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Hearing Dose and Perceptions of Hearing and Singing Effort Among University Choir Singers in Varied Rehearsal and Performance Settings

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Abstract

This collective case study documented university choral students' (N = 4) hearing doses, acquired through Etymotic Personal Noise Dosimeters (ER200D), as they rehearsed and performed a program of opera choruses during five time periods in three venues. Acquisition periods included one choir only rehearsal, two choir-orchestra-soloist rehearsals, and two public performances with choir-orchestra-soloists. Participants also responded to a brief survey that solicited their perceptions of hearing and singing voice status immediately following each acquisition period.

Among primary results: (a) three of four participants acquired sound doses in one or more of these approximately one-hour time periods that exceeded National Institute for Occupational Safety and Health (NIOSH) recommendations for eight hours; (b) the soprano participant acquired the highest Leq dB(A) readings; (c) acquired sound doses varied according to context; and (d) participant surveys indicated that although these singers perceived slightly more than desired hearing and singing effort in one or more of the acquisition periods, they may not have been fully aware of the cumulative sound doses they acquired.

Results were discussed in terms of recommendations for future research and hearing conservation awareness among choral conductors and teachers.

Keywords

noise induced hearing loss (NIHL), choir singers, hearing dose, noise dosimeter

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Noise induced hearing loss (NIHL) is cumulative and irreparable with a faster rate of loss during the first years of exposure (International Organization for Standardization (ISO), 1999). While a growing body of research addresses hearing loss among instrumental music performers, fewer studies to date examine potential NIHL among choral singers.

Axelsson and Lindgren (1981) administered hearing tests to 139 classical orchestra musicians. They found that 43% of these musicians had worse pure tone thresholds than would be expected for their ages. Kähäri, Axelsson, Hellström, and Zachau (2001a) conducted a follow up study with 56 of the musicians examined by Axelsson and Lindgren (1981). Findings indicated no significant hearing decline among participants in the intervening 16 years from the first study. In another study by Kähäri, Axelsson, Hellström, and Zachau (2001b) pure-tone audiometric tests were performed on classical orchestral musicians ($N = 140$). The results did not indicate severe hearing losses attributable to playing in an orchestra. Male participants, who tended to play the loudest instruments, exhibited worse hearing than the female participants studied.

Westmore and Eversden (1981) performed pure-tone audiometry on orchestral musicians ($N = 34$). Findings indicated abnormal hearing consistent with NIHL in 23 of the 68 (34%) ears studied. Karlsson, Lundquist and Olaussen (1983) suggested that the average threshold levels for the symphony orchestra musicians ($N = 417$) they examined were within the range expected for their age. These researchers concluded that performing with an orchestra was not a risk to hearing. However, results from a study by Ostri, Eller, Dahlin and Skylv (1989) suggested otherwise. These researchers found that audiograms administered to symphony orchestra participants ($N = 96$) indicated increased median hearing thresholds in all age groups compared with normative data collected by the ISO. Fifty-eight percent of participants exhibited hearing impairments.

In two other studies, Emmerich, Ruder, and Richter (2008) and Jansen, Helleman, Reschler, and de Laat (2009) administered audiometric tests to professional orchestral musicians ($N = 109$ and $N = 241$, respectively). Results indicated a hearing loss of 15 dB(A) or more in over 50% of the musicians studied. Results from the study by Jansen et al. categorized 48% of the participants' hearing as normal, yet showed notches at 6 kHz in a majority of those studied, indicating NIHL. Royster, Royster and Killion (1991) found that 52.5% of the 59 professional orchestral musicians they tested had notched audiograms at 6 kHz, consistent with NIHL.

Behar, Eng, Wong and Kunov (2006) reviewed 13 papers on noise exposure and possible NIHL among orchestral musicians. They concluded that the existing literature indicated minimal risk of NIHL among orchestral musicians. However, these researchers cautioned there was not a clear answer due in part to problems with measurement techniques, data calculations and data analysis.

Henoch and Chesky (2000) acquired noise dosimeter readings from a university jazz rehearsal room over a three-day period. Results indicated that 10 of the 15 readings exceeded allowable exposure levels per the Occupational Safety and Health Administration (OSHA) recommendations of 90 dB over an eight-hour period. Stewart (2009) measured sound exposure levels of university wind band members ($N = 46$). Results indicated that 52% of these wind players took part in one or more rehearsals where they were exposed to sound levels greater than 100% of the daily dose recommended by the National Institute for Occupational Safety and Health (NIOSH). Seventeen participants received mean daily sound doses over 100% of the NIOSH recommended dose. Stewart found that these jazz ensemble musicians' placement in the room did not have an effect on sound dose.

Walter (2011) measured high school marching band members' ($N = 16$) sound dose in

a two-day camp measurement period. Results showed that 15 of the 16 participants experienced sound levels in excess of 100% of the recommended NIOSH dose during the two-day period. Mean daily sound levels for the majority of the participants were over 800% of the daily NIOSH dose on the first day and over 496% the second day.

Two studies to date examined hearing loss among vocalists, one utilizing audiological tests and the other utilizing dosimeters. Steurer, Simak, Denk and Kautzky (1998) measured the hearing threshold levels of 62 professional choir members of the Vienna State Opera and compared them with the normative distribution of hearing thresholds from the ISO Standard 7029. These singers exhibited impaired hearing thresholds with the low frequency regions affected most. Researchers surmised that the permanent threshold shifts found among participants at 250 Hz and above were most likely NIHL but those below 125 Hz were probably due to another source. Although women exhibited better hearing in the 3 to 8 kHz range than the men, no significant differences were found according to voice classification.

Laitinen, Toppila, Olkinuora and Kuisma (2003) measured sound exposure among personnel of the Finnish National Opera, including choir singers, orchestra players, and technical staff. Measurements were taken during individual rehearsals (choir members only or orchestra members only), group rehearsals (choir, orchestra and ballet members) and performances. Results indicated mean chorister sound exposure levels of 94 dB(A) for sopranos and 92 dB(A) for altos, tenors and basses. Individual rehearsals (choir only) were the major source of exposure at 100 dB(A) for choir members, even though these rehearsals accounted for only 13 percent of the measured singing time. Sound levels for orchestra members ranged from 82 dB(A) to 98 dB(A) and from 77dB(A) to 92 dB(A) for technical personnel. Findings from the Laitinen, et al. study contributed to the development of a Hearing Conservation Programme (HCP) in accordance with Finnish legislation. As a result, all opera personnel purchased Hearing Protective Devices (HPDs) of their choice at the Opera's expense.

In recent years, researchers have begun to focus on NIHL among college music students. Hearing loss among music students has become prevalent, prompting schools of music to establish hearing conservation programs (Chesky, 2008; Hodges, 2009; Phillips, Shoemaker, Mace and Hodges, 2008). Fearn (1993) studied orchestral music students (N = 32) and found that 31% of those studied had elevated hearing thresholds, with 75% of those at the 6 kHz region. Phillips (2008) administered individual audiometric tests to undergraduate music students (N = 338) during a three-year period at the University of North Carolina. Student participation varied each year and the number of repeat volunteers was small. Over half of the students demonstrated hearing loss, most often at 6 kHz, consistent with NIHL. In year one, 2% of the students displayed noise notches at 4 kHz while in year three that number had grown to 30%. During the three-year period, noise notches were found in all instrument and voice groups.

Phillips, Henrich and Mace (2011) administered audiometric tests to instrumental and vocal music students aged 18-25 years (N = 329) and found that 148 of these students had noise notches. Mace, Phillips, Bhatt, Henrich and Richter (2012) found hearing loss (HL) in 43% of 558 music students from five universities. Hearing loss was defined as a 15 dB HL decrease in sensitivity, with a noise notch (increased sensitivity) at higher frequencies (6 to 8 kHz).

Phillips and Mace (2008) measured music student (N = 50) sound levels utilizing personal sound level dosimeters in college practice rooms and found average readings of 87-95.2 dB(A). Brass players received the highest noise dose at 95.2 dB(A) followed by woodwind and percussion players at 90.4 dB(A) and 90.1 dB(A), respectively. Voice students' sound levels were

88.4 dB(A), resulting in an estimated three-hour dose of 82.3% of the daily noise dose recommended for an eight-hour period.

OSHA has set hearing dose standards for the United States (OSHA, 1983). These standards have been typically limited to general industry and have not been applied to musicians or students. OSHA determined noise exposure be limited to 90 dB(A) averaged over an eight-hour day with a 5 dB(A) exchange rate, based on an acceptable risk of hearing loss. This exchange rate is significant because decibels are measured on a logarithmic scale. A small increase in decibels equals a large change in loudness. An increase of 5 dB(A) would decrease allowable noise exposure time by half.

The National Institute for Occupational Safety and Health (NIOSH) recommended stricter guidelines with noise levels equivalent to 85 dB(A) for eight-hours with a 3 dB(A) exchange rate (NIOSH, 1998). These guidelines have been considered the standard for musicians (Suter, 2000).

Ear protection has been one of the standard protections against noise exposure in the workplace. Laitinen and Poulsen (2008) surveyed members of three Danish symphonic orchestras (*N* = 145) and found that although aware of the dangers of loud music, few musicians wore ear protection and wore it correctly. Of those surveyed, 15% reported always using hearing protection and 83% used protection only occasionally. The reasons cited for not wearing ear protection included difficulty hearing others play, a perception of compromising their own performance, problems with intonation, and discomfort in wearing the devices.

Overall, research to date indicates music students may be exposed to intense sound levels during their solo and ensemble practice and performances. Noise levels and hearing dosage have been seen as key factors in contributing to NIHL in some studies of professional instrumental musicians (Emmerich et al., 2008; Jansen et al., 2009; Ostri et al., 1989; Royster et al., 1991; Westmore and Eversden 1981). To date, however, only two studies (Laitinen et al., 2003; Steurer et al., 1998) have examined choral singers' hearing dosages and hearing thresholds. Moreover, there appears to be no study that has investigated sound doses acquired by university choral singers engaged in rehearsal and performance of the same literature in different venues.

The purpose of this collective case study was to document university choral singers' (N = 4) hearing doses and their perceptions of hearing and singing effort during five time periods (one choir only rehearsal, two choir-orchestra-soloist rehearsals, and two public performances with choir-orchestra-soloists) as they rehearsed and performed a program of opera choruses in three venues.

The following research questions guided this investigation:

1. What do data acquired through Etymotic Personal Noise Dosimeters (ER200D) indicate about participants' (N = 4) hearing doses in varied rehearsal and performance settings when compared to NIOSH recommendations?
2. What do participant surveys indicate about these singers' perceptions of hearing and singing effort during the five rehearsal and performance periods?

Definitions

Noise dosimeter is an instrument that measures sound pressure level over a period of time and provides a dose reading, usually in accordance with OSHA or NIOSH standards.

Decibel (dB) is a ratio unit of measurement used to express sound intensity levels on a logarithmic scale.

A-weighting measures the decibel level for sounds of all frequencies, but weights them differently across time depending upon the human ear's response to sound. Because the human ear is more sensitive in the 1 to 4kHz region, higher sound pressures are acceptable at lower and higher frequencies than they are in this mid-range. To weight measurements, sound level meters are fitted with filters adapting the measured sound

response to the human sense of sound. The most common filter used is the "A", which is less sensitive to very high and very low frequencies. A-weighted measurements result in sound levels expressed as dBA.

Leq represents an A-weighted equivalent continuous sound pressure level expressed in dBA.

Noise dose is the total sound exposure received in a given time period and expressed as a percentage of the allowable daily exposure. For NIOSH standards, a 100% dose would be 85 dBA during an 8-hour time period with a 3 dB(A) exchange rate. A 3 dB increase results in a doubling of sound pressure; therefore, an increase from 85 dB(A) to 88 dB(A) halves the allowable exposure time.

Noise Induced Hearing Loss (NIHL) is typically characterized by an elevated threshold of hearing in the higher frequencies, (4-6 kHz and above), and is caused by repeated exposure to loud sounds.

Method and Procedures

Participants

Four choral singers, pseudonyms Sonja (soprano), Alissa (alto), Terrence (tenor) and Brandon (bass), wore personal noise dosimeters during rehearsals and performances of a program of selected opera solos and choruses. All four participants were music majors at a large Midwestern University. The soprano was a 20-year-old sophomore, the alto a 24-year-old junior, the tenor a 22-year-old junior, and the bass was a 20-year-old junior. Participants were self-screened for hearing difficulty. No participant reported hearing problems.

The choir (N = 85) in which these participants sang consisted of 32 sopranos, 26 altos, 12 tenors and 15 basses. Among these choristers were fourteen (6 sopranos, 5 altos, 1 tenor, 2 basses) university opera majors who also performed as soloists during the program.

The symphony orchestra (N = 61) was an established orchestra from the same Midwestern University as the choir and soloists. The orchestra consisted of: 2 flutes, piccolo, 3 clarinets, bass clarinet, 2 oboes, 3 bassoons, 4 French horns, 3 trumpets, 3 trombones, tuba, 15 violins, 7 violas, 8 cellos, 4 contrabasses, 2 harps, organ (stage organ Venue A and pipe organ Venue B), timpani, vibraphone, chimes, bass drum, 2 snares.

Dosimeters

During all rehearsal and performance periods (N = 5) examined for this study, Sonja, Alissa, Terrence, and Brandon wore an ER-200D Personal Noise Dosimeter (Etymotic Research Inc.). This dosimeter conforms to ANSI S1.25-1991 (R2002) Specifications for Personal Noise Dosimeters and NIOSH Criteria for a Recommended Standard (NIOSH, 1998). The dosimeter can be calibrated to NIOSH or OSHA standards. The dosimeter was calibrated to the more conservative NIOSH standard with a 100% daily dose equaling an eight-hour exposure to a continuous 85 dB(A) noise and a 3 dB exchange rate. The calibration accuracy was ± 2.5 dB(A). The dosimeter incorporated an Omni-directional microphone (flat from 100 Hz to 15 kHz).

The dosimeter obtained dose values every 220 milliseconds, averaged over a 3.75-minute interval and saved in non-volatile memory (16 times per hour). After each trial, information extracted from the dosimeters included: (a) run length (HH:MM:SS), (b) final dose percentage, (c) overall Leq (A-weighted continuous equivalent sound level) in dB, and (d) dose and Leq values for each 3.75-minute time block.

Dosimeter placement on participants' bodies and the distance from dosimeter microphone to the ear of each participant remained consistent through all trials. Participants wore the dosimeter attached to their clothing on their right side collarbone area, at the same distance from their right ear for each acquisition period (Soprano 5.5 inches, Alto 7 inches, Tenor 5.5 inches, Bass 5 inches). Participants rehearsed and performed as

part of an "Opera Gala" event. The dosimeters began recording at the beginning of the second half of the program, which included chorus singing, and had synchronized starts and stops during each recording period for uniformity in results.

Participant Survey

Immediately following each examined rehearsal or performance period, Sonja, Alissa, Terrence, and Brandon completed a brief, two-part survey (Appendix A). The first part of the survey contained 5-point Likert-type scale items ($N = 4$). Anchors for three of the scales were "All of the time" and "None of the time:" (a) I could hear myself clearly during tonight's rehearsal; (b) I could hear the choir clearly during tonight's rehearsal; and (c) I could hear the orchestra clearly during tonight's rehearsal. The fourth item solicited perceptions of singing effort during each rehearsal and performance period. The second part of the survey invited written comments pertaining to participants' perceptions of their hearing and singing during each of the rehearsals and performances.

Rehearsal and Performance Venues

The five rehearsal and performance periods measured occurred in two venues. Both venues were large performing arts centers. A choir only rehearsal (CO) in a rehearsal studio, a rehearsal with choir, orchestra, and soloists (COS) on the stage, and a COS performance on the stage occurred at Venue A. At Venue B there was a COS rehearsal on stage and a COS performance on the stage.

The dosimeters recorded Sonja, Alissa, Terrence and Brandon during each of these five rehearsals and performances. The conductor originally determined standing positions of these singers within the chorus. Thereafter, they shifted positions slightly according to the dimensions of the various venues and the different placement of soloists in Venues A and B.

*Venue A***.** Venue A featured a large stage area for performances and rehearsals, as well as a rehearsal studio behind the stage area utilized for a choir only rehearsal. Studio dimensions were 44' by 24'. During the CO rehearsal in this venue, singers (N = 61; 23 sopranos, 18 altos, 8 tenors, 12 basses) alternated between standing and sitting in chairs with close spacing between and among the singers. Singers faced the conductor and a piano at the back wall of the room in a half circle. Sonja, Alissa, Terrence and Brandon sat in the front row during this rehearsal (See Figure 1).

S S S S S S B B B B B
S S S S B B B B T T B A A A A A A
S S S S S S S S T T T T T A A A A A A A
S S S S S S T B B A A A A A

Figure 1. Venue A: Arrangement of the choir in the dance studio. Study participants are marked in red. Front three rows sat and the back row stood.

The stage area of Venue A was reduced using acoustical shells, resulting in a 50'4" by 42" performance area (See Figure 2). The choir was on three-step risers across the upstage wall of shells. Orchestra seating occupied the rest of the stage area. The distance between the back row of orchestra and first row of choir was 4 inches.

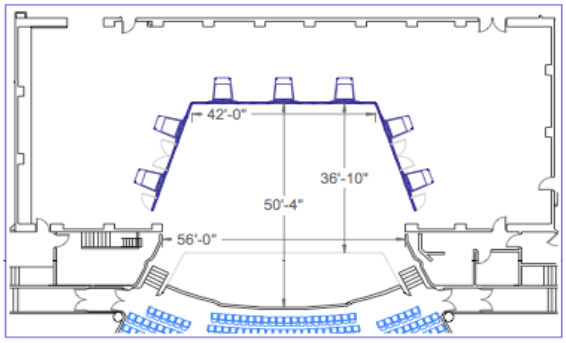

Figure 2. Venue A: Stage set up with stage shells

During on stage rehearsal and performance periods in Venue A, the choir stood in four rows, with three rows of choristers standing on three-step riser units and one downstage row standing on the stage floor. Choristers stood with close

inter-singer spacing (an inch or less lateral distance between singers) with an eight-inch elevation between rows. (See Figure 3).

S S S S S S S S B B B B T T T A A A A A A A
S S S S S S S S B B B B T T T A A A A A A A A
S S S S S S S S S S T T T T A A A A A A A
S S S S S S B B B B B T T T A A A A A

Downstage

Figure 3. Venue A: Choir standing arrangement for rehearsal and performance on the stage. Study participants are designated by red, soloists by blue, and choir members by black font colors.

The on stage rehearsal with choir, orchestra, and soloists lasted just under an hour (dosimeter recording time of 00:54:55). The performance, one day later, was an hour (dosimeter recording time of 00:59:48). Venue A contained 1911 audience seats. For the public performance in Venue A, 248 persons were seated in the audience area.

*Venue B***.** The staging area at Venue B featured the orchestra on floor level and the chorus in an elevated (8 ft.) loft behind the orchestra. There was 15' of floor space between the back row of the orchestra and the front of the choir loft. The pipe organ keyboard and player were 10' directly above the back of the choir loft (See Figure 4).

The choir with soloists ($N = 72$; 26 sopranos, 21 altos, 10 tenors, 15 basses) stood in close spacing

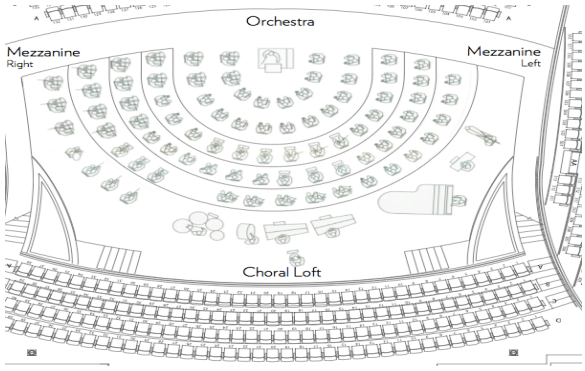

Figure 4. Venue B: Stage and choral loft

in three rows in the choir loft for the rehearsal and the performance. There was a 1' elevation and 3' distance between rows. The soloists stood in the back row of the choir when they were not singing solos on the stage floor (See Figure 5).

B S S S B B B B B B B B T T T A A A A T A
S S S S S S S S S S B B B T T T A A A A A A A A
S S S S S S S S S S S S S B B T T T T A A A A A A A A A

Downstage

Figure 5. Venue B: Choir standing arrangement for rehearsal and performance on the stage. Study participants are designated by red, soloists by blue, and choir members by black font colors.

A two-hour break occurred between the rehearsal and the performance in Venue B. There were 1600 audience seats in Venue B. On the evening of the performance, there were 1419 people in attendance.

Table 1. *The Five Dosimeter Recording Sessions by Location and Duration*

Day 1	**Day 2**	**Day 4**
Period One Rehearsal Choir Only Venue A, Dance Studio 01:06:00	Period Three Performance Choir/Orchestra/Soloists Venue A, Stage 00:59:48	Period Four Rehearsal Choir/Orchestra/Soloists Venue B, Stage 00:48:05
Period Two Rehearsal Choir/Orchestra/Soloists Venue A, Stage 00:54:55		Period Five Performance Choir/Orchestra/Soloists Venue B, Stage 01:14:33

The pubic performances were promoted as a university "Opera Gala." The first half of the program featured orchestra and solo pieces. The second half included performance by the chorus. Thus, Sonja, Alissa, Terrence and Brandon all sang and listened for roughly equal periods of time during the two public performances. Table 2 lists the repertoire presented on the second half of the program.

Table 2. *Concert Order for the Second Half of the Opera Gala Concert*

Title and Opera	**Composer**	**Performers**
Prelude to Act III and Bridal Chorus from *Lohengrin*	Richard Wagner	Choir Orchestra
Meditation from *Thais*	Jules Massenet	Choir Orchestra
Easter Prayer from *Cavalleria Rusticana*	Pietro Mascagni	Choir Orchestra Soloists
Chorus of the Hebrew Slaves (va, pensiero) from *Nabucco*	Giuseppe Verdi	Choir Orchestra
Quintet from Die Meistersinger von Nurnberg	Richard Wagner	Orchestra Soloists
Aragonaise from *Carmen*	Georges Bizet	Orchestra
Make Our Garden Grow from *Candide*	Leonard Bernstein	Choir Orchestra Soloists
Fugato finale from *Falstaff*	Giuseppe Verdi	Choir Orchestra Soloists

Table 3 describes the relative dynamic markings appearing in each measure of the compositions sung by the choir and in the chorus repertoire as a whole. The choir sang a total of 334 measures (measures of rest not included in the count). While scored dynamic ranges varied overall and according to the particular compositions sung, over a third of the total measures sung (38.02%) were marked *forte* or louder and over half of the measures sung (51.79%) were marked mezzo forte or louder.

Table 3. *Number of Measures Per Relative Dynamics Scored in Each Composition Sung by the Choir*

Dynamic Marking	*Lohengrin (142 meas.)*	*Thais (22 Meas.)*	*Cavalleria (80 Meas.)*	*Nabucco (39 Meas.)*	*Candide (12 Meas.)*	*Falstaff (39 Meas.)*	Total	Total % of Measures
	N meas.	*N* meas.	*N* meas.	*N* meas.	*N* meas.	*N* meas.	*N* meas.	
pp	7	0	0	11	0	10	28	8.38
p	115	7	0	1	0	0	123	36.83
mp	0	10	0	0	0	0	10	2.99
mf	17	0	0	23	1	5	46	13.77
f	3	5	80	0	7	19	114	34.13
ff	0	0	0	4	2	5	11	3.29
fff	0	0	0	0	2	0	2	0.60

Results

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

Research Question One: Dosimeter Data

Tables 4 – 7 present dosimeter data for Sonja, Alissa, Terrence, and Brandon from the five acquisition periods in both venues.

Table 4. *Overall Dosimeter Data Sonja (Soprano)*

Acquisition Periods	Dosimeter Duration	Overall Leq (dB)	Dose % (NIOSH)
Period 1	01:05:36	97.82	260%*
Period 2	00:56:37	99.65	350%*
Period 3	01:03:22	96.98	210%*
Period 4	00:48:08	93.74	76%
Period 5	01:14:33	96.15	200%*
Total:	05:08:16	*M*=96.87	*M*=219.2%

Table 5. *Overall Dosimeter Data for Alissa (Alto)*

Acquisition Periods	Dosimeter Duration	Overall Leq (dB)	Dose % (NIOSH)
Period 1	01:06:56	89.86	41%
Period 2	00:54:55	93.19	76%
Period 3	00:59:48	94.51	110%*
Period 4	00:48:05	90.59	36%
Period 5	01:14:33	92.04	79%
Total:	05:04:17	*M*= 92.04	*M* = 68.4%

Table 6. *Overall Dosimeter Data Terrence (Tenor)*

Acquisition Periods	Dosimeter Duration	Overall Leq (dB)	Dose % (NIOSH)
Period 1	01:07:10	87.69	26%
Period 2	00:54:43	93.26	77%
Period 3	00:59:51	90.13	41%
Period 4	00:48:04	85.25	11%
Period 5	01:14:33	87.86	30%
Total:	05:03:21	*M*=88.44	*M* = 37%

Table 7. *Overall Dosimeter Data Brandon (Bass)*

Acquisition Periods	Dosimeter Duration	Overall Leq (dB)	Dose % (NIOSH)
Period 1	01:06:22	90.40	48%
Period 2	00:54:36	95.34	120%*
Period 3	01:01:26	91.43	57%
Period 4	00:47:22	91.85	48%
Period 5	01:14:33	89.14	40%
Total:	05:04:19	*M*= 91.63	*M* = 62.6%

* Exceeds NIOSH daily dose

Note: Period 1 = Choir rehearsal only, Period 2 = Combined choir and orchestra rehearsal, Period 3 = Performance, Period 4 = Combined choir and orchestra rehearsal, Period 5 = Performance. Periods 1 and 2 occurred consecutively on the same day. Period 3 occurred on a separate day. Period 4 and 5 occurred two hours apart on the same day.

Three of the four participants acquired hearing doses in excess of NIOSH 8-hour recommendations. As dosage is cumulative, combining those periods that occurred on the same day (Periods 1 and 2, Periods 4 and 5) was a particular matter of interest. Sonja consistently had the highest Leq doses followed in descending order by Alissa, Brandon, and Terrence. During Periods 1 and 2, in slightly over two hours (02:02:03) Sonja experienced a combined noise dose of 610% or 6.1 times the NIOSH recommendation. Her Period 3 dose was 210 % and her combined Periods 4 and 5 dosage was 276% for approximately two hours of rehearsal and performance (02:02:41).

During each of the three days of rehearsals and/or performances, Alissa accumulated over 100% of her daily hearing dose. Her accumulated doses for Periods 1 and 2 were 117%, Period 3 was 110% and accumulated doses for Periods 4 and 5 were 115%. Terrence experienced the lowest sound dosage of the four study participants, yet he still experienced over 85 dB(A) in all rehearsals and performances. In Periods 1 and 2,

both occurring in the same day, he accumulated 103% of his daily hearing dose. Brandon's highest combined noise dose occurred on the first day (Periods 1 and 2) where he received 168% of his 8-hour dose in approximately two hours (02:00:58). In each of the acquisition periods, (Periods 1-5), Brandon experienced an overall Leq of 89 dB(A) and above.

Table 8 presents (a) the Leq means for the five rehearsals and/or performances in both venues in order of highest hearing dosage to lowest, and (b) the highest recorded decibel level reached during the five recording periods for each participant.

A 3 dB increase indicates a doubling of sound pressure. Therefore, the 3 dB difference between the highest level experienced by Terrence (Tenor) and Alissa (Alto) indicated that Alissa experienced double the sound pressure at her peak decibel level than Terrence experienced at his peak decibel level.

Table 8. *Leq Means From All Five Recording Periods and Highest Recorded dB Level*

Participant	Leq *M* (dB)	Highest dB Level
Sonja (Soprano)	96.87	105.17
Alissa (Alto)	92.04	99.65
Brandon (Bass)	91.63	98.14
Terrence (Tenor)	88.84	96.60

Disaggregation of COS Dose Data by Venue

Of the four COS periods examined, two occurred in Venue A and two occurred in Venue B. Figure 6 compares participant doses acquired during COS rehearsals in the two venues. Figure 7 compares participant doses acquired during COS performances in the two venues.

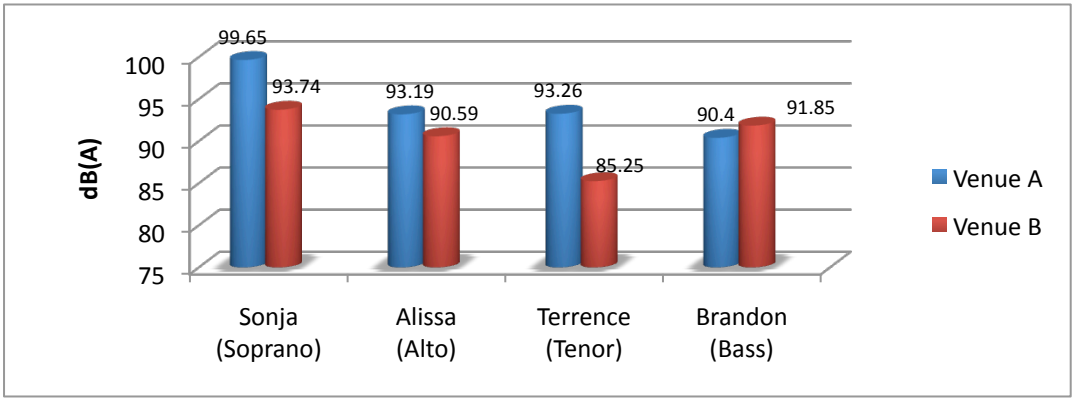

Figure 6. Participants' Leq in COS rehearsals in Venue A (Period 2) and Venue B (Period 4)

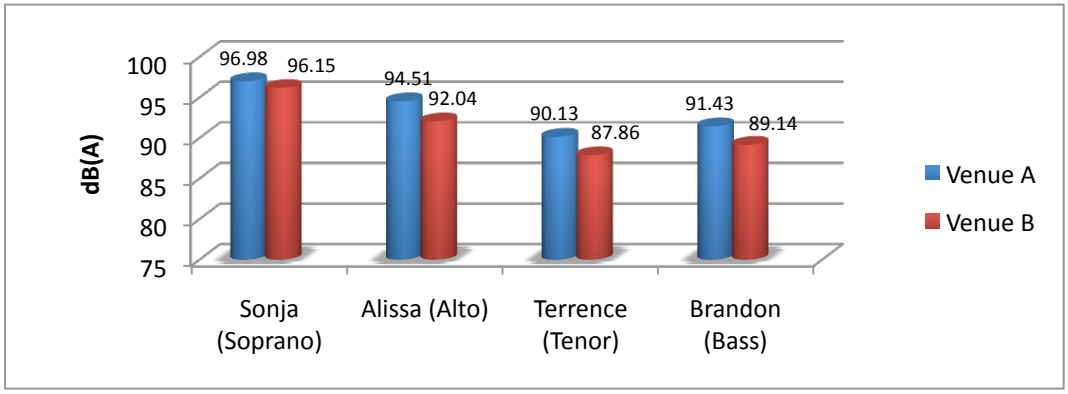

Figure 7. Participants' Leq in performances in Venue A (Period 3) and Venue B (Period 5)

In Venue A, the choir was directly behind the orchestra on risers. In Venue B the choir was in a loft 8' above the orchestra with 15' of intervening floor space between the back row of the orchestra and the choir loft. The overall Leq levels during onstage COS rehearsals were higher in Venue A than in Venue B for three of the four singers (Figure 6). During the performances, the acquired doses were greater in Venue A than Venue B for all four participants (Figure 7). The lower Leq levels in Venue B could be a reflection of the difference in position of the choir, namely the distance and elevation from the orchestra.

Research Question Two: Singer Surveys

Table 9 presents participants' combined responses to part one of the survey.

Participants indicated they were able to hear themselves and the choir best during the choir only rehearsal, Period 1. Survey results indicated participants thought they were able to hear themselves more clearly in Venue B than in Venue A, and that they could hear the orchestra better in Venue A than B. Participant results were based on a 5-point Likert-type scale.

Table 9. *Aggregate Participant Survey Responses, Means and Standard Deviations for Periods 1-5*

Survey Statement	Period One		Period Two		Period Three		Period Four		Period Five	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
1. I could hear myself clearly	1.50	1.00	2.75	0.96	3.25	0.50	2.25	0.96	1.75	0.96
2. I could hear the choir clearly	1.50	1.00	2.50	1.29	2.25	1.50	2.75	1.26	3.50	0.10
3. I could hear the orchestra clearly	n/a	n/a	1.75	1.75	2.00	1.41	3.00	1.41	2.00	0.82
4. Effort in singing	3.50	1.29	3.50	1.29	3.25	0.50	3.00	0.00	3.75	0.50

Mean responses to perceived singing effort ranged from 3.25 (Period 3) to 3.75 (period 5). Tables 10-13 present each participant's responses to survey statements 1-3.

Table 10. *Survey Responses for Sonja (Soprano) on Hearing Questions 1-3*

Statement	Period One	Period Two	Period Three	Period Four	Period Five	Overall *M*	*SD*
1. I could hear myself clearly	1	3	3	3	3	2.60	0.90
2. I could hear the choir clearly	1	2	3	1	4	2.20	1.30
3. I could hear the orchestra clearly	n/a	1	2	1	1	1.25	0.50

Table 11. *Survey Responses for Alissa (Alto) on Hearing Questions 1-3*

Statement	Period One	Period Two	Period Three	Period Four	Period Five	Overall *M*	*SD*
1. I could hear myself clearly	1	2	4	1	1	1.80	1.30
2. I could hear the choir clearly	1	1	1	3	4	2.00	1.41
3. I could hear the orchestra clearly	n/a	1	1	4	2	2.25	1.64

Table 12. *Survey Responses for Terrence (Tenor) on Hearing Questions 1-3*

Statement	Period One	Period Two	Period Three	Period Four	Period Five	Overall *M*	*SD*
1. I could hear myself clearly	3	4	3	3	2	3.00	0.71
2. I could hear the choir clearly	3	3	4	3	4	3.40	0.55
3. I could hear the orchestra clearly	n/a	1	1	3	2	1.75	0.96

Table 13. *Survey Responses for Brandon (Bass) on Hearing Questions 1-3*

Statement	Period One	Period Two	Period Three	Period Four	Period Five	Overall *M*	*SD*
1. I could hear myself clearly	1	2	3	2	1	1.80	0.84
2. I could hear the choir clearly	1	4	1	4	2	2.40	1.50
3. I could hear the orchestra clearly	n/a	4	4	4	2	3.50	1.00

Although reported perceptions varied by participant and acquisition period, mean response trends indicated each participant reported a less than even balance between hearing of self, choir, and orchestra.

Figure 8 presents participant responses to survey item four (perception of singing effort). Participants perceived they sang with slightly more than normal effort (indicated by a 3 on the survey) the majority of the time in at least one of the venues. Alissa perceived her effort to be greater than normal in Venue A, while Terrence perceived he sang with less than normal effort in Venue A.

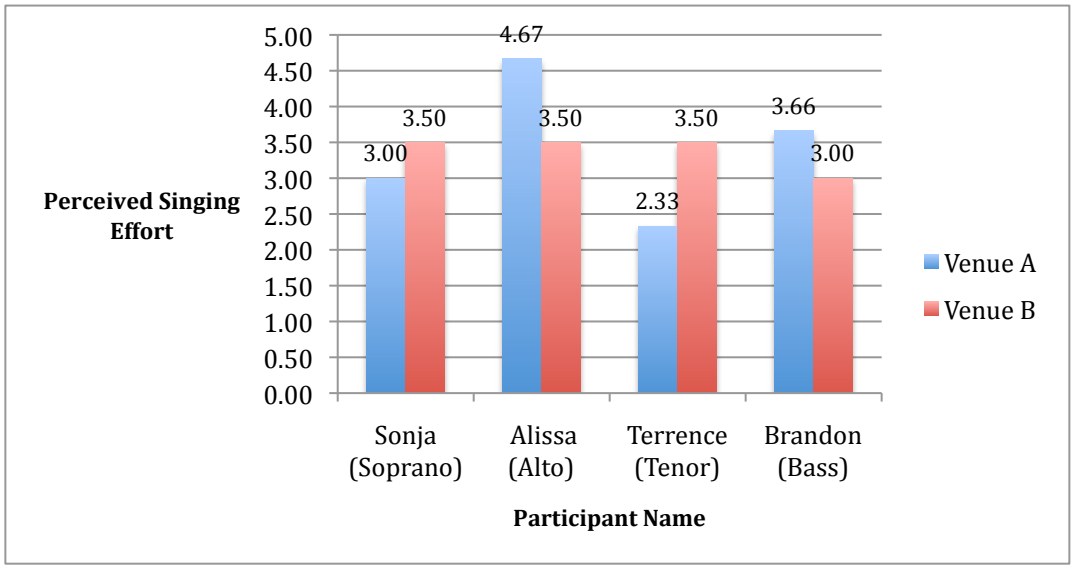

Figure 8. Participants' perceptions of singing effort by venue.

Written Comments

The second section of the survey invited participants to comment freely. Only three comments were provided. Alissa (Alto) wrote two comments after Period 2 (COS in Venue A). She commented, "That was loud, that was really loud" and "I am over-singing." Terrence (Tenor) commented after Period 3 (Performance in Venue A), "I was surrounded by big, sweaty opera guys." No participant volunteered comments for acquisition periods in Venue B.

Discussion

Few investigations to date provide information about hearing doses acquired by choral singers during rehearsal and performance tasks. The primary finding of this collective case study is that three of its four chorister participants acquired hearing doses that exceed NIOSH 8-hour daily standards during one or more of the approximately one-hour rehearsal and performance periods examined. Dosimeter and perceptual results suggest that hearing doses and perceived hearing ability vary according to context (voice part sung, position within the choir, venue). Given, however, that participants engaged in both rehearsal and performance on two of the single days measured, cumulative, per-day sound doses indicate that all but one participant (Terrence) acquired doses that exceed NIOSH standards while engaged in approximately two hours of choral singing. Sonja (the soprano), for instance, acquired a combined sound dose of 610%, or 6.1 times the NIOSH daily standard, during her approximately two hours as a chorister in Venue A.

These findings are limited to the particular participants and conditions of this study, and also circumscribed by the particular dosimeters and procedures employed. Nonetheless, results appear to merit reflection and continued research by the profession.

That the soprano participant (Sonja) acquired the highest sound doses appears consistent with findings of the Laitinen et al. (2003) study in which sound exposure levels acquired by sopranos singing in the Finnish National Opera Chorus exceeded levels acquired by other voice parts. However, results from Steurer et al. (1998) who administered audiograms to choir members, indicate no difference in hearing impairment according to voice part sung. Future investigations might well consider (a) using both audiometric and sound dosimeter measures and (b) acquiring measures over a longer period of time.

Noise dosimeters calculate overall Leq, which includes not only the sound generated by the

musicians as a whole in particular venues and contexts, but also the airborne sound of a participant's own voice. Thus, a portion of the overall sound dose may be self-inflicted. Data from this particular study indicate that the female soprano and alto participants acquired greater mean sound doses than the male tenor and bass participants.

One might conjecture that part of the reason for this finding may be that the higher frequency sound waves generated by the female singers are shorter in length than the lower frequency sound waves emitted by the male singers; thus the shorter-length waves do not refract as easily or directly to these singers' ears. Efforts to gain sufficient airborne feedback from the sound of one's own voice, perhaps coupled with pitch-amplitude effects, may occasion somewhat louder singing by these female participants in order for them to hear their own voices in this context. Subsequent studies might consider a design with simultaneous acquisition of hearing dose and vocal dose data. Selected singers, for example, might wear both sound dose dosimeters and ambulatory phonation monitors.

Results from a survey of orchestral musicians by Laitinen and Poulsen (2008) indicate that 83% of respondents wear hearing protection devices occasionally, yet many perceive these devices as either uncomfortable or in some way detrimental to musical performance. No studies to date address singers' perceptions of using hearing protection. Future studies could also test intonation among singers wearing hearing protection.

Operatic choral repertoire is a variable in all chorister studies to date employing sound dosimeter measurements. While performance of this repertoire is not the foundation of many university choral programs, it is not atypical for singers in university programs to perform this repertoire occasionally and to perform it with an orchestra. However, because composer and conductor expectations for this particular literature may call for more energetic, and hence louder singing (as indicated by Table 3) than might be the case when programming other compositions, future studies should acquire sound exposure doses from choristers engaged in rehearsing and performing a variety of repertoire with and without instrumental accompaniment.

Results of the present study appear to indicate that sound exposure levels vary according to singing venue. Most data for this study were acquired in large performing halls. Future studies should investigate doses acquired in a variety of choral rehearsal room venues, because university choral singers might be expected to spend more time singing in these rehearsal rooms than in larger performance halls.

Measures in this collective case study occurred with only four singers, one singer from each voice part in this particular choir. In order to acquire potentially interesting data relative to a singer's positioning within a particular voice section and his or her position in the choir as a whole (ends or middle of a section or row, back row, front row, etc.) subsequent investigations might well acquire simultaneous data from a larger number of choir singers. Future studies that entail choral singing in different venues might also insure that the position of individual singers within the choir remains absolutely consistent.

Instrumentation costs may be a factor in pursuing future studies of chorister acquired sound doses. The personal noise dosimeters (ER-200D) used for this study are relatively cost-effective (about $250.00 per unit) and user-friendly. While not intended primarily as research instruments, they are factory calibrated and conform to ANSI specifications and NIOSH criteria for personal dosimeters. Nonetheless, higher cost noise badges ($1500-$2000), such as those used in some studies of instrumental musicians to date, may be desirable.

Possible relationships between sound exposure and perceived hearing and voice effort warrant further investigation. Only one participant (Alissa) wrote comments after one acquisition period (Period 2, Venue A, the first rehearsal with choir and orchestra): "That was loud, that was really loud" and "I am over-singing."

By contrast, participants' responses to Likert-type scale items of hearing effort following every acquisition period appear to indicate majority perceptions of hearing difficulty slightly above the "some of the time" anchor and majority perceptions of singing effort as slightly more than "normal effort" in at least one of the venues. Survey wording prompted participants to respond according to a "during this rehearsal" or "during this performance" rubric. However, once participants became used to each of the acquisition-period sonic environments, it may be their overall perceptions solicited at the conclusion of these periods reflected this accommodation. Alissa, for example, notes the "loud" sound of the first COS rehearsal, but the absence of further written comments from her could suggest that thereafter she simply takes such an environment in stride, i.e., as an accepted part of her overall experience in rehearsing and performing this particular program. It may also be that these participants, overall, were simply not aware of the cumulative sound doses they were acquiring.

In future studies, singer perceptions might be solicited at intervals throughout the sound dose acquisition periods, with survey wording to the effect, "Right now, I am hearing…," or "Right now, I am singing…." Visual analog scales might afford more discrete data than Likert-type scale items. Participants might also respond to particular hearing or voice health indicator statements, such as "I have ringing in my ears."

Clearly, more research is warranted. We caution that data from this particular case study should not be generalized to other choir singers and other choral singing contexts. Nor should these data necessarily be viewed with alarm. However, findings of the present study suggest it may be prudent for choir directors to think about sound doses acquired by their singers during intensive periods of rehearsing and performing a large-scale program of vocally challenging repertoire with choir and orchestra. Because noise induced hearing loss is cumulative, choral conductors might also consider educating their singers about ways to conserve hearing acuity throughout their daily activities. IJRCS

Institutional Review Board Approval and Compliance
The authors obtained approval from an appropriate Institutional Review Board to conduct this research in a manner that assured the ethical treatment of participants and the confidentiality of participant information.

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Appendix: Sample Participant Survey

Voice part in this choir (circle one): Soprano Alto Tenor Baritone/Bass

Beneath each statement below, please circle the number which best corresponds to your perception:

1. I could hear myself clearly during tonight's rehearsal:

1	2	3	4	5
All of the time		Some of the time		None of the time

2. I could hear the choir clearly during tonight's rehearsal:

1	2	3	4	5
All of the time		Some of the time		None of the time

3. I could hear the orchestra clearly during tonight's rehearsal

1	2	3	4	5
All of the time		Some of the time		None of the time

4. During tonight's rehearsal, I was singing:

1	2	3	4	5
With much less effort than normal		With normal effort		With much more effort than normal

Please add any additional comments below: