. However, of those with hearing loss, 83.9% presented with bilateral sensorineural hearing loss, a type of loss associated with exposure to loud noise.[26]

The results from hearing screenings of voice teachers and voice students (N = 158) revealed that 36 participants had some degree of hearing loss. Of those diagnosed with hearing loss, 51.7% were voice teachers and 7.5% were voice students. The number of years teaching and age were both predictors of hearing loss. Researchers recommended providing singers with more information as to how to protect their hearing.[27]

Amidst concerns about the hearing health of music students and music instructors, NASM and PAMA joined forces in 2011 to provide information and recommendations to schools of music. Their recommendations included taking sound level measurements, using HPDs, acoustical treatments to reduce sound levels, providing rehearsal breaks, and monitoring repertoire to provide for dynamic contrast.[14] Of these recommendations, the only option consistently under the control of the student musician is wearing hearing protection.

Data from several studies[28–31] suggested that musicians may be resistant to wearing HPDs for a variety of reasons, including distorted timbre or dynamics, difficulties hearing themselves or others, unbalanced attenuation, too much overall attenuation, and musicians' attitudes toward hearing protection.[32–38] The results from surveys administered to professional musicians revealed that while they were aware of the potential for hearing loss due to their profession, few musicians wore hearing protection on a regular basis. A survey of 429 professional orchestra musicians found that although 107 of the musicians (25%) felt their hearing was impaired to some degree, less than 16% of the participants used hearing protection, citing distortion of sonority as their primary objection to using HPDs.[39]

Surveys administered to college age students regarding their use of HPDs revealed similar results to those of professional musicians. College music students indicated an awareness of the danger of high SPLs along with an unwillingness to protect their hearing by wearing HPDs. Music majors reported that wearing HPDs while performing negatively affected their performance due to difficulties hearing environmental sounds and problems verbally communicating with other musicians. Additionally, the survey participants expressed negative reactions to the appearance of the earplugs, reported experiencing discomfort from the HPDs, and indicated that wearing earplugs was a hassle.[40,41]

The majority of existing research regarding HPDs used by musicians consists of survey instruments. The purpose of this study was to explore two of the survey concerns expressed by musicians regarding use of hearing protection: timbre and the ability to hear oneself and others. To that end, the following research questions informed this investigation:

(1) Does the use of earplugs while singing affect the choral timbre of female singers over time in an intact university choir, according to long-term average spectra analysis?

(2) Does the use of earplugs while singing affect the solo timbre of female singers over time in a solo context, according to long-term average spectra analysis?
(3) Perceptually, do earplugs affect participants' ability to hear in choral and solo contexts?

METHODS

Singer participants

Participants (N = 24) were members of an intact, auditioned women's choir at a large Midwestern University. The choristers ranged in age from 18 to 22 years, with a mean age of 19.71 years. Half of the students (n = 12) were undergraduate vocal music performance majors. The student grade classifications included freshmen (n = 16), sophomore (n = 1), juniors (n = 3), seniors (n = 3), and graduate student (n = 1). All singers wore earplugs for three 50-minute rehearsals each week for 4 weeks (12 rehearsal periods). All participants signed an institutional review board preapproved consent form.

I randomly selected one-half of the singers from the choir ($n = 12$) to participate in weekly solo recording sessions. Due to one participant's schedule, she was unable to complete the solo portion of the study, resulting in 11 participants. Using the same singers enabled a comparison of the effects of earplugs on singers in two different contexts, choral and solo singing. Soloists included 11 females with a mean age of 19.33 years. The majority of these participants ($n = 10$) were music majors and grade classifications were freshmen ($n = 9$) and juniors ($n = 2$).

Hearing screening and earplugs

All participants (N = 24) received an individual hearing screening from a trained screener before the first recording session. Participants completed a short questionnaire, detailing hearing health and hearing attitudes as well as demographic information. The audiology screenings used standard, best practice, clinical procedures and took place in a quiet vocology laboratory. All participants exhibited normal hearing, thus no one was excluded from the study. At the conclusion of the hearing screen, I fitted each participant with her own set of earplugs.

Participants received one pair of ETY•Plugs® High Fidelity Earplugs (Etymotic Research, Inc., Elk Grove Village, IL, USA), which became theirs to keep. I chose the ETY plugs because they were designed specifically for musicians, provided a nearly equal attenuation of 20 dBA at all frequencies, and were affordable (under $15/pair). They came in two sizes (standard and large), and were fitted according to the participant's comfort. I relayed manufacturer's directions for proper care, insertion, and use to each participant. After the instructions, the participant inserted the earplugs under my guidance. I visually verified proper earplug seal and confirmed proper fit.

Several researchers have suggested that it may take some time to become adjusted to wearing earplugs, anytime from several weeks to several months.[29,35] Based on that information and the performance schedule of the director of the choir, I chose a time period of 4 weeks for this study. To strictly control the amount of time the earplugs were worn, each choir member received her personal set of earplugs from me at the start of the rehearsal, wore them during the rehearsal, and returned her earplugs to me at the conclusion of the practice.

Recording procedures and equipment

Recording procedures and equipment, choral context

Choral singers rehearsed and performed "Dona Nobis Pacem" by Giulio Caccini. I selected this composition because it was homophonic, was unfamiliar to the singers, was relatively easy to learn, could be sung a cappella, and was of a moderate tempo. The choir rehearsed the piece for three 15-minute sessions during the three choir classes prior to the first recording session.

The choral singing portion of this study took place in the choir's regular rehearsal space. Choristers stood on the floor in two rows in a semi-circle formation, arranged by voice type. The position of the singers, including spacing between choristers, was consistent throughout all recording sessions. To control for potential confounding variables due to possible inconsistencies in tempo or conductor gestural behaviors and affect between recording sessions, choral singers followed a videotaped conductor during each recording. During the recording sessions, singers viewed a life-sized projection of the videotaped conducting.

In an effort to maintain as normal a choir environment as possible, the choir participated in their usual vocal warm-up segment (without earplugs), lead by their own director. During each recording session, the choir recorded the excerpt the first time without earplugs. The starting pitches were played on the piano and the choir, following the stimulus video, sang the excerpt. I reminded the singers of the method for proper insertion as recommended by the manufacturer. Each chorister then inserted her own earplugs and I checked all singers to ensure the earplugs were correctly inserted and properly sealed. The starting pitches were played on the piano and the choir, again following the stimulus video, recorded the excerpt a second time. After the without-earplugs recordings at the beginning of rehearsals, choristers wore the earplugs for the entirety of the rehearsals. This same procedure was repeated at the following intervals: 1 week following earplug fitting, 2 weeks following fitting, and 3 weeks post-fit for a total of four recordings.

Immediately following each recording, participants completed a brief perceptual questionnaire. This questionnaire consisted of four Likert-type scale items, anchored by *poor* and *excellent*, that solicited perceptions with respect to (a) ability to hear self while singing without the earplugs; (b) ability to hear self while singing with the earplugs; (c) ability to hear choir when singing without the earplugs; and (d) ability to hear the choir when singing with the earplugs. The questionnaire form invited participants to write additional comments of their choosing.

In the choral recordings, a digital sound recorder captured each performance at a sampling rate of 44.1 kHz (16 bits) in .wav format. The recorder was positioned 10′1″ (3.07 m) from the front row of the choir, in a mixed to diffuse sound field, at a height of 5′4″ (1.65 m), commensurate with conductor ear height. Volume and gain controls were set manually at the beginning of the recording session and remained consistent throughout all recording sessions.

Recording procedures and equipment, solo context

The sung melody used for this study was an excerpt from "Over the Rainbow" by Harold Arlen. This piece was chosen due to the octave leap in the first measure, interval of a sixth in the third measure, moderate tempo, and participant familiarity. Participants received a copy of the song excerpt 2 weeks before the start of the study and were asked to practice the song until they were able to sing it a cappella.

Singers wore a head-mounted factory calibrated condenser microphone positioned at a consistent 7 cm from the corner of their mouths, out of the direct air stream. A thin 7-cm rod confirmed the distance prior to each recording. The placement followed the standards and procedures of previous research that recommended a distance of less than 10 cm between mouth and microphone to ensure high signal to noise ratios.[42] The recordings (16 bit.wav files, 44.1 kHz sampling rate) were saved for subsequent analysis. All participants were asked to warm-up on their own prior to the recording session. During each data collection, the participant recorded the excerpt twice, once without earplugs and the second time while wearing the earplugs. This same procedure was repeated at the following intervals: 1 week following earplug fitting, 2 weeks following fitting, and 3 weeks post-fit for a total of four recordings.

Immediately following the sung trials each week, participants completed a brief post-trial perceptual questionnaire. The questionnaire was similar to the one used in the choral context, but did not solicit participants' perception of singing with others when using earplugs. It consisted of two Likert-type scale items, anchored by *poor* and *excellent*, that solicited perceptions with respect to (a) ability to hear oneself while singing without the earplugs, and (b) ability to hear oneself while singing with the earplugs.

Analyses

One of the challenges in evaluating timbre is the judgment of quality using perceptual or auditory measures due to the complexity of human vocal sound. Vocal sound is complex sound. The array of simultaneous frequencies, each of which constitutes a part of the complex whole, makes analysis difficult. The perceived timbre (color or quality) of vocal sound includes the sung pitch (fundamental frequency) as well as numerous other simultaneous frequencies with each spectral frequency exhibiting power or energy. Some partials may be dampened (exhibit less energy) or amplified (exhibit more energy) depending on context.

LTAS analysis provides a scientific acoustical measurement that provides information about timbre averaged over a period of time. LTAS data include both frequency and sound pressure density (amplitude intensity) across the spectrum of complex sound. LTAS graphs portray sound pressure power as a function of frequency. SPL amplitude is presented according to a decibel (dB) scale and frequency is presented as hertz (the number of sound cycles per second, abbreviated as Hz). Higher frequency partials may entail thousands of sound cycles per second; therefore, kilohertz (kHz) serves as a shorthand way of expressing cycles per second for these partials.

I used the same LTAS analysis procedures for both solo and choral sound files. I used *KayPentax Computerized Speech Lab* (CSL) Model 4500 software (Pentax Medical Company, Lincoln Park, NJ, USA) to analyze the recordings. LTAS data were obtained using a window size of 512 points with no pre-emphasis or smoothing, a bandwidth of 86.13 Hz, and a Blackman window. All sound levels remained constant throughout each recording session.

RESULTS

Results are presented according to the research questions posed for this investigation.

Research question one: choral timbre according to LTSA

According to Howard and Angus,[43] a 1 dB difference in the mean signal energy of complex sound may constitute a perceived just noticeable difference, depending on the nature of the sound and the hearing acuity of listeners. Thus, obtained differences of 1 dB or greater may be useful for interepreting results presented here.

Figure 1 presents mean LTAS contours from all 4 weeks. These results indicated that the choir members sang with a greater than 1 dB decrease in the mean signal amplitude while wearing the earplugs. These LTAS contours depict data across the 2–4 kHz spectrum, the frequency range where the human ear is most responsive. Visual comparisons of differences between the two conditions (with and without earplugs) indicate that choir members sang with a large decrease in the mean signal energy of higher frequency partials, affecting the choir's timbre, while wearing the earplugs. This dampening of energy persisted across the 4-week time period studied. LTAS results demonstrated more resonant singing when choir members sang without earplugs.

LTAS analyses indicated 5.06 dB mean changes in the choral timbre attributable to the with-earplug condition. I analyzed the data from each week separately, using a paired-samples *t* test to compare the LTAS means between the two conditions, no earplugs and with earplugs. The results indicated that there was a significant difference in LTAS results between the two conditions, and that wearing the earplugs contributed to dampened mean signal amplitude for the choir. This difference furthermore persisted across all 4 weeks studied (Table 1).

Research question two: Solo timbre according to LTAS

Each soloist sang for two recordings during their weekly recording sessions: (a) no earplugs and (b) with earplugs. Figure 2

TABLE 1.
Results of Paired-Samples *t* Tests for Weeks 1–4 in a Choral Context

	M	SD	*t*	*P*
Week 1	6.87 dB	1.26	26.10	0.000
Week 2	4.27 dB	0.36	57.50	0.000
Week 3	3.52 dB	0.54	31.12	0.000
Week 4	5.59 dB	0.47	57.14	0.000

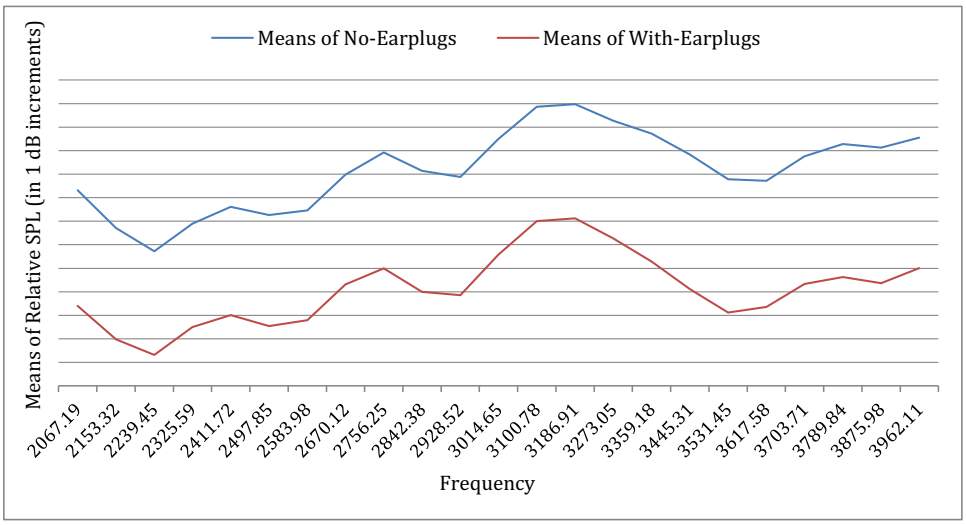

FIGURE 1. Means of all 4 weeks: LTAS contours in the 2–4 kHz region of performances under two conditions, no earplugs and with earplugs. LTAS, long-term average spectra; SPL, sound pressure level.

indicates the means of relative SPLs in the 2–4 kHz region. As indicated by LTAS data, the wearing of earplugs resulted in a minimal decrease (<1 dB) of higher partial signal energy in solo sound across the 2–4 kHz region in 3 of the 4 weeks studied. In week 1, there was a slight increase in the higher partial signal energy when the participants wore earplugs. Week 4 LTAS data (Figure 3) show that the difference in mean energy is 0.12 dB, as indicated by the LTAS contours.

I analyzed the data from each week separately, using a paired-samples *t* test to compare the LTAS means between the two conditions: no earplugs and with earplugs (Table 2). The results indicated that there was a significant difference in LTAS results between the two conditions in weeks 1–3. In week 4, however, there was not a significant difference between the two conditions (no earplugs and with earplugs).

Comparison of choral and solo LTAS data

Using the same participants in both the solo and choral contexts afforded comparisons of timbre in a choral setting versus a solo setting. By examining LTAS data from both the choral and solo settings, I compared the effects of earplugs in a choral environment where singers had to hear both themselves and others and in a solo environment where the only feedback was self. For that reason, I looked at the mean signal amplitude LTAS differences between (a) no earplugs and (b) with earplugs across 4 weeks in both choral and solo contexts (Table 3).

As indicated in Table 3, the differences in mean signal amplitudes between the no-earplugs and with-earplugs conditions in a choral setting consistently exceeded 1 dB (range: 3.52–6.87 dB) during each of the four weekly recording sessions. The wearing of earplugs resulted in a dampening or attenuation of

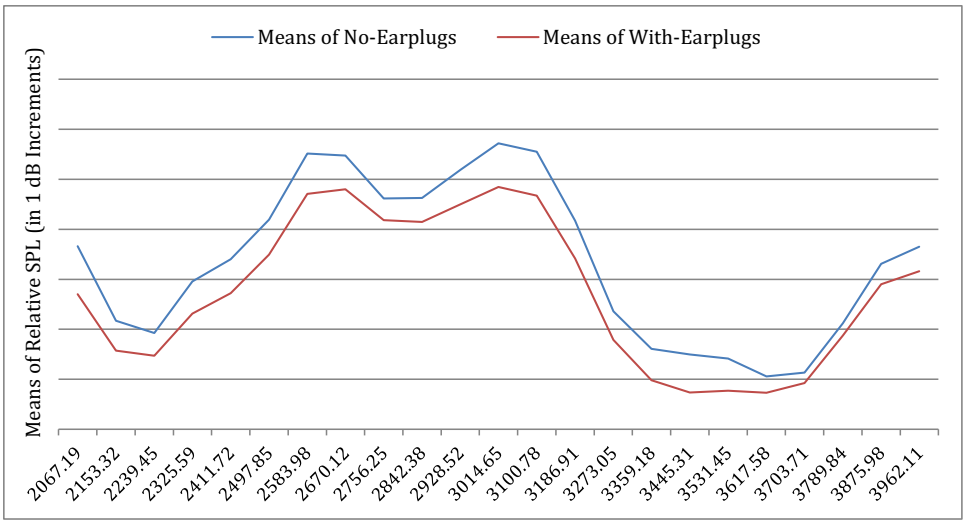

FIGURE 2. Means of all 4 weeks: LTAS contours in the 2–4 kHz region of mean solo performances under two conditions, no earplugs and with earplugs. LTAS, long-term average spectra; SPL, sound pressure level.

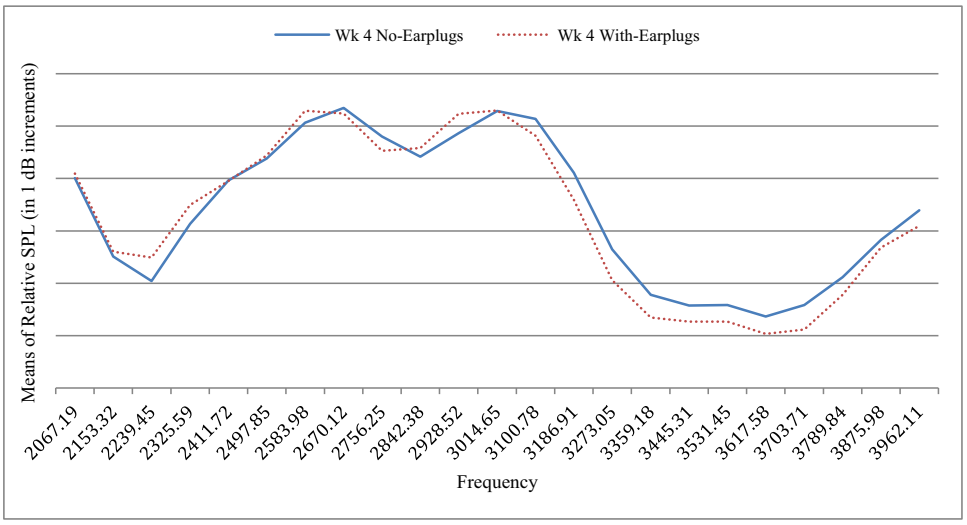

FIGURE 3. Week 4: LTAS contours in the 2–4 kHz region of mean solo performances under two conditions, no earplugs and with earplugs. LTAS, long-term average spectra; SPL, sound pressure level.

higher partial signal energy in the choral sound of the ensemble across all four weeks. The differences in mean signal amplitudes between the no-earplugs and with-earplugs conditions for soloists were less than 1 dB (likely imperceptible) in 2 of the 4 weeks studied. Solo recordings for week 1 indicated a slight (0.14 dB) increase of mean signal energy when the participants wore earplugs. In week 3, the mean signal amplitude difference for soloists slightly exceeded 1 dB (1.40 dB SPL).

Question three: Participant questionnaire

Immediately following the recording sessions, participants completed a brief post-trial perceptual questionnaire. The questionnaire for choral participants consisted of four Likert-type scale items that solicited perceptions with respect to (a) ability to hear self while singing without and with the earplugs, and (b) ability to hear choir when singing without and with the earplugs. Solo participants responded only to the questions soliciting their perceptions of ability to hear self while singing with and without earplugs. Tables 4 and 5 present participants' mean aggregate responses for choral and solo contexts, respectively.

The results from the choral participant questionnaires indicated that most choristers (75%) reported they were able to hear themselves (Self) better when not wearing the earplugs in three of the four time periods surveyed. Response means from week 3 indicated that these choristers on the whole heard themselves (Self) equally well with or without earplugs.

When asked if they could hear the choir (Other) clearly under the two conditions (no earplugs and with earplugs), response means indicated that these choristers on the whole could hear the choir (Other) better without the earplugs in all time periods studied. There was a smaller difference between chorister's perceptions of being able to hear themselves clearly without and with earplugs (ranging from 0.15 to 0.39) when compared with their perceptions of ability to hear the choir without and with earplugs (ranging from 1.45 to 2.15).

Responses from soloists reported no difference in their ability to hear themselves between the two conditions (no earplugs and with earplugs) for weeks 1 and 3 and slight differences (0.18 and 0.27) between the two conditions in weeks 2 and 4. Figure 4 presents a comparison of solo participants' mean response to question two (ability to hear myself when wearing earplugs) to the mean response of those same singers from the choral survey.

TABLE 2.
Results of Paired-Samples *t* Tests for Weeks 1–4 in a Solo Context

	M	SD	*t*	*P*
Week 1	–0.13 dB	0.31	–2.09	0.048
Week t2	0.53 dB	0.26	9.82	0.000
Week 3	1.40 dB	0.13	50.12	0.000
Week 4	0.12 dB	0.30	1.83	0.082

TABLE 3.
Differences and Ranges in Mean Energy Signals (2–4 kHz) Between No Earplugs and With Earplugs in Choral and Solo Contexts

	Week 1	Week 2	Week 3	Week 4	Mean Difference	Range in dB
Choral context	6.87 dB*	4.27 dB*	3.52 dB*	5.58 dB*	5.06 dB*	3.52–6.87
Solo context	–0.13 dB	0.53 dB	1.40 dB*	0.12 dB	0.55 dB	–0.13–1.40

* >1 dB between no-earplugs and with-earplugs conditions.

TABLE 4.
Aggregate Means and Standard Deviations of Choral Participant Questionnaire Responses

	Week 1		Week 2		Week 3		Week 4	
Questionnaire Statement—Choral Context	M	SD	M	SD	M	SD	M	SD
1. I heard myself clearly without the earplugs	4.17	0.89	4.35	0.93	4.32	0.78	4.45	0.83
2. I heard myself clearly with the earplugs	3.78	0.10	4.20	0.95	4.32	0.84	4.20	0.77
3. I heard the choir clearly without the earplugs	4.74	0.54	4.75	0.55	4.82	0.39	4.75	0.72
4. I heard the choir clearly with the earplugs	2.74	1.05	2.60	0.75	3.09	0.68	3.30	0.92

Notes: Likert scale anchored with poor (1) to excellent (5).

Question two was of particular interest since singing in a solo context differs from choral singing. Soloists receive feedback only from themselves, whereas in a choral context, singers receive feedback from themselves as well as other choir members. Participants indicated that when compared with the with-earplugs condition in a choral setting, they could hear themselves better with earplugs in a solo setting in all four weeks.

Written comments

The second section of the questionnaire invited participants to comment freely. The only written responses came from the singers in the choral context. One singer commented in week 1, "My right ear kind of feels uncomfortable but the left is okay." In week 2, a chorister wrote, "I can hear myself really well and those right around me seem amplified. It's hard to hear those across the room." Six comments were from week 3, when the choir sight-read a new piece. Week 3 comments included, "It's difficult to sight read/learn new music when you can't hear where you fit," "It's hard to learn new pieces or to sight read," "It was really hard to learn a new piece because we can hardly hear the piano," and "Hard to learn a new piece with earplugs because it is hard to hear anyone past the people directly next to you. I can't hear the other voice parts."

The remarks from week 4 indicated choir members' difficulties hearing while wearing earplugs in the choral setting. Choristers commented, "It is hard to hear my singing part (Soprano 2) with earplugs," "As far as the pitch and my perception with the ear plugs, I could not tell as clearly if I was in tune with the ensemble," and "It's hard to hear dissonance." The overriding perception of participant comments appeared to remain

TABLE 5.
Aggregate Means and Standard Deviations of Solo Participant Questionnaire Responses

	Week 1		Week 2		Week 3		Week 4	
Questionnaire Statement—Solo Context	M	SD	M	SD	M	SD	M	SD
1. I heard myself clearly without the earplugs	4.70	0.67	4.82	0.40	4.82	0.40	4.82	0.40
2. I heard myself clearly with the earplugs	4.70	0.48	4.55	0.69	4.82	0.40	4.64	0.50

Notes: Likert scale anchored with poor (1) to excellent (5).

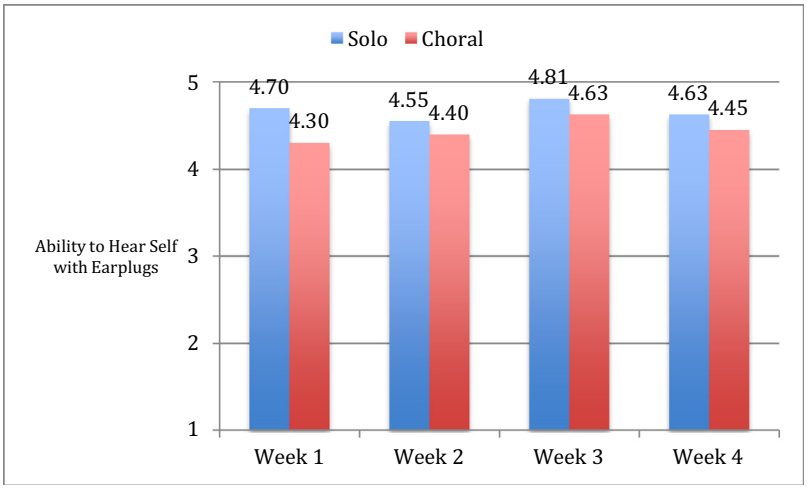

FIGURE 4. Solo participant (N = 11) responses to "Ability to hear self with earplugs" in solo and choral contexts.

consistent across the 4 weeks studied with choristers expressing difficulties hearing other choir members when wearing earplugs, particularly when learning new music.

DISCUSSION

The primary findings of this investigation are (a) choral LTAS data indicated significant differences in mean signal amplitudes between the no-earplugs and with-earplugs conditions in all 4 weeks; (b) choir members sang with less resonance while wearing earplugs; (c) solo LTAS data indicated significant differences in mean signal amplitudes between the two conditions in 3 of the 4 weeks studied, and (d) singers perceived more difficulty hearing while wearing earplugs in a choral setting than in a solo setting. Findings are limited to the participants in this study and to the particular methods, procedures, and measures employed. Because this study focused only on one existing female choir, the results of this study should not be generalized to other singers or contexts.

The LTAS choral data indicate that when participants recorded with the earplugs, the mean signal amplitude decreased between 1.30 and 5.29 decibels when compared with the without-earplug recordings. One message these data might convey is that choir members experienced an unbalanced self-to-other ratio (SOR) while wearing the earplugs, hearing self more and other less. A chorister might sing with less energy in an effort to receive sufficient auditory feedback from the rest of the choir and thereby blend.

The director of the choir expressed some concerns when working with the choir while the choristers were wearing earplugs. She referred to the choir's sound while wearing earplugs as the "earplug effect," and said she perceived an immediate dampening of the sound when choir members inserted their earplugs. Twice during rehearsals, the director asked choir members to remove the earplugs briefly, sing the section of the piece they were rehearsing and concentrate on how that felt rather than sounded. As singers mature and develop an increased sense of muscle memory, they tend to rely less on aural feedback alone. The choir in this study, however, consisted of relatively young, inexperienced singers, many of whom were not music majors and did not study voice privately. One might conjecture that the choir relied primarily on aural feedback and had difficulties adjusting when that feedback was diminished. Future studies might test the effects of earplugs with more experienced singers who are not as dependent on aural feedback.

In this study, the conductor had the option of keeping the earplugs in place or removing them when she deemed it necessary. Future studies might include time within the choral rehearsal singing first without the earplugs and then inserting the earplugs for the remainder of the rehearsal. A protocol such as this could be beneficial, particularly when learning new music. This could allow the singers a more balanced SOR and help them better understand their role in the conglomerate choral sound.

Some researchers recommend that musicians adjust to wearing earplugs in a solo setting prior to wearing them in a group rehearsal.[29,35] The results from this investigation seem to indicate that singers found it easier to adapt to wearing earplugs in a solo context when they were only seeking feedback from self than they did in a choral context when they were listening for feedback from others. Solo vocalists' LTAS data revealed that singers experienced less dampening of mean signal amplitude in higher frequency partials when wearing the earplugs in a solo context than in a choral context. The mean signal amplitude difference between the no-earplugs condition and the with-earplugs condition was less than 1 dB in 3 of the 4 weeks studied for solo participants, suggesting that there were minimal differences in overall vocal timbre between wearing or not wearing the earplugs for solo singing. From a pedagogical standpoint, voice teachers and choir directors might consider working with students to establish a period of adjustment to earplugs prior to performances that include exposure to high SPLs. This procedure could benefit vocalists particularly if their performance schedule includes operatic literature or repertoire that will require instrumental accompaniment.

The amount of time choral participants wore their earplugs was strictly controlled in this study and was limited to the three 50-minute rehearsal periods/week for 4 weeks. Given this specific time frame, results from this investigation suggest that participants need greater than 150 minutes over 4 weeks to acclimatize to earplugs. Researchers differ in the amount of time necessary to acclimatize to earplugs, suggesting anywhere from several weeks to several months.[29,35] Future research could investigate longer acclimatization periods in both a choral and solo context.

The feasibility of a 2- to 3-month study in a naturalistic choral setting may be problematic. It is doubtful that directors would be willing to rehearse their choir for 3 months while the singers wore earplugs. The director in this study faced several challenges related to the wearing of earplugs including reduced singer amplitude and choir members having difficulty hearing verbal directions from the director. Choral directors typically work within the confines of performance schedules and earplugs might hinder concert preparation.

In previous survey studies, participants listed additional concerns they had regarding using hearing protection. These included the ability to accurately perceive pitches and dynamic contrasts. Future studies might look at those concerns both in instrumental and in vocal contexts.

Current research indicates that vocalists are exposed to high sound doses, which may put them at risk of developing hearing loss. Music educators and voice professionals have an excellent opportunity to provide hearing health education to students in a positive manner. Study participants in this investigation included future music educators and music therapists. Their chosen professions demand a high degree of personal hearing acuity while placing them in environments where they may be exposed to high SPLs. Studies such as this one may provide insights into incorporating earplugs into an effective hearing conservation program for themselves and their future students.

In this particular study, wearing earplugs in a choral setting where singers were trying to hear both self sound and other sound was not effective. However, the primary finding indicates that earplugs can provide hearing protection to singers in a solo context without negatively impacting their singing. This finding is promising for singers, providing them with the knowledge that they

can protect their hearing during personal practice with the use of earplugs.

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