THE ACCLIMATIZATION EFFECTS

OF EARPLUGS ON ACOUSTIC AND PERCEPTUAL MEASURES OF UNIVERSITY

SINGERS' VOCAL PERFORMANCES IN CHORAL AND SOLO SETTINGS

By

Sheri Cook-Cunningham

Submitted to the graduate degree program in Music Education and Music Therapy and the Graduate Faculty of the University of Kansas in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Music Education.

Chairperson Dr. James F. Daugherty

Dr. Alicia Clair

Dr. Mariana Farah

Dr. Christopher Johnson

Dr. Angie Reeder

Date Defended: June 13, 2013

The Dissertation Committee for Sheri Cook-Cunningham
certifies that this is the approved version of the following dissertation:

THE ACCLIMATIZATION EFFECTS

OF EARPLUGS ON ACOUSTIC AND PERCEPTUAL MEASURES OF UNIVERSITY

SINGERS' VOCAL PERFORMANCES IN CHORAL AND SOLO SETTINGS

____

Chairperson Dr. James F. Daugherty

Date approved: July 3, 2013

ABSTRACT

The purpose of this study was to assess with female university-singers (*N* = 34) the potential acclimatization effects of wearing one brand of earplugs marketed to musicians on selected acoustic and perceptual measures of choral and vocal sound. Data were acquired during four data collection sessions across four weeks. Participants were members of two established women's choirs, Group A (*n* = 24) and Group B (*n* = 10). Each choir sang the same musical excerpt three times during weekly data collection periods: without-earplugs at rehearsal start, with-earplugs at rehearsal start, and with-earplugs at rehearsal end. For comparison purposes, Group A wore the earplugs at each of three rehearsals per week, while Group B wore the earplugs only during data collection rehearsals. Additionally, one-half of the singers, randomly selected, participated in weekly solo recording sessions that followed a similar protocol. Digital audio recordings of the choral and solo singing performances were used for analyses of long term average spectra (LTAS), intonation, and amplitude. Among primary results: (a) choral and solo LTAS data indicated significant differences in mean signal amplitudes between the no-earplugs and with-earplugs conditions, (b) solo amplitude means indicated a < 1 dB difference between conditions in 90% of the recordings, (c) choral pitch analyses indicated earplugs did not cause choristers to sing less in-tune, (d) fundamental frequency analyses indicated that earplugs did not cause soloists to sing significantly more or less in-tune, and (e) the majority of choral (87.50%) and solo singers (75%) reported being able to hear themselves best when not wearing earplugs during the weekly recording sessions. The results were discussed in terms of possible acclimatization effects, limitations of the study, and suggestions for future research.

Acknowledgements

When I began my pursuit of my doctoral degree, I had no idea of the amount of work involved, not by me, but by those around me. The following acknowledgements express my gratitude for all those who have assisted me in attaining my doctoral degree.

Thank you to my advisor, Dr. James Daugherty who shared his knowledge, expertise, and wisdom with me over the past three years. From him I learned innumerable lessons about research, writing, and perseverance. His classes challenged me to expand my thinking and I will forever be grateful.

Thank you to the members of my committee, Dr. Clair, Dr. Farah, Dr. Johnson, and Dr. Reeder, who gave me advice, words of encouragement, and many laughs during this process. Your support has been invaluable to me.

Thank you to recent University of Kansas graduates, Dr. Melissa Brunkan and Dr. Jeremy Manternach, who shared their time and expertise with me. I appreciate your willingness to answer my many questions.

Thank you also to my fellow Graduate Teaching Assistants and members of the University of Kansas Vocal/Choral Pedagogy Research Group: Katie Hom, Heather Nelson, Amelia Rollings, and Matthew Schloneger. I value your friendships and thank you for offering ideas from your experiences. Thank you to Melissa Grady who helped me build charts, offered daily encouragement, and always brought fresh ideas and enthusiasm to the process.

Without the support, love and encouragement from family members, this task would not have been possible. Thank you to my dad who encouraged me to keep going and taught me to never give up. Thank you to my sisters and brothers, Lori, Jennette, Jim, and Jon who listened to me and shared my goal. Thank you to my children; Alissa, Daniel, and Maggie, who assisted with data entry, formatting, and have patiently waited for me to finish my task.

Thank you to my wonderfully understanding and patient husband, Kevin. His willingness to support me throughout this process has been invaluable and I cannot thank him enough.

And finally, to my mother, who taught me three important lessons: love your husband, love your children, and value education. Your lessons will never be forgotten.

Table of Contents

List of Figures

List of Tables

CHAPTER ONE

INTRODUCTION

Hearing Conservation Programs protect employees in the workplace and are commonplace in manufacturing, utilities, mining, transportation, and warehousing industries where high sound pressure levels abound (Martínez, 2012). Untreated exposure to high noise levels may result in noise induced hearing loss (NIHL), a condition that is irreparable but also avoidable (OSHA, 1983). Music induced hearing loss (MIHL) describes gradual hearing loss caused by habitual exposure to loud music (Einhorn, 2006).

The Occupational Safety and Health Administration (OSHA) enforces noise exposure regulations in the workplace, a role OSHA has held since 1971. The Hearing Conservation Amendment (1983) requires companies to include specific factors related to hearing protection, audiometric testing and training in their hearing and conservation programs. Hearing conservation programs, developed for industrial settings, typically include assessment of the working environment, removal of the sound source if necessary, measuring noise exposure, and providing the employee with hearing protection in the form of hearing muffs or earplugs (OSHA, 1983).

Musicians, too, are often exposed to high sound pressure levels, yet the music industry is exempt from OSHA hearing conservation regulations. While it is not possible to predict accurately how many musicians may be at risk for exposure to high sound pressure levels (SPLs), it is possible to examine the number of people working in the music industry (Santucci, 2009). The United States Department of Labor estimates that 264,000 US Citizens work either full-time or part-time as musicians (Labor Department (US) Bureau of Labor Statistics, 2008-09). These numbers reflect only those persons in the work force and do not include student musicians who may also be exposed to high sound pressure levels.

Unlike an industrial setting in which the sound source can often be eliminated or dampened, a musician must hear the environmental sound, as that is an integral part of what musicians do. Musicians cannot eliminate the sound source or remove themselves from the sound source and still remain musicians.

Increased Hearing Loss

Recent studies suggest that children and teenagers may also be exposed to high SPLs (Berg & Serpanos, 2011; Olsen Widen & Erlandsson, 2004). Audiogram results from 5,249 United States children reveal noise notches (a notch in the 3 kHz to 6 kHz region) in 12.5% of those tested (Niskar, Kiesezak, & Holmes, 2001). Results from the first ever conference on Noise-Induced Hearing Loss in Children at Work and Play (sponsored in part by the National Institute of Occupational Safety and Health, NIOSH) indicate that monitoring and controlling sound exposures for this population group (children) is necessary (Morata, 2007).

Robb (2002) suggests that the number of 15-year olds with some degree of hearing loss is almost equal to the number of 45 to 50-year olds reporting hearing loss. He proposes that possible causes of teen-agers' hearing loss may include exposure to environmental noise, listening to amplified music, and the prevalence of ear buds and personal hearing devices for music listening.

Sherman (2000) reports on the 20th century epidemic of hearing loss and cites amplified music as one of the causes. Sound level measurements from rock concerts typically average between 120-130 dBA, enough to cause some permanent hearing damage. Sherman cites the example of Peter Jefferey, a Princeton University professor of music history, who sued the rock group Smashing Pumpkins, claiming he suffered permanent hearing loss after attending a concert by the band. According to the lawsuit, Jefferey's left ear is damaged and he now suffers from ongoing tinnitus in both ears due to sound levels of up to 125 dBA during the performance.

Rock music is not the only genre of music producing high sound levels. Sherman (2000) suggests in an article that early music (from Gregorian chant to Bach) is much safer to the ears than much of the standard orchestral and opera repertoire currently performed.

Prior to the 19th century, classical music catered to relatively small aristocratic audiences. As the audience base grew to include more middle class listeners, the size of the halls also increased to accommodate them. Larger performance venues necessitated more performers (orchestral and vocal) to fill the space with sound. Composers of the Romantic era wrote music with more dynamic contrasts and for large ensembles with the intent of producing grandiose effects (Shrock, 2009).

Wilhelm Furtwängler (1886 – 1954), a leading orchestra conductor in Europe, conducted many of the symphonies of the Romantic composers, particularly Beethoven, Brahms, Bruckner, and Wagner. Furtwängler suffered from deafness most likely caused by the many years of standing in front of the fortissimo brass sections while conducting compositions by Wagner and Bruckner (Sherman, 2000). During one of Furtwängler's final rehearsals with the Berlin Symphony, the maestro shook his baton to begin a Beethoven symphony. The orchestra entered but even with the speakers amplifying the instrumentalists and positioned at the podium, Furtwängler was still unable to perceive the music of the orchestra.

Anatomy of the Ear

There is a difference between "hearing" sound and "perceiving" sound. The process of hearing involves the transmission of physical vibrations to the brain. The ear intensifies these vibrations, then converts the vibrations to electrochemical energy and sends them to the brain. The brain in turn translates these signals into the sounds or musical tones we perceive (Wagner, 2009).

The ear is divided into three parts, the outer, middle and inner ear (see figure 1). The outer ear, or pinna, is the visible portion of the ear, acting as a canal through which sound travels and protecting the middle and inner ear from foreign bodies. The tympanic membrane (eardrum) sits at the end of the canal. Sound waves enter through the canal and hit the tympanic membrane, which changes the waves to mechanical motion (Wagner, 2009).

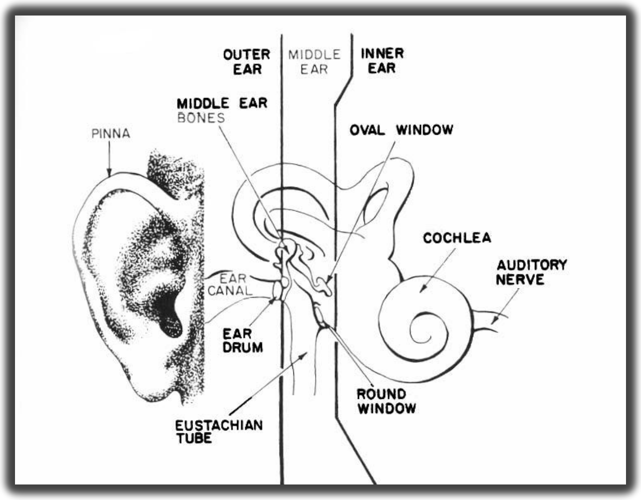

Figure 1. The three parts of the ear (outer, middle, and inner).

The middle ear consists of three small bones in an air-filled space (see figure 2). These three bones are called the ossicles and consist of the malleus, incus, and stapes. The ossicles are the smallest bones in the body and transmit energy from the tympanic membrane to the oval window of the inner ear. The middle ear also provides some protection from loud sounds by reducing extreme amounts of pressure on the oval window (Wagner, 2009).

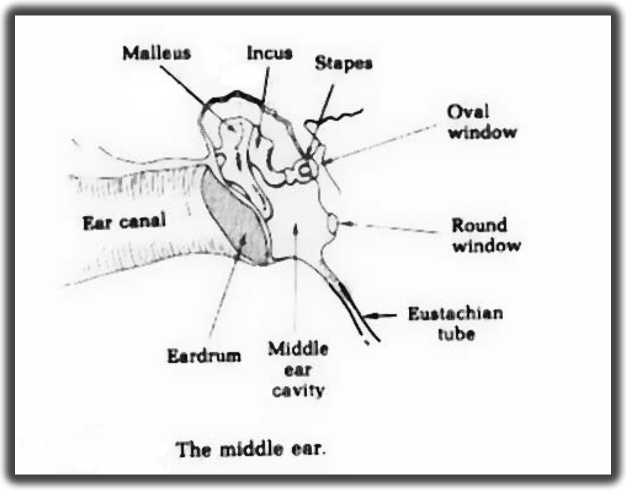

Figure 2. The ossicles and major components of the middle ear.

The three major mechanisms of the inner ear are the cochlea, the vestibule, and the semicircular canals (see figure 3). The part of the inner ear most concerned with hearing is the cochlea and is considered the true organ of hearing. The cochlea acts as a transducer, converting mechanical energy to electrochemical energy that travels to the brain through the auditory nerve. The brain then interprets this energy and translates it into the sounds we hear (Wagner, 2009).

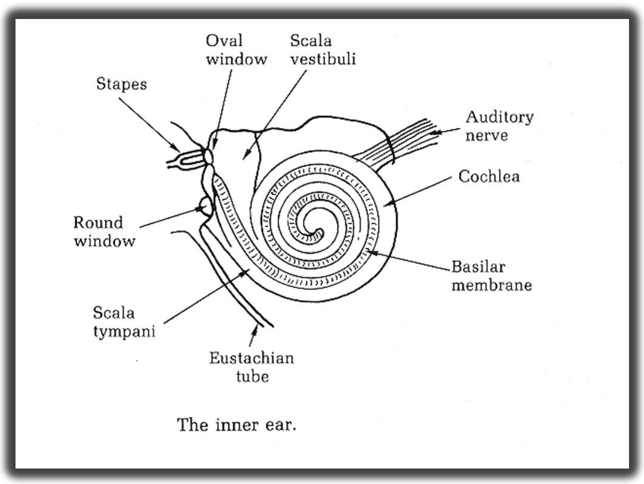

Figure 3. The inner ear components.

Within the cochlea, lies the Organ of Corti, which contains approximately 23,500 inner and outer hair cells (see figure 4). The sound waves ripple the fluid inside the cochlea, which in turn cause the hair cells to move up and down, transforming the sound vibrations into electrical signals that are transmitted to the brain. The hair cells are not regenerative and can be damaged by exposure to high sound pressure levels. This damage is gradual, often going unnoticed at first and eventually resulting in a loss of hearing (Wagner, 2009).

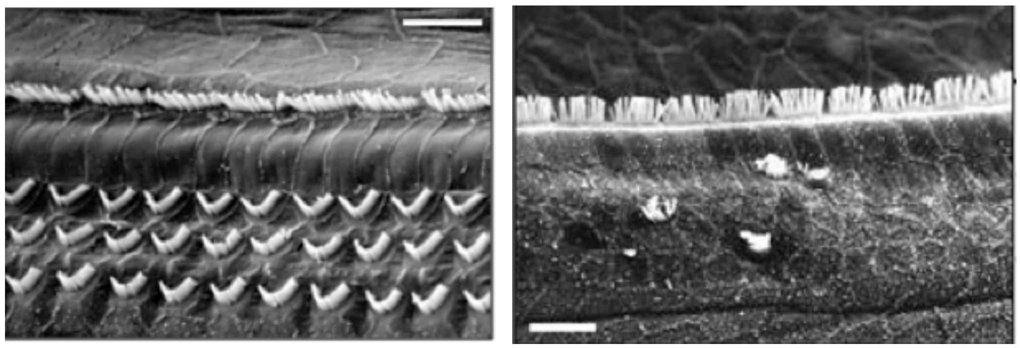

Figure 4. Healthy hair cells and noise damaged hair cells.

The Importance of Hearing Health to Musicians

Sataloff (1991) opined that a professional musician's hearing loss could equate to a loss of income. Because musicians must hear accurately over a wider number of frequencies, even a small loss of hearing may be detrimental to a musician's ability to perform. If an orchestra violinist's impaired hearing causes out of tune playing, it is conceivable the orchestra management will dismiss the violinist.

Amidst concerns about the hearing health of music students and music instructors, the National Association of Schools of Music (NASM) and the Performing Arts Medicine Association (PAMA) joined forces in 2011 to provide information and recommendations to schools of music. Their recommendations include taking sound level measurements, using hearing protection devices, acoustical treatments to reduce sound levels, providing rehearsal breaks, and monitoring repertoire to provide for dynamic contrast (NASM/PAMA, 2011).

NASM/PAMA offers suggestions to reduce dangerous sound levels, but with no laws requiring safe hearing environments for the music industry, musicians themselves are responsible for maintaining and protecting their own hearing. A musician's ability to accurately perceive and interpret sounds is crucial to effective teaching, conducting, and performing and the loss of that hearing can be devastating.

Ludwig Van Beethoven's (1770 – 1827) well-documented hearing decline rendered him unable to publicly perform and eventually, to conduct. In a letter dated June 29, 1801, Beethoven recounted his struggles with his hearing loss to Dr. Franz Wegeler, Professor of Medicine at the University of Bonn, Germany. "I really lead a wretched life, for nearly two years I have been avoiding almost all company, just because I find it impossible to say to people: I am deaf" (Robbins, 1974).

Air and bone conducted sound. Beethoven's situation underscores orchestral and choral musicians' need for auditory feedback not only from their own playing or singing but also from other ensemble members (Naylor, 1987; Ternström, 1999). This feedback is supplied via sound pressure waves, which are perceived in two ways, by air conduction and bone conduction (Pörschmann, 2000).

Sounds that travel from the outer ear through the external auditory canal, to the middle ear, the inner ear, and then the brain's auditory cortex are heard by air conduction (Martin & Clark, 2009). Those sounds that bypass the outer ear and vibrate the bones of the head can stimulate the inner ear and produce sound via bone conduction (Durrant & Lovrinic, 1984).

Most sounds are transmitted by air conduction alone; however, some instrumentalists and singers perceive their own sounds through both air and bone conduction. The motion of blowing into a mouthpiece or the act of phonating causes the jaw to conduct one's sound to the bone and tissue surrounding the ear canal, providing auditory feedback via bone conduction (Niquette, 2006).

Ware (2001) suggests that bone conducted sounds often transmit kinesthetically to singers through vibrations they feel most in their faces but also in the head, neck, and upper body. Both air and bone conduction provide feedback that is roughly equal in amplitude and both types of conduction appear to attenuate higher frequencies (von Békésy, 1949). Perceptions of the lower frequency sounds (700 Hz - 1200 Hz) tend to be dominated by bone conduction (Pörschmann, 2000).

Self to other ratio. Choral singers concurrently hear airborne and bone conducted feedback from their own voices (Self) and the sound of the rest of the choir, including sound reverberations (Other). The ability to hear oneself in an ensemble is often determined by the difference in sound pressure levels between "self" sound and "other" sound. In choral singing, Self-to-Other Ratio (SOR) describes this difference in sound pressure levels (SPLs) between oneself and other choristers, expressed in decibels (Ternström, 1999). The inability to hear one's own voice can result in pitch and timbre errors (Naylor, 1987; Ternström & Sundberg, 1988). 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. Chorister SOR preferences are fairly narrow, usually ±2 dBA for each singer but can vary over 6 dBA within a choir (Ternström, 1999).

Choral singing requires choristers to produce a unified blending of voices. Producing this harmonious sound requires choir members to constantly adjust their own sound (Self) to that of the rest of the choir (Other). It appears that singers adjust their articulation and phonation resulting in the fundamental tone being accentuated with a simultaneous dampening of the upper partials (Rossing, Sundberg, & Ternström, 1986, 1987).

The masking of one sound by another occurs in both instrumental and vocal settings with more masking occurring when the sounds are the same frequency (Mehta, Johnson & Rocafort, 1999). Hence, in a choral setting, when two singers singing the same voice part are positioned next to each other, a singer's output may be masked by another singer in his/her section. This in turn may produce the Lombard effect wherein a vocalist will raise his or her voice in an effort to receive feedback from Self (Tonkinson, 1994). Increasing the lateral and vertical space between singers and mixing the sections may improve a singer's perception of SOR as well as their tuning (Daugherty, 1996, 1999, 2003, 2005, 2012, 2013; Ternström, 1999).

While solo singers and choral singers both rely on their hearing to produce accurate and in-tune sounds, there are inherent differences between the two types of singing and both require different skills. Vocalists adjust their singing depending on whether they are singing in a solo or choral setting (Rossing, et al., 1986, 1987). In a choral setting the emphasis is on producing one homogenous sound with no voice more audible than any other. 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 (Sundberg, 1977).

Accurate tuning. Musicians are often judged by their ability to play or sing in tune. While all musical instruments produce musical tones through three essential parts (an actuator, a vibrator, and a resonator), tuning procedures vary from instrument to instrument. Vocalists, in particular, face some specific challenges inherent to the uniqueness of their instrument (McKinney, 1994).

Most instrumentalists tune their instrument by making physical adjustments to some exterior tuning mechanism such as a slide, tuning pegs, or a barrel. 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 (Titze, 2006).

Titze (2006) suggests that because pitch is also affected by sound intensity, with louder tones usually perceived as higher in pitch, a hearing loss might cause vocalists to sing louder. Turner offers that while hearing loss might make one sing “off key,” the direction (high or low) varies across patients (Titze, 2006). Ware (2001) submits that accurate hearing for singers is crucial not only in correctly matching pitch but also in monitoring one’s own vocal feedback and allowing them to accurately adjust to what they hear. 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.

Hearing Protection for Singers

Whereas accurate hearing is a key component to beautiful singing, over-exposure to music may actually put a singer at risk of developing hearing loss (Sataloff, 1997). Professional singers typically have more control of their performance and practice schedules than do college-age singers. Musicians’ unions safeguard the length of rehearsal times and venues and professionals often are more aware of vocal health and hearing health hygiene. Additionally, professionals are able to regulate the repertoire they sing, individual practice time and personal practice space (Rosen, 2001; Smith, 2003).

By contrast, university singers are often involved in more than one ensemble, each of which might practice three to five times a week. In addition to a singer’s schedule of private lessons and concert attendances, vocalists involved in student performances often have intense practice schedules prior to performances (Schloneger, 2011).

Schloneger (2011) studied voice use of two university opera singers for a five-day intensive rehearsal week. During the time period studied, the vocalists' music exposure included 4-12 hours of opera rehearsal, 1.5 – 6.33 hours of singing outside of rehearsals, and 4 – 7 hours of teaching voice lessons. These exposure times did not include noise exposure to non-musical activities.

College and university singers often practice in school-provided music spaces, which typically are small rooms with limited acoustical treatments. Nelson (2012) studied the acoustical properties of university practice rooms and found unsatisfactory noise reduction from the hallway into the practice room.

University singers may acquire high sound doses during rehearsals and performances. Cook-Cunningham, Grady and Nelson (2012) measured sound pressure levels of four university singers participating in a concert featuring opera solos and choruses. During a one-hour rehearsal, all four participants recorded sound levels between 87.69 dBA and 97.82 dBA.

Results from hearing tests of senior university music students ($N = 26$) reveal a noise notch in 5 (19.2%) of their audiograms. Of the five students with noise notches, three are voice majors, one a percussionist and one a saxophone player (Cook-Cunningham, 2013).

Clearly, student musicians are exposed to numerous source sounds, many of which they have little control over. Of the recommendations NASM/PAMA provide (taking sound level measurements, using hearing protection devices, acoustical treatments to reduce sound levels, providing rehearsal breaks, and monitoring repertoire to provide for dynamic contrast), the only option under the control of the student musician is wearing hearing protection.

Need for the Study

Although there are numerous perceptual studies regarding ear protection devices for orchestra musicians, only one study to date explores the use of hearing protection devices by singers (Laitinen, Toppila, Olkinuora, & Kuisma, 2003). No study to date measures the acoustical and perceptual effects of acclimatization to worn earplugs on vocalists in both choral and solo singing contexts.

Purpose of the Study

The purpose of this study was to assess with female university singers (*N* = 34) the potential acclimatization effects of wearing one brand of earplugs marketed to musicians on selected acoustic and perceptual measures of choral and vocal sound. Data were acquired during four data collection sessions across four weeks. Participants were members of two established women's choirs, Group A (*n* = 24) and Group B (*n* = 10). Each choir sang the same musical excerpt three times during weekly data collection periods: without-earplugs at rehearsal start, with-earplugs at rehearsal start, and with-earplugs at rehearsal end. For comparison purposes, Group A wore the earplugs at each of three rehearsals per week, while Group B wore the earplugs only during data collection rehearsals. Additionally, one-half of the singers, randomly selected, participated in weekly solo recording sessions that followed a similar protocol.

The following research questions informed the two contexts (choral singing, solo singing) of this investigation:

1. Are there differences across time in Group A and Group B recordings of choral sound produced with and without the wearing of earplugs, as determined by long-term average spectra (LTAS) analyses, Pitch Analyzer 2.1 procedures, and expert listener perceptions?

2. Are there differences across time in Group A and Group B recordings of solo vocal

sound produced with and without the wearing of earplugs, as determined by long-term average spectra (LTAS) analyses, expert listener perceptions, obtained fundamental frequencies, and amplitude analyses?

3. What do participant surveys across time indicate about Group A and Group B choral and solo singer perceptions of their vocal production, hearing of self in a choral and solo context, hearing of others in a choral singing context, and acclimatization to wearing hearing protection earplugs?

Definitions

The following definitions clarify the terms employed in this study.

This study follows the definition of auditory acclimatization adopted by leading auditory scientists at the Eriksholm Workshop on Auditory Deprivation (Arlinger, S., Gatehouse, S., Bentler, R.A., Byrne, D., Cox, R.M., Dirks, D.D., Humes, L., Neuman, A., Ponton, C., Robinson, K., Silman, Sl, Summerfield, A. Q., Turner, C.W., Tyler R. S., and Wilcott, J.F., 1996).

Auditory acclimatization is a systematic change in auditory performance with *time* [emphasis added], linked to a change in the acoustic information available to the listener. It involved an improvement in performance that cannot be attributed purely to task, procedural or training effects.

Types of Hearing Disorders

NIHL or noise induced hearing loss is the gradual hearing loss due to over exposure to loud noises.

MIHL or music induced hearing loss is similar to NIHL in that the hearing loss is gradual but the source of the hearing loss is chronic exposure to loud music.

Diplacusis is an abnormal perception of sound that can result in one sound being perceived as two or a frequency increase sounding only as an increase in dynamics.

Hyperacusis describes hypersensitivity to normal sounds.

Occlusion effect is the perceived feeling of a blockage in the ears, resulting in a perceptual distortion of pitch and amplitude.

Tinnitus is the perception of sound when there is no external sound source. It is often described as a high-pitched constant sound and as a "ringing in the ears."

Hearing protection device (HPD) describes all types of hearing protection, including earplugs, ear muffs, and in ear monitoring devices.

Hearing Doses and Measurements

Noise dose is the total sound exposure received in a given time period as related to the criterion level. According to OSHA, an employee could be exposed to a time weighted average of 90 dBA during an 8-hour workday. Following the more conservative NIOSH guidelines, a 100% dose would be 85 dBA during an 8-hour time frame and following

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

A-weighting measures the decibel levels for all frequencies and weights them differently across time. Sound level meters and noise dosimeters are fitted with filters to adapt the measured sound to what human ears hear. An A weighting filter attenuates frequencies below several hundred hertz and above six thousand hertz.

Criterion level is the average sound pressure level resulting in a 100% noise dose over a specified time period, typically 8 hours.

Criterion time is the time used to calculate the noise dose. It is usually 8 hours.

LAVG is the average sound level measured during the run time.

Leq represents an equivalent sound level measured during the run time. When the A-weighted scale is used, the measurement is expressed either as LAeq or Leq dBA. LAVG and Leq are basically the same except Leq is used when the exchange rate is set to 3 dBA.

Time Weighted Average (TWA) is the average of the sampled sound over an 8-hour period. Under OSHA guidelines, TWA is the number to report.

CHAPTER TWO

REVIEW OF LITERATURE

This chapter reviews empirical research literature both directly and indirectly related to hearing loss, the potential role of hearing protection devices, and the acclimatization experienced by wearers of such devices. In so doing, it will consider research related to (a) the importance of hearing to musicians and types of hearing loss, (b) hearing loss among musicians, (c) hearing conservation programs, (d) hearing protection for musicians, and (e) acclimatization.

Musicians' Hearing and Types of Hearing Loss

The vocational demands of musicians require an acute sense of hearing, probably more so than in any other profession. The aural demands of an orchestra conductor, for instance, include hearing every instrument part, verifying the accuracy of the played notes, determining the desired dynamic levels, and assessing nuances of timbre. A choral singer must be able to accurately hear herself or himself as well as the rest of the choir and make pitch and dynamic adjustments based on that aural feedback. A music teacher's ability to assess student performance aurally is considered a core component of teaching. 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 (Sataloff, 1997).

Einhorn (2006) identified five auditory disorders that arise from noise induced otologic damage. These disorders included noise induced hearing loss, tinnitus, hyperacusis, diplacusis and recruitment.

Noise Induced Hearing Loss

Noise induced hearing loss (NIHL) is gradual and cumulative, often going unnoticed until after the damage has already occurred. NIHL caused by industrial noise usually presents as an audiometric notch in the 3 kHz to 6 kHz range and is symmetrical between the worker's ears (Chasin, 2009).

Morata (2007) described music induced hearing loss (MIHL) as hearing loss due to over-exposure to loud music, characterized by a noise notch in the 4 to 6 kHz region. According to Morata, MIHL goes unnoticed at first. For musicians, hearing loss in the upper frequencies could occasion an inability to correctly match pitch or correctly respond to dynamic changes, resulting in over-singing or overplaying (Einhorn, 2006).

Unlike NIHL, musicians who suffered from MIHL often experienced asymmetrical hearing loss, possibly due to their position in an ensemble, the instrument they played, or time spent performing and practicing in non-reverberant spaces (Chasin, 2009). Regular audiometric tests provided the only means with which to diagnosis MIHL. Early diagnosis proved crucial, before the hearing loss widens into the 2 kHz – 3 kHz range where speech comprehension would be affected (Einhorn, 2006).

Tinnitus

Tinnitus, another type of hearing disorder that often accompanies NIHL and MIHL, has been defined as a perception of sound in the absence of a physical stimulus and often described as a "ringing or hissing in the ears" (Einhorn, 2006). Tinnitus has affected many popular musicians including Barbra Streisand, Pete Townshend of *The Who*, and Liberty DeVitto, Billy Joel's drummer (Tyler, Chang, Tao, Gogel, & Gehringer, 2009). Romantic composers Ludwig Van Beethoven, Robert Schumann, and Bedrich Smetena reportedly suffered from tinnitus and hearing loss (Morgenstern, 2005).

Hyperacusis

Hyperacusis, or hypersensitivity to normal sound may be induced by exposure to loud noise or loud music (Einhorn, 2006). Laitinen (2005) reported that 43% of symphony orchestra musicians surveyed experienced hyperacusis, describing it as "smart, sharp pain", "ripping, grating, jarring pain", "sense of pressure", "distortion of sounds", "humming in the head", and "nausea."

Diplacusis

Diplacusis, attributed to exposure to loud sounds, has resulted in an abnormal sound perception, inability to discern increased frequency and pitch distortion (Chasin, 2009; Einhorn, 2006). Peter Townshend, lead guitarist of the rock band, *The Who* attributed his hearing problems to long-term exposure to loud music (Chasin, 2009). Townshend's diplacusis caused him to perceive musical pitches as two semi-tones lower than the actual performed pitch.

Hearing Loss and Musicians

Musicians rely on their hearing acuity as performers, teachers, students and, concert-goers. However, over-exposure to loud music may compromise a musicians' fine-tuned sense of hearing. Early indications of hearing loss were often temporary tinnitus or a "ringing in the ears" caused by loud sounds. High sound pressure levels, long exposure to sound, and exposure to impluse sounds (cymbals, percussion) have contributed to the development of tinnitus in musicians (Johnson, Sherman, Aldridge, & Lorraine, 1985).

Gilles, De Ridder, Van Hull, Punte, and Van de Heyning (2012) evaluated the attitudes of university undergraduate and graduate medical students towards noise, noise-induced tinnitus (NIT), and hearing protection. Of the 145 students surveyed, 89.5% reported experiencing transient tinnitus after exposure to loud music and 14.8% reported permanent tinnitus. Most participants were unaware of the risks of noise exposure and only 11% of the students reported using hearing protection.

Laitinen (2005) surveyed symphony orchestra musicians (*N* = 196) about hearing protection and hearing health. Questionnaire results revealed that 37% of the respondents experienced temporary tinnitus.

Music majors (*N* = 407) at Göteborg University responded to a questionnaire soliciting students' practice hours, musculoskeletal disorders, and hearing health, in particular tinnitus (Hagberg, Thiringer, & Brandström, 2005). Of the 407 students surveyed, 96 (23%) music students reported suffering from tinnitus. Results revealed a strong positive relationship between number of practice hours and impaired hearing with an incidence rate of 10.6 cases of tinnitus per 1000 performance/practice hours.

Zeigler (1997) studied the prevalence of tinnitus and hearing protection use among 498 university students including music majors (*n* = 249) and non-music majors (*n* = 249). A significantly higher number of music majors (*n* = 188, 75.5%) reported experiencing tinnitus than non-music students (*n* = 145, 58.2%). Among instrument classifications, percussionists recorded the highest incidence of tinnitus (*n* = 12, 80%), followed by vocalists (*n* = 43, 78%). Music majors who reported wearing hearing protection occasionally or regularly numbered 46 (18.5%) while 202 (81.5%) of the music majors responded they never wore hearing protection devices (HPDs).

Results from a survey administered to freshman university music majors (*n* = 200) at a large public university and a smaller private university (*n* = 28) indicated that over half of those surveyed (*n* = 146, 58.9%) claimed to have some type of tinnitus, yet the majority (*n* = 211, 85%) of the students did not wear hearing protection during solo or ensemble rehearsals (Zeigler & Taylor, 2001).

Attempts to establish a causal relationship between over-exposure to music and hearing loss among musicians have resulted in conflicting data. Audiograms administered to professional symphony orchestra musicians (*N* = 139) revealed that 43% of the musicians had hearing loss greater than expected for their age (Axelsson & Lindgren, 1981). Other studies investigating classical musicians' hearing corroborated Axelsson and Lindgren's study, finding hearing loss in the 4-6 kHz region, consistent with MIHL (Emmerich, Ruder, & Richter, 2008; Jansen, Helleman, Dreschler, & de Laat, 2009; Ostri, Eller, Dahlin, & Skylv, 1989; Royster, Royster, & Killion, 1991; Westmore & Eversden, 1981).

However, in a follow-up to Axelsson and Lindgren's 1981 study, Kähäri, Axelsson, Hellström, and Zachau (2001a) examined the results of audiology exams administered to 56 of the musicians from the original 1981 study. Results indicated that the musicians' hearing had not significantly declined in the 16 years from the original study. Additional studies yielded similar results with orchestral musicians' hearing registering within normal ranges when compared to that of other workers or to a normative population (Johnson et al., 1985; Kähäri, Axelsson, Hellström, & Zachau 2001b; Karlsson, Lundquist, & Olaussen 1983; Obeling & Poulsen, 1999).

Amidst concerns about noise exposure among arts and entertainment employees, the Association for Safety and Health in Arts Production and Entertainment (SHAPE) requested a review of literature from the School of Occupational and Environmental Hygiene at the University of British Columbia (Peters, Thom, McIntyre, Winters, Teschke, & Davies, 2005). Based on a review of the literature, researchers concluded that musicians were at risk for developing hearing loss.

By contrast, Behar, Eng, Wong and Kunov (2006) reviewed 13 papers on NIHL among orchestra musicians, determining that the risk to orchestral musicians of developing NIHL was minimal. Behar et al. (2006) and Sataloff (1991) suggested the conflicting research results might have been due to poor research design, different definitions of hearing loss, data calculations, and data analysis.

Several investigations obtained sound level measurements over the course of a working day from school music teachers. Behar et al. (2004) obtained sound doses from 18 public school music teachers (elementary through high school) over the course of a regular teaching day. In 78% of the sound measurements, the sound pressure level (Leq) exceeded the 8-hour 85 dBA NIOSH recommendation. Band, singing, and recorder playing produced the highest sound levels and no significant difference was found between elementary and high school music instructors' mean Leq.

Owens (2004) measured sound pressure levels experienced by 10 band directors while conducting high school ensembles. Study results showed that 6 (60%) of the directors acquired sound doses over 90 dBA and exceeded the NIOSH eight-hour acceptable hearing dose.

Sink and Mace (2004) measured sound pressure levels of music teachers ($N = 18$) during two regular teaching days. Mean daily sound pressure levels ranged rom 75.7 dBA to 90.4 dBA, leading researchers to suggest that music teachers were at risk for developing NIHL due to exposure to high sound levels.

Concern about the possible effects of loud music on university music students' hearing health led researchers to study hearing tests of music students. Audiogram results from 329 university music students revealed noise notches in 148 (44%) of those persons tested (Phillips, Henrich, & Mace, 2010). Mace, Phillips, Bhatt, Henrich, and Richter (2012) administered audiology exams to 558 music students from five universities. Hearing loss, defined as a 15 dBA HL drop sensitivity with an increased sensitivity between 6 kHz and 8 kHz, was found in 239 (43%) of the participants.

Barlow (2011) examined hearing thresholds of undergraduate university students (*N* = 50) enrolled in popular/rock music courses, who were exposed to amplified music. Examination results revealed noise notches in the 4 kHz - 6 kHz region in 22 (44%) of the students, while 8 (16%) of participants were classified as having mild hearing loss. This finding was consistent with the results of audiograms of music students obtained by Mace et al. (2012) and Phillips et al. (2011), suggesting a need for noise exposure education for young people.

Various studies have examined acquired sound doses among high school and university music students. Walter (2011) measured sound pressure levels of 16 high school marching band members over a two-day camp period. Results revealed that 15 (93%) of the 16 participants acquired sound doses in excess of the NIOSH eight-hour recommendation.

Presley (2007-08) measured university drum and bugle corps musicians' (*N* = 15) acquired sound doses during a full-day (12 hours) rehearsal. All percussionists experienced doses greater than 100% of the NIOSH standards for a 12-hour workday. The snare drummers acquired sound doses of between 5319.92% and 9145.99%.

Phillips and Mace (2008) acquired sound level measurements of university music students (*N* = 40) during individual practice sessions in music practice rooms. Mean sound levels recorded during an average 47-minute practice session ranged from 87 dBA to 95 dBA. Researchers suggested hearing conservation measures, which included requiring students identified as having high frequency hearing loss to wear musician's earplugs.

Mace (2005) measured sound levels of 37 music performance teachers during two consecutive teaching days. Results indicated that 13 (35%) of the teachers exceeded NIOSH standards for an 8-hour period and that two-day averages resulted in 12 (32%) of the participants exceeding NIOSH standards for a safe sound dose.

Walter (2009) measured university wind band players (*N* = 46) sound exposure during wind band rehearsals. Dosimeter results indicated that 52% of the wind band players received sound doses greater than 100% of the NIOSH daily-recommended dose during one or more rehearsal. Sound level measurements from music student practice rooms revealed mean sound levels of 87-95 dBA during an average 47-minute practice session (Phillips & Mace, 2008).

Results from these studies occasioned a number of music schools to establish hearing conservation programs (Chesky, 2008, 2011; Hodges, 2009; Lehman, Miller, & Stewart, 2007; Phillips et al., 2010). The National Association of Schools of Music (NASM) and the Performing Arts Medicine Association (PAMA) recommended providing education to university music teachers and students and to institute hearing conservation programs. Their recommendations included taking sound level measurements, using hearing protection devices, acoustical treatments to reduce sound levels, providing rehearsal breaks, and monitoring repertoire to provide for dynamic contrast (NASM/PAMA 2011).

While hearing loss among instrumentalists generated a great deal of research, few studies to date investigated hearing loss among singers. Steurer, Simak, Denk and Kautzky (1998) measured hearing thresholds of professional opera chorus members (*N* = 62) of the Vienna State Opera and compared them to thresholds from a normative population distribution. Results revealed noise notches in the lower frequencies, atypical of MIHL, of a significant number of study participants.

Sound exposure levels taken among members of the Finnish National Opera personnel indicated that 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. During choir only rehearsals, sound pressure levels for all voice parts measured 100 dBA. Results of this study lead to the establishment of a Hearing Conservation Programme for all opera personnel (Laitinen et al., 2003).

Cook-Cunningham, Grady, and Nelson (2012) measured vocalists' ($N = 4$) sound doses during various choir and combined choir-orchestra performances. Results indicated that in one or more of the one-hour time periods studied, 3 of the 4 participants acquired sound doses in excess of the NIOSH recommended daily eight-hour noise exposure.

Cook-Cunningham (2012) acquired sound pressure levels of female university singers ($N = 4$) during a choir concert accompanied exclusively by either piano or organ. Mean SPLs for sopranos ranged from 93.32 dBA to 95.05 dBA while alto mean SPLs ranged from 84.83 dBA to 86.79 dBA.

Hearing Conservation Program

Although there is no cure for noise induced hearing disorders, hearing loss due to noise exposure is entirely preventable by reducing the noise 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, musicians looked to occupational noise exposure standards to establish safe music sound levels and hearing conservation measures (Niquette, 2006).

Hearing conservation in the workplace has been regulated by two United States agencies, the Occupational Safety and Health Administration (OSHA) and the National Institute for

Occupational Safety and Health (NIOSH). OSHA, which governs noise exposure in the workplace, mandated that employees' eight-hour exposure not exceed 90 decibels dBA with a 5 dBA exchange rate (OSHA, 1983). NIOSH, acting as the research arm, conducted research and provided recommendations to OSHA. NIOSH recommended a more conservative hearing dose, with an eight-hour time-weighted average of 85 dBA and a 3 dBA exchange rate. The exchange rate is significant because a 3 dBA increase in sound pressure level equals a doubling in loudness and cuts the allowable exposure time in half. The risk of developing occupational NIHL over a 40-year time frame would be 8% under NIOSH guidelines and 25% using OSHA guidelines (NIOSH, 1998). Music researchers have adopted the more conservative NIOSH standards (Suter, 2009).

NIOSH standards were developed for industrial noise, concentrated more in the lower frequency ranges and with very little energy above 1500 Hz. This type of noise provided a more constant sound source with little difference between the most intense and least intense noise. As Chasin (2009) suggested, however, musicians typically experience varying sound levels, fluctuating frequencies and intermittent sounds.

Although the United States has not yet regulated noise exposure due to musical sound, many of continental Europe's music venues have followed International Organization for Standardization ISO 9612:2009 recommendations (ISO, 2009). ISO mandated an 85 dBA criterion level with a 3 dBA exchange rate, essentially the same as NIOSH requirements. Moreover, the 2005 Noise at Work Regulations issued in the United Kingdom 2005 mandated the entertainment industry to comply with controlling noise exposure in the United Kingdom (Barlow & Castilla-Sanchez, 2012).

Laitinen, Toppila, Olkinuora and Kuisma (2003) measured sound pressure levels for personnel of the Finnish National Opera. Sound doses exceeded the Finnish national action level of 85 dBA averaged over an 8-hour period. Finnish legislation dictates that employers must establish a Hearing Conservation Programme if noise levels exceed the national action level. An industrial hygienist measured performance and rehearsal spaces and reported that the rooms used for personal rehearsals were too small and the reverberation time was too long. The opera provided all personnel with hearing protection devices (HPDs) of each member's choice with instructions on appropriate use and information on hearing risks.

NIOSH (1998) recommended implementing a hearing loss prevention program when any worker's TWA eight-hour exposure equaled or exceeded 85 dBA. The components of the HL prevention program included: noise exposure assessment, engineering and administrative controls and work practices to reduce the noise source, audiometric evaluations, communication to workers of dangerous noise levels, training, program evaluation, and use of hearing protection devices. NIOSH advocated first for environmental changes to ensure workers noise exposure was under an eight-hour TWA of 85 dBA. Failing that, NIOSH required employers to provide hearing protection to their employees that would attenuate noise levels enough to keep the employee below the established safe standard (NIOSH, 1988).

NIOSH (1998) identified communicating dangerous sound levels to workers and training of employees as important elements of a successful hearing conservation program. Various studies from symphony orchestra members, university musicians, and high school students indicated that awareness of and training about the dangers of hearing loss did not necessarily translate into hearing conservation.

Chesky, Pair, Lanford, and Yoshimura (2009) surveyed 467 university students, disaggregated by music majors and non-music majors. Results indicated that music majors had a greater awareness of the risks of high noise levels when compared to non-music majors. Researchers suggested that music majors might be more likely to benefit from a hearing conservation program.

Erlandsson and Widen (2004) surveyed high school students (N = 1285) ages 13 to 19 years regarding use of hearing protection and self-reported hearing conditions. Student participants completed a Youth Attitude to Noise Scale (YANS) Questionnaire as well as a demographic survey. Survey results indicated that 111 (8.7%) of the students reported permanent tinnitus and 219 (17.1%) recorded noise sensitivity. The students who reported tinnitus and noise sensitivity reported themselves to be more likely to use hearing protection than their counterparts who were not experiencing noise-related health symptoms.

Owens (2007) and Santucci (2009) suggested five components necessary for a successful music hearing conservation program: (a) sound level survey, (b) audiometric monitoring, (c) education and motivation, (d) reducing level of exposure through environmental control, and (e) hearing protection devices. Tyler, Chang, Tao, Gogel, and Gehringer (2009) suggested prevention of MIHL by reducing the loudness of music played, putting distance between self and the music source, providing barriers between self and the music, modifying acoustic environments, and using hearing protection. Zembower (2000) listed the following steps to reduce hearing risks to musicians: ear protection, modifying the environment, installing acoustical tile or carpet on ceilings and walls, carpet hardwood or tile floors, separating sections of instruments at wider distances, and placing protective sound shields and reflective devices around certain instrumental sections.

Unlike eliminating noise in industrial contexts, eliminating or modifying sound sources has not been an option for hearing conservation programs in music contexts. The American Speech and Hearing Association (ASHA) recommended improving acoustics in the classroom by adding carpets or rugs to the floor, adding drapes to the window, reducing reflective surfaces by using corkboard on walls, creating quiet spaces by dividing the room with bookshelves, reducing outside noise by landscaping with trees, closing the doors to hallways, and suspending acoustic tile from the ceiling (ASHA, 1995).

Chasin and Chong (1995) suggested four environmental adaptations to reduce sound exposure to performing musicians. Their suggestions included: (a) elevating speakers/amplifiers from the floor, (b) situating treble brass instruments (trumpets) on risers to reduce the sound exposure to those seated downwind of the trumpet section, (c) insuring two meters of unobstructed floor space in front of an orchestra, allowing for improved self-monitoring of shorter frequencies for the musicians, and (d) providing two meters of unobstructed space above small stringed instruments. When seated under an overhang of an orchestra pit, violinist and violists tend to overplay to compensate for the loss of high frequency harmonic energy, which was absorbed into the overhang. Providing two meters of unobstructed space above the string players allowed the musicians to monitor their own sound without the potential for overplaying.

Hearing Protection for Musicians

Although NIOSH and OHSA recommendations consider hearing protection devices as the last resort in providing a safe work environment, earplugs may be the only viable option for musicians. Chasin and Chong (1991) reported on the challenges of using HPDs in a musical environment, which are foreign to HPDs in industrial settings.

Earplugs for musicians must allow the wearers to still hear clearly and hear well in order to effectively perform their jobs. Traditional earplugs presented problems for musicians in the following areas: (a) unbalanced attenuation, (b) too much overall attenuation, (c) occlusion, and (d) musicians attitudes towards hearing protection (Chasin & Chong, 1991; Chasin & Chong, 1992; Iltis, 2009; Killion, DeVilbiss, & Stewart, 1988; Killion, 2012; Niquette, 2006; Ostri et al., 1989).

The ear has a natural resonant peak of about 17 dBA at 2700 Hz. This peak is removed when traditional earplugs are inserted into the ear (Niquette, 2006). The decrease in this peak coupled with the attenuation of sound caused by the earplugs reduced the higher frequencies by as much as 15 to 20 dBA. Traditional earplugs could cause a muffled sound with an uneven tonal balance, causing musicians to overcompensate by playing or singing louder (Niquette, 2006).

Iltis (2009) reported that typical earplugs tended to provide more attenuation than necessary for musicians. A foam earplug attenuated sound by 30 to 40 dBA, which may result in a misrepresentation of Self sound and Other sound. In addition, the foam plugs tended to distort the sound by attenuating higher frequencies more than lower ones. The amount of recommended attenuation varies according to one's instrument, position within the ensemble, and exposure time.

Laitinen et al. (2003) queried personnel of the Finnish National Opera ($N = 148$) about their hearing health and personal use of HPDs. Questionnaire results revealed that 76% of the musicians never used hearing protection when performing alone and less than three percent always used HPDs. According to the questionnaire findings, 80% of the musicians had their hearing tested every three years and NIHL was reported in 20% of the cases. Among singers, 32% expressed concern about their hearing, however the usage rate of HPDs among vocalists was low. Of the singers, 87% received hearing examinations every three years, with 14% reporting continuous tinnitus and 41% recording a decrease in their hearing from the previous exam. Problems with HPD included sense of pressure in the ears, ear infections, discomfort from the earplugs, problems in the settings on custom molded plugs, altered balance between the musician's own instrument and other instruments, and dizziness.

Laitinen (2005) surveyed members of five classical orchestras (*N* = 196) querying musicians about their hearing health, their attitudes towards HPDs and the usage rates of hearing protection. Although 60 (31%) of the study participants reported experiencing some hearing loss and 72 (37%) reported temporary tinnitus, only 11 (6%) of the musicians surveyed reported always wearing HPDs. Participants with hearing symptoms used HPDs more than musicians without hearing damage. During individual rehearsals 12% of musicians with reported hearing symptoms used HPDs while only 2% of those without hearing symptoms wore HPDs.

In the same study, Laitinen surveyed musicians regarding types of HPDs used and problems in using earplugs. Musicians used custom molded earplugs the most (47%), followed by disposable plugs (25%), cotton, hands, tissues (12%) and high fidelity (HIFI) plugs (3%). Motives for not wearing protection included hindering their own performance (*n* = 155, 79%), difficulties hearing others play (*n* = 88, 44%), unpleasant sensations from the earplugs (*n* = 15, 7%), problematic to insert (*n* = 12, 6%), communication problems during rehearsals (*n* = 4, 2%), and current hearing loss made usage a problem (*n* = 3, 1%).

Laitinen and Poulsen (2008) investigated hearing protection use among 145 members of three professional symphony orchestras. After a short lecture about hearing loss, orchestra members completed a questionnaire soliciting responses to hearing protection usage and general hearing health. Results indicated the lowest usage rates were while teaching and during personal rehearsals. Only 21 (15%) of the participants reported using any type of hearing protection on a regular basis.

In the same study, the occlusion effect, or increased sound pressure level at the eardrum, resulted in 43% of the wearers discontinuing use of hearing protection. When questioned about the adjustment period for earplugs, 13% of those wearing HPDs reported adjusting immediately to hearing protection, 15% reported needing some time to adjust, 43% were not yet adjusted but still used HPDs. Of the responding musicians, 29% quit using hearing protection, claiming it was too difficult. Very few musicians responded to the questions detailing length of adjustment period and their answers varied between “weeks”, “months”, and “years.”

According to Niquette (2006) the occlusion effect produced a booming or hollow sound when a musician played or sang. Typical earplugs provide a shallow seal of the outer portion of the ear canal, the result is occluded, the vibrations produced by the singer or instrumentalist reverberate off the earplugs, causing a hollow or booming sound to the earplug wearer. The shallow seal of many earplugs results in elevated SPLs behind the earplug.

Zander, Spahn, and Richter (2008) surveyed 429 professional orchestra musicians with respect to the use of hearing protection. Although 107 (25%) of the musicians 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.

Huttunen, Sivonen, and Pöykkö (2011) studied professional musicians’ use of hearing protection devices. Symphony orchestra musicians ($N = 15$) either already owned or were provided with, ER-15 custom-molded earplugs and completed a questionnaire detailing their hearing protection usage habits. Survey results showed low earplug usage, with only one to three of the musicians wearing the earplugs greater than 95% of the time. Musicians reported occlusion, problems using the HPDs, difficulties hearing their own and other musicians' playing, and discomfort of the plugs. A large number of the participants (80 %) cited distorted timbre and/or dynamics as the cause for non-use of the earplugs.

Professional symphony orchestra musicians (*N* = 32) responded to a survey occasioning responses to questions about occupational health risks (Delbert, Romeo, & Kumke, 2012). Nearly all of the participants (31 of 32) indicated awareness of hearing loss and concern about HL. A total of 23 musicians reported having had their hearing tested in the past and 8 indicated the results showed some hearing loss. When queried about hearing protection, 25 (78.1%) participants reported wearing HPD and 20 (80.0%) musicians perceived them as effective.

Barlow (2010) surveyed university students (*N* = 100) enrolled in popular music courses where amplified music is typically in use. Although 76 (76%) of the participants reported experiencing symptoms associated with NIHL, only 18 (18%) reported always or usually wearing earplugs. When asked what type of hearing education they received in the popular music courses, 64 (64%) reported having received HL education and 51 (51%) confirmed receipt of noise level awareness.

University student musicians (*N* = 27) participated in a survey soliciting information regarding their time spent practicing, sound exposure, knowledge of hearing conservation, and tinnitus condition (Miller, 2007). Sound levels measured during rehearsal and sporting event contexts revealed that students acquired noise doses in excess of the recommended OSHA and NIOSH 8-hour daily dosage. Survey results revealed that 19 (74%) of the respondents had knowledge of NIHL, 17 (63%) reported experiencing tinnitus after exposure to loud music, and 21 (78%) of the student musicians did not wear HPDs when playing musical instruments. Of the students who did report using hearing protection (*n* = 6, 22%), foam plugs were used most often.

Callahan et al. (2011) surveyed college student musicians (*N* = 130) soliciting number of hours they played/practiced their instrument per week, recreational weekly sound exposure and their attitudes towards HPD use, weekly sound exposure (school and recreational) and self-perceived hearing difficulties. Participant responses indicated that while 70 (54%) of students reported occasional tinnitus, 102 (79%) of the participants never wore hearing protection during solo practice and 117 (90%) of respondents did not wear HPD during ensemble performances. More than half of the students (*n* = 68, 53%) felt they did not need hearing protection with other concerns listed as inability to hear environmental sounds, comfort, inability to verbally communicate, hassle, and appearance.

Chesky et al. (2009) evaluated the effect of hearing protection devices on college students' (*N* = 323) perception of music loudness, ability to communicate in a music environment, perceived comfort, and the ability to perform. Results indicated that although participants generally liked the HPDs and realized the value of earplugs in reducing risk to excessive noise levels, music majors reported that using earplugs while performing negatively affected their playing.

Killion (2012) suggested that a lack of acclimatization time, loss of "fortissimo blare", and shallow earmold seal might impact brass player's decisions regarding the use of ear protection. Sealed- earmold earplug wearers complained about the occluded feeling, due to the lack of a deep seal. Killion suggested returning to the audiologist who made the earmold impressions to insure a proper fit, thus eliminating that hollow or occluded sound.

For musicians previously diagnosed with HL in the upper frequencies, the addition of a 15 dBA attenuation from the earplugs rendered them unable to hear the higher harmonics.

Killion suggested that players would adjust to this change through practice, monitoring their playing in the still-audible lower frequencies (Killion, 2012).

To meet the specific needs of musicians**,** Elmer Carlson, an engineer for Knowles Electronics, designed the first high fidelity hearing protector in the 1980s. Carlson engineered the earplugs to duplicate the ear's natural response so that sounds would maintain their original quality, only softer. Etymotic Research determined there was a need for the hearing protector and trademarked the earplug design as "Musicians Earplugs" in 1985 (Niquette, 2006). Carlson's design included **a** deeply fitted custom molded earplug with a central sound filter that provided an accurate representation of the sound (Dawson, 2007). Musicians could choose from filters that attenuated sound by 9 dBA, 15 dBA, or 25 dBA (Niquette, 2006).

The ER 20 HF (Etymotic Research) earplug provided affordable hearing protection that reduced noise by approximately 20 dBA at all frequencies, yet preserved sound quality (Dawson, 2007). Dawson cautioned that the attenuators in the earplugs altered a musician's perception of their own sound, which may lead to playing louder until the musician becomes accustomed to the plugs.

Hearing Acclimatization

Acclimatization

Acclimatization refers to the automatic physiological adjustments that occur due to environmental changes such as increases or decreases in temperature or increased altitude. In the case of higher altitude, over a period of time the body acclimates to decreased oxygen levels by producing more hemoglobin (Borg, 2000). It appears that the auditory system may also undergo an acclimatization period, requiring time to adapt to changes in the auditory environment. To date, there has been little research specific to acclimatization and HPDs. The majority of the research in auditory acclimatization concerned hearing aid acclimatization and has produced mixed results, due in part to varying study designs and measurement methods.

Gatehouse (1989) posited that the ear undergoes a perceptual acclimatization period when presented with high levels of stimulation. To test this hypothesis, four participants with bilateral symmetric sensorineural hearing loss were each fitted with one hearing aid and underwent a series of assessments during a 12-week period after the initial hearing aid fitting (Gatehouse, 1992). Researchers tested participants' speech identification ability using the hearing aid in both the normally unaided ear and the aided ear. Researchers found no differences between the normally unaided ear and the aided ear at the two to three-week mark. However, results from the four to six week mark indicated benefits to the control (unaided) ear remained stable while benefits to the aided ear increased and continued to intensify through the 12-week period.

Taylor (1993) employed a series of objective and subjective assessment tools to study hearing amplification benefits in hearing aid users ($N = 58$) over a one-year period. Initial testing did not occur until the third week after the initial fitting thus there were no initial scores available for comparison. Results did not indicate a significant improvement in objective measurements and one test witnessed a decline at the 12-week mark.

Results from subjective and objective measurements provided mixed results among 65 new and experienced hearing aid (HA) users (Bentler, Niebuhr, Gretta, & Anderson, 1993 a, b). None of the objective test results and only one subjective measurement suggested positive hearing aid benefit over time. By contrast, Horwitz (1997) found no increase in subjective benefit to 26 HA users, 13 new users and 13 longstanding users, but new users experienced increased objective benefit measures.

Gatehouse (1993) identified 36 long-time (12 to 15 months) hearing aid users as having hearing aids with insufficient gain at the 2kHz, 3kHz, and 4 kHz regions. Participants were re-fitted with hearing aids with the National Acoustics Laboratory recommended gain in the upper frequencies. Researchers administered a speech-in-noise test and a sentence verification test and compared the results between the original hearing aid and the newly prescribed aid. Initial testing resulted in similar results between the original hearing aids and the new aids, but over a 16-week period performance with the newly prescribed hearing aids improved while performance with the original aids remained constant.

Leading auditory scientists convened at the Eriksholm Workshop on Auditory Deprivation in 1995, in part, to standardize auditory research terminology (Arlinger, S., Gatehouse, S., Bentler, R.A., Byrne, D., Cox, R.M., Dirks, D.D., Humes, L., Neuman, A., Ponton, C., Robinson, K., Silman, Sl, Summerfield, A. Q., Turner, C.W., Tyler R. S., and Wilcott, J.F., 1996). Attendees at the workshop adopted the term *auditory acclimatization* with the official definition as "a systematic change in auditory performance with time, linked to a change in the acoustic information available to the listener. It involved an improvement in performance that cannot be attributed purely to task, procedural or training effects" (Arlinger et al., 1969). Workshop attendees cited the need for additional research regarding auditory acclimatization.

Several studies indicated there was no auditory acclimatization. Humes et al. (1995) measured speech recognition of ten new hearing aid users and ten experienced hearing aid users over a 24-week period. Results did not indicate significant gains in speech recognition tests during the time period studied.

Saunders and Cienkowski (1997) studied 48 hearing aid users (24 new users and 24 experienced users) during a 90-day period. Hearing aid users were fitted with one of three types of hearing aids and participated in two types of speech and hearing tests at initial fit, 30 days post-fit, 60 days after fit and 90 days after the initial fitting. Test results yielded small non-significant changes in hearing aid benefit during the 90 day period, indicating no acclimatization effect.

Questionnaires measuring HA users' perception of hearing aid benefit indicated a perceived increase of benefit over the first few weeks of use followed by a decline in the next few months (Demorest & Walden, 1984; Malinoff & Weinstein, 1989; and Seyfried, 1990). Additional subjective studies suggested that hearing aid benefit stayed constant over the time-period studied (Brooks, 1989; Henrichsen, Noring, Lindemann, Christensen, & Parving, 1991, Mulrow, Tuley, & Aguilar, 1992; and Schum, 1992).

Turner, Humes, Bentler, and Cox (1996) conducted a review of the literature on acclimatization and concluded that while there appeared to be some increase in hearing aid benefit over time, there were other more robust factors that could cause an increase or decrease in hearing aid benefit. They reported no consensual agreement as to the best way to measure hearing ability or hearing aid benefit, two items typically evaluated in the studies. They argued that a pure acclimatization effect was due to perceptual learning and that in some studies there were additional variables, e.g., volume gain or increased familiarity, which may have produced confounding results. The large variability across participants and studies were additional areas of concern.

Humes, Wilson, Barlow, and Garner (2002) studied the objective and subjective benefits of hearing aids to new hearing-aid wearers during the first year of use. Elderly hearing-aid users

(*N* = 132) underwent a series of tests at one month, six months and twelve months after the initial fit. Results from the subjective measures suggested that patients perceived the benefit of the hearing aids to be significantly less at the six months and twelve months intervals than they did at the one - month interval, indicating there was no acclimatization of hearing aid benefit.

Kuk, Potts, Valente, Lee, and Picirrillo (2003) studied acclimatization in experienced binaural hearing aid wearers (*N* = 20). All participants had worn binaural hearing aids for an average of 20 years and 19 of the participants had severe-to-profound sensorineural hearing loss. Participants were fitted with new hearing aids and took speech-in-noise tests (SPIN) one-month after the fitting and at three-months post-fitting. Results supported the hypothesis of acclimatization, evidencing significant improvement in SPIN scores at the one-month evaluation when compared to the initial fitting evaluation. There was not a significant difference between the one-month and three-month SPIN scores.

Munro and Lutman (2003) administered the Four Alternative Auditory Feature (FAAF) word recognition test to 16 new hearing aid users during a 12-week period following the initial hearing aid fitting. Results indicated an acclimatization effect at the higher presentation levels and not at the lowest levels. Self-reported benefits to new hearing aid users resulted in mixed results (Munro & Lutman, 2004). The researchers recruited 32 new hearing aid users and divided them pseudo-randomly into two groups, labeled F and M. Both groups reported perceived benefits of and satisfaction with their hearing aids over a 24-week post-fitting period. Group F used the initial fit as a comparison point while group M compared perceived benefits to each previous visit. Median scores indicated a significant improvement among members of group F only.

Prates and Iório (2006) evaluated new hearing aid users (N = 16) over a three-month period using objective speech tests and subjective evaluations (questionnaire). Results from objective tests indicated that acclimatization started after the first month of hearing aid use and continued through the third month of the study. Questionnaire results did not evidence a perceived improvement from the first month to the third month of hearing aid use.

Yund, Roup, Simon, and Bowman (2006) studied the effects of two different types of hearing amplification on 39 new HA users. Study results indicated an acclimatization effect on one type of HA only and researchers concluded that acclimatization depended on the type of HA and previous experience with amplification.

Munro (2010) discussed the variance of acclimatization study results and opined that study length factored into the mixed results. He suggested Gatehouse's 1989 monaural study ended at 12 weeks and the benefits had not yet peaked.

Gatehouse and Killion (1993) proposed that gradual changes occurred in the brain that impacted new hearing aid users' ability to adjust to their newly amplified environment. They referenced research in the areas of neurophysiology and neuropsychology that suggested evidence of cortical plasticity in mature brains.

Brain plasticity, once thought to exist only in immature brains, is now known to exist in mature adult brains as well (Munro, 2010). Munro defined brain plasticity as the brain's ability to alter neurons and connections in the brain (or to reorganize) in response to changes in the environment. The brain was not fixed but was malleable or plastic and could adapt and change through adulthood. Without brain plasticity, humans could not adapt to an injury and adults would be unable to learn new skills. Munro likened brain plasticity to auditory acclimatization.

Several studies revealed evidence of brain plasticity among hearing aid users (Hamilton & Munro, 2010; Munro, 2008; Munro & Trotter, 2006; Munro, Walker, & Purdy, 2007; Philibert, Collet, Vesson, & Veuillet, 2002; Tremblay, 2005). Munro and Blount (2009) investigated adaptive plasticity in the auditory system of 11 normal-hearing adults. Participants continuously wore a customized noise-attenuating earplug in one ear for a period of 7 days. The earplugs provided a mean attenuation of 22 dB at 0.25 kHz and increased to a 46 dB mean attenuation at 8kHz. The middle ear acoustic reflex threshold (ART) was measured in both ears at 0, 7, and 14 days. Both ears significantly changed in mean ART at day 7, increasing in the control ear and decreasing in the plugged ear. Day 14 ART measurements were consistent with day zero ART measurements. Results indicated the presence of adaptive brain plasticity as well as the brain's capacity to reverse itself upon the return of normal environmental conditions.

Acclimatization for HPD

To date, there exists scant empirical research related to an actual acclimatization period for earplugs. When the Finnish National Opera established their hearing conservation program, opera personnel received guidelines for proper HPD use and the recommendation to adapt to earplugs by gradually using the plugs (Laitinen, et al., 2003).

In their discussion section, Huttunen et al. (2011) suggested a necessary acclimatization period for hearing protection and proposed a time frame of two to three months. They recommended starting hearing protection in individual rehearsals, moving into orchestra rehearsals and lastly, in concert settings. They further recommended constant support of the musicians during the HPD acclimatization period.

Killion (2012), president of Etymotic Research, suggested it usually took only a few weeks for trumpeters to acclimatize to Etymotic high-fidelity earplugs. He recommended practicing with the earplugs prior to performing with them to adjust to the attenuated dynamics.

Summary

Results from the studies reviewed in this chapter offered conflicting data regarding musicians' risk for developing hearing loss. Some investigators reported evidence of hearing disorders such as tinnitus, hyperacusis, diplacusis and music induced hearing loss, among musicians (Emmerich et al., 2008; Hagberg et al., 2005; Jansen et al., 2009; Laitinen, 2005; Royster et al., 1991; Ostri et al., 1989; Westmore & Eversden, 1981; Zeigler, 1997; Zeigler & Taylor, 2001). On the other hand results from symphony orchestra musicians' audiograms have yielded inconsistent results. Some researchers, for instance, found hearing loss consistent with MIHL in musicians' hearing tests (Axelsson & Lindgren, 1981; Emmerich et al., 2008; Jansen et al., 2009; Royster et al., 1991; Ostri et al., 1989; and Westmore & Eversden, 1981). Audiograms from university music students revealed noise notches, consistent with MIHL, in more than 43% of those studied (Barlow, 2011, Phillips et al., 2011; Mace, et al., 2012). By contrast, data from additional musicians' audiometric studies indicated no hearing loss when compared to the hearing thresholds from a normal population (Johnson et al., 1985; Kähäri, et al., 2001a; Kähäri et al., 2001b; Karlsson et al., 1983; Obeling & Poulsen, 1999).

Dosimeter readings have clearly indicated that musicians are regularly exposed to sound levels that exceed the NIOSH eight-hour recommendation of 85 dBA over an eight-hour time period (Barlow, 2011; Behar et al., 2004; Henoch & Chesky, 2000; Mace, 2006; Owens, 2004; Phillips & Mace, 2008; Sink & Mace, 2004; Walter, 2009; Walter, 2011). Four studies specific to singers indicated vocalists are also exposed to high sound levels (Cook-Cunningham, 2012, Cook-Cunningham et al., 2012; Laitinen et al., 2003; Steurer et al., 1998).

Recommendations for hearing conservation programs in industrial settings suggested eliminating the sound source, altering the environment, and providing ear protection (NIOSH, 1998). For musicians, often the only option available is ear protection. Data from several studies (Barlow, 2010; Callahan et al., 2011; Chesky et al., 2009; Huttunen et al., 2011; Laitinen et al., 2003; Miller, 2007; Zander et al., 2008) suggested that musicians may be resistant to wearing ear protection for a variety of reasons, including unbalanced attenuation, too much overall attenuation, occlusion, and musicians' attitudes towards hearing protection (Chasin & Chong, 1991; Chasin & Chong, 1992; Iltis, 2009; Killion, DeVilbiss, & Stewart, 1988; Killion, 2012; Niquette, 2006; Ostri et al., 1989).

Researchers suggested using earplugs specifically designed for musicians that would provide the correct attenuation and a deep enough seal to avoid the effect of occlusion (Dawson, 2007; Niquette, 2006). In addition, some investigators recommended an acclimatization period to allow the brain time to adjust to the auditory effects of earplugs (Huttunen et al., 2011; Killion, 2012; Laitinen et al., 2003)

This review of literature indicated that no study to date has measured the effects of musician's earplugs on university solo or choral singers' performances. To that end, the current study will use acoustical (LTAS, fundamental frequency, amplitude) and perceptual (expert listening panel, Pitch Analyzer 2.1, singer survey) measurements to determine singers' ability to acclimatize to wearing hearing protection and what effect musician's earplugs may have on vocalists' performances in solo and choral contexts.

CHAPTER THREE

METHOD

Purpose of the Study

The purpose of this study was to assess with 34 female singer participants, who were divided into Group A (*n* = 24) and Group B (*n* = 10), the potential acclimatization effects of wearing one brand of earplugs marketed to musicians (ETY•Plugs® HD) on selected acoustic and perceptual measures of choral and vocal sound acquired during four data collection sessions across four weeks (initial earplug fit, one-week following fit, two-weeks after fit, and three weeks post-fit). This chapter details the participants, procedures, and methods of the study.

Singer Participants

Participants (*N* = 34) were members of two intact women's choirs at a large Midwestern University. One choir (Group A) wore earplugs for three rehearsals each week for four weeks (12 rehearsal periods). The other choir (Group B) wore earplugs for one rehearsal each week across four weeks (4 rehearsal periods). All participants signed an International Review Board (IRB) pre-approved consent form (see Appendices A and B).

Group A. Group A choristers consisted of 24 singers, ranging in age from 18 – 22 years, with a modal age of 19 years and a mean age of 19.71 years. Participating singers consisted of seven women singing the soprano I part, five women singing the soprano II part and twelve women singing the alto part. Half of the students (*n* = 12) were undergraduate music majors. The student grade classifications included freshmen (*n* = 16), sophomore (*n* = 1), juniors (*n* = 3), seniors (*n* = 3) and graduate student (*n* = 1).

Group B. Group B choristers consisted of 10 singers, ranging in age from 17 – 35 years, with a modal age of 19 years and a mean age of 20.80 years. Participating singers consisted of three women singing the soprano I part, four women singing the soprano II part and three women singing the alto part. The majority of the students (*n* = 7, 77.78%) were undergraduate music majors and student grade classifications included freshmen (*n* = 2), sophomores (*n* = 5), juniors (*n* = 2) and one graduate student.

Solo participants. I randomly selected approximately one-half of the singers (Group A, *n* = 11 solo participants from 24 choral participants and Group B, *n* = 5 solo participants from 10 choral participants) to participate in weekly solo recording sessions. Using the same singers enabled a comparison of the effects of earplugs on the same singers in two different contexts, choral and solo singing.

Hearing screening. All participants received an individual hearing screening before the first recording session. Participants completed a short questionnaire, detailing hearing health and hearing attitudes as well as demographic information (see Appendix C). The audiology screenings used standard, best practice, clinical procedures and took place in a quiet vocology laboratory located at the end of the hallway and separated from practice rooms.

The researcher placed the headphones on the participant, ensuring that the headphone speakers covered the singer's ears. The researcher presented the participant with a pure-tone at 25 dBHL for each of the following frequencies: 250, 500, 1000, 2000, 4000, 6000 and 8000 Hz. The researcher asked the singers to raise their hand when they heard the tone. Each stimuli was presented twice. Participants who raised their hand in response to each of the frequencies in both ears passed the hearing screening. Participants exhibiting hearing loss were excluded from the experiment and referred to a licensed, certified audiologist. At the conclusion of the hearing screen, the researcher fitted each participant who had passed the hearing screening with his or her own set of earplugs.

Earplugs

Participants received one pair of ETY•Plugs® High-Definiton Earplugs (Etymotic Research Inc.) which was theirs to keep. The ETY plugs offered an affordable (under $13 /pair) high fidelity earplug. The manufacturer states the earplug was designed to maintain speech and music clarity while providing a nearly equal attenuation of 20 dBA at all frequencies. The ETY plug employed a tuned resonator and acoustic resistor aimed at duplicating the ear's natural response. The manufacturer claimed that regular use of the earplugs while practicing, performing and listening to music would protect the ears from overexposure to loud sound and recommended "a little time" to acclimate to the earplug (http://www.etymotic.com/hp/er20.html).

The ETY•Plugs® were non-custom earplugs, came in two sizes (standard and large), and were fitted according to the participant's comfort (see figure 5). The researcher relayed manufacturer's directions for proper care, insertion and use to each participant. After the instructions, the participant inserted the earplugs under the guidance of the investigator. The researcher visually verified proper earplug seal and confirmed proper fit on a weekly basis.

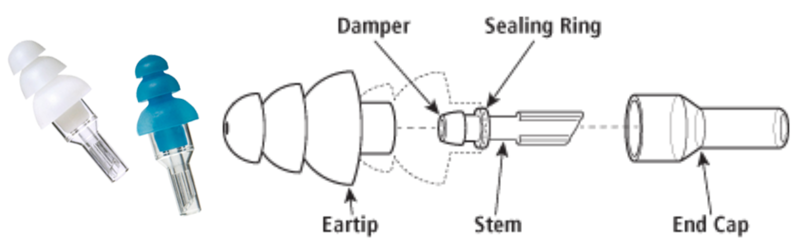

Figure 5. ETY Plugs HD High-Definition Earplugs and earplug design.

In order to compare acclimatization periods to the ETY•Plugs®, Group A participants (*n* = 24) wore the earplugs during every choir rehearsal (3 x week for 40 minutes) and Group B participants (*n* = 10) wore the earplugs during one choir rehearsal (1 x week for 50 minutes). Both groups wore the ear protectors for a period of four weeks.

The researcher distributed each chorister's personal set of ETY•Plugs® to choir members prior to class and collected the earplugs at the conclusion of each rehearsal. The researcher stored all the earplugs for both Group A and B participants in between choir class sessions.

Due to the unique nature of choral and vocal sound, recording procedures, equipment, and analyses varied between the two recording contexts. Thus, the procedures are presented by context, with choral procedures first followed by solo procedures.

Choral Context Recording Session Procedures and Equipment

Musical Excerpt and Rehearsals

Choral singers in Groups A and B rehearsed and performed "Dona Nobis Pacem" by Giulio Caccini (see figure 6). I selected this composition because it was homophonic, was unfamiliar to the singers, could be sung a cappella, and was of a moderate tempo. Participants received a copy of the music two weeks prior to the start of the study. Both choirs rehearsed the piece for three fifteen-minute sessions during the three choir classes prior to the first recording session.

Figure 6. Musical excerpt used for choir recordings.

Research Room

The choral singing portion of this study took place in a Midwestern University Choir Room. The room measured 44’5” x 35’5” (see figure 7).

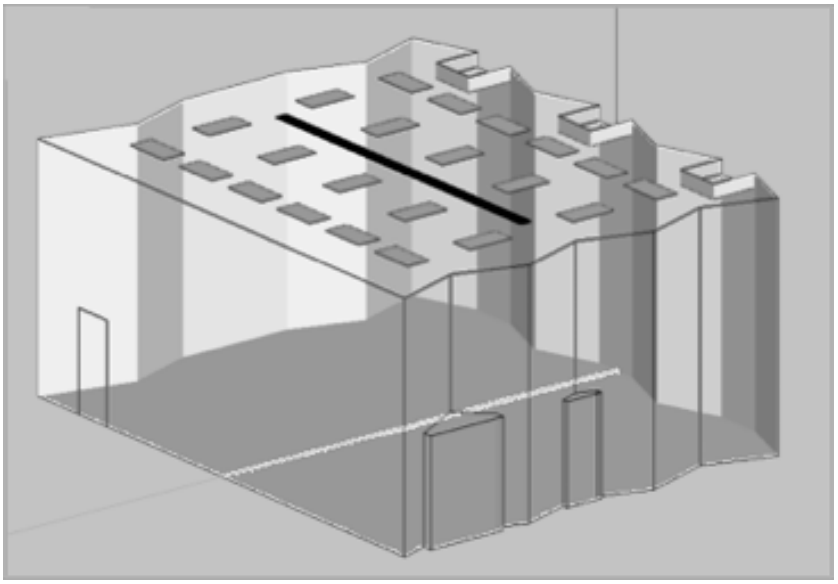

Figure 7. Rendering of the choir room used for Choral Context Recordings.

Choristers in Group A stood on the floor in two rows in a semi-circle formation, arranged by voice type (see figure 8). Choir members in Group B stood by voice section in a single row semi-circle (see figure 9). The position of the singers within the choir was consistent through all recording sessions. Inter- singer spacing (18-inches) remained constant through all trials as well.

S S S S SII SII SII SII A A A A A A
S S S SII SII SII A A A A

Figure 8. Choir formation for Group A.

S S S SII SII SII SII A A A

Figure 9. Choir formation for Group B.

Stimulus Conductor Videos

In order to control for possible 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. The researcher was also the conductor in the video. I used a metronome (MM = 104) and a ZOOM Q3 handy Video Recorder to record the video. A panel of experienced choral conductors ($N = 3$) rated the video for (a) consistent tempo, (b) clarity of hand position, (c) precise cues, (d) ancillary body movement, and (e) facial affect. Results of that panel yielded a reliability measure of .94.

During the recording sessions, singers viewed a life-sized projection of the videotaped conducting, as determined beforehand by the conductor standing by the projection screen. The projection screen was positioned 15 feet from the first row of singers, a distance commonly assumed by the choirs' directors during rehearsals of their respective ensembles.

Procedures for Recording Days, Choral Groups A and B

The choral recordings occurred every Monday during regular choir class time for a period of four weeks. Each recording utilized the same procedure. On recording days, choristers received their earplugs upon entering but did not immediately insert them. Choir members took their places as established by the researcher during the rehearsals.

In an effort to maintain as normal choir environment as possible, both choirs participated in their usual vocal warm-up segment, lead by their own directors. In order to acclimate the choir to the stimulus video in week one, choristers sang the excerpt two times while following the videotaped conductor before the recording began. The opening pitches were played on the piano prior to each iteration of the sung excerpt. During each recording session, the choir sang the excerpt the first time without-earplugs.

Each chorister then inserted her own earplugs and researcher and research assistants checked all singers to insure the earplugs were correctly inserted and properly sealed. The starting pitches were played on the piano and the choir, again following the stimulus video, sang the excerpt a second time. At the conclusion of each rehearsal, the choir recorded the excerpt again with-earplugs. This same procedure was repeated at the following intervals: one-week following earplug fitting, two-weeks following fitting, and three-weeks post-fit.

Procedure for Non-Recording Days, Group A Only

Upon entering the choir room, each choir member received her personal set of earplugs and inserted them. The researcher or a research assistant checked the earplugs for accurate placement and seal. At the completion of each choir session, choir members returned their earplugs to one of the researchers. Group B did not use the earplugs on non-recording days hence there was no need for this procedure.

Participant Survey

Immediately following the trials, participants completed a brief post-trial perceptual survey. This survey (see Appendix D) consisted of nine 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, (d) ability to hear the choir when singing with the earplugs, (e) pitch perception while singing without the earplugs, (f) pitch perception while singing with the earplugs, (g) singing ability without the earplugs, (h) singing ability with the earplugs, and (i) comfort level of the earplugs. The survey form invited participants to write additional comments of their choosing.

After the first week, an additional question was added to the survey to solicit participants' perception of acclimatization to the earplugs when compared to the previous recording session (see Appendix E). Using a Likert-type scale item anchored by *strongly disagree* and *strongly agree*, singers responded to the statement, "I am better adjusted to wearing the earplugs this recording session than I was during the previous recording session."

Recording Equipment

An Edirol R-109 digital sound recorder captured each performance at a sampling rate of 44.1kHz (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.

Choral Context Acoustical Analysis

Long Term Average Spectra Measurements

Human vocal sound is complex sound with an array of simultaneous frequencies, each of which constitutes a part of the complex whole. The perceived timbre (color or quality) of choral 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.

Long-term average spectra (LTAS) measurement 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. Sound pressure level 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.

For analysis purposes the sound files were trimmed using Praat Software (version 5.33.9) and transferred to a Dell Latitude 830 laptop computer. I used KayPentax Computerized Speech

Lab (CSL) Model 4500 software to analyze the recordings. Long Term Average Spectra (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. I used data from one channel of the Edirol recordings, because differences between the two channels were negligible. All LTAS data were entered into Excel spreadsheets for statistical analysis.

Choral Context Perceptual Analyses

Pitch Measurements

I digitally transferred the recorded, sung trials to a MacBook Pro laptop computer to use with Pitch Analyzer 2.1 software in order to analyze perceptual "pitch" (see figure 10). For pitch analysis, I used the midpoint of the [ɔ] vowel in measure 3 (indicated by "1" in figure 6) and corresponding to the first syllable of the word "dona." I analyzed the midpoint of the [ɛ] vowel in measure 10, (indicated by "2" in figure 6) the second syllable of the word "pacem." I compared intonation between the three sung trials (no-earplugs at rehearsal start to with-earplugs at rehearsal start and with-earplugs at rehearsal start to with-earplugs at rehearsal end) from each data collection period.

Pitch Analyzer 2.1 software produced a reference tone set to the pitch notated on the score for comparison to the extracted samples. The reference tone intensity remained constant across all conditions to control for potential subjective pitch variations caused by varying intensity levels (Terhardt, 1974). I adjusted the frequency of the reference tone until it matched the perceptual pitch of the excerpt.

The Pitch Analyzer 2.1 software facilitated trimming the sound samples to one-second intervals and then playing the samples in a constant loop. The software assists a listener to estimate the frequency of the sample, presented in Hz. The investigator adjusted the frequency of the reference tone until it matched the perceived pitch of the sung sample. The Pitch Analyzer 2.1 displayed the difference between the recorded pitch and the notated pitch. I converted the score-notated fundamental frequency, the fine-tune setting, and the perceived pitch from Hertz to cents (1200 cents are equal to one octave), using an online frequency conversion calculator (http://www2.siba.fi/akustiikka/?id=38&la=en). I recorded them on an Excel spreadsheet for statistical analyses.

To verify reliability of these results, I repeated the same procedures for all excerpts one day later. Obtained reliability (agreements divided by agreements plus disagreements) was 0.89.

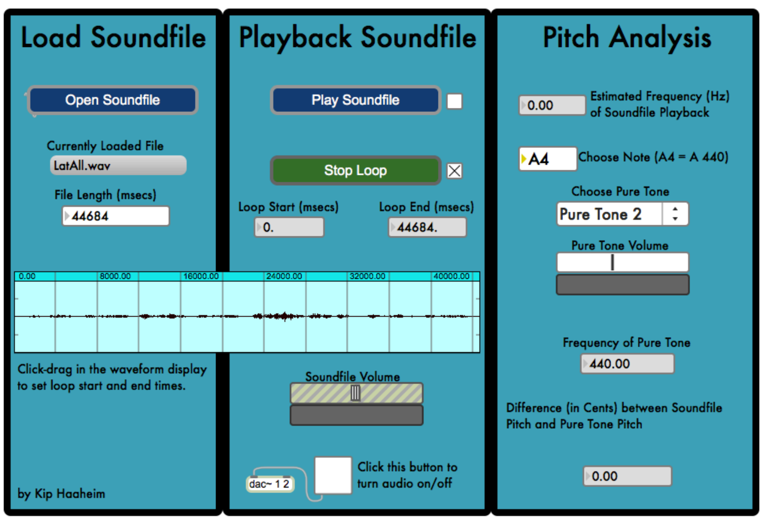

Figure 10. Pitch Analyzer 2.1 configuration.

Expert Panel Participants and Panel Evaluations

Members of the expert panel (*N* = 9) were experienced choral conductors and/or voice teachers. The panel included persons with a bachelor's degree in music education (*n* = 4), a master's degree in choral music education (*n* = 3), and a master's degree in voice performance (*n* = 2). These auditors ranged in age from 28 to 54 years. All expert panel members had taught a minimum of 6 years (*M* = 10 years) in a choral and/or solo singing context. Panel members received a hearing screening identical to participants' screenings. Results showed no hearing loss in any of the listeners.

In a quiet room the auditor participants listened to 14 contrasting pairs of excerpts, randomly ordered, taken from the same recordings used for LTAS analyses. Listeners compared weekly recordings of earplug conditions: (a) no-earplugs at rehearsal start and with-earplugs at rehearsal start acquired from both choirs across four weeks, and (b) with-earplugs at rehearsal start to with-earplugs at rehearsal end for each group across three weeks. Each excerpt, 25 s in duration, featured measures 3 - 26 of Caccini's "Dona Nobis Pacem." I manually transferred these trimmed .wav recordings to a compact disc subsequently played on a Sony Compact Disc Player (CDP-497) connected to a PreSonus HP4 distribution amplifier. Auditors listened through AKG 240 headphones. Volume controls remained consistent. At no time was there compression of the electronic signal.

Panelists responded to one question for each paired sample. The question asked listeners to compare the overall sound of the choir in the two performances and to indicate if they heard (a) no difference, (b) a little difference, (c) much difference, (d) very much difference, or (e) were not sure if they heard a difference (see Appendix F).

Solo Context Recording Session Procedures and Equipment

Solo Participants

I randomly selected approximately half of the vocalists from each Groups A and B to participate in the solo recording sessions. Soloists from Group A included 11 females with a mean age of 19.33 years and a modal age of 19. Group A solo participants included nine freshmen and two juniors. The majority of these participants (n = 10) were music majors. Group

B solo participants (*n* = 5) consisted of four sophomores and one junior, all music majors. The mean age of Group B solo singers was 19.6 years and the modal age was 19 years.

Solo Song Excerpt

The sung melody used for this study was an excerpt from *Over the Rainbow* (see figure 11). 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 two weeks prior to the start of the study and were asked to practice the song until they were able to sing it a cappella. Participants sang verses one and two of the excerpt on text. I placed a copy of the excerpt on a music stand 2 feet (.61 m) in front of the vocalists to assist them with the text.

Over the Rainbow

Music by Harold Arlen

Figure 11. Solo participant song excerpt.

Solo Context Room and Recording Equipment

Solo recordings occurred in a quiet research room approximately 13 feet (3.96 m) by 19 feet (5.79 m). Singers stood at a marked position with their tones on a line, in the center of the research room approximately 10 feet (3.05 m) from the front and back walls and about 6 feet (1.83 m) from either side wall.

Singers wore a head-mounted AKG C-420III (cardioid polar recording pattern) factory calibrated condenser microphone (AKG Acoustics, Vienna, Austria) 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 to microphone to ensure high signal to noise ratios (Wheeler, Collin, & Sapienza, 2006).

An M-Audio Mobile Pre-Amplifier, connected via USB to a MacBook Pro Laptop computer, amplified the computer signal. The computer ran Adobe Audition CS6 software. The recordings (16 bit.wav files, 44.1kHz sampling rate) were saved for subsequent analysis.

In order to maintain a consistent tempo during the recording sessions, a metronome (MM = 92) in silent mode was placed on the music stand in front of the singer. I played the starting pitch on a Master-Key pitch pipe (C – C range) before each recording. During each data collection, the participant recorded the excerpt twice, once without earplugs and the second time while wearing the earplugs.

Upon completion of both recordings, the singer returned the earplugs to the researcher who properly cleaned and stored them for the next use. This same procedure was repeated at the following intervals: one-week following earplug fitting, two-weeks following fitting, and three-weeks post-fit.

Solo Context Singer Survey

Immediately following the sung trials each week, participants completed a brief post-trial perceptual survey. The survey was similar to the questionnaire used in the choral context, but did not solicit participants' perception of singing with others when using earplugs.

This survey (see Appendix G) consisted of seven 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, (b) ability to hear oneself while singing with the earplugs, (c) pitch perception while singing without the earplugs, (d) pitch perception while singing with the earplugs, (e) singing ability without the earplugs, (f) singing ability with the earplugs, and (g) comfort level of the earplugs. The survey form invited participants to write additional comments of their choosing.

After the first week, an additional question was added to the survey to solicit participants' perception of acclimatization to the earplugs when compared to the previous recording session (see Appendix H). Using a Likert-type scale item anchored by *strongly disagree* and *strongly agree*, singers responded to the statement, "I am better adjusted to wearing the earplugs this recording session than I was during the previous recording session."

Solo Context Acoustical Analyses

Long Term Average Spectra Measurement

I used the same LTAS analysis procedures for both solo and choral sound files. I trimmed the sound files using Praat Software, version 5.33.9, which was transferred onto a Dell Latitude 830 laptop computer. To acquire long term average spectra data (LTAS) I analyzed each recording using a window size of 512 points with no pre-emphasis or smoothing, a bandwidth of 86.13 Hz, and a Blackman window. For consistency among recordings, the sound levels were set manually to the same level prior to each session and remained constant throughout each recording session. All data were entered into Excel spreadsheets for statistical analysis.

***F_0* Intonation Measurements**

I trimmed the sound files using Praat Software, version 5.33.9, which was loaded onto a Dell Latitude 830 laptop computer. For F_0 analysis, I used the midpoint of the [ʌ] vowel in the first note, corresponding to the word “some” in measure one and the midpoint of the [ai] vowel in measure four, corresponding to the word “high.”

At each of the data points, I extracted a steady portion of the sung vowel for analysis with Praat (version 5.3.39) software. For F_0 measures, I compared the extracted samples to the target frequencies in the score. I then converted each measurement from Hertz to cents (1200 cents are equal to one octave) by comparing the frequency of the target pitch to the sung pitch, using an online frequency conversion calculator (http://www2.siba.fi/akustiikka/?id=38&la=en). I entered the numbers into an Excel spreadsheet for later analysis.

Amplitude Measures

I used KayPentax Computerized Speech Lab (CSL) Model 4500 software to obtain a weekly sung amplitude mean for each soloist under both conditions, no-earplugs and with-earplugs. I calculated the mean amplitude difference between the no-earplugs and with-earplugs conditions for each soloist for every week and entered it into an Excel spreadsheet for subsequent analysis.

Solo Context Perceptual Analyses

Expert Panel Participants and Panel Evaluations

I used the same expert panel members for both solo and choral recording evaluations. Members of the expert panel ($N = 9$) were experienced choral conductors and/or voice teachers. The panel included persons with a bachelor’s degree in music education ($n = 4$), a master’s degree in choral music education ($n = 3$), and a master’s degree in voice performance ($n = 2$).

These auditors ranged in age from 28 to 54 years. All expert panel members had taught a minimum of 6 years (*M* = 10 years) in a choral and/or solo singing context. Panel members received a hearing screening identical to participants' screenings. Results showed no hearing loss in any of the listeners.

Howard and Angus (2001) reported that a difference of 1 dB in the amplitude of human sound may constitute a just noticeable difference. Hence, auditors for the solo singing phase of this investigation listened to any pairs of samples in which there was a difference of ≥ 1 dB in mean signal amplitude between the no-earplugs and with-earplugs conditions. Expert panel members listened to four contrasting pairs of excerpts randomly ordered, taken from the same recordings used for LTAS analyses. Listeners compared recordings of no-earplugs and with-earplugs conditions. Each excerpt, 20 s in duration, featured measures 1 - 8 of Arlen's "Over the Rainbow." I manually transferred these trimmed .wav recordings to a compact disc subsequently played on a Sony Compact Disc Player (CDP-497) connected to a PreSonus HP4 distribution amplifier. Auditors listened through AKG 240 headphones. Volume controls remained consistent. At no time was there compression of the electronic signal.

Panelists responded to one question for each paired sample. The question asked listeners to compare the overall sound of the soloist in the two performances and to indicate if they heard (a) no difference, (b) a little difference, (c) much difference, (d) very much difference, or (e) were not sure if they heard a difference (see Appendix I).

Statistical Analyses

Choral and Vocal Contexts

In the choral context, I used results from LTAS to calculate the mean signal amplitude differences between no-earplugs at rehearsal start and with-earplugs at rehearsal start and the two with-earplugs conditions (rehearsal start and rehearsal end) from each data collection period for Groups A and B. I conducted a repeated-measures analysis of variance (ANOVA) to evaluate whether or not there were significant changes in vocal timbre as indicated by higher frequency partials across the 0 to 10 kHz and 2 to 4 kHz spectra.

For soloists, I used the LTAS results and calculated the mean signal amplitude differences between the no-earplugs and with-earplugs recordings from each data collection period, weeks one through four. I conducted a repeated-measures analysis of variance (ANOVA) to evaluate whether or not there were significant changes in vocal timbre as indicated by higher frequency partials across the 0 to 10 kHz and 2 to 4 kHz spectra.

I analyzed responses to the two types of singer surveys, calculating means and standard deviations for each survey item. I compared item responses for both choral and solo contexts between Group A and Group B for each data collection period.

Intonation analyses. In the choral context, I compared results of no-earplugs and with-earplugs from each data collection period for Groups A and B. In the solo context, I compared mean results of no-earplugs and with-earplugs from each data collection period for Groups A and B. I compared Group A results from each collection period to Group B collection period results.

Expert panel participants. In order to assess whether panel participants ($N = 9$) would report differences in tone quality of Group A and Group B choral recordings, panel members listened to 14 contrasting pairs of performances. Listeners compared weekly recordings of earplug conditions: (a) no-earplugs at rehearsal start and with-earplugs at rehearsal start and (b) with-earplugs at rehearsal start to with-earplugs at rehearsal end for each group, A and B. Results were analyzed by listener response and compared for each data collection period.

In order to assess whether expert listeners ($N = 9$) would report differences in tone quality of Group A and Group B solo recordings, panel members listened to six contrasting pairs of performances in which the difference in mean signal amplitude between the no-earplugs and with-earplugs conditions was ≥ 1 dB. Results were analyzed by listener response and compared for each data collection period.

CHAPTER FOUR

RESULTS

The purpose of this study was to assess the potential acclimatization effects of wearing one brand of earplugs marketed to musicians (ETY•Plugs® HD) on selected acoustic and perceptual measures of choral and vocal sound. This chapter presents results according to the dependent measures used for this investigation. Choral context results are presented first, followed by solo context results. A predetermined alpha level of .05 served to indicate significance in statistical tests.

Digital recordings provided data for analyses of choral sound and solo sound in terms of tone quality, intonation, and amplitude. The two choirs (Groups A and B) were recorded weekly for four weeks in the same rehearsal hall as they sang the same musical excerpt ("Dona Nobis Pacem") without-earplugs and with-earplugs. Solo singers from both choirs likewise were recorded weekly as they sang the same melody ("Somewhere Over the Rainbow") without-earplugs and with earplugs.

Choral Context Results

Each choir sang for three recordings during the weekly recording sessions: (a) beginning of rehearsal without-earplugs, (b) beginning of rehearsal with-earplugs, and (c) end of rehearsal with-earplugs. The two beginning of rehearsal recordings (without- and with-earplugs) afforded indication of trends with respect to a possible lessening of differences between the two earplugs conditions across the four weeks. After the without-earplugs recordings at the beginning of rehearsals, choristers wore the earplugs for the entirety of the rehearsals at which recordings were obtained. Contrasts between the beginning of rehearsal and end of rehearsal with-earplugs conditions served to indicate possible acclimatization trends within each rehearsal period.

Recall that Group A choristers wore the earplugs for three rehearsal periods each week. By contrast, Group B choristers wore the earplugs for one rehearsal period each week. Thus, comparisons of Group A and Group B recordings afforded possible indications of whether or not the cumulative time spent wearing the earplugs in rehearsals might be a variable of interest with respect to singer acclimatization.

Choral Context Long-term Average Spectra

Human vocal sound is complex sound with an array of simultaneous frequencies, each of which constitutes a part of the complex whole. The perceived timbre (color or quality) of choral 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.

Long-term average spectra (LTAS) data supply information about the timbre or tone quality of complex sound averaged over a specified period of time. Specifically, LTAS measures use sound pressure power (SPL dB) as a function of frequency (Hz) to describe the behaviors of partials over time within a particular spectrum range. These measures can be useful in detection of persisting spectral events.

According to Howard & Angus (2001), a 1 dB difference in the signal energy of complex sound may constitute a perceived just noticeable difference, depending upon 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.

Overall choral context LTAS results. Figure 12 presents the mean signal amplitude LTAS differences (0 - 10 kHz) in comparisons between (a) no-earplugs and with-earplugs at rehearsal start, and between (b) with-earplugs at rehearsal start and with-earplugs at rehearsal end across four weeks.

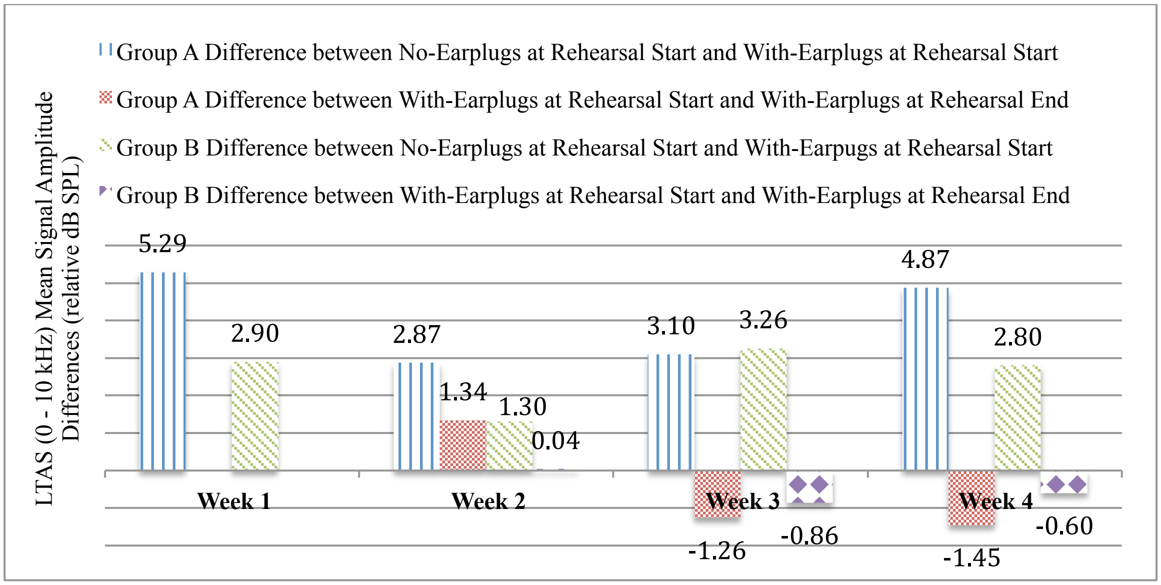

Figure 12. Differences in mean LTAS signal amplitudes (0 - 10 kHz) between (a) no-earplugs at rehearsal start and with-earplugs at rehearsal start and (b) with-earplugs at rehearsal start and with-earplugs at rehearsal end for Groups A and B. Due to technical difficulties, no end of rehearsal data were obtained for Week 1.

As indicated by Figure 12, the differences in mean signal amplitudes between the with-earplugs and without-earplugs conditions for both choirs at rehearsal start consistently exceeded 1 dB (Group A range: 2.87 - 5.29 dB; Group B range: 1.30 - 2.90 dB) during each of the four weekly recording sessions. Comparison of differences between first week and fourth week recordings, moreover, indicated that these differences persisted, i.e., did not exceed 1 dB (Group A: first week difference = 5.29 dB; final week difference = 4.87 dB; Group B: first week difference = 2.90 dB; final week difference = 2.80 dB).

Interestingly, however, comparison of week one and week two recordings indicated that both choirs narrowed the mean signal energy difference between their beginning of rehearsal without-earplugs and with-earplugs singing (Group A by 2.42 dB, Group B by 1.60 dB). For Group A, moreover, comparison of week two and week three recordings revealed that this narrowing trend remained with less than a 1 dB difference in overall mean signal amplitudes (0 - 10 kHz) between week three and week two. With the exception of week two, however, Group B differences each week did not exceed 1 dB.

As illustrated by Figure 12, differences between the with-earplugs recordings obtained at the beginning and end of rehearsal period recording sessions remained less than 1 dB for Group B (who wore the earplugs for one rehearsal each week) across the rehearsal periods measured. This finding may suggest little acclimatization within a rehearsal period for this particular choir. By contrast, LTAS differences in signal energy between the with-earplugs recordings for Group A (who wore the earplugs during three rehearsals each week) consistently exceeded 1 dB, perhaps indicating some degree of acclimatization within rehearsal periods for this choir.

LTAS contours across the 2 – 4 kHz spectral region are of particular interest because this region contains frequencies to which the human ear is the most sensitive (Fletcher & Munson, 1933). Figure 13 presents the mean signal amplitude LTAS differences (2 - 4 kHz) in comparisons between (a) no-earplugs and with-earplugs at rehearsal start, and between (b) with-earplugs at rehearsal start and with-earplugs at rehearsal end across four weeks.

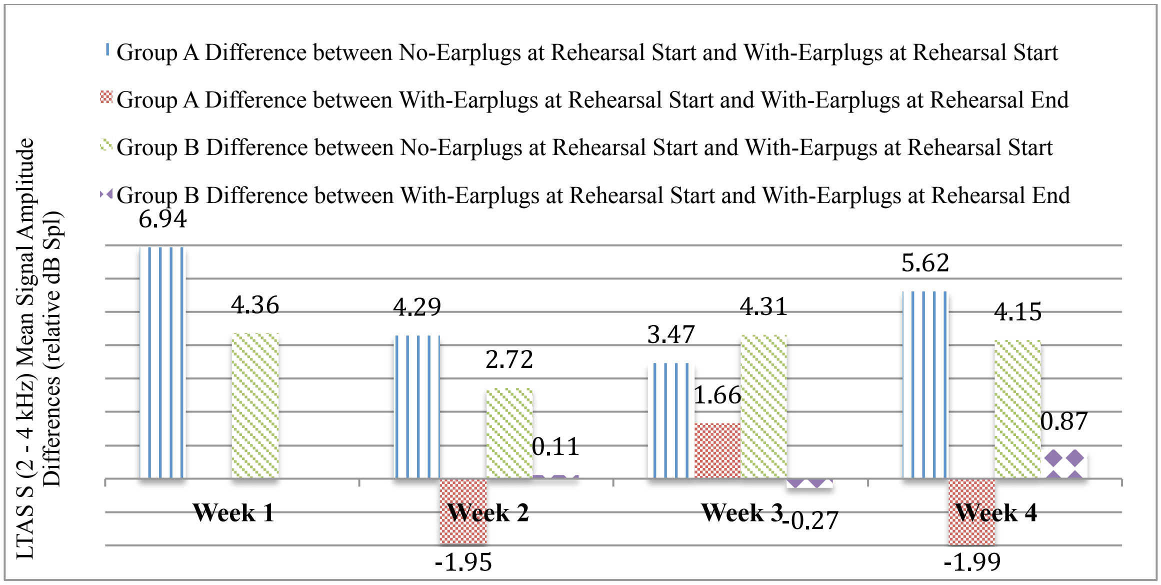

Figure 13. Differences in mean LTAS signal amplitudes (2 - 4 kHz) between (a) no-earplugs at rehearsal start and with-earplugs at rehearsal start and (b) with-earplugs at rehearsal start and with-earplugs at rehearsal end for Groups A and B. Due to technical difficulties, no end of rehearsal data were obtained for Week 1.

As indicated by Figure 13, results from the 2 – 4 kHz region indicated the same trends as 0 -10 kHz region results. The differences in mean signal amplitudes between the with-earplugs and without-earplugs conditions for both choirs at rehearsal start consistently exceeded 1 dB (Group A range: 3.47 – 6.94 dB; Group B range: 2.72 – 4.36 dB) during each of the four weekly recording sessions. Comparison of differences between first week and fourth week recordings indicated that these differences persisted, i.e., did not exceed 1 dB (Group A: first week difference = 6.74 dB; final week difference = 5.82 dB; Group B: first week difference = 4.36 dB; final week difference = 4.15 dB).

Similarly to results from the 0 – 10 kHz region, comparison of week one and week two recordings indicated that both choirs narrowed the mean signal energy difference between their beginning of rehearsal without-earplugs and with-earplugs singing (Group A by 2.65 dB, Group B by 1.64 dB). For Group A, comparison of week two and week three recordings revealed that this narrowing trend remained with less than a 1 dB difference in overall mean signal amplitudes

(2 - 4 kHz) between week three and week two. With the exception of week two, however, Group B differences each week did not exceed 1 dB.

Results in the 2 – 4 kHz region from the with-earplugs conditions (at rehearsal start and at rehearsal end) were consistent with 0 – 10 kHz region results. As indicated by Figure 13, differences between the with-earplugs conditions for Group B recordings remained less than 1 dB, suggesting little acclimatization occurring during rehearsals for this choir who wore the earplugs for one rehearsal each week. LTAS differences in mean signal energy between the with-earplugs recordings for Group A (who wore the earplugs during three rehearsals each week) consistently exceeded 1 dB, perhaps indicating some degree of acclimatizing during rehearsals for this choir.

The differences indicated in Figures 12 and 13 were derived from LTAS data charted for each of the choral earplug conditions across four weeks. Appendix J contains each of those charts. For illustrative purposes, Figures 14 and 15 present representative LTAS graphs for Group A across 0 - 10 kHz and 2 - 4 kHz spectra.

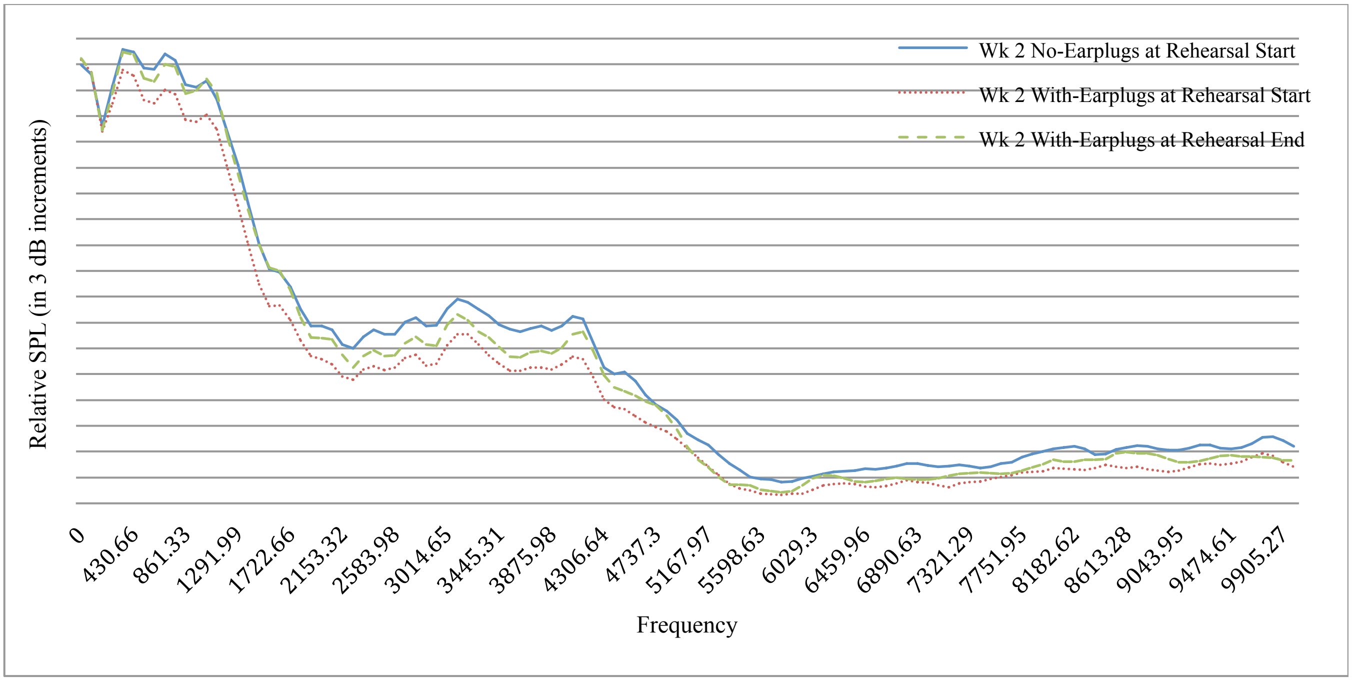

Figure 14. Week 2 Group A: LTAS contours of performances in the 0 – 10 kHz region under three conditions: no-earplugs at rehearsal start, with-earplugs at rehearsal start and with-earplugs at rehearsal end.

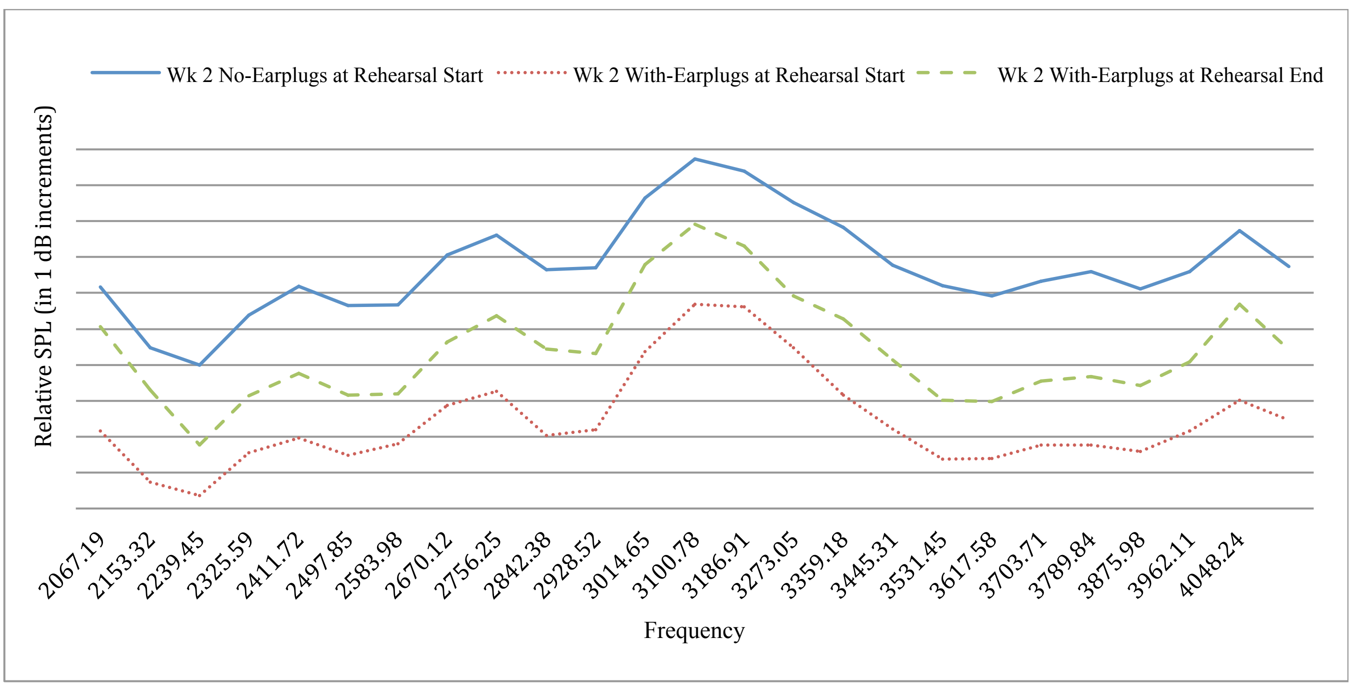

Figure 15. Week two Group A: LTAS contours in the 2 – 4 kHz region of performances under three conditions: no-earplugs at rehearsal start, with-earplugs at rehearsal start, and with-earplugs at rehearsal end.

As indicated by Figures 14 - 15, the wearing of earplugs resulted in a dampening or attenuation of higher partial signal energy in the choral sound of these ensembles. As indicated by the LTAS graphs in Appendix I, this dampened signal amplitude energy occurred with every recording for which these choristers wore the earplugs. The following sections present week by week statistical analyses of these LTAS data.

Choral LTAS data: Week one. LTAS comparisons of first week Group A and Group B mean signal amplitude differences between the two conditions (no-earplugs and with-earplugs) indicated that signal energy in the recorded sound of both groups decreased when participants wore earplugs. The mean signal amplitude difference across the entire spectrum for Group A (M = 5.29 dB) was greater than that of Group B (M = 2.90 dB) by 2.39 dB.

To analyze week one LTAS data, I used a 2 x 2 between-subjects, within-subjects factorial design. Due to technical difficulties, no end of rehearsal data were available for this week. The between-subjects factor was choir (Group A and Group B). The within-subjects factors were "earplug conditions" (no-earplugs at rehearsal start and with-earplugs at rehearsal start). The dependent variable was LTAS spectrum data.

A 2 x 2 repeated measures ANOVA of the between-subject factor (Group A and Group B) in the 0 – 10 kHz spectrum indicated significant main effects in signal amplitude according to earplug conditions $F(2, 234) = 152.555$, $p < .001$. Within-subjects effects analyses revealed a significant main effect between no-earplugs at rehearsal start and with-earplugs at rehearsal start $F(2, 234) = 1042.701$, $p < .001$. Two follow-up t-tests (two-tailed) measured specific differences in the model with a Bonferroni adjustment of alpha levels to provide conservative tests of significance ($p = 0.025$). T-tests indicated significant differences ($p < .001$) in both pairs compared (no-earplugs at rehearsal start and with-earplugs at rehearsal start for Group A and Group B), with decreased signal amplitude in the with-earplug conditions.

A 2 x 2 repeated measures ANOVA of the between-subject factor (Group A and Group B) in the 2 – 4 kHz spectrum indicated significant main effects in signal amplitude according to earplug conditions $F(2, 46) = 76.548$, $p < .001$. Within-subjects effects analyses revealed a significant main effect between no-earplugs at rehearsal start and with-earplugs at rehearsal start $F(2, 46) = 57.099$, $p < .001$. Two follow-up *t*-tests (two-tailed) measured specific differences in the model with a Bonferroni adjustment of alpha levels to provide conservative tests of significance ($p = 0.025$). *T*-tests indicated significant differences ($p < .001$) in both pairs compared (no-earplugs at rehearsal start and with-earplugs at rehearsal start for Group A and Group B), with decreased signal amplitude in the with-earplug conditions.

Choral LTAS data: Week two. To analyze the data in weeks 2 – 4, I used a 2 x 3 between-subjects, within-subjects factorial design. The between-subjects factor was choir (Group A and Group B). The within-subjects factors were “earplug conditions” (no-earplugs at rehearsal start, with-earplugs at rehearsal start, and with-earplugs at rehearsal end). The dependent variable was LTAS spectrum data.

For week two LTAS contours across the 0 – 10 kHz and 2 -4 kHz spectrums, see Appendix J. A 2 x 3 repeated measuress ANOVA in the 0 – 10 kHz region of the between-subject factor (Group A and Group B) indicated significant week two main effects in amplitude according to earplug conditions $F(2, 234) = 261.180$, $p < .001$ Within-subjects effects analyses revealed a significant interaction effect for Group A and B participants between with-earplugs at rehearsal start and with-earplugs at rehearsal end $F(2, 468) = 48.842$, $p < .001$ (see figure 16).

A 2 x 3 repeated measures ANOVA in the 2 – 4 kHz region of the between-subject factor (Group A and Group B) indicated significant week two main effects in amplitude according to earplug conditions $F(2, 46) = 6537.416$, $p < .001$. Within-subjects effects analyses revealed a significant interaction effect for Group A and B participants between with-earplugs at rehearsal start and with-earplugs at rehearsal end $F(2, 92) = 49.178$, $p < .001$.

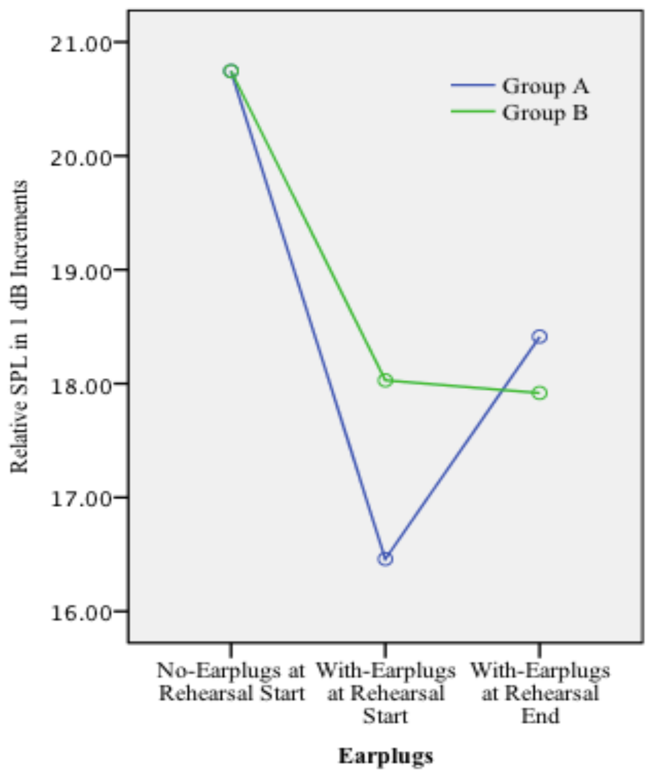

Figure 16. Week two data indicating a significant interaction effect between with-earplugs at rehearsal start and with-earplugs at rehearsal end for Group A and Group B.

Four follow-up *t*-tests (two-tailed) measured specific differences in the model with a Bonferroni adjustment of alpha levels to provide conservative tests of significance ($p = 0.013$). *T*-tests indicated significant differences ($p < .001$) in all four pairs compared (no-earplugs at rehearsal start and with-earplugs at rehearsal start, with-earplugs at rehearsal start and with-earplugs at rehearsal end for Group A and Group B), with decreased signal amplitude in the with-earplug conditions.

Choral LTAS data: Week three. For week three LTAS contours across the 0 – 10 kHz and 2 -4 kHz spectrums, see Appendix J. A 2 x 3 repeated measures ANOVA in the 0 – 10 kHz region of the between-subject factor (Group A and Group B) indicated significant main effects in signal amplitude according to earplug conditions $F(2, 234) = 261.180$, $p < .001$ Within-subjects effects analyses revealed a significant main effect between earplug conditions $F(2, 468) = 3.387$, $p < .05$. Four follow-up *t*-tests (two-tailed) measured specific differences in the model with a Bonferroni adjustment of alpha levels to provide conservative tests of significance ($p = 0.013$). *T*-tests indicated significant differences ($p < .001$) in all six pairs compared (no-earplugs at rehearsal start and with-earplugs at rehearsal start, with-earplugs at rehearsal start and with-earplugs at rehearsal end for Group A and Group B), with decreased signal amplitude in the with-earplug conditions.

A 2 x 3 repeated measures ANOVA in the 2 – 4 kHz region of the between-subject factor (Group A and Group B) indicated significant main effects in signal amplitude according to earplug conditions $F(2, 46) = 14{,}466.66$, $p < .001$. Within-subjects effects analyses revealed a significant main effect between earplug conditions $F(2, 92) = 4.762$, $p < .05$. Four follow-up *t*-tests (two-tailed) measured specific differences in the model with a Bonferroni adjustment of alpha levels to provide conservative tests of significance ($p = 0.013$). *T*-tests indicated significant differences ($p < .001$) in all four pairs compared (no-earplugs at rehearsal start and with-earplugs at rehearsal start, with-earplugs at rehearsal start and with-earplugs at rehearsal end for Group A and Group B), with decreased signal amplitude in the with-earplug conditions.

Choral LTAS data: Week four. For week four LTAS contours across the 0 – 10 kHz and 2 -4 kHz spectrums, see Appendix J.

A 2 x 3 repeated measures ANOVA in the 0 – 10 kHz region of the between-subject factor (Group A and Group B) indicated significant main effects in signal amplitude according to earplug conditions $F(2, 234) = 1086.037$, $p < .05$. Within-subjects effects analyses revealed a significant main effect between earplug conditions $F(2, 468) = 114.683$, $p < .001$. Four follow-up *t*-tests (two-tailed) measured specific differences in the model with a Bonferroni adjustment of alpha levels to provide conservative tests of significance ($p = 0.013$). *T*-tests indicated significant differences ($p < .001$) in all four pairs compared (no-earplugs at rehearsal start and with-earplugs at rehearsal start, with-earplugs at rehearsal start and with-earplugs at rehearsal end for Group A and Group B), with decreased signal amplitude in the with-earplug conditions.

A 2 x 3 repeated measures ANOVA in the 2 – 4 kHz region of the between-subject factor (Group A and Group B) indicated significant main effects in signal amplitude according to earplug conditions $F(2, 46) = 14{,}190.63$, $p < .05$. Within-subjects effects analyses revealed a significant main effect between earplug conditions $F(2, 92) = 36.03$, $p < .001$. Four follow-up *t*-tests (two-tailed) measured specific differences in the model with a Bonferroni adjustment of alpha levels to provide conservative tests of significance ($p = 0.013$). *T*-tests indicated significant differences ($p < .001$) in all four pairs compared (no-earplugs at rehearsal start and with-earplugs at rehearsal start, with-earplugs at rehearsal start and with-earplugs at rehearsal end for Group A and Group B), with decreased signal amplitude in the with-earplug conditions.

Summary: Choral LTAS data. Long-term average spectra (LTAS) analyses indicated potentially perceptible (1 dB or greater) mean changes in the choral timbre of Group A and Group B attributable to both of the with-earplug conditions (with-earplugs at rehearsal start and with-earplugs at rehearsal end). The with-earplugs at rehearsal start and with-earplugs at rehearsal end both contributed to dampened mean signal amplitude for both groups across all four weeks studied.

Choral Context: Listener Perceptions

In order to assess whether expert listeners (*N* = 9) would report heard differences in the overall choral sound between conditions, auditors individually listened to 14 paired samples of weekly performances (no-earplugs at rehearsal start vs. with-earplugs at rehearsal start, and with-earplugs at rehearsal start vs. with-earplugs at rehearsal end) for each group, A and B. Panel members listened to the same recordings used for LTAS analyses.

Listeners were asked to report if they heard "no difference", "little difference", "much difference", "very much difference", or if they were "not sure" about differences between recordings. Table 1 presents listeners' (*N* = 9) combined responses to Group A recordings, weeks one through four.

Table 1. *Group A Combined Expert Panel Responses Means and Standard Deviations, Weeks 1-4.*

Survey Statement	No-Earplugs at Start With-Earplugs at Start		With-Earplugs at Start With-Earplugs at End	
	M	*SD*	*M*	*SD*
1. I heard no difference	1.00	0.82	0.00	0.00
2. I heard little difference	4.50	2.52	3.33	2.89
3. I heard much difference	3.00	2.45	5.00	2.65
4. I heard very much difference	0.50	0.58	0.67	0.58
5. Not sure	0.00	0.00	0.00	0.00

As indicated by Table 1, 88.89% of the listeners reported a heard difference in choral sound between the no-earplugs and with-earplugs recordings at rehearsal start for Group A. All listeners (100%) reported hearing a difference between the two with-earplugs conditions at rehearsal start and rehearsal end.

Table 2 presents listeners' ($N = 9$) combined responses to Group B recordings, weeks one through four.

Table 2. *Group B Combined Expert Panel Responses, Means and Standard Deviations for Question One, Weeks 1-4.*

Survey Statement	No-Earplugs at Start With-Earplugs at Start		With-Earplugs at Start With-Earplugs at End	
	M	*SD*	*M*	*SD*
1. I heard no difference	1.50	0.82	1.00	1.00
2. I heard little difference	4.00	1.15	4.00	1.73
3. I heard much difference	2.50	2.08	2.67	2.52
4. I heard very much difference	0.50	0.58	1.00	1.00
5. Not sure	0.50	0.58	0.33	0.58

As indicated by Table 2, 83.33% of the listeners reported a heard difference in choral sound between the no-earplugs and with-earplugs recordings at rehearsal start for Group B. The majority of the listeners (88.89%) reported hearing a difference between the two with-earplugs conditions at rehearsal start and rehearsal end.

Summary: Listener perceptions. Expert listener results revealed that majorities of listeners heard a difference between no-earplugs at rehearsal start and with-earplugs at rehearsal start recordings of Group A and Group B choral singing. More listeners reported hearing a difference between the with-earplugs conditions (at rehearsal start and at rehearsal end) than the no-earplugs at rehearsal start and with-earplugs at rehearsal start conditions for both Group A and Group B.

Choral Context Pitch Analyzer Results

Germane to this study was whether the choirs sang more or less in tune while wearing the earplugs as compared to the no-earplugs condition. For the purpose of interpreting results, a difference of ± 7 cents was considered a just noticeable difference in intonation and therefore out of tune (Sundberg, 1982; Sundberg, Prame & Iwarrson, 1996).

Appendix K contains week-by-week pitch analyses results for Groups A and B. Overall mean results across the four weeks are presented here.

Figure 17 presents Group A mean choral pitch analyses ($N = 3$) for the without-earplugs and with-earplugs conditions at rehearsal start for weeks 1 – 4.

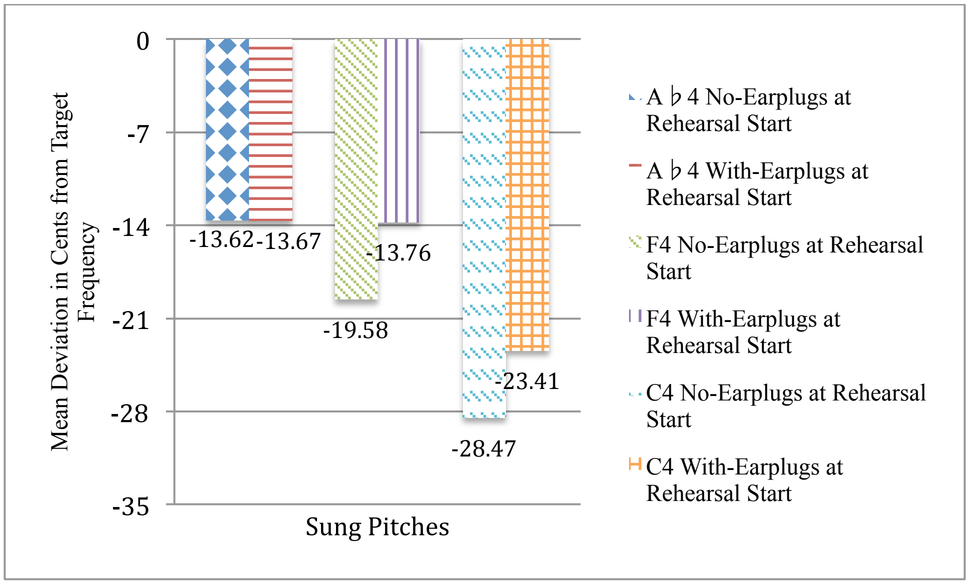

Figure 17. Group A mean pitch deviation in cents from target frequency (weeks 1 – 4) according to no-earplugs at rehearsal start and with-earplugs at rehearsal start.

As indicated in Figure 17, earplugs did not appear to adversely affect intonation for Group A participants. Pitch analysis results revealed that Group A participants sang two of the pitches (F4 and C4) more in-tune during the with-earplug condition at rehearsal start than they did during the no-earplug at rehearsal start condition. When compared to the no-earplugs at rehearsal start condition, Group A choristers sang the third pitch (A♭4) in tune when wearing earplugs at rehearsal start.

Figure 18 presents Group B choral pitch analyses ($N = 3$) for the without-earplugs and with-earplugs conditions at rehearsal start for weeks one through four.

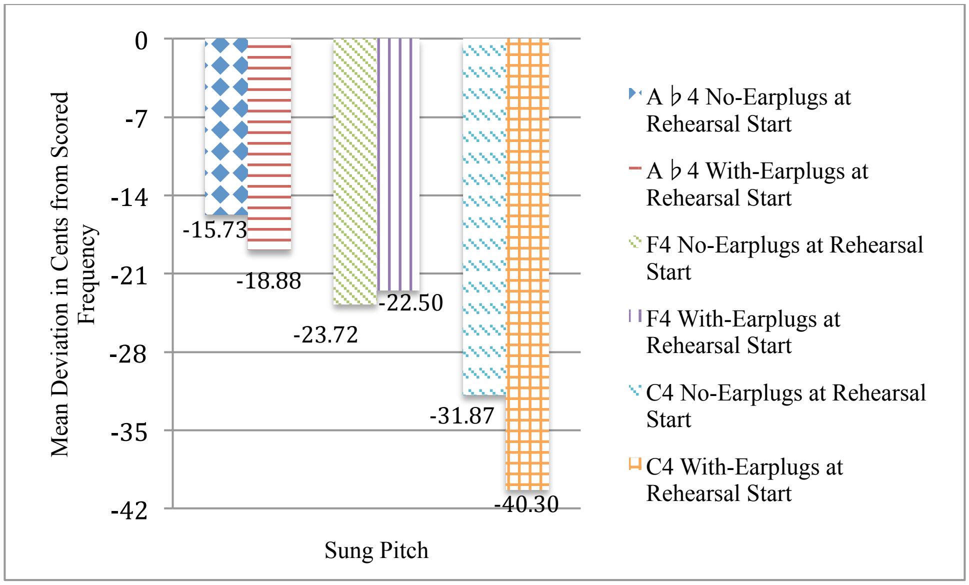

Figure 18. Group B mean pitch deviation in cents from target frequency (weeks 1 – 4) according to no-earplugs at rehearsal start and with-earplugs at rehearsal start.

As indicated by Figure 18, Group B participants sang two of the three pitches in tune (± 7 cents) during the with-earplugs at rehearsal start condition when compared to the no-earplugs at rehearsal start condition. The third pitch (C4) sung with-earplugs at rehearsal start was just slightly out of tune (-8.43 cents) when compared to the no-earplugs at rehearsal start.

Mean pitch analyses results comparing the no-earplugs at rehearsal start to the with-earplugs at rehearsal start indicated that Group A participants sang all three of the pitches in tune while wearing earplugs. Group B participants sang two of the three analyzed pitches in tune while wearing earplugs and the third pitch was slightly out of tune.

Figure 19 presents Group A mean choral pitch analyses ($N = 3$) for the with-earplugs conditions at rehearsal start and rehearsal end for weeks two through four.

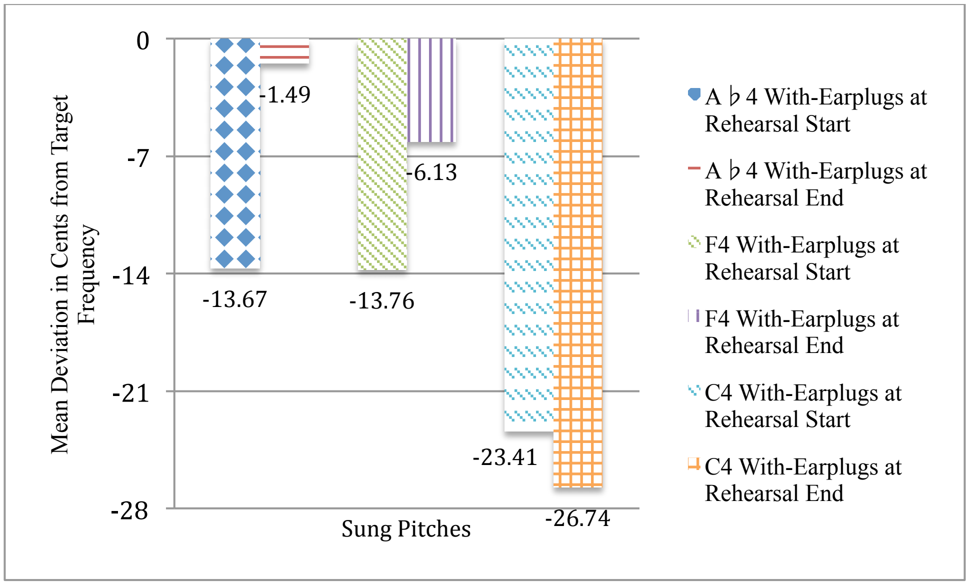

Figure 19. Group A mean pitch deviation in cents from target frequency (weeks 2 – 4) according to with-earplugs at rehearsal start and with-earplugs at rehearsal end.

As indicated in Figure 19, Group A participants sang two (A♭4 and F4) of the three pitches more in-tune when compared to the target frequency with-earplugs at rehearsal end than with-earplugs at rehearsal start. The remaining pitch (C4) sung with-earplugs at rehearsal end was in-tune when compared to with-earplugs at rehearsal start.

Figure 20 shows Group B mean choral pitch analyses ($N = 3$) for the with-earplugs conditions at rehearsal start and rehearsal end for weeks two through four.

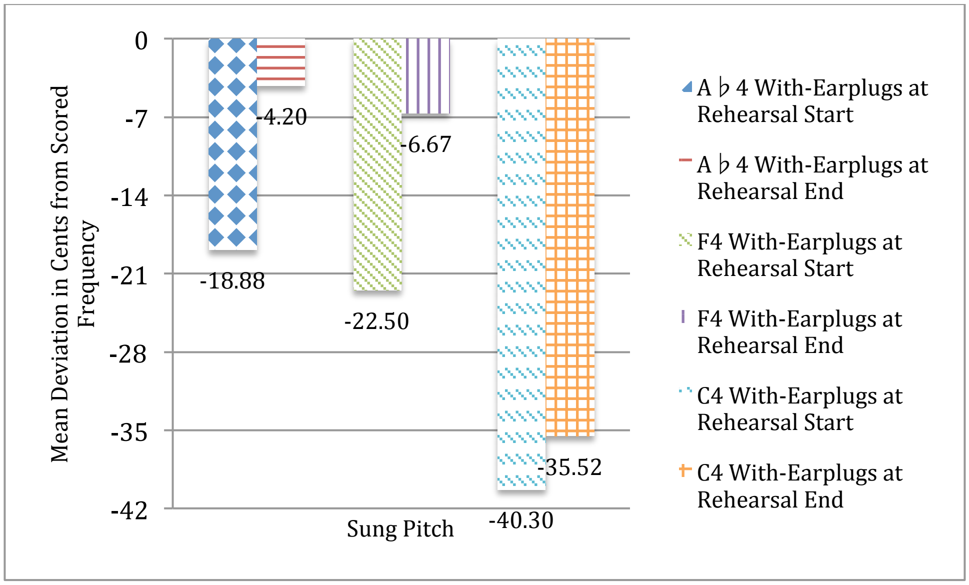

Figure 20. Group B mean pitch deviation in cents from target frequency (weeks 2 – 4) according to with-earplugs at rehearsal start and with-earplugs at rehearsal end.

As indicated in Figure 20, Group B participants sang two (A♭4 and F4) of the three pitches more in-tune when compared to the target frequency with-earplugs at rehearsal end than with-earplugs at rehearsal start. The remaining pitch (C4) sung with-earplugs at rehearsal end was in-tune when compared to with-earplugs at rehearsal start.

Mean pitch analyses results comparing the with-earplugs at rehearsal start to the with-earplugs at rehearsal start indicated that both Group A and Group B participants sang two of the three pitches closer to the target frequency when wearing earplugs at rehearsal end than they did when wearing earplugs at rehearsal start. Groups A and B both sang the third pitch (C4) in tune while wearing earplugs at rehearsal end when compared to with-earplugs at rehearsal start.

Summary: Choral pitch analyses. Group A mean pitch analyses results indicated that when compared to the no-earplugs at rehearsal start condition, singers did not sing more out of tune (± 7 cents) when wearing earplugs at rehearsal start. A comparison of with-earplugs at rehearsal start and with-earplugs at rehearsal end indicated that Group A choristers sang closer to the scored frequency in two of the three pitches analyzed when wearing earplugs at rehearsal end. The remaining pitch sung with-earplugs at rehearsal end was in-tune (± 7 cents) when compared to the with-earplugs at rehearsal start frequency.

Group B mean pitch analyses results revealed that when compared to the no-earplugs at rehearsal start condition, singers did not sing more out of tune (± 7 cents) when wearing earplugs at rehearsal start on two of the three pitches. When singing with-earplugs at rehearsal end, choristers sang one pitch 8.43 cents lower than they did under the with-earplugs at rehearsal start condition. Similar to Group A results, a comparison of with-earplugs at rehearsal start and with-earplugs at rehearsal end indicated that Group B choristers sang closer to the scored frequency in two of the three pitches analyzed when wearing earplugs at rehearsal end. The remaining pitch sung with-earplugs at rehearsal end was in-tune (± 7 cents) when compared to the with-earplugs at rehearsal start frequency. (For weekly pitch analyses results, see Appendix J).

Choral Context: Singer Perceptions

Upon completion of the weekly recording session, Group A (*n* = 24) and Group B (*n* = 10) choristers responded to survey items that solicited overall perceptions of (a) singing with and without earplugs and (b) adjustment to the earplugs.

Table 3 presents Group A participants' aggregate mean responses to items soliciting their perceptions of their ability to hear themselves and the choir under two conditions (no-earplugs and with-earplugs). Participants responded to 5-point Likert-type scales, anchored by *poor* and *excellent.*

Table 3. *Group A Aggregate Means and Standard Deviations of Participant Survey Responses for Questions 1 – 4.*

Survey Statement	Week One		Week Two		Week Three		Week Four	
	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

The first survey item asked choristers to rate their ability to hear themselves while singing without-earplugs and with-earplugs. Most choristers (75%) in Group A reported they were able to hear themselves better when not wearing the earplugs in three of the four time periods surveyed. Group A response means from week three indicated that these choristers on the whole heard themselves equally well with or without earplugs.

When asked if they could hear the choir clearly under the two conditions (no-earplugs and with-earplugs), Group A response means indicated that these choristers on the whole could hear the choir better without the earplugs in all time periods studied. Results showed Group A participants' perceived ability to hear the choir while wearing earplugs improved in weeks three and four.

Table 4 presents Group B participants' aggregate mean responses across the four weeks to items soliciting their perceptions of their ability to hear themselves and the choir under two conditions (no-earplugs and with-earplugs). Participants responded to 5-point Likert-type scales, anchored by *poor* and *excellent.*

Table 4. *Group B Aggregate Means and Standard Deviations of Participant Survey Responses for Questions 1 – 4.*

Survey Statement	Week One		Week Two		Week Three		Week Four	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
1. I heard myself clearly without the earplugs	4.33	0.87	4.57	0.79	5.00	0.00	4.45	0.83
2. I heard myself clearly with the earplugs	3.33	1.41	3.29	1.11	3.86	0.90	4.20	0.77
3. I heard the choir clearly without the earplugs	4.56	0.73	4.86	0.38	5.00	0.00	4.75	0.72
4. I heard the choir clearly with the earplugs	2.44	1.13	2.71	1.11	3.09	0.82	3.30	0.92

Response means to the first question asking them to rate their ability to hear themselves while singing without-earplugs and with-earplugs indicated that Group B choristers on the whole were able to hear themselves better when not wearing the earplugs in all four of the time periods surveyed. When asked if they could hear the choir clearly under the two conditions (no-earplugs and with-earplugs), Group B mean responses indicated that these choristers on the whole could hear the choir better without the earplugs in all time periods studied. Results indicated Group B participants' perceived ability to hear the choir while wearing earplugs improved across the four weeks.

Table 5 presents Group A participant's aggregate mean responses to questions detailing their perceptions of pitch and singing effort. Choristers responded to 5-point Likert-type scales, anchored by *poor* and *excellent*.

Table 5. *Group A Aggregate Means and Standard Deviations of Participant Survey Responses for Questions 5 – 8.*

Survey Statement	Week One		Week Two		Week Three		Week Four	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
5. My perception of the pitch without earplugs was	4.00	0.85	4.20	0.89	4.27	0.83	4.20	0.77
6. My perception of the pitch with earplugs was	3.39	0.94	3.60	0.94	3.95	0.79	3.75	0.91
7. My singing ability with earplugs was	3.78	0.80	4.10	0.72	4.50	0.60	4.30	0.66
8. My singing ability without earplugs was	2.91	0.85	3.35	1.14	3.68	1.09	3.80	0.89

As indicated in Table 5, response means from Group A participants indicated that these choristers on the whole were able to perceive the pitch better when not wearing the earplugs than when wearing the earplugs. Group A mean results indicated an increased ability to perceive pitch while wearing earplugs in weeks one through three and a slight decrease in week four.

Mean results from Group A participants indicated that on the whole they were able to sing better when they were not wearing earplugs as compared to the with-earplug condition. Choristers in Group A reported their ability to sing with earplugs improved over time.

Table 6 presents Group B participants' aggregate mean responses to questions detailing their perceptions of pitch and singing effort. Choristers responded to 5-point Likert-type scales, anchored by *poor* and *excellent*.

Table 6. *Group B Aggregate Means and Standard Deviations of Participant Survey Responses for Questions 5 – 8.*

Survey Statement	Week One		Week Two		Week Three		Week Four	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
5. My perception of the pitch without earplugs was	3.78	1.09	4.14	0.69	4.29	0.49	4.20	0.79
6. My perception of the pitch with earplugs was	2.89	0.78	3.00	1.29	3.14	0.69	3.30	0.68
7. My singing ability with earplugs was	3.67	0.71	3.86	1.29	4.29	0.76	4.00	0.94
8. My singing ability without earplugs was	2.67	0.87	3.14	0.69	3.42	0.79	3.20	0.92

Group B response means indicated that these choristers on the whole were able to perceive the pitch better when not wearing the earplugs than when wearing the earplugs. Choristers from Group B reported steady increases in pitch perception while wearing earplugs across all four weeks.

Response means from Group B participants indicated that on the whole they were able to sing better when they were not wearing earplugs as compared to the with-earplug condition. Group B survey results suggested a perceived improvement in singing ability when wearing earplugs during the first three weeks and a slight decrease in perceived ability in week four.

Table 7 presents Group A choristers' aggregate mean responses to 5-point Likert-type scales soliciting their general perceptions of the comfort of earplugs (anchored by *poor* and *excellent*) and acclimatizing to the earplugs (anchored by *strongly disagree* and *strongly agree*).

Table 7. *Group A Aggregate Means and Standard Deviations of Participant Survey Responses for Questions 9 – 10.*

Survey Statement	Week One		Week Two		Week Three		Week Four	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
9. Please rate the comfort level of the earplugs	3.00	1.28	3.40	1.23	3.60	1.10	3.70	1.17
10. I am better adjusted to the earplugs this recording session than I was the previous recording session	N/A	N/A	3.85	0.88	4.05	0.86	4.15	0.93

Group A participant responses revealed an increased perception of comfort level across the four weeks studied. Participants recorded feeling more adjusted to the earplugs as the weeks progressed.

Table 8 presents Group B choristers' aggregate mean responses to 5-point Likert-type scales soliciting their general perceptions of the comfort of earplugs (anchored by *poor* and *excellent*) and acclimatizing to the earplugs (anchored by *strongly disagree* and *strongly agree*).

Table 8. *Group B Aggregate Means and Standard Deviations of Participant Survey Responses for Questions 9 – 10.*

Survey Statement	Week One		Week Two		Week Three		Week Four	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
9. Please rate the comfort level of the earplugs	2.55	0.73	3.14	0.69	3.29	0.95	3.20	0.79
10. I am better adjusted to the earplugs this recording session than I was the previous recording session.	N/A	N/A	3.29	0.76	4.00	0.58	3.70	0.82

Group B choristers recorded improvements in the comfort level and adjustment through week three. Week four results indicated a slight decrease in participants' comfort level and a decreased perception of acclimatization to the earplugs.

Written comments. The second section of the survey invited participants to comment freely. Only two comments were provided for Group A. One singer commented in week one, "My right ear kind of feels uncomfortable but the left is okay." In week two, 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.”

Group B participants provided 11 comments. One chorister in Group B commented in the first week survey, “I definitely was much more aware of my intonation while wearing my earplugs.” Six of the eleven comments were from week 3, when Group B sight-read a new piece. Week three 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 Group B, week four, indicated choir members’ difficulties hearing while wearing earplugs in the choral setting. Choristers commented, “It is hard to hear my singing part (S2) 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 tenor of participant comments appeared to remain consistent across the four weeks studied. Choristers expressed difficulties hearing other choir members when wearing earplugs, particularly when learning new music.

Summary: Singer perceptions. Participants in both groups perceived they heard themselves and choir members best when not wearing earplugs and that earplugs negatively effected their pitch perception and singing abilities. Choristers in Group A perceived improved earplug comfort and adjustment to the earplugs across the four weeks. Group B singers reported improvements in earplug comfort and adjustment to the earplugs in weeks two and three and a decrease in both measures in week four. Written comments were consistent with Likert-type survey responses, indicating participants' challenges when wearing earplugs.

Choral Context Summary

Results from Long-term average spectra analyses indicated that the with-earplug conditions (with-earplugs at rehearsal start and with-earplugs at rehearsal end) dampened mean signal amplitude for Group A and Group B choral singing. This attenuated signal energy resulted in changes (1 dB or greater) in the choral timbre both groups (A and B) that majorities (83.33% - 100%) of expert listeners reported hearing.

Pitch analyses indicated that when compared to the no-earplugs at rehearsal start condition, Groups A and B choristers sang in-tune the majority of the time while wearing earplugs. When compared to the with-earplugs at rehearsal start condition, Group A and Group B participants sang closer to the scored frequency in two of the three pitches analyzed when wearing earplugs at rehearsal end. Both groups (A and B) sang the remaining pitch in tune while wearing earplugs at rehearsal end when compared to the with-earplugs at rehearsal start frequency.

Singer surveys indicated that singers in both Group A and B perceived the earplugs hindered their ability to hear themselves and others while singing in a choral context and adversely affected their pitch perception and singing ability.

Solo Context Results

Each soloist sang for two recordings during their weekly recording sessions: (a) no-earplugs and (b) with-earplugs. The two recordings offered indications of possible acclimatization trends across the four weeks. Soloists were members of either Group A (wore the earplugs during three rehearsal periods a week) or Group B (wore the earplugs during one rehearsal period a week). Using the same participants in both the solo and choral contexts afforded comparisons of whether the cumulative time spent wearing the earplugs in choral rehearsals would affect solo recordings.

Solo Context Long-term Average Spectra

Of particular interest in this study were the differences in LTAS data between the no-earplugs and with-earplugs conditions. A difference of 1 dB in the amplitude of complex human sound may constitute a just noticeable difference (Howard & Angus, 2001). Thus differences of 1 dB or greater may be helpful in explaining the solo results.

Figure 21 presents Group A and Group B the mean signal amplitude LTAS differences (0 – 10 kHz) in comparisons between (a) no-earplugs and (b) with-earplugs across four weeks.

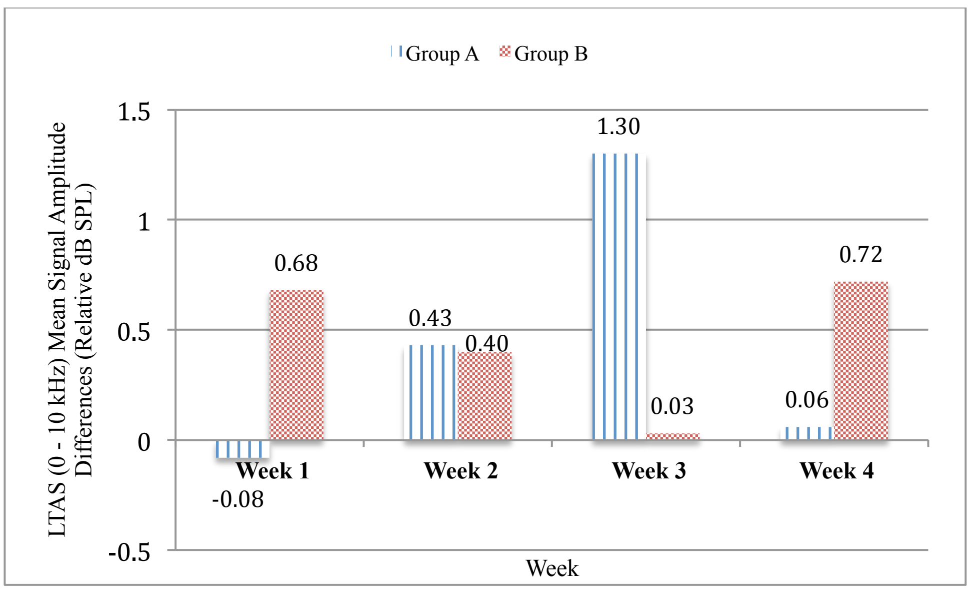

Figure 21. Differences in mean LTAS signal amplitudes (0 - 10 kHz) between (a) no-earplugs and with-earplugs for soloists in Groups A and B.

As indicated by Figure 21, the differences in mean signal amplitudes between the no-earplugs and with-earplugs conditions for both Group A and Group B soloists were less than 1 dB (likely imperceptible) in all four weeks for Group B singers and in three of the four weeks for

Group A soloists. In week three the mean signal amplitude difference for Group A soloists slightly exceeded 1 dB (1.30 dB SPL). Group A solo recordings for week one indicated a slight (.08 dB) increase of mean signal energy when the participants wore earplugs.

Figure 22 presents Group A and Group B mean signal amplitude LTAS differences between (a) no-earplugs and (b) with-earplugs across four weeks in the 2 -4 kHz spectral region where the ear is most sensitive (Fletcher & Munson, 1933).

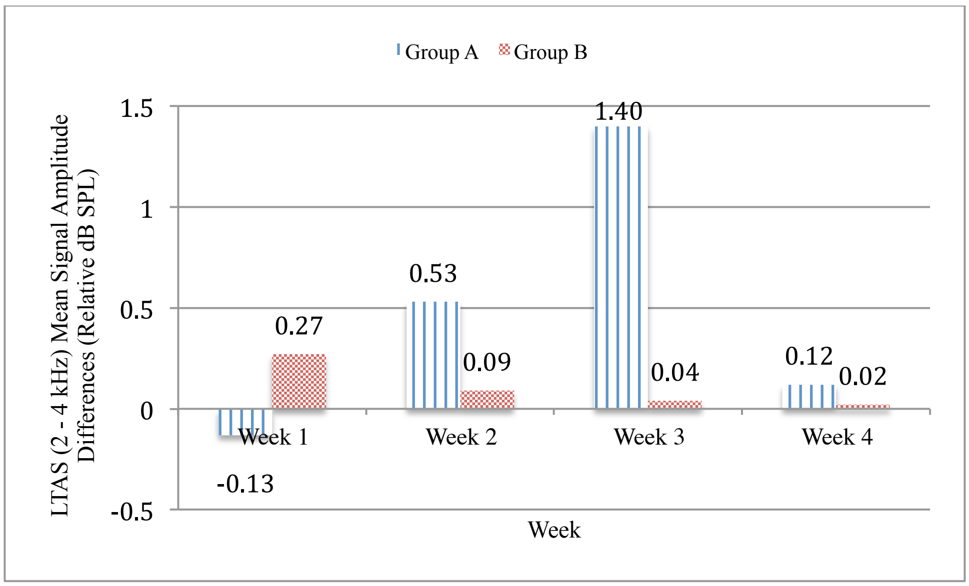

Figure 22. Differences in mean LTAS signal amplitudes (2 - 4 kHz) between (a) no-earplugs and with-earplugs for soloists in Groups A and B.

As indicated by Figure 22, the differences in mean signal amplitudes between the no-earplugs and with-earplugs conditions in the 2 – 4 kHz region were almost identical to the differences found in the 0 – 10 kHz region. For that reason, solo LTAS results will be presented for the entire 0 – 10 kHz spectra.

The differences indicated in Figures 21 and 22 were derived from LTAS data charted for each of the soloist earplug conditions across four weeks. Appendix L contains each of these charts. For illustrative purposes, Figures 23 and 24 present representative LTAS graphs for Group A and Group B soloists across the 0 – 10 kHz spectrum.

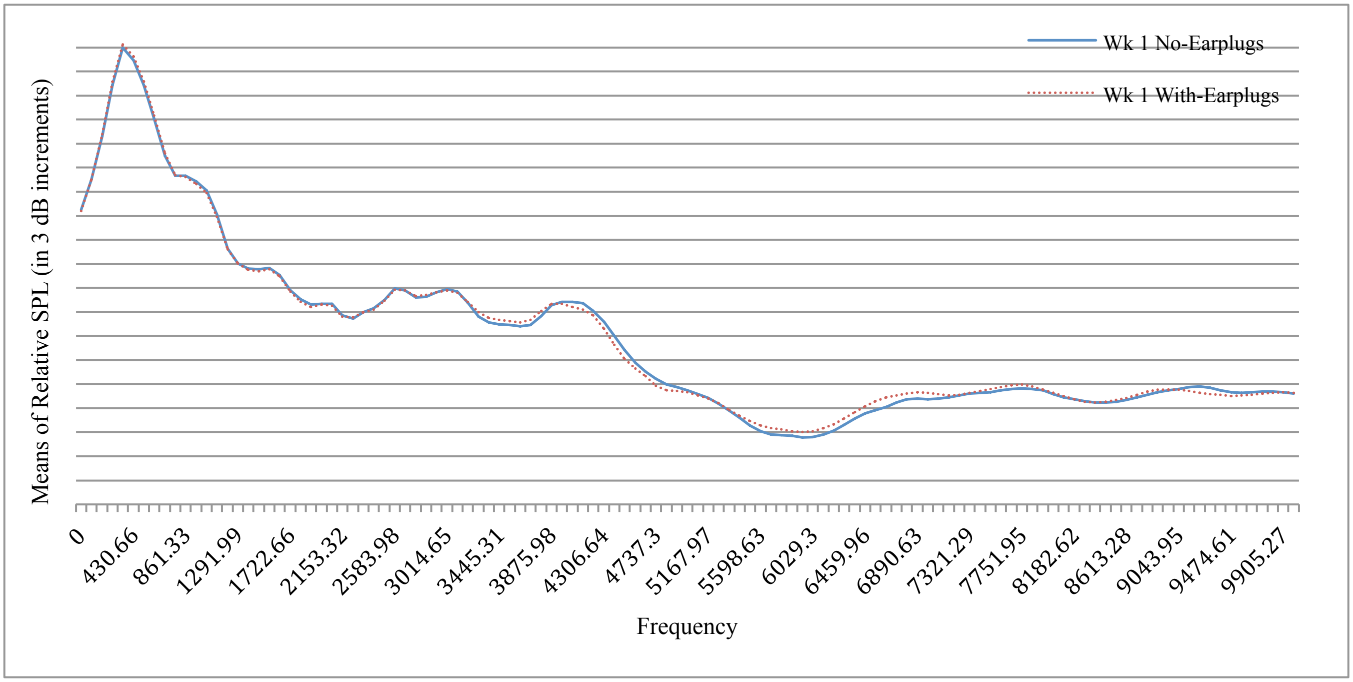

Figure 23. Week one Group A: LTAS contours in the 0 – 10 kHz region of mean solo performances under two conditions, no-earplugs and with-earplugs.

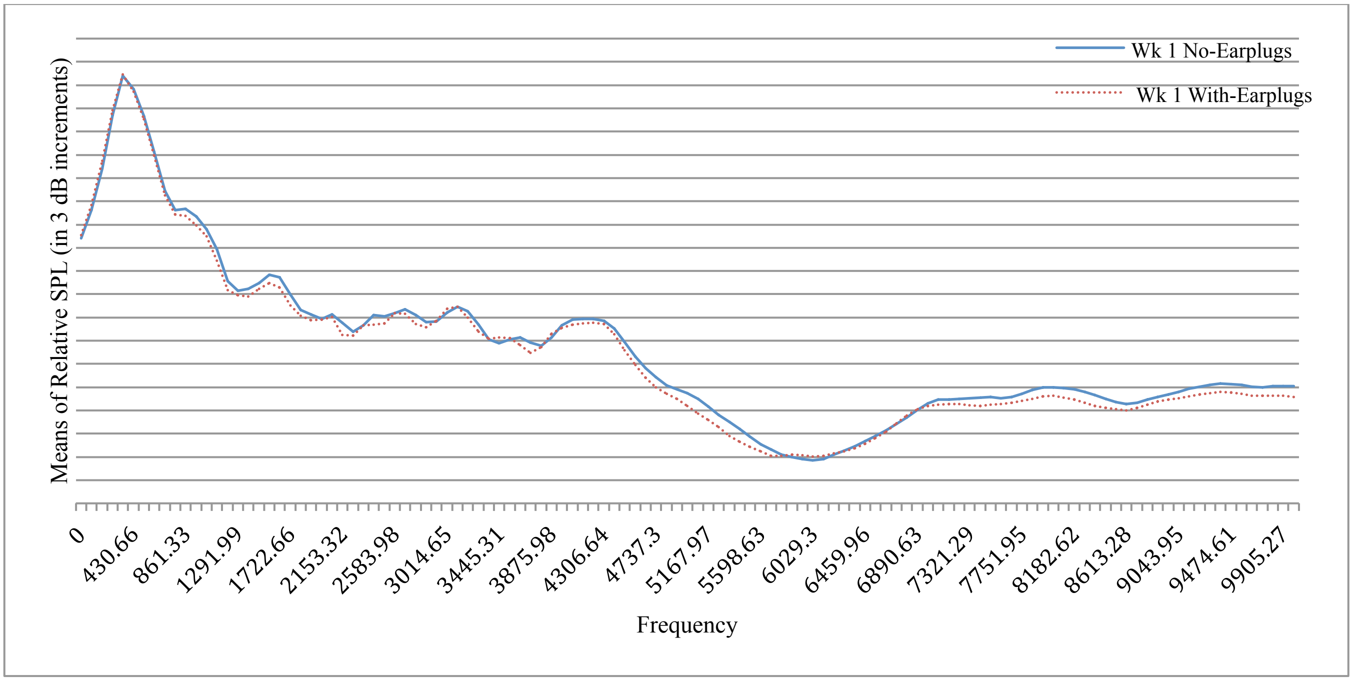

Figure 24. Week one Group B: LTAS contours in the 0 – 10 kHz region of mean solo performances under two conditions, no-earplugs and with-earplugs.

As indicated by Figures 23 and 24, the wearing of earplugs resulted in a minimal decrease of higher partial signal energy in solo sound across the 2 – 4 kHz region for Group A soloists. This dampened signal amplitude energy occurred with every recording when soloists wore earplugs (see Appendix K, LTAS graphs).

To analyze the data in weeks one through four, I used a 2 x 2 between-subjects, within-subjects factorial design. The between-subjects factor was choir (Group A and Group B). The within-subjects factors were "earplug conditions" (no-earplugs at rehearsal start and with-earplugs at rehearsal start). The dependent variable was LTAS spectrum data. The following sections present week by week statistical analyses of these LTAS data.

Solo LTAS data: Week one. LTAS comparisons of first week Group A and Group B mean signal ampitude differences between the two conditions (no-earplugs and with-earplugs) indicated that signal energy in the recorded sound of Group A increased when participants wore earplugs and decreased in the recorded sound of Group B singers. A 2 x 2 repeated measures ANOVA of the between-subject factor (Group A and Group B) indicated significant main effects in amplitude according to earplug conditions $F(2, 234) = 5869.64$, $p < .001$. Within-subjects effects analyses revealed a significant main effect between no-earplugs and with-earplugs $F(2, 234) = 93.56$, $p < .001$. Two follow-up *t*-tests (two-tailed) measured specific differences in the model with a Bonferroni adjustment of alpha levels to provide conservative tests of significance ($p = 0.025$). *T*-tests indicated significant differences ($p < .001$) in both pairs compared (no-earplugs and with-earplugs for Group A and Group B), with increased mean signal amplitude in the with-earplug condition for Group A and decreased mean signal amplitude in the with-earplug condition for Group B.

Solo LTAS data: Week two. A 2 x 2 repeated measures ANOVA of the between-subject factor (Group A and Group B) indicated significant main effects in amplitude according to earplug conditions $F(2, 234) = 3322.67$, $p < .001$. Within-subjects effects analyses revealed a significant main effect between no-earplugs and with-earplugs $F(2, 234) = 29.51$, $p < .001$. Two follow-up *t*-tests (two-tailed) measured specific differences in the model with a Bonferroni adjustment of alpha levels to provide conservative tests of significance ($p = 0.025$). *T*-tests indicated significant differences ($p < .001$) in both pairs compared (no-earplugs and with-earplugs for Group A and Group B), with decreased mean signal amplitude in the with-earplug conditions.

Solo LTAS data: Week three. A 2 x 2 repeated measures ANOVA of the between-subject factor (Group A and Group B) indicated significant main effects in amplitude according to earplug conditions $F(2, 234) = 3560.729$, $p < .001$. Within-subjects effects analyses revealed a significant main effect between no-earplugs and with-earplugs $F(2, 234) = 259.706$, $p < .001$.

Two follow-up *t*-tests (two-tailed) measured specific differences in the model with a Bonferroni adjustment of alpha levels to provide conservative tests of significance ($p = 0.025$). *T*-tests indicated significant differences ($p < .001$) in both pairs compared (no-earplugs and with-earplugs for Group A and Group B), with decreased mean signal amplitude in the with-earplug conditions.

Solo LTAS data: Week four. A 2 x 2 repeated measures ANOVA of the between-subject factor (Group A and Group B) indicated significant main effects in amplitude according to earplug conditions $F(2, 234) = 2678$, $p < .001$. Within-subjects effects analyses revealed a significant main effect between no-earplugs and with-earplugs $F(2, 234) = 23.812$, $p < .001$. Two follow-up *t*-tests (two-tailed) measured specific differences in the model with a Bonferroni adjustment of alpha levels to provide conservative tests of significance ($p = 0.025$). *T*-tests indicated significant differences ($p < .001$) in both pairs compared (no-earplugs and with-earplugs for Group A and Group B), with decreased mean signal amplitude in the with-earplug conditions.

Summary: Solo LTAS data. Long-term average spectra (LTAS) analyses indicated likely imperceptible (1 dB or less) mean changes in solo timbre in all of Group B recordings and in the majority of Group A recordings attributable to with-earplugs conditions. LTAS analyses indicated one instance (week three for Group A soloists) in which there was a potentially perceptible (1 dB or greater) mean change in solo timbre due to the with-earplugs condition.

Solo Context: Listener Perceptions

Expert panel members ($N = 9$) listened to all paired soloist recordings ($N = 4$) in which there was a difference of ≥ 1 dB in mean signal amplitude between the no-earplugs and with-earplugs conditions. A difference of 1 dB may constitute a just noticeable difference (Howard and Angus, 2001). Listeners were asked to report if they heard "no difference", "little difference", "much difference", "very much difference", or if they were "not sure" about differences between recordings. All expert listeners (*N* = 9) reported hearing "no difference" between the no-earplugs and with-earplugs recordings in all four paired samples.

Solo Context F_0 Analyses

Of particular interest to this study was whether solo vocalists would sing more or less in tune when wearing the earplugs compared to no-earplug F_0 analyses. Consistent with the choral pitch analysis procedures, I considered a difference of ± 7 cents barely perceptible and therefore out of tune (Sundberg, 1982; Sundberg, Prame & Iwarrson, 1996). Thus, a difference of ≤ 7 cents from the scored pitch was considered in-tune singing.

Appendix M contains week-by-week F_0 analyses results for Groups A and B. Overall results across the four weeks are presented here.

Figure 25 presents the total number of in-tune frequencies sung by Group A soloists under two conditions (no-earplugs and with-earplugs) according to F_0 analyses across four weeks.

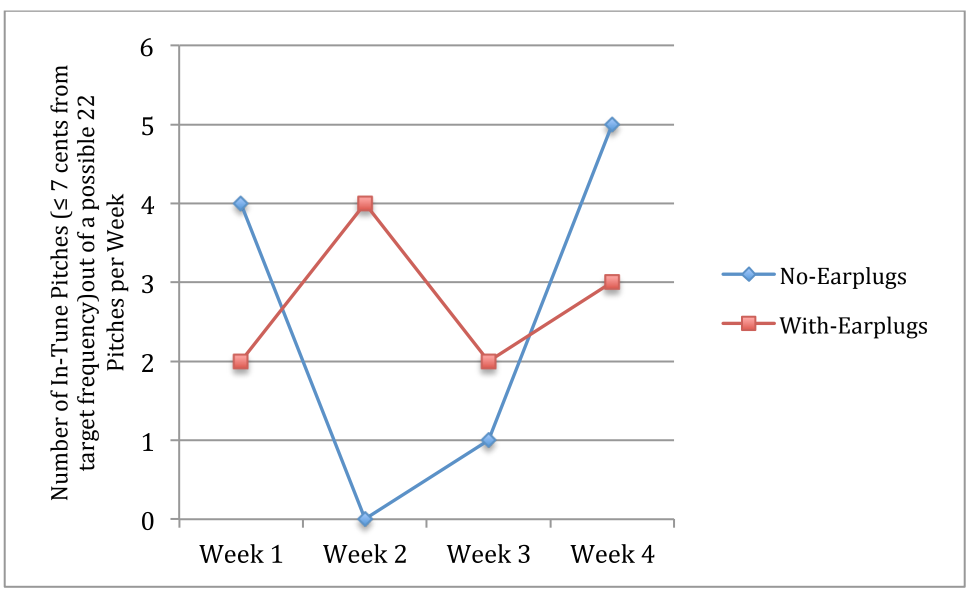

Figure 25. Solo In-Tune Singing (≤ 7 cents from target frequency) for Group A, weeks 1 – 4.

As indicated by figure 25, singing with-earplugs did not occasion more out of tune singing than singing without earplugs for Group A soloists. Results from F_0 analyses revealed that Group A soloists (no-earplugs) sang slightly fewer frequencies in tune (*n* = 10, 11.36%) than soloists with-earplugs (*n* = 11, 12.50%).

Figure 26 presents the total number of in-tune frequencies sung by Group B soloists under two conditions (no-earplugs and with-earplugs) according to F_0 analyses across four weeks.

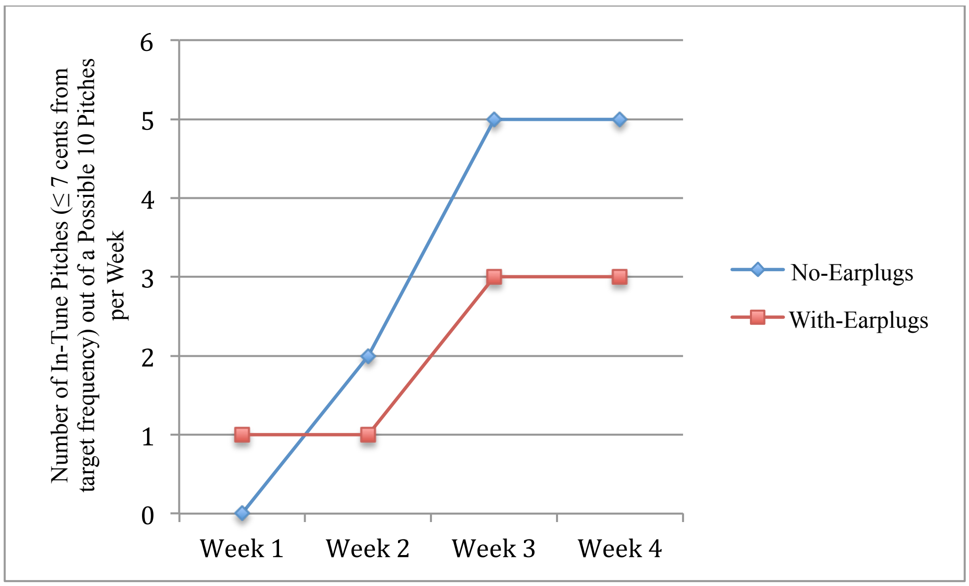

Figure 26. Solo In-Tune Singing (≤ 7 cents from target frequency) for Group B, weeks 1 – 4.

As indicated by Figure 26, Group B soloists without earplugs sang more pitches in tune (*n* = 12, 30%) than soloists with-earplugs (*n* = 8, 20%). F_0 analyses revealed that Group B soloists sang more pitches in tune in weeks three and four, which might indicate a possible acclimatization trend.

Summary: Solo F_0 analyses. Fundamental frequency analyses indicated that when compared to the no-earplugs condition, earplugs did not necessarily cause more or less in tune singing. Group B sang a greater percentage (20%) of frequencies in tune than Group A soloists (12.50%). Group A soloists sang more frequencies in tune (≤ 7 cents) when wearing earplugs than without earplugs. Group B F_0 analyses indicated that soloists sang more in tune without earplugs when compared to the with-earplugs conditions. Results from Group B soloists from weeks three and four revealed a trend towards more in-tune singing while wearing the earplugs, which may indicate some degree of acclimatization occurred during those two weeks.

Solo Context Amplitude Analyses

I used KayPentax Computerized Speech Lab (CSL) Model 4500 software to obtain a weekly sung amplitude mean for each soloist under both conditions, no-earplugs and with-earplugs. I calculated the mean amplitude difference between the no-earplugs and with-earplugs conditions for each soloist for every week and entered it into an Excel spreadsheet for subsequent analysis.

Mean amplitude results for Group A and Group B solo singers found that during the with-earplug condition, mean signal energy decreased slightly in 100% (N = 16) of the soloists. Over the four week period, 93.18% of Group A soloists recorded a decrease in mean amplitude of < 1 dB and 6.81% of the soloists recorded a decreased mean amplitude of between 1 and 2 decibels. Results for Group B revealed that 90% of the soloists recorded a mean amplitude difference of < 1 decibel between no-earplugs and with-earplugs conditions. Results further revealed that 10% of Group B solosits recorded a decreased mean amplitude of between 1 and 2 decibels.

Solo Context Singer Perceptions

Upon completion of weekly individual recording sessions, Group A soloists (*n* = 11) and Group B soloists (*n* = 5) responded to survey questions that solicited overall perceptions of (a) singing with and without earplugs and (b) their adjustment to the earplugs.

Table 9 presents Group A participants' aggregate mean responses to items soliciting their perceptions of their ability to hear themselves under the two conditions (no-earplugs and with-earplugs). Participants responded to 5-point Likert-type scales, anchored by *poor* and *excellent.*

Table 9. *Group A Aggregate Means and Standard Deviations of Participant Survey Responses for Questions 1 – 2.*

Survey Statement	Week One		Week Two		Week Three		Week Four	
	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

As indicated in Table 9, soloists in Group A reported no difference in their ability to hear themselves between the two conditions (no-earplugs and with-earplugs) for weeks one and three and slight differences between the two conditions in weeks two and four.

Table 10 presents Group B participants' aggregate mean responses to questions soliciting their perceptions of their ability to hear themselves under the two conditions (no-earplugs and with-earplugs). Participants responded to 5-point Likert-type scales, anchored by *poor* and *excellent.*

Table 10. *Group B Aggregate Means and Standard Deviations of Participant Survey Responses for Questions 1 – 2.*

Survey Statement	Week One		Week Two		Week Three		Week Four	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
1. I heard myself clearly without the earplugs	5.00	0.00	5.00	0.00	4.60	0.89	5.00	0.00
2. I heard myself clearly with the earplugs	3.60	1.34	3.40	0.55	3.80	0.45	3.80	0.45

Group B solo participant responses indicated they could hear themselves better without the earplugs in all four weeks studied as indicated by table 10. Results from question two indicated an improved ability to hear when wearing earplugs in weeks three and four for Group B singers.

Figure 27 presents a comparison of Group A 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.

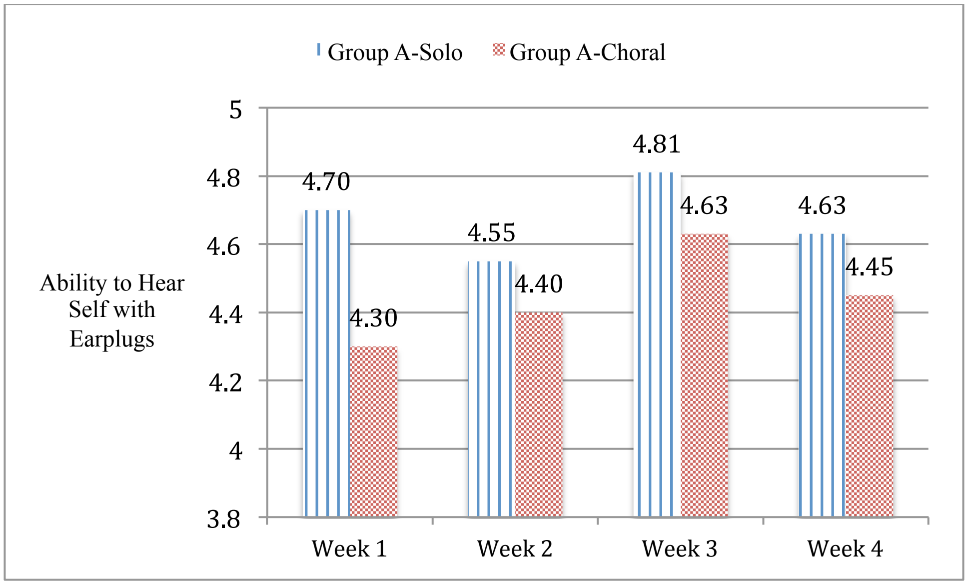

Figure 27. Group A solo participant responses to *Ability to hear self with earplugs* in Solo and Choral Contexts.

Question two was of 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 (Ternstrom, 1999). Group A participants indicated that when compared to the with-earplugs in a choral setting, they could hear themselves better with-earplugs in a solo setting in all four weeks.

Figure 28 presents a comparison of Group B 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.

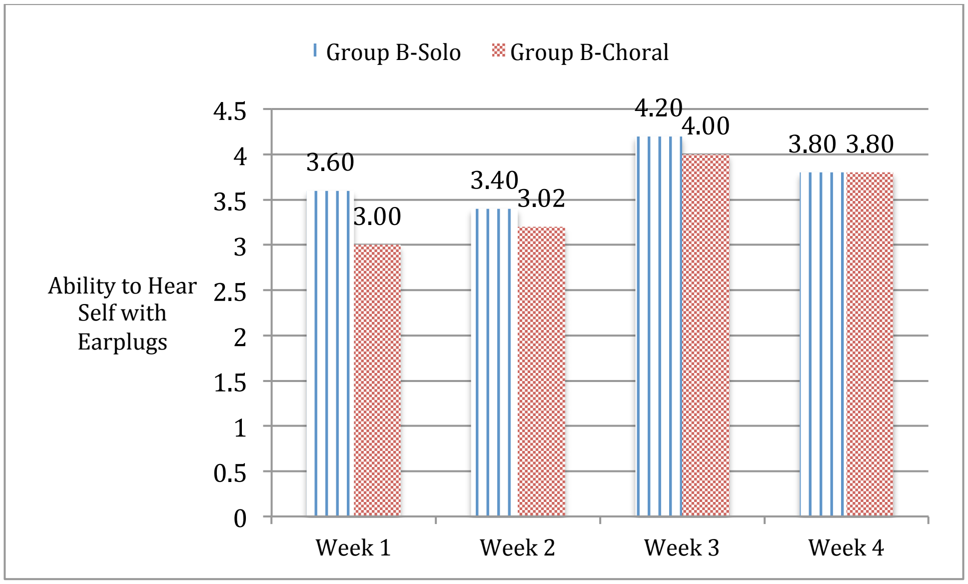

Figure 28. Group B Solo participant responses to *Ability to hear self with earplugs* in Solo and Choral Contexts.

As indicated by figure 28, Group B participants indicated that when compared to the with-earplugs in a choral setting, they could hear themselves better with-earplugs in a solo setting in three of the four weeks. In week four, Group B soloists perceived their ability to hear themselves with-earplugs was the same in a solo and choral context.

Table 11 presents Group A soloists' aggregate mean responses to questions detailing their perceptions of pitch and singing effort. Soloists responded to 5-point Likert-type scales, anchored by *poor* and *excellent.*

Table 11. *Group A Aggregate Means and Standard Deviations of Participant Survey Responses for Questions 3 – 6.*

Survey Statement	Week One		Week Two		Week Three		Week Four	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
3. My perception of the pitch without the earplugs	4.30	0.67	4.09	0.54	4.36	0.67	4.55	0.52
4. My perception of the pitch with the earplugs	4.00	0.82	3.82	0.75	4.09	0.83	4.18	0.87
5. Singing ability without earplugs	4.20	1.14	4.27	0.90	4.55	0.52	4.45	0.69
6. Singing ability with earplugs	3.80	0.63	4.09	0.83	4.09	0.70	4.18	0.75

As indicated in table 11, Group A solo participants on the whole reported they were able to perceive the pitch better when they were not wearing earplugs when compared to the with-earplugs condition. When queried about their singing ability, Group A participant responses indicated that while they felt they sang better without the earplugs, they perceived an improvement in singing ability across time when wearing the earplugs.

Table 12 presents Group B soloists' aggregate mean responses to questions detailing their perceptions of pitch and singing effort. Soloists responded to 5-point Likert-type scales, anchored by *poor* and *excellent*.

Table 12. *Group B Aggregate Means and Standard Deviations of Participant Survey Responses for Questions 3 – 6.*

Survey Statement	Week One		Week Two		Week Three		Week Four	
	M	*SD*	*M*	*SD*	*M*	*SD*	*SD*	*M*
3. My perception of the pitch without the earplugs	4.40	0.89	4.60	0.55	4.20	0.45	4.60	0.55
4. My perception of the pitch with the earplugs	3.00	1.00	3.60	0.55	3.40	0.55	3.80	0.45
5. Singing ability without earplugs	3.60	0.55	3.60	0.55	4.20	0.84	3.80	0.45
6. Singing ability with earplugs	2.75	0.50	3.00	0.71	3.40	0.55	3.80	0.45

As indicated in table 12, Group B solo participants indicated on the whole that they could perceive the pitch better without earplugs when compared to with-earplugs condition. Group B soloists reported they were able to sing better when they were not wearing in three of the four weeks when compared to the with-earplug conditions. Responses from week four showed participants perception of their singing ability to be equal with or without earplugs.

Table 13 presents Group A soloists' aggregate mean responses to 5-point Likert-type scales soliciting their general perceptions of the comfort of earplugs (anchored by *poor* and *excellent*) and acclimatizing to the earplugs (anchored by *strongly disagree* and *strongly agree*).

Table 13. *Group A Aggregate Means and Standard Deviations of Participant Survey Responses, Questions 7 – 8.*

Survey Statement	Week One		Week Two		Week Three		Week Four	
	M	*SD*	*M*	*SD*	*M*	*SD*	*SD*	*M*
7. Comfort level of the earplugs	4.00	0.82	4.00	0.89	4.00	0.89	4.09	0.94
8. I am better adjusted to wearing the earplugs this week than last	N/A	N/A	4.36	0.67	4.36	0.81	4.36	0.50

Group A participants perceived the comfort level of the earplugs was very good (indicated by a 4 on the survey) in all time periods studied. Group A participants agreed they felt more adjusted to wearing the earplugs each week when compared to the previous week.

Table 14 presents Group B soloists' aggregate mean responses to 5-point Likert-type scales soliciting their general perceptions of the comfort of earplugs (anchored by *poor* and *excellent*) and acclimatizing to the earplugs (anchored by *strongly disagree* and *strongly agree*).

Table 14. *Group B Aggregate Means and Standard Deviations of Participant Survey Responses, Questions 7 – 8.*

Survey Statement	Week One		Week Two		Week Three		Week Four	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
7. Comfort level of the earplugs	3.40	0.55	3.80	0.84	3.60	0.55	3.80	0.84
8. I am better adjusted to wearing the earplugs this week than last	N/A	N/A	3.00	0.71	4.00	0.00	4.20	0.84

Group B participants recorded the comfort level as slightly above good (indicated by 3.40 – 3.80) with improvements in weeks two and four. Soloists in Group B recorded feeling better adjusted to the earplugs each week.

Written comments. The second section of the survey invited participants to comment freely. Only one singer commented and she was from Group B, week three. She wrote, "My ears have gotten a little more raw with them. And when I hit the high note in "Somewhere" my ears felt like they were ringing."

Summary: Singer perceptions. Participants in both groups (A and B) perceived they heard themselves best when not wearing earplugs during the majority of the times studied. Group A and B soloists reported difficulties with pitch perception and singing ability when wearing the earplugs but also perceived an improvement in their vocal ability over time. Singers in both groups perceived improved earplug comfort and adjustment to the earplugs across the four weeks. An analysis of results from singers who participated in both the solo and choral contexts of the study indicated that while wearing earplugs, all of Group A singers and a majority of Group B singers heard themselves better in a solo context than in a choral context

Solo Context Summary

Results from solo LTAS analyses indicated mean changes in solo timbre of 1 dB or less in all of Group B recordings while wearing earplugs when compared to the no-earplugs condition. LTAS analyses from Group A soloists indicated only one recording (week three) in which there was a greater than 1 dB difference between the no-earplugs and with-earplugs conditions. Expert listeners did not report hearing a difference in the solo timbre of recordings in which there was a mean change of ≥ 1 dB.

According to fundamental frequency analyses, earplugs did not significantly affect soloists' ability to sing more or less in tune. Group B soloists sang a higher percentage of pitches in tune (20%) than Group A soloists (12.50%). When compared to the no-earplugs condition, Group A soloists sang more pitches in tune (≤ 7 cents) when wearing earplugs and Group B soloists sang slightly fewer pitches in tune when wearing earplugs. Group B soloists sang more in tune in weeks three and four while wearing earplugs when compared to weeks one and two.

Mean amplitude results for Group A and Group B solo singers revealed that while wearing earplugs, mean signal energy decreased in 100% (N = 16) of the soloists. However, those decreases would be barely perceptible (< 1dB) for the majority of the soloists in both groups (A and B).

Group A and Group B singers perceived their hearing of self, ability to sing, and perception of pitch were negatively impacted when wearing earplugs. Group A and Group B singers who participated in the solo and choral contexts perceived they could hear themselves better in the solo context than they could in the choral context.

Summary of Overall Study Results

The first research question posed for this investigation asked whether there would be differences across time in Group A and Group B recordings of choral sound produced with and without the wearing of earplugs, as determined by long-term average spectra (LTAS) analyses, Pitch Analyzer 2.1 procedures, and expert listener perceptions. Results indicated there were significant differences in LTAS analyses between the with-earplugs and without-earplugs conditions in both choirs, and that expert listeners perceived differences in choral sound between these conditions. Pitch analyses indicated that wearing earplugs did not contribute to more out of tune singing when compared to the no-ear-plugs conditions.

LTAS results across the four weeks did not indicate a trend towards acclimatization past week two. Mean signal amplitude differences between the no-earplugs at rehearsal start and with-earplugs at rehearsal start increased in weeks three and four for both groups, A and B.

Expert listener results aligned with LTAS analyses in suggesting that Group A and Group B singers did not appear to acclimatize fully to the earplugs during the four weeks. A majority of listeners reported heard differences in both groups' (A and B) choral sound across the four weeks according to with-earplugs and without-earplugs conditions. Moreover, a greater percentage of listeners perceived differences in Group A recordings than Group B recordings. This finding might indicate the cumulative time the choirs wore earplugs (during three rehearsal periods a week for Group A and during one rehearsal period a week for Group B) was not a primary factor in singer acclimatization.

The highest percentage of listeners (100% for Group A and 88.89% for Group B) perceived a difference between with-earplugs conditions (at rehearsal start and rehearsal end).

This finding may indicate that no perceptible acclimatization occurred during the rehearsal periods.

Choral intonation analyses revealed that wearing earplugs did not contribute to more out of tune singing when compared to the no-earplugs conditions. When compared to the no-earplug at rehearsal start condition, Group A choristers sang all three pitches in tune while wearing earplugs and Group B choristers sang two out of three pitches in tune while wearing earplugs. Both choral groups (A and B) sang two of the three pitches closer to the scored frequency while wearing earplugs at the end of rehearsal when compared to the with-earplugs at rehearsal start condition. This may indicate some sort of pitch perception acclimatization occurring during the rehearsal period.

The second research question inquired about differences across time in Group A and Group B recordings of solo vocal sound produced with and without the wearing of earplugs, as determined by long-term average spectra (LTAS) analyses, expert listener perceptions, obtained fundamental frequencies, and amplitude analyses. Solo results indicated there were significant differences in LTAS analyses between the with-earplugs and without-earplugs conditions in groups, A and B. However, the earplugs appeared to have less effect on vocalists in a solo context than in a choral context, with only one instance of a > 1 dB (1.30 dB) difference between the no-earplug and the with-earplug condition (Group A, week 3 recordings). The difference in mean signal amplitude between the two conditions (no-earplugs and with-earplugs) varied little across the four weeks for Group A (-0.08 dB to 1.30 dB) and Group B (0.03 dB to 0.72).

Mean signal amplitude analyses for solo singers indicated a < 1 dB difference between conditions (no-earplugs and with-earplugs) in 90% of the recordings. Expert listener results indicated that when listening to recordings in which there was a difference in mean signal amplitude ≥ 1 dB, panel members did not perceive a difference between the no-earplugs and with-earplugs recordings.

Solo intonation results indicated that earplugs did not occasion Group A or Group B vocalists to sing less in tune when compared to results from the no-earplug condition. Group B soloists sang a higher percentage of pitches in tune than Group A soloists, suggesting that the amount of time spent wearing earplugs (during one rehearsal period per week for Group B and during three rehearsal periods per week for Group A) was not a factor in intonation results. Group B F_0 results indicated more in-tune singing in weeks three and four and Group A F_0 results indicated soloists sang less in-tune in weeks three and four than they had in week two.

The third research question posed for this study asked what participant surveys across time indicated about Group A and Group B choral and solo singer perceptions of their vocal production, hearing of self in a choral and solo context, hearing of others in a choral singing context, and acclimatization to wearing hearing protection earplugs. Singer survey results revealed that participants reported difficulties hearing themselves while wearing earplugs in both contexts studied (choral and solo). Choristers expressed particular concern when trying to learn new music while wearing earplugs. Choristers and soloists indicated that they perceived that wearing earplugs adversely affected their pitch perception in both contexts (choral and solo).

Because all solo singers participated in the choral context recordings as well, analyses of survey responses provided a comparison of the two contexts. Group A participants reported a greater ability to hear themselves in the solo context than in the choral context in all four weeks. Group B participants reported they were able to hear themselves better in the solo context than in the choral context in three of the four weeks studied. In week four, Group B soloists perceived that they heard themselves equally well in a solo and choral context.

CHAPTER FIVE

DISCUSSION

This four-week longitudinal study examines the use of musicians' earplugs by university singers from multiple perspectives (acoustical, perceptual, and contextual). The majority of the research available regarding hearing conservation and hearing protection focuses on instrumentalists, soliciting their patterns of earplug use and their perceptions of the effectiveness of the devices (Chasin & Chong, 1991; Chasin & Chong, 1992; Iltis, 2009; Killion, DeVilbiss, & Stewart, 1988; Killion, 2012; Laitinen, 2005; Laitinen and Poulsen, 2008; Niquette, 2006; Ostri et al., 1989).

Although several studies suggest that singers may be exposed to potentially harmful sound doses during their years of study, practice, teaching, and performing (Cook-Cunningham, 2012; Cook-Cunningham, Grady, & Nelson, 2012; Laitinen, Toppila, Olkinuora, & Kuisma, 2003; Steurer, Simak, Denk, & Kautzky, 1998), only one investigation studies vocalists' use of earplugs during practice and performance events (Laitinen et al., 2003). This current investigation is the first study to provide longitudinal empirical evidence regarding the use of musician's earplugs among singers. As such, this study may prove beneficial for future investigations.

The primary findings of this investigation are: (a) choral and solo LTAS data indicated significant differences in mean signal amplitudes between the no-earplugs and with-earplugs conditions, (b) solo amplitude means indicated a < 1 dB difference between conditions in 90% of the recordings, (c) choral pitch analyses indicated earplugs did not cause choristers to sing less in-tune, (d) fundamental frequency analyses indicated that earplugs did not cause soloists to sing significantly more or less in-tune, and (e) the majority of choral (87.50%) and solo singers

(75.00%) reported being able to hear themselves best when not wearing earplugs during the weekly recording sessions.

The following discussion frames these results in these contexts: (a) relationships between choral and solo acoustic data, (b) relationships between choral and solo intonation data, (c) relationships between choral and solo surveys, (d) limitations of the study and suggestions for future research, and (e) implications for music educators.

Findings are limited to the participants in this study and limited to the particular methods, procedures and measures employed. Because this study focused only on two existing female choirs, results of this study should not be generalized to other singers or contexts.

Relationship of Choral and Solo LTAS Data

This study utilized the same singers in both choral and solo contexts. The principal reason for this approach was to enable comparisons of the effects of earplugs on the same singers in two different contexts.

One of the primary findings of this study is that there are significant differences in LTAS mean signal amplitudes between the no-earplugs and with-earplugs conditions in choral and solo contexts. Because all choristers participated in the choral recordings, that context merits discussion first.

Choral singing differs from solo singing in that choristers require auditory feedback not only from themselves but also from others (Ternström, 1999). Singers receive this feedback from air conducted and bone conducted sound waves and require a balance between "self" sound and "other" sound. Humans hear predominantly through the more efficient air conduction pathway, a pathway that is occluded when earplugs are inserted.

The LTAS choral data for Groups A and B indicate that when participants recorded with the earplugs, the mean signal amplitude decreased between 1.30 and 5.29 decibels when compared to 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. Comments from singer surveys in which participants remarked that they could hear themselves very well while wearing the earplugs but could not hear the rest of the choir members support this theory.

Both choir directors expressed some concerns when working with the choirs while wearing earplugs. The director of Group B 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 of Group A 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. Choristers then re-inserted their earplugs and tried to re-produce the same sound relying more on their sense of feel rather than depending only on auditory feedback.

As singers mature and develop an increased sense of muscle memory, they tend to rely less on aural feedback alone. The two choirs in this study however, consisted of relatively young, inexperienced singers, many of who were not music majors and did not study voice privately. One might conjecture that both groups (A and B) relied primarily on aural feedback and had difficulties adjusting when that feedback was diminished. Future studies might test the effects of acclimatization to earplugs with more experienced singers who are not as dependent on aural feedback.

One might expect to see the data points from the no-earplug and with-earplug conditions start to converge each week as the singers became more acclimatized to wearing the earplugs. One might further speculate that this convergence would be greater for Group A because they wore the earplugs three times as much as Group B.

Upon initial investigation, it appears that choral singers in both groups (A and B) experienced some degree of acclimatization to the earplugs during week two. LTAS results from week two revealed that mean signal amplitude differences between the no-earplugs at rehearsal start condition and the with-earplugs at rehearsal start condition decreased by 45.75% for Group A and by 55.17% for Group B when compared with week one results. At that point in the study, Group A choristers had worn the earplugs during three rehearsal periods and Group B singers had worn the earplugs during one rehearsal period.

The possible initial acclimatization occurring during week two, however, did not transpire again in the following weeks. The mean signal amplitude differences between the no-earplugs and with-earplugs conditions increased in weeks three and four and no clear trend emerged to indicate the singers had progressively adjusted to the earplugs during the four weeks studied.

LTAS data suggest that some small degree of acclimatization may have occurred within rehearsals for Group A. Mean signal amplitude differences between the with-earplugs conditions (at rehearsal start and at rehearsal end) were consistently less than mean signal amplitude differences between no-earplugs at rehearsal start and with-earplug at rehearsal start. Moreover, these differences always exceeded 1 dB, considered a just noticeable difference (Howard & Angus, 2001). Differences for Group B however were less than 1 dB, indicating little acclimatization occurred within the rehearsal. That Group A results differed from Group B results may reflect the amount of time each choir wore the earplugs, Group A during three rehearsal periods a week and Group B during one rehearsal period a week.

Some previous research indicating evidence of the auditory systems' ability to acclimatize to environmental alterations included a study design in which participants wore earplugs constantly for a period of seven consecutive days except during daily ablutions (Munro and Blount, 2009). One might speculate that similar to the initial fitting of a hearing aid (HA) in which new users are encouraged to wear the device during all waking hours, new earplug users might acclimatize better by wearing the earplugs for extended periods of time and on consecutive days.

This study strictly controlled the amount of time each participant wore the earplugs, limiting Group A singers to three rehearsal periods per week and Group B choir members to one rehearsal period per week. Choir rehearsals were on Mondays, Wednesdays, and Fridays, thus study participants never wore the earplugs on consecutive days. Future investigations might explore whether more time singing with earplugs, or having choristers wear earplugs for the full day in which a rehearsal or performance occurs, or having choristers wear earplugs everyday for all their activities for some length of time might yield different results.

The musician's earplugs used in this investigation (ETY•Plugs® HD) are designed to attenuate the sound reaching the wearer by 20 decibels while maintaining speech and music clarity. Perhaps in the two choral contexts studied, this level of attenuation was too great. There are certain limitations when choosing a naturalistic setting, one of which is the amplitude of the ensemble. Choir B consisted of just 10 members so their overall output was not as "loud" as a larger choir might be. Future investigations might study the use of earplugs in an opera chorus or during rehearsals and performances of a choral/orchestral masterwork where singers' sound exposure includes both instrumental and vocal music.

Some researchers recommend that musicians adjust to wearing earplugs in a solo setting prior to wearing them in a group rehearsal (Killion, 2012; Huttunen, Sivonen, and Pöykkö, 2011). Results from this investigation seem to indicate singers had less to adapt to in an a cappella solo context than in a choral context.

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 three of the four weeks studied for solo participants in Groups A and B, suggesting that there were minimal differences in overall vocal timbre between wearing or not wearing the earplugs for solo singing.

Findings from overall amplitude means obtained through KayPentax software revealed there were slight amplitude differences (< 1 decibel) between no-earplugs and with-earplugs conditions for 93.18% of Group A soloists and 90% of Group B solo participants. These results tend to confirm in a solo singing context comments by Dawson (2007), Niquette (2006), and others that instrumentalists might play louder while wearing earplugs, yet these singers increased their amplitude only minimally. Given the decreased signal energy in higher partials present when singing chorally with earplugs, it may be that the earplugs provide sufficient auditory feedback when singers have to attend to only themselves, but complicate such feedback when having to attend to the singing of others as well. Anecdotal comments from the solo participants support this possibility. Several soloists responded that they believed the earplugs actually helped them to hear themselves better in a solo situation. One solo participant from Group A commented that she liked wearing the earplugs during her solo recordings but felt they negatively impacted her ability to hear others when she was singing in the choir rehearsal.

Relationship of Choral and Solo Intonation Measures

Choral pitch analyses indicated that, on the whole, earplugs do not occasion out of-tune singing when compared to no-earplugs conditions. Interestingly, this finding is at odds with the perceptions of the singers, many of whom perceived that wearing the earplugs made in-tune singing more difficult. Perhaps wearing earplugs caused choral singers to listen more carefully than they did when not wearing earplugs. Thus intonation consistency between no-earplugs and with-earplugs conditions may be at least in part a product of more intense and focused listening.

What is of particular interest is that both Group A and Group B choral participants sang two of the three analyzed pitches closer to the target frequency while wearing earplugs at rehearsal end when compared to with-earplugs at rehearsal start. One possible explanation may be that participants became more adjusted to the earplugs during the rehearsal period.

Throughout the rehearsal periods, directors of both groups (A and B) worked with choristers on many musical elements, including intonation. The improvement in intonation at rehearsal end while wearing earplugs may also be attributable to a learning effect over time as the choirs developed and improved their sense of intonation. Additionally, choristers' familiarity with the recorded selection improved by the end of rehearsal, as they had already sung the selection two times previously during the practice period.

Solo intonation results appear consistent with choral intonation results, suggesting that earplugs may not contribute to vocalists singing out of tune. In the solo context, Group B soloists sang a higher percentage of pitches in tune than Group A soloists, suggesting that the amount of time each group wore the earplugs may have somewhat influenced intonation.

Results from the expert listener panel suggest that listeners readily heard differences across the four weeks in choral sound between the excerpts sung without-earplugs and the excerpts sung with-earplugs. If one aspect of acclimatization is achievement of little, or no, perceived difference from an audience perspective between the overall sound of a choir singing with and without earplugs, then clearly, that goal was not achieved by the two choirs in this study.

However, more listeners perceived differences in Group A choral recordings than Group B choral recordings. This difference might indicate the cumulative time the choirs wore earplugs (during three rehearsal periods a week for Group A and during one rehearsal period a week for Group B) was not a factor in singer acclimatization.

In addition, the highest percentages of differences recorded by the auditors in the choral phase of this investigation were between the with-earplugs conditions (at rehearsal start and at rehearsal end) for Group A and B. These results may suggest that some degree of perceivable acclimatization occurred during the course of each rehearsal period. Future studies might explore this possibility by asking auditors to express a preference for excerpts sung with earplugs at rehearsal beginning and excerpts sung with earplugs at a rehearsal's end.

Relationship of Choral and Solo Singer Perceptions

The results from several previous studies indicate that musicians do not wear earplugs for a variety of reasons including: (a) difficulties hearing other musicians, (b) the earplugs hinder their own performance, (c) distorted sonority, and (d) distortion of timbre and or dynamics (Huttunen et al., 2011; Laitinen, 2005; Zander, Spahn, & Richter, 2008). Results from this current investigation appear to align with the aforementioned studies. Group A and Group B choral participants perceived they heard themselves and other choir members better without earplugs in both choral and solo contexts. Although participants from both groups reported some improvement in hearing abilities while wearing earplugs, choristers never perceived their hearing abilities while wearing earplugs to be equal to their abilities to hear without earplugs. Similar to prior survey results in which musicians reported concerns that earplugs hindered their performance, Group A and Group B choristers in this study perceived they sang better without earplugs than when they wore the earplugs (Huttunen et al., 2011; Laitinen, 2005; Zander, Spahn, & Richter, 2008).

Perhaps the most enlightening results can be gleaned from Group B participants written comments about how earplugs adversely affected their abilities to learn new music. It seems that in this particular rehearsal and for these choristers, earplugs made hearing pitches of newly introduced songs more difficult.

Solo results from Group A and Group B were similar to choral results with participants perceiving difficulties hearing themselves, distorted pitch perception, and decreased singing ability when wearing the earplugs. As in the choral context, soloists perceived improved abilities in pitch perception and singing ability during the four weeks studied but ranked their abilities while wearing earplugs lower than their abilities without earplugs.

Choral survey results disaggregated by solo participants indicated that when wearing earplugs, singers perceived they were able to hear themselves better in a solo environment than a choral setting. This finding is consistent with LTAS data and solo mean amplitude data, which revealed less differences between no-earplugs and with-earplugs in the solo context as compared to the choral context.

Limitations of the Study and Suggestions for Future Research

Lack of microphone calibration limited a direct comparison of results from week to week.

Future investigations should consider calibrating the microphone before each recording session.

This study included three choral context recordings: no-earplugs at rehearsal start, with-earplugs at rehearsal start, and with-earplugs at rehearsal end. An interesting comparison would have been an additional no-earplug condition at rehearsal end. Future study designs might include an additional recording to provide for a direct comparison of data from the start of rehearsal to the end of rehearsal.

This study employed selected acoustic (LTAS, F_0, amplitude) and perceptual (pitch analysis, singer perception, listener perception) measures. Future studies might consider other measures, such as middle ear acoustic reflex threshold measurements.

Practice and performance schedules limited this study to a four-week time period. Given this specific time frame, results from this investigation suggest that four weeks either is not an adequate time period to acclimatize to earplugs or that whatever acclimatization occurs happens within the first two weeks. Researchers differ on the amount of time necessary to acclimatize to earplugs, suggesting anywhere from several weeks to several months (Huttunen et al., 2011; Killion, 2012).

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

Results from this study suggest that acclimatizing to earplugs may be best accomplished in an a cappella solo environment in which the wearer only has to become accustomed to the sounds he or she is producing. An alternative to studying the earplugs in a choral setting for several months might be to first introduce students to earplugs in an a cappella solo setting, allowing them to acclimatize on their own. A gradual introduction into a more challenging choral setting involving more voices might then prove more successful. Future studies might well explore such possibilities.

To control for possible confounding variables in data acquisition due to the presence of instrumental accompaniment, this study was limited to a cappella singing in both solo and choral contexts. Subsequent investigations may wish to consider whether singers' acclimatization to earplugs is enhanced or further complicated by the simultaneous presence of instrumental accompaniment while singing.

From a pedagogical standpoint, voice teachers and choir directors might consider working with students to establish a period of acclimatization prior to performances that may include exposure to high sound pressure levels. This procedure could benefit vocalists particularly if their performance schedule includes operatic literature or repertoire that will require instrumental accompaniment.

The findings of previous studies in which female vocalists recorded higher sound doses than male singers contributed to the decision to use all female choirs for this investigation (Cook-Cunningham, 2012; Cook-Cunningham et al., 2012; Laitinen, Toppila, Olkinuora, & Kuisma, 2003). Researchers suggested the female singers' own voices contributed to the overall sound dose due in part to the higher frequency sound waves they emitted.

The higher frequency sound waves generated by female singers are shorter in length than those produced by male singers, which may have influenced the results of this investigation. Shorter sound waves emitted by female singers do not refract as directly to these singers' ears.

The shortness of the sound waves coupled with the earplug occluded airborne pathway could result in a greater dampening of sound for singer singers than male singers. Future studies might consider investigating the use of earplugs in an all male choir or in a mixed ensemble.

A prior as yet unanswered question is when earplugs would be prudent for singers, in either choral or solo contexts. Few studies to date have measured singers' sound doses (Cook-Cunningham, 2012; Cook-Cunningham et al., 2012; Laitinen, Toppila, Olkinuora and Kuisma, 2003; Phillips, Henrich, & Mace, 2010; Phillips & Mace, 2008). Future study designs might include acquiring sound pressure level readings in a variety of practice and performance situations to determine what environments might necessitate hearing protection for singers. Future studies might also investigate the use of earplugs in a variety of rehearsal and performance spaces with varied acoustic properties.

University students typically are on a budget and earplug costs may be a factor for many musicians considering wearing hearing protection. The Etymotic ER20 earplugs provide musicians with affordable hearing protection (under $13/pair) yet they are limited in the options they offer. Future study designs might consider using custom molded devices with interchangeable buttons that offer different levels of sound attenuation.

Singers in this investigation perceived their singing abilities were negatively affected when wearing earplugs. Possible relationships between earplugs and voice use warrant further study. Future investigations could employ ambulatory phonation monitors to acquire time doses, distance doses, and frequency and amplitude measurements of singers while wearing earplugs.

Industrial hearing conservation programs recommend several steps in providing safe hearing environments with hearing protection as the last resort (OSHA, 1983). Several researchers suggest adapting musician's rehearsal and performance environments as a key factor in preserving musician's hearing (Chasin & Chong, 1995; Einhorn, 2006; Tyler, Chang, Tao, Gogel & Gehringer, 2009; Zembower, 2000). Continuing investigation of the effectiveness of environmental adaptations could not only provide valuable information in the prevention of hearing loss for musicians, but perhaps also lessen the need to wear earplugs in some rehearsal and performance contexts where they might now be prudent.

Proponents of hearing conservation suggest that education and motivation are necessary components of a successful hearing conservation program (Owens, 2008; Santucci, 2009). The students in this study responded well to hearing health information and proved receptive to using the earplugs. Participants from this study all kept their own set of earplugs upon completion of the investigation. A future study might survey these same singers regarding their continued use of the earplugs in both musical and non-musical settings.

From a pedagogical viewpoint, music educators have an excellent opportunity to provide hearing health education to students in a positive manner. Study participants in this investigation include 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 sound pressure levels (Behar et al., 2004; Owens, 2004; Sink & Mace, 2009). Studies such as this one may provide insights into incorporating earplugs into an effective hearing conservation program for themselves and their future students and clients.

References

American Speech-Language-Hearing Association (1995). Guidelines for acoustics in educational environments. *Asha*, 37 (Suppl.14), 15-19

Arlinger, S., Gatehouse, S., Bentler, R. A., Byrne, D., Cox, R. M., Dirks, D. D., . . . Willott, J. F. (1996). Report of the Eriksholm Workshop on auditory deprivation and acclimatization. *Ear and Hearing, 17*(3 Suppl), 87S-98S.

Axelsson, A. & Lindgren, F. (1981). Clinical noise research. *Acta Oto-Laryngologica Supplment 377*, 3-74.

Axelsson, A., & Lindgren, F. (1981). Hearing in classical musicians. *Acta Oto-Laryngologica Supplement 377,* 3-75

Barlow, C. (2010). Potential hazard of hearing damage to students in undergraduate popular music courses. *Medical Problems of Performing Artists, 25*(4), 175-182.

Barlow, C. (2011). Evidence of noise-induced hearing loss in young people studying popular music. *Medical Problems of Performing Artists, 26*(2), 96.

Barlow, C., & Castilla-Sanchez, F. (2012). Occupational noise exposure and regulatory adherence in music venues in the United Kingdom. *Noise and Health, 14*(57), 86.

Behar, A., Eng, M., Wong, W., & Kunov, H. (2006). Risk of hearing loss in orchestra musicians: Review of the literature. *Medical problems of performing artists, 21*, 164-168.

Behar, A., MacDonald, E., Lee, J., Cui, J., Kunov, H., & Wong, W. (2004). Noise Exposure of Music Teachers. *Journal of Occupational Environmental Hygiene, 1*(4), 243-247. doi:10.1080/15459620490432178.

Bentler, R. A., Niebuhr, D. P., Getta, J. P., & Anderson, C. V. (1993). Longitudinal study of hearing aid effectiveness. II: Subjective measures. *Journal of Speech, Language and Hearing Research, 36*(4), 820.

Berg, A. L., & Serpanos, Y. C. (2011). High Frequency Hearing Sensitivity in Adolescent Females of a Lower Socioeconomic Status Over a Period of 24 Years (1985–2008). *Journal of Adolescent Health, 48*(2), 203-208. http://dx.doi.org/10.1016/j.jadohealth.2010.06.014

Borg, E. (2000). Ecological Aspects of Auditory Rehabilitation. *Acta Oto-Laryngologica, 120*(2), 234-241. doi:10.1080/000164800750001008.

Brooks, D. (1989). The effect of attitude on benefit obtained from hearing aids. *British Journal of Audiology, 23*(1), 3-11.

Callahan, A. J., Lass, N.J., Foster, L.B., Poe, J.E., Steinberg, E. L., & Duffe, K.A. (2011). Collegiate musicans'noise exposure and attitudes on hearing protection. *Hearing Review, 18*(6), 36-44.

Chasin, M. (2009). *Hearing loss in musicians Prevention and management*. San Diego, CA.: Plural Publishing, Inc.

Chasin, M., & Chong, J. (1991). An in situ ear protection program for musicians. *Hearing instruments, 42*(12), 26-28.

Chasin, M., & Chong, J. (1992). A clinically efficient hearing protection program for musicians. *Medical Problems of Performing Artists, 7*(2), 40-43.

Chasin, M., & Chong, J. (1995). Four environmental techniques to reduce the effect of music exposure on hearing. *Medical Problems of Performing Artists, 10*(2), 66-69.

Chesky, K. (2008). Preventing music-induced hearing loss. *Music Educators Journal 94*(3), 36-41.

Chesky, K. (2011). Schools of music and conservatories and hearing loss prevention. *International Journal of Audiology 50*, S32-S37.

Chesky, K., Pair, M., Lanford, S., & Yoshimura, E. (2009). Attitudes of college music students towards noise in youth culture. *Noise and Health, 11*(42), 49-53.

Cook-Cunningham, S.L. (2012). *University singers' hearing dose and voice use during a choir concert: A case study*. Unpublished manuscript.

Cook-Cunningham, S.L., (March, 2013). *Personal noise dosimeters: Accuracy and reliability in varied settings*. Poster presented at the University of Kansas Graduate Research Competition, Lawrence, KS.

Cook-Cunningham, S.L., Grady, M.L., & Nelson, H.R., (2012). Hearing doses and perceptions of hearing and singing effort among university choral singers in varied rehearsal and performance settings. *International Journal of Research in Choral Singing 4*(1), 19-35.

Daugherty, J. (1996). *Differences in choral sound as perceived by auditors and choristers relative to physical positioning and spacing of singers in a high school choir: A pilot study.* Paper presented at the Research presentation, MENC National Convention, Kansas City, MO.

Daugherty, J. F. (1999). Spacing, formation, and choral sound: Preferences and perceptions of auditors and choristers. *Journal of Research in Music Education, 47*(3), 224-238.

Daugherty, J. F. (2003). Choir spacing and formation: Choral sound preferences in random, synergistic, and gender-specific chamber choir placements. *International Journal of Research in Choral Education, 1*(1), 48-59.

Daugherty, J. F. (2005). The effects of choir spacing and choir formation on the tuning accuracy and intonation tendencies of a mixed choir. *The Journal of the Acoustical Society of America*, *118*, 2008.

Daugherty, J.F., Grady, M.L. & Coffeen, R.E. (2013, March). *The effect of three singer spacing conditions and two riser step heights on acoustic and perceptual measures of SATB choir sound acquired from four microphone positions in two performance halls.* Podium presentation, International Symposium on Research in Music Behavior. Seattle, WA.

Daugherty, J.F., Manternach, J.N. & Brunkan, M.C. (2012). Acoustic and perceptual measures of SATB choir performances on two types of portable riser units in three singer-spacing conditions. *International Journal of Music Education*. Advance online publication. doi: 0255761411434499.

Dawson, W. J. (2007). Hearing loss from music - causes, treatment, and prevention. *The Double Reed, 30*(2), 97-99.

Delbert, M. R., Romeo, J.H., & Kumke, K.V. (2012). A pilot study of occupational injury and illness experienced by classical musicians. *Health and Safety, 60*(1), 19-24.

Demorest, M. E., & Walden, B. E. (1984). Psychometric principles in the selection, interpretation, and evaluation of communication self-assessment inventories. *Journal of Speech and Hearing Disorders, 49*(3), 226.

Durrant, J.D. & Lovrinic, J.H. (1984). Bases of hearing science (2nd ed.). Baltimore, MD: Williams & Wilkins.

Einhorn, K. (2006). The medical aspects of noise induced otologic damage in musicians: awareness of music induced hearing loss is necessary for diagnostics, treatment, counseling, and hearing conservation. *The Hearing Review, 13,* 38+.

Emmerich, E., Rudel, L. & Richter, F. (2008). Is the audiologic status of professional musicians a reflection of the noise exposure in classical orchestral music? *European Archives of Otorhinolaryngol 265*, 753-758.

Erlandsson, S., & Widen, S. O. (2004). Self-reported tinnitus and noise sensitivity among adolescents in Sweden. *Noise and Health, 7*(25), 29.

Fletcher, H., & Munson, W.A. (1933). Loudness, its definition, measurements and calculation. *Journal of the Acoustical Society of America 5*, 82-108

Gatehouse, S. (1989). Apparent auditory deprivation effects of late onset: the role of presentation level. *Journal of the Acoustical Society of America, 86*, 2103.

Gatehouse, S. (1992). The time course and magnitude of perceptual acclimatization to frequency responses: Evidence from monaural fitting of hearing aids. *Journal of the Acoustical Society of America, 92*, 1258.

Gatehouse, S. (1993). Role of perceptual acclimatization in the selection of frequency responses for hearing aids. *Journal of the American Academy of Audiology, 4*(5), 296-306.

Gatehouse, S. A., & Killion, M. C. (1993). HABRAT: Hearing aid brain rewiring accommodation time. *Hearing Instruments*, *44*, 32-32.

Gilles, A., De Ridder, D., Van Hal, G., Wouters, K., Punte, A., & Van de Heyning, P. (2012). Prevalence of leisure noise-induced tinnitus and the attitude toward noise in university students. *Otology and Neurology, 33*(6), 899 - 906.

Hagberg, M., Thiringer, G., & Brandström, L. (2005). Incidence of tinnitus, impaired hearing and musculoskeletal disorders among students enroled in academic music education—a retrospective cohort study. *International Archives of Occupational and Environmental Health, 78*(7), 575-583. doi: 10.1007/s00420-005-0621-y

Hamilton, A. M., & Munro, K. J. (2010). Uncomfortable loudness levels in experienced unilateral and bilateral hearing aid users: Evidence of adaptive plasticity following asymmetrical sensory input? *International Journal of Audiology, 49*(9), 667-671. doi:10.3109/14992021003713114

Henoch, M. & Chesky, K. (2000). Sound exposure levels experienced by a college Jazz band ensemble – comparison with OSHA risk criteria. *Medical problems of performing artists, 15*(1), 17-22.

Henrichsen, J., Noring, E., Lindemann, L., Christensen, B., & Parving, A. (1991). The use and benefit of in-the-ear hearing aids: A four-year follow-up examination. *Scandinavian Audiology, 20*(1), 55-59.

Hodges, D. (2009). Brains and music, whales and apes, hearing and learning…and more. *Update - Applications of Research in Music Education, 27*(2), 62-75.

Horwitz, A. R., & Turner, C. W. (1997). The time course of hearing aid benefit. *Ear and Hearing, 18*(1), 1-11.

Howard, D.M., & Angus, J.A.S. (2001). Acoustics and psychoacoustics. Second ed. Oxford, UK: Focal Press.

Humes, L., Halling, D., Schmit, K., Coughlin, M., Wilson, D., & Kinden, S. (1995). *Longitudinal study of hearing-aid use, satisfaction and benefit in a group of elderly* *hearing-aid users.* Paper presented at the Hearing Aid Research and Development Conference, National Institutes of Health, Bethesda, MD.

Humes, L. E., Wilson, D. L., Barlow, N. N., & Garner, C. (2002). Changes in hearing-aid benefit following 1 or 2 years of hearing-aid use by older adults. *Journal of Speech Language and Hearing Research, 45*(4), 772-782. doi: 10.1044/1092-4388(2002/062)

Huttunen, K. H., Sivonen, V.P., & Pöykkö, V.T. (2011). Symphony orchestra musicians' use of hearing protection and attenuation of custom-made hearing protectors as measured with two different real-ear attenuation at threshold methods. *Noise and Health, 13*(51), 176-188.

Iltis, P. W. (2009). Medical and scientific issues: hearing protection. *The Horn Call - Journal of the International Horn Society, 40*(1), 39-41.

International Organization for Standardization. (1990). Acoustics-determination of Occupational noise exposure and estimation of noise-induced hearing impairment. 2nd ed. Geneva, Switzerland: Reference No. ISO 1999 1990(E).

Jansen, E., Helleman, H., Dreschler, W. & de Laat, J. (2009). Noise induced hearing loss and other complaints among musicians of symphony orchestras. *International Archives of Occupational and EnvironmentalHhealth 82,* 153-164.

Johnson, D. W., Sherman, R.E., Aldridge, J., & Lorraine, A. (1985). Effects of instrument type and orchestral position on hearing sensitivity for 0.25 to 20kHZ in the orchestal musician. *Scandinavian Audiology, 14*, 215-221.

Kähäri, K., Axelsson, A. , Hellström, P., & Zachau, G. (2001a). Hearing development in classical orchestral musicians. A follow-up study. *Scandinavian Audiology 30*, 141-149.

Kähäri, K., Axelsson, A., Hellström, P., & Zachau, G. (2001b). Hearing assessment of classical orchestral musicians. *Scandinavian Audiology 30*, 13-23.

Karlsson, K., Lundquist, P., & Olaussen, T. (1983). The hearing of symphony musicians. *Scandinavian Audiology, 12*(4), 257-64.

Killion, M. C. (2012). Factors influencing use of hearing protection by trumpet Players. *Trends in Amplification, 16*(3), 173-178. doi: 10.1177/1084713812468514

Killion, M., DeVilbiss, E., & Stewart, J. (1988). An earplug with uniform 15-dB attenuation. *Hearing Journal, 41*(5), 14-17.

Kuk, F. K., Potts, L., Valente, M., Lee, L., & Picirrillo, J. (2003). Evidence of acclimatization in persons with severe-to-profound hearing loss. *Journal of the American Academy of Audiology, 14*(2), 84-99.

Labor Department (US) Bureau of Labor Statis (Ed.). (2008). *Occupational Outlook Handbook 2008-2009*. Government Printing Office.

Laitinen, H. (2005). Factors affecting the use of hearing protectors among classical music players. *Noise and Health, 7*(26).

Laitinen, H., & Poulsen, T. (2008). Questionnaire investigation of musicians' use of hearing protectors, self reported hearing disorders, and their experience of their working environment. *International Journal of Audiology, 47*(4), 160-168. doi: 10.1080/14992020801886770

Laitinen, H. M., Toppila, E. M., Olkinuora, P. S., & Kuisma, K. (2003). Sound Exposure Among the Finnish National Opera Personnel. *Applied Occupational and Environmental Hygiene, 18*(3), 177-182. doi: 10.1080/10473220301356.

Lehman, M., Miller, V. L., & Stewart, M. (2007). Noise exposure levels for student musicians. *Medical Problems of Performing Artists, 22*(4), 160+.

Lockwood, A. H., Salvi, R. J., & Burkard, R. F. (2001). Tinnitus and the performer. *Medical Problems of Performing Artists, 16*(4), 133-135.

Mace, S. T. (2005). *A descriptive analysis of university music performance teachers' sound-level exposures during a typical day of teaching, performing, and rehearsing* (Doctoral dissertation). Retrieved from ProQuest Dissertations and Theses (Order No. 3182834, The University of North Carolina at Greensboro).

Mace, S., Phillips, S., Bhatt, I., Henrich, V. & Richter, S. (April, 2012). *Hearing loss among university music students*. Poster session presented at the NAfME conference, St. Louis, MO.

Malinoff, R. L., & Weinstein, B. E. (1989). Changes in self-assessment of hearing handicap over the first year of hearing aid use by older adults. *Journal of the Academy of Rehabilitative Audiology, 22*, 54-60.

Martin, F.N. & Clark, J.G. (2009). Introduction to audiology: USA. Pearson Education Inc.

Martínez, L. F. (2012). Can you hear me now? Occupational hearing loss, 2004–2010. *Monthly Labor Review*, *135*(7), 48-55.

McKinney, J. C. (1994). *The diagnosis & correction of vocal faults* (Revised ed.). Nashville, Tennessee: Broadman Press.

Mehta, M., Johnson, J., & Rocafort, J. (1999). Architectural acoutsis: principles and design. Upper Saddle River, New Jersey: Prentice Hall.

Miller, V. L. (2007). Noise exposure levels for student musicians. *Medical Problems of Performing Artists, 22*(4), 160-164.

Morata, T. C. (2007). Young people: Their noise and music exposures and the risk of hearing loss. *International Journal of Audiology, 46*, 111-112.

Morgenstern, L. (2005). The bells are ringing: tinnitus in their own words. *Perspectives in biology and medicine, 48*(3), 396-407.

Mulrow, C. D., Tuley, M. R., & Aguilar, C. (1992). Sustained benefits of hearing aids. *Journal of Speech, Language and Hearing Research, 35*(6), 1402.

Munro, K. J. (2008). Reorganization of the Adult Auditory System: Perceptual and Physiological Evidence From Monaural Fitting of Hearing Aids. *Trends in Amplification, 12*(3), 254-271. doi: 10.1177/1084713808323483

Munro, K. J. (2010). Brain plasticity: There's more to hearing than your ears. *The Hearing Journal, 63*(9), 10-12.

Munro, K. J., & Blount, J. (2009). Adaptive plasticity in brainstem of adult listeners following earplug-induced deprivation. *Journal of the Acoustical Society of America, 126*(2), 568-571.

Munro, K. J., & Lutman, M. E. (2003). The effect of speech presentation level on measurement of auditory acclimatization to amplified speech. *Journal of the Acoustical Society of America, 114*(1), 484-495.

Munro, K. J., & Lutman, M. E. (2004). Self-reported outcome in new hearing aid users over a 24-week post-fitting period. *International Journal of Audiology, 43*(10), 555-562.

Munro, K. J., & Trotter, J. H. (2006). Preliminary evidence of asymmetry in uncomfortable loudness levels after unilateral hearing aid experience: Evidence of functional plasticity in the adult auditory system. *International Journal of Audiology, 45*(12), 684-688. doi: 10.1080/14992020600640444

Munro, K. J., Walker, A. J., & Purdy, S. C. (2007). Evidence for adaptive plasticity in elderly monaural hearing aid users. *Neuroreport, 18*(12), 1237-1240.

National Association of Schools of Music and Performing Arts Medicine Association. (2011). Basic information on hearing health: Information and recommendations for faculty and staff in schools of music. Retrieved from: http://nasm.artsaccredit.org/index.jsp?page=NASM- PAMA_Hearing_Health.

National Institute of Occupational Safety and Health. (1998). Preventing occupational hearing loss -A practical guide (publication No. 96-110). Washington, D.C. : U.S. Department of Health and Human Services Publication.

Naylor, G. M. (1987). *Musical and acoustical influences upon the achievement of ensemble* (Unpublished doctoral dissertation). Heriot-Watt University, Edinburgh, UK.

Nelson, H. R. (June, 2012). *Perceptual and acoustical characteristics of individual university practice rooms for vocal music*. Paper session presented at the Voice Foundation Symposium, Philadelphia, PA.

Niquette, P. (2006). Hearing protection for musicians. *The Hearing Review, 13*(3), 52,55,56,58.

Niskar, A. S., Kieszak, S. M., Holmes, A. E., Esteban, E., Rubin, C., & Brody, D. J. (2001). Estimated prevalence of noise-induced hearing threshold shifts among children 6 to 19 years of age: the Third National Health and Nutrition Examination Survey, 1988–1994, United States. *Pediatrics, 108*(1), 40-43.

Obeling, L., & Poulsen, T. (1999). Hearing ability in Danish symphony orchestra musicians. *Noise and Health, 1*(2), 43.

Occupational Safety and Health Administration. (1983). Occupational noise exposure; Hearing conservation amendment: Final rule. (Fed. Reg. 48:9738-9785). Washington, D.C.: U.S. Department of Health and Human Service Publication.

Olsen Widen, S., & Erlandsson, S. (2004). The influence of socio-economic status on adolescent attitude to social noise and hearing protection. *Noise and Health, 7*(25), 59.

Ostri, B., Eller, E., Dahlin, E., & Skylv, G. (1989). Hearing impairment in orchestral musicians. *Scandinavian Audiology 18*, 243-249.

Owens, D. T. (2004). Sound pressure levels experienced by the high school band director. *Medical Problems of Performing Artists, 19*(3), 109-115.

Owens, D. T. (2007). Noise-induced hearing loss. *The Instrumentalist, 62*(3), 23-28.

Peters, C., Thom, J., McIntyre, E., Winters, M., Teschke, K., & Davies, H. (2005). Noise and Hearing Loss in Musicians.

Philibert, B., Collet, L., Vesson, J. F., & Veuillet, E. (2002). Intensity-related performances are modified by long-term hearing aid use: a functional plasticity? *Hearing Research, 165*(1–2), 142-151. doi: http://dx.doi.org/10.1016/S0378-5955(02)00296-4

Phillips, S. L., Henrich, V. C., & Mace, S. T. (2010). Prevalence of noise-induced hearing loss in student musicians. *International Journal of Audiology, 49*(4), 309-316. doi: 10.3109/14992020903470809

Phillips, S. & Mace, S. (2008). Sound level measurements in music practice rooms. *Music Performance Research 2,* 36-47.

Pörschmann, C. (2000). Influences of bone conduction and air conduction on the sound of one's own voice. *Acta Acustica united with Acustica, 86*(6), 1038-1045.

Prates, L. P. C. S., & Iório, M. C. M. (2006). Acclimatization: speech recognition in hearing aid users. *Pró-Fono Revista de Atualização Científica, 18*(3), 259-266.

Presley, D. (2007-08). An analysis of sound-level exposures of drum and bugle corps percussionists. *Percussive Notes, 45*(4), 70-75.

Robb, I. (2002). The British-North America act: Unsafe sax. *Sing out! The Folk Song Magazine 45*(4), 95-96.

Robbins London, H. (1974). Beethoven: London: Thames and Hudson.

Rosen, C.A. (2001). Care of the singing voice: Fact and fiction. *Choral Journal 41(9)*, 51-54.

Rossing, T. D., Sundberg, J., & Ternström, S. (1986). Acoustic comparison of voice use in solo and choir singing. *Journal of the Acoustical Society of America, 79*, 1975.

Rossing, T. D., Sundberg, J., & Ternström, S. (1987). Acoustic comparison of soprano solo and choir singing. *Journal of the Acoustical Society of America, 82*, 830.

Royster, J., Royster, L., & Killion, M. (1991). Sound exposures and hearing thresholds of symphony orchestra musicians. *Journal of the Acoustical Society of America 89*(6), 2793-2803.

Santucci, M. (2009). Review: Protecting Musicians from Hearing Damage: A Review of Evidence-based Research. *Medical Problems of Performing Artists, 24*(3), 103-107.

Sataloff, R. T. (1991). Hearing loss in musicians. *American Journal of Otology, 12*(2), 122-127.

Sataloff, R. T. (1997). Hearing loss in singers and other musicians. *Medical Problems of Performing Artists, 3*(1), 87.

Saunders, G. H., & Cienkowski, K. M. (1997). Acclimatization to hearing aids. *Ear and Hearing, 18*(2), 129-139.

Schloneger, M. J. (2011). Graduate Student Voice Use and Vocal Efficiency in an Opera Rehearsal Week: A Case Study. *Journal of Voice, 25*(6), e265-e273. doi: 10.1016/j.jvoice.2010.09.010

Schum, D. J. (1992). Responses of elderly hearing aid users on the hearing aid performance inventory. *Journal of the American Academy of Audiology, 3*(5), 308.

Seyfried, D. A. (1990). *Use of self-reports to monitor hearing aid and counseling effects.* (Order No. 9103264, The University of Iowa). *ProQuest Dissertations and Theses,* , 203-203 p. Retrieved from http://search.proquest.com/docview/303857342?accountid=14556. (prod.academic_MSTAR_303857342).

Sherman, B. (2000). Hearing loss: A 20th century epidemic. *Early Music America 6*(1) 27-29.

Shrock, D. (2009). Choral repertoire.New York, NY: Oxford University Press.

Sink, P. & Mace, S. (2004). *A Preliminary Analysis of Sound-Level Exposures of Fulltime Choral, General, and Instrumental Music Educators During Typical Work Days*. Paper presented at the North Carolina Music Educators Association Conference, Winston-Salem, NC.

Smith, B. (2003). Care of the professional voice: Choral pedagogy and vocal health. *Journal of Singing, 59*(3), 223-239.

Steurer, M., Simak, S., Denk, D., & Kautzky, M. (1998). Does choir singing cause noise-induced hearing loss? *Audiology 37*(1), 38-51.

Sundberg, J. (1977). The acoustics of the singing voice. *Scientific American, 236*(3), 82-84, 86, 88-91.

Sundberg, J. (1982). In tune or not? A study of fundamental frequency in music practice. *Tiefenstruktur der Musik*, 69-97.

Sundberg, J, Prame, E, & Iwarsson, J. (1996). *Replicability and accuracy of pitch patterns in professional singers.* Paper presented at the Controlling Complexity and Chaos: 9th Vocal Fold Physiology Symposium. Singular Press, San Diego, CA.

Suter A. (2009). The hearing conservation amendment: 25 years later. *Noise Health, 11*, 2-7.

Taylor, K. S. (1993). Self-perceived and audiometric evaluations of hearing aid benefit in the elderly. *Ear and Hearing, 14*(6), 390.

Terhardt, E. (1974). Pitch, consonance and harmony. *The Journal of the Acoustical Society of America*, *55*, 1061-1069.

Ternström, S. (1994). Hearing myself with others: Sound levels in choral performance measured with separation of one's own voice from the rest of the choir. *Journal of Voice, 8*(4), 293-302. doi: http://dx.doi.org/10.1016/S0892-1997(05)80277-2

Ternström, S. (1999). Preferred self-to-other ratios in choir singing. *Joural of the Acoustical Society of America, 105*, 3563.

Ternström, S., & Sundberg, J. (1988). Intonation precision of choir singers. *Joural of the Acoustical Society of America, 84*, 59.

Titze, I. R. (2006). Voice research and technology: Hearing loss and singing sharp. *Journal of singing, 62(5)*, 547-548.

Tonkinson, S. (1994). The Lombard effect in choral singing. *Journal of Voice, 8(1)*, 24-29.

Tremblay, K. L. (2005). *Beyond the ear: physiological perspectives on auditory rehabilitation.* Paper presented at the Seminars in Hearing.

Turner, C. W., Humes, L. E., Bentler, R. A., & Cox, R. M. (1996). A review of past research on changes in hearing aid benefit over time. *Ear and Hearing, 17*(3 Suppl), 14S.

Tyler, R.S., Chang, S.A., Tao, P., Gogel, S. & Gebringer, A.K. (2009). Tinnitus, hyperacusis, and music. In M. Chasin (ed.) *Hearing loss in musicians Prevention and management* (pp. 41-52). San Diego, CA.: Plural Publishing, Inc.

von Békésy, G. (1949). The structure of the middle ear and the hearing of one's own voice by bone conduction. *Journal of the Acoustical Society of America 21*, 217-232.

Wagner, M.J. (2009). Introductory musical acoustics (4th ed.). Raleigh, NC: Contemporary Publishing Company of Raleigh, Inc.

Walter, J. S. (2009). Sound exposure levels experienced by university wind band members. *Medical Problems of Performing Artists 24*(2), 63-70.

Walter, J. S. (2011). Sound exposures of high school marching band members during band camp: A pilot study. *Journal of Band Research, 46*(2), 18-28.

Ware, C. (2001). High Notes: The Singer as Processor. *Opera Journal*, *35*(1), 27-37.

Westmore G., & Eversden I. (1981) Noise-induced hearing loss and orchestral musicians. *Archives of Otolaryngology - Head and Neck Surgery, 107*(12)*,* 761-764.

Yund, E. W., Roup, C. M., Simon, H. J., & Bowman, G. A. (2006). Acclimatization in wide dynamic range multichannel compression and linear amplification hearing aids. *Journal of Rehabilitation Research and Development, 43*(4), 517.

Zander, M., Spahn, C., & Richter, B. (2008). Employment and acceptance of hearing protectors in classical symphony and opera orchestras. *Noise and Health, 10*(38), 14-26.

Zeigler, M. (1997). An investigation of the prevalence of tinnitus in college music majorsand nonmusic majors (Doctoral dissertation, Florida State University, 1997). *Dissertation Abstracts International, 58*, 2120.

Zeigler, M. C., & Taylor, J. A. (2001). The effects of a tinnitus awareness survey on college music majors' hearing conservation behaviors. *Medical Problems of Performing Artists, 16*(4), 136-143.

Zembower, C. M. (2000). Caution: Music can be hazardous to your health. *Update - Applications of Research in Music Education, 18*(2), 8-11.

Appendices

Appendix A

Choral Participant Informed Consent Statement

Approved by the Human Subjects Committee University of Kansas, Lawrence Campus (HSCL). Approval expires one year from 2/15/2013. HSCL # 20628

Dear Choir Participant:

The Department of Music at the University of Kansas supports the practice of protection for human subjects participating in research. The following information is provided for you to decide whether you wish to participate in the present study. You may refuse to sign this form and not participate in this study. You should be aware that even if you agree to participate, you are free to withdraw at any time. If you do withdraw from this study, it will not affect your relationship with this unit, the services it may provide to you, or the University of Kansas.

We are interested in studying student musicians' hearing acuity and ability to acclimate to musician's earplugs. You will be asked to complete a case history of past medical and hearing events and to take a standard hearing screening that will test for hearing loss. This exam uses standard clinical procedures, which represent best practices by certified audiologists. The researcher, trained by a certified audiologist, will administer individual hearing screenings in the Vocology Lab in Murphy Hall.

You will be listening to pure tone stimuli of various frequencies through a set of headphones and will be asked to raise your hand to indicate when the tone is just audible. It is estimated that the hearing screening will take approximately 10 minutes. The researcher will not be providing a diagnosis or analysis of results and the screening should not be viewed as a medical diagnosis.

You will receive a pair of ER-20, High Fidelity, Etymotic Research Musician's Earplugs. The earplugs are non-custom fit and come in two sizes, standard and large. You will choose, according to their comfort, the correct size. The earplugs are standard issue earplugs, confoming consist of a tuned resonator and acoustic resistor to replicate the natural response of the ear canal. The earplug will be inserted into the ear and will provide approximately 20dBA attenuation at all frequencies. You will receive individual instructions as to proper insertion, removal, and care of the earplugs.

Women's Chorale Participants--The Women's Chorale will perform, as a choir, a portion of a song, once without the earplugs, and once while wearing the earplugs. Choir members will be conducted by a pre-recorded video and the performances will be audio and video taped for future analysis. After the recording session, participants will be asked to compete a short study questionnaire. This same procedure will take place once a week for four weeks. The entire study will take four weeks.

The researcher only, will review all video recordings. Audio recordings will be edited so as not to include participant name or any identifying information. Video and audio recordings will be kept in a locked cabinet in the Music Lab in Murphy Hall for the period of two years.

It is doubtful that you will feel uncomfortable during this project and there are no risks anticipated with this study. If hearing loss is indicated, you will be referred to a licensed and certified audiologist who can further evaluate your hearing and make recommendations regarding appropriate audiological or medical follow up if warranted. The information gained from this study will add to the body of research concerning noise-induced hearing loss among musicians and hearing conservation programs. Your participation is completely voluntary and no payment will be made to you.

To perform this study, researchers will collect information about you. This information will be obtained from the audiology exam and a case history of past hearing events.

Only the researcher of this study and Dr. Angie Reeder will view your hearing screening results. The original copy of the hearing screening will be retained in a locked cabinet in the Music Vocology Lab In Murphy Hall. Your name will not be associated in any way with the information collected about you or with the research findings from this study. The researcher will use a study number or a pseudonym instead of your name.

The information collected about you will be used by: Sheri Cook-Cunningham, Dr. Angie Reeder and Dr. Jim Daugherty. In addition, Sheri Cook-Cunningham, Dr. Angie Reeder, and Dr. Jim Daugherty may share the results of this study, with members of the KU School of Music and with refereed research journals. This information may provide useful information about the effectiveness of musician's earplugs.

Permission granted on this date to use and disclose your information remains in effect indefinitely. By signing this form you give permission for the use and disclosure of your information for purposes of this study at any time in the future.

You may withdraw your consent to participate in this study at any time. You also have the right to cancel your permission to use and disclose information collected about you, in writing, at any time, by sending your written request to: Sheri Cook-Cunningham, 1530 Naismith Dr. Lawrence, KS. 66045. If you cancel permission to use your information, the researchers will stop collecting additional information about you. However, the research team may use and disclose information that was gathered before they received your cancellation, as described above. Questions about procedures should be directed to the researcher listed at the end of this consent form.

I have read this Consent and Authorization form. I have had the opportunity to ask, and I have received answers to, any questions I had regarding the study and the use and disclosure of information about me for the study. I understand that if I have any additional questions about my rights as a research participant, I may call (785) 864-7429 or write the Human Subjects Committee Lawrence Campus (HSCL), University of Kansas, 2385 Irving Hill Road, Lawrence, Kansas 66045-7563, email irb@ku.edu.

I agree to take part in this study as a research participant. I further agree to the uses and disclosures of my information as described above. By my signature I affirm that I am at least 18 years old and that I have received a copy of this Consent and Authorization form.

_______________________________ _____________________

Type/Print Participant's Name Date

____

Participant's Signature

Researcher Contact Information: Sheri Cook-Cunningham , Dr. James Daugherty
University of Kansas School of Music
1530 Naismith Drive
Lawrence, KS. 66045
scunningham@ku.edu
jdaugher@ku.edu

Appendix B

Solo Participant Informed Consent Statement

Approved by the Human Subjects Committee University of Kansas, Lawrence Campus (HSCL). Approval expires one year from 2/15/2013. HSCL # 20628

Dear Vocalist:

The Department of Music at the University of Kansas supports the practice of protection for human subjects participating in research. The following information is provided for you to decide whether you wish to participate in the present study. You may refuse to sign this form and not participate in this study. You should be aware that even if you agree to participate, you are free to withdraw at any time. If you do withdraw from this study, it will not affect your relationship with this unit, the services it may provide to you, or the University of Kansas.

We are interested in studying student musicians' hearing acuity and ability to acclimate to musician's earplugs. You will be asked to complete a case history of past medical and hearing events and to take a standard hearing screening that will test for hearing loss. This exam uses standard clinical procedures, which represent best practices by certified audiologists. The researcher, trained by a certified audiologist, will administer individual hearing screenings in the Vocology Lab in Murphy Hall.

You will be listening to pure tone stimuli of various frequencies through a set of headphones and will be asked to raise your hand to indicate when the tone is just audible. It is estimated that the hearing screening will take approximately 10 minutes. The researcher will not be providing a diagnosis or analysis of results and the screening should not be viewed as a medical diagnosis.

You will receive a pair of ER-20, High Fidelity, Etymotic Research Musician's Earplugs. The earplugs are non-custom fit and come in two sizes, standard and large. You will choose, according to their comfort, the correct size. The earplugs are standard issue earplugs, confoming consist of a tuned resonator and acoustic resistor to replicate the natural response of the ear canal. The earplug will be inserted into the ear and will provide approximately 20dBA attenuation at all frequencies. You will receive individual instructions as to proper insertion, removal, and care of the earplugs.

Solo Choir Participants--Soloists will be asked to wear the earplugs for an hour a day, during music making activities. Participants will perform, as a soloist, a portion of a song, once without the earplugs, and once while wearing the earplugs. Soloists will be conducted by a pre-recorded video and the performances will be audio and video taped for future analysis. After the recording session, participants will be asked to compete a short study questionnaire. This same procedure will happen once a week for four weeks. The entire study will take four weeks.

All video recordings will be reviewed by the researcher only. Audio recordings will be edited so as not to include participant name or any identifying information. Video and audio recordings will be kept in a locked cabinet in the Music Lab in Murphy Hall for the period of two years.

The researcher only, will review all video recordings. Audio recordings will be edited so as not to include participant name or any identifying information. An expert panel will listen to the recordings. Video and audio recordings will be kept in a locked cabinet in the Music Lab in Murphy Hall for the period of two years.

It is doubtful that you will feel uncomfortable during this project and there are no risks anticipated with this study. If hearing loss is indicated, you will be referred to a licensed and certified audiologist who can further evaluate your hearing and make recommendations regarding appropriate audiological or medical follow up if warranted. The information gained from this study will add to the body of research concerning noise-induced hearing loss

among musicians and hearing conservation programs. Your participation is completely voluntary and no payment will be made to you.
To perform this study, researchers will collect information about you. This information will be obtained from the audiology exam and a case history of past hearing events.

Only the researcher of this study and Dr. Angie Reeder will view your hearing screening results. The original copy of the hearing screening will be retained in a locked cabinet in the Music Vocology Lab In Murphy Hall. Your name will not be associated in any way with the information collected about you or with the research findings from this study. The researcher will use a study number or a pseudonym instead of your name.

The information collected about you will be used by: Sheri Cook-Cunningham, Dr. Angie Reeder and Dr. Jim Daugherty. In addition, Sheri Cook-Cunningham, Dr. Angie Reeder, and Dr. Jim Daugherty may share the results of this study, with members of the KU School of Music and with refereed research journals. This information may provide useful information about the effectiveness of musician's earplugs.

Permission granted on this date to use and disclose your information remains in effect indefinitely. By signing this form you give permission for the use and disclosure of your information for purposes of this study at any time in the future.

You may withdraw your consent to participate in this study at any time. You also have the right to cancel your permission to use and disclose information collected about you, in writing, at any time, by sending your written request to: Sheri Cook-Cunningham, 1530 Naismith Dr. Lawrence, KS. 66045. If you cancel permission to use your information, the researchers will stop collecting additional information about you. However, the research team may use and disclose information that was gathered before they received your cancellation, as described above. Questions about procedures should be directed to the researcher listed at the end of this consent form.

I have read this Consent and Authorization form. I have had the opportunity to ask, and I have received answers to, any questions I had regarding the study and the use and disclosure of information about me for the study. I understand that if I have any additional questions about my rights as a research participant, I may call (785) 864-7429 or write the Human Subjects Committee Lawrence Campus (HSCL), University of Kansas, 2385 Irving Hill Road, Lawrence, Kansas 66045-7563, email irb@ku.edu.

I agree to take part in this study as a research participant. I further agree to the uses and disclosures of my information as described above. By my signature I affirm that I am at least 18 years old and that I have received a copy of this Consent and Authorization form.

____ _______________________

Type/Print Participant's Name Date

____

Participant's Signature

Researcher Contact Information: Sheri Cook-Cunningham , Dr. James Daugherty
University of Kansas School of Music 1530 Naismith Drive Lawrence, KS. 66045

scunningham@ku.edu

Appendix C

The University of Kansas Hearing Screening

Student Name_______________________________Birthdate__________________Sex M/F

Address____ Telephone(___)________

Year in school______________________ College Major__________________

List all noise exposure (job and school related) Begin with most recent first.

JOB OR ACTIVITY	NOISE SOURCE	DURATION (Months & Years)

List your major instrument______________________ Number of years played/sung______

List any other instruments ______________________ Number of years played/sung______

On average, how much time do you spend practicing daily? __________

Where do you practice the majority of the time? Murphy Hall Practice Room____
Other (apt., dorm room, etc.) ____
(Please specify where you practice and give estimated square footage of the room, e.g. 8' x 10')

Do you wear hearing protection? Yes or No (Circle one) If yes, for which music activities?_________________

Do your ears ever ring after a practice or performance? Yes or No (circle one)

List all ensembles you participate in and the amount of time spent practicing and /or performing in each. (e. g. Marching Band—6 hours practice/week and 2 hours performing in a home game)

Ensemble Name	Practice time per week	Performance time per week	Practice Venue	Performance Venue

Circle current or past non-occupational noise exposure and specify number of years.

1. Amplified Music ________
2. Flying ________
3. Gunfire ________
4. Fireworks ________
5. Engines ________
6. Military Service ________
7. Artillery ________
8. Home Power Tools ________
9. Any other noise ________
   Specify:

If you use ear protection for any of the above, please indicate how often on the line beside the noise source: often, occasional, seldom, never

Put a check by the items that apply to you in the table below:

Hear or Ear Injury	**Family Hearing Loss**	**Ear infections and symptoms**	**Diseases or disorders**
___Eardrum rupture	___Sister(s)	___Draining ears	___Meningitis
___Explosive blast	___Brother(s)	___Ear medication	___Scarlet Fever
___Skull fracture	___Son(s)	___Ear aches	___Measles
___Concussion	___Daughter(s)	___Ear infection(s)	___Mumps
___Hard blow to head	___You	___Ear surgery	___Chicken pox
___Falling accident	___Mother	___Ear wax build up	___Diabetes
___Diving accident	___Father	___Ringing in ears	___Allergies
___Auto accident	___Aunt(s)	___Dizziness/nausea	___High fever
___Burn to ear(s)	___Uncle(s)	___Pressure in ear	___Blood pressure
___Lack of oxygen		___Ear deformity	___Upper respiratory infection

Are you aware of any hearing problem or disorder that you have? YES or NO If YES, describe below.

Has this problem been professionally evaluated or treated? YES or NO If YES, explain below.

Number of hours since last noise exposure__________________ Please list what your noise exposure was.

Signature____

Date ________________________

Appendix D

Choral Participant Survey (Week One)

Name____ Age_________

Voice part sung (circle one): Soprano I Soprano II Alto I Alto II

Number of years of voice lessons ______ Major__________________

Number of years in Elementary Choir ____ Number of years in Junior High Choir
Number of year in High School Choir _______ Number of years in College Choir______

Please circle the year of school you are currently in:

Undergraduate: Freshman Sophomore Junior Senior

Graduate: ____Masters ____ Doctorate (Indicate which year of the program you are enrolled in)

Please circle the number which best corresponds to your perception of your hearing and singing today:

1. My ability to clearly hear myself singing without the earplugs was:

1	2	3	4	5
Poor	Fair	Good	Very Good	Excellent

2. My ability to clearly hear myself singing with the earplugs was:

1	2	3	4	5
Poor	Fair	Good	Very Good	Excellent

3. My ability to clearly hear the rest of the choir when singing without the earplugs was:

1	2	3	4	5
Poor	Fair	Good	Very Good	Excellent

4. My ability to clearly hear the rest of the choir when singing with the earplugs was:

1	2	3	4	5
Poor	Fair	Good	Very Good	Excellent

5. My perception of the pitch without earplugs was:

1	2	3	4	5
Poor	Fair	Good	Very Good	Excellent

6. My perception of the pitch with earplugs was:

1	2	3	4	5
Poor	Fair	Good	Very Good	Excellent

7. My singing ability without earplugs was:

1	2	3	4	5
Poor	Fair	Good	Very Good	Excellent

8. My singing ability with earplugs was:

1	2	3	4	5
Poor	Fair	Good	Very Good	Excellent

9. Please rate the comfort level of the earplugs:

1	2	3	4	5
Poor	Fair	Good	Very Good	Excellent

Please add any additional comments below:

Appendix E

Choral Participant Survey (Weeks Two - Four)

Name____ Age_________

Please circle the number which best corresponds to your perception of your hearing and singing today:

1. My ability to clearly hear myself singing without the earplugs was:

1	2	3	4	5
Poor	Fair	Good	Very Good	Excellent

2. My ability to clearly hear myself singing with the earplugs was:

1	2	3	4	5
Poor	Fair	Good	Very Good	Excellent

3. My ability to clearly hear the rest of the choir when singing without the earplugs was:

1	2	3	4	5
Poor	Fair	Good	Very Good	Excellent

4. My ability to clearly hear the rest of the choir when singing with the earplugs was:

1	2	3	4	5
Poor	Fair	Good	Very Good	Excellent

5. My perception of the pitch without earplugs was:

1	2	3	4	5
Poor	Fair	Good	Very Good	Excellent

6. My perception of the pitch with earplugs was:

1	2	3	4	5
Poor	Fair	Good	Very Good	Excellent

7. My singing ability without earplugs was:

1	2	3	4	5
Poor	Fair	Good	Very Good	Excellent

8. My singing ability with earplugs was:

1	2	3	4	5
Poor	Fair	Good	Very Good	Excellent

9. Please rate the comfort level of the earplugs:

1	2	3	4	5
Poor	Fair	Good	Very Good	Excellent

10. I am better adjusted to wearing the earplugs this recordings session than I was during the previous recording session:

1	2	3	4	5
Strongly disagree		Agree		Strongly Agree

Please add any additional comments below

Appendix F

Expert Panel Survey

Thank you for participating in this study! Please complete the following:

Name_________________________________ Age_________

Education: *Please circle all that apply and list your emphasis in each*:

Bachelor of Music ____

Masters of Music ____

PhD in progress ____

Work Experience: *Please list the number of years you've taught at each level and your choir conducting experiences below.*

Elementary School ____ Choir: Yes ____ No ____

Junior High ____ Choir: Yes ____ No ____

High School ____ Choir: Yes ____ No ____

College ____ Choir: Yes ____ No ____

Solo Voice ____

How many years did you sing in a high school choir? _______

How many years have you sung in a college choir? _______

How many years have you sung in a professional choir? _______

INSTRUCTIONS

Thank you for participating in this study! Please feel free to ask questions at any time.

Please place your headphones on your head with the side marked “R” over your right ear and the side marked “L” over your left ear. You may adjust them so they fit comfortably on your head. Once your headphones are properly in place, please do not move or adjust them unnecessarily until the study is concluded.

In a few moments, you will hear 14 pairs of brief choral music performances. Listen carefully to each performance. At the conclusion of each pair of performances, you will be asked to indicate whether you heard any differences in overall choral sound between the two performances.

Each pair of performances will be announced, e.g., “Pair One, “Pair Two,” etc. Thereafter you will hear two performances, separated in time by three seconds. After the second performance in each pair, you will have 15 seconds to mark your answers for that pair, before presentation of the next performance pair.

Do you have any questions at this point?

1. PAIR ONE. *Listen carefully to each of these two sung excerpts. After hearing both performances, respond to each item below.*

a. Comparing the overall sound of the choir in these two performances, I heard (circle one):

No difference   A Little difference   Much difference   Very much difference   Not sure

2. PAIR TWO. *Listen carefully to each of these two sung excerpts. After hearing both performances, respond to each item below.*

a. Comparing the overall sound of the choir in these two performances, I heard (circle one):

No difference   A Little difference   Much difference   Very much difference   Not sure

3. PAIR THREE. *Listen carefully to each of these two sung excerpts. After hearing both performances, respond to each item below.*

a. Comparing the overall sound of the choir in these two performances, I heard (circle one):

No difference   A Little difference   Much difference   Very much difference   Not sure

4. PAIR FOUR. *Listen carefully to each of these two sung excerpts. After hearing both performances, respond to each item below.*

a. Comparing the overall sound of the choir in these two performances, I heard (circle one):

No difference   A Little difference   Much difference   Very much difference   Not sure

5. PAIR FIVE. *Listen carefully to each of these two sung excerpts. After hearing both performances, respond to each item below.*

a. Comparing the overall sound of the choir in these two performances, I heard (circle one):

No difference   A Little difference   Much difference   Very much difference   Not sure

***6. PAIR SIX**. Listen carefully to each of these two sung excerpts. After hearing both performances, respond to each item below.*

a. Comparing the overall sound of the choir in these two performances, I heard (circle one):

No difference   A Little difference   Much difference   Very much difference   Not sure

***7. PAIR SEVEN**. Listen carefully to each of these two sung excerpts. After hearing both performances, respond to each item below.*

a. Comparing the overall sound of the choir in these two performances, I heard (circle one):

No difference   A Little difference   Much difference   Very much difference   Not sure

***8. PAIR EIGHT**. Listen carefully to each of these two sung excerpts. After hearing both performances, respond to each item below.*

a. Comparing the overall sound of the choir in these two performances, I heard (circle one):

No difference   A Little difference   Much difference   Very much difference   Not sure

***9. PAIR NINE**. Listen carefully to each of these two sung excerpts. After hearing both performances, respond to each item below.*

a. Comparing the overall sound of the choir in these two performances, I heard (circle one):

No difference   A Little difference   Much difference   Very much difference   Not sure

***10. PAIR TEN**. Listen carefully to each of these two sung excerpts. After hearing both performances, respond to each item below.*

a. Comparing the overall sound of the choir in these two performances, I heard (circle one):

No difference   A Little difference   Much difference   Very much difference   Not sure

11. PAIR ELEVEN*. Listen carefully to each of these two sung excerpts. After hearing both performances, respond to* <u>*each*</u> *item below.*

a. Comparing the overall sound of the choir in these two performances, I heard (circle one):

No difference A Little difference Much difference Very much difference Not sure

12. PAIR TWELVE. *Listen carefully to each of these two sung excerpts. After hearing both performances, respond to* <u>*each*</u> *item below.*

a. Comparing the overall sound of the choir in these two performances, I heard (circle one):

13. PAIR THIRTEEN*. Listen carefully to each of these two sung excerpts. After hearing both performances, respond to* <u>*each*</u> *item below.*

a. Comparing the overall sound of the choir in these two performances, I heard (circle one):

No difference A Little difference Much difference Very much difference Not sure

14. PAIR FOURTEEN*. Listen carefully to each of these two sung excerpts. After hearing both performances, respond to* <u>*each*</u> *item below.*

a. Comparing the overall sound of the choir in these two performances, I heard (circle one):

No difference A Little difference Much difference Very much difference Not sure

Appendix G

Solo Participant Survey (Week One)

Name____ Age_________

Voice part sung (circle one): Soprano I Soprano II Alto I Alto II

Number of years of voice lessons ______ Major__________________
Number of years in Elementary Choir ____ Number of years in Junior High Choir
Number of year in High School Choir ____ Number of years in College Choir______

Please circle the year of school you are currently in:
Undergraduate: Freshman Sophomore Junior Senior
Graduate: ____Masters ____ Doctorate (Indicate which year of the program you are enrolled in)
Please circle the number which best corresponds to your perception of your hearing and singing today:

1. My ability to clearly hear myself singing without the earplugs was:

1	2	3	4	5
Poor	Fair	Good	Very Good	Excellent

2. My ability to clearly hear myself singing with the earplugs was:

1	2	3	4	5
Poor	Fair	Good	Very Good	Excellent

3. My perception of the pitch without earplugs was:

1	2	3	4	5
Poor	Fair	Good	Very Good	Excellent

4. My perception of the pitch with earplugs was:

1	2	3	4	5
Poor	Fair	Good	Very Good	Excellent

5. My singing ability without earplugs was:

1	2	3	4	5
Poor	Fair	Good	Very Good	Excellent

6. My singing ability with earplugs was:

1	2	3	4	5
Poor	Fair	Good	Very Good	Excellent

7. Please rate the comfort level of the earplugs:

1	2	3	4	5
Poor	Fair	Good	Very Good	Excellent

Please add any additional comments below:

Appendix H

Solo Participant Survey (Weeks Two - Four)

Name____ Age_________

Please circle the number which best corresponds to your perception of your hearing and singing today:

1. My ability to clearly hear myself singing without the earplugs was:

1	2	3	4	5
Poor	Fair	Good	Very Good	Excellent

2. My ability to clearly hear myself singing with the earplugs was:

1	2	3	4	5
Poor	Fair	Good	Very Good	Excellent

3. My perception of the pitch without earplugs was:

1	2	3	4	5
Poor	Fair	Good	Very Good	Excellent

4. My perception of the pitch with earplugs was:

1	2	3	4	5
Poor	Fair	Good	Very Good	Excellent

5. My singing ability without earplugs was:

1	2	3	4	5
Poor	Fair	Good	Very Good	Excellent

6. My singing ability with earplugs was:

1	2	3	4	5
Poor	Fair	Good	Very Good	Excellent

7. Please rate the comfort level of the earplugs:

1	2	3	4	5
Poor	Fair	Good	Very Good	Excellent

8. I am better adjusted to wearing the earplugs this recordings session than I was during the previous recording session:

1	2	3	4	5
Poor	Fair	Good	Very Good	Excellent

Please add any additional comments below or on the back of the page:

Appendix I

Expert Panel Survey

Thank you for participating in this study! Please complete the following:

Name___________________________________ Age_________

Education: *Please circle all that apply and list your emphasis in each*:

Bachelor of Music ____

Masters of Music ____

PhD in progress ____

Work Experience: *Please list the number of years you've taught at each level and your choir conducting experiences below*.

Elementary School ____ Choir: Yes ____ No ____

Junior High ____ Choir: Yes ____ No ____

High School ____ Choir: Yes ____ No ____

College ____ Choir: Yes ____ No ____

Solo Voice ____

How many years did you sing in a high school choir? _______

How many years have you sung in a college choir? _______

How many years have you sung in a professional choir? _______

INSTRUCTIONS

Thank you for participating in this study! Please feel free to ask questions at any time.

Please place your headphones on your head with the side marked “R” over your right ear and the side marked “L” over your left ear. You may adjust them so they fit comfortably on your head. Once your headphones are properly in place, please do not move or adjust them unnecessarily until the study is concluded.

In a few moments, you will hear six pairs of brief solo music performances. Listen carefully to each performance. At the conclusion of each pair of performances, you will be asked to indicate whether you heard any differences in overall solo sound between the two performances.

Each pair of performances will be announced, e.g., “Pair One, “Pair Two,” etc. Thereafter you will hear two performances, separated in time by three seconds. After the second performance in each pair, you will have 15 seconds to mark your answers for that pair, before presentation of the next performance pair.

Do you have any questions at this point?

***1. PAIR ONE**. Listen carefully to each of these two sung excerpts. After hearing both performances, respond to each item below.*

a. Comparing the overall sound of the soloist in these two performances, I heard (circle one):

No difference A Little difference Much difference Very much difference Not sure

***2. PAIR TWO**. Listen carefully to each of these two sung excerpts. After hearing both performances, respond to each item below.*

a. Comparing the overall sound of the soloist in these two performances, I heard (circle one):

No difference A Little difference Much difference Very much difference Not sure

***3. PAIR THREE**. Listen carefully to each of these two sung excerpts. After hearing both performances, respond to each item below.*

a. Comparing the overall sound of the soloist in these two performances, I heard (circle one):

No difference A Little difference Much difference Very much difference Not sure

***4. PAIR FOUR**. Listen carefully to each of these two sung excerpts. After hearing both performances, respond to each item below.*

a. Comparing the overall sound of the soloist in these two performances, I heard (circle one):

No difference A Little difference Much difference Very much difference Not sure

Much difference Very much difference Not sure

Appendix J

LTAS Choral Charts from Weeks One – Four

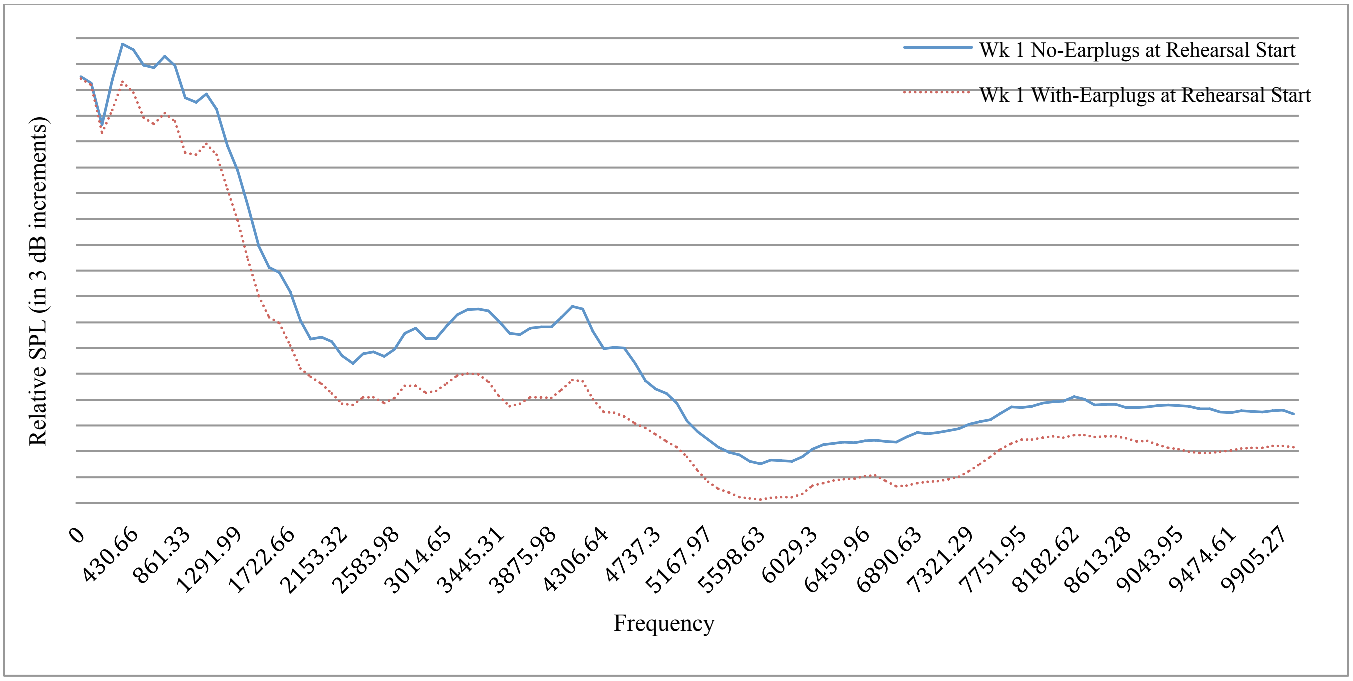

Figure J-1. Week one Group A: LTAS contours in the 0 – 10 kHz region of performances of no-earplugs and with-earplugs at rehearsal start.

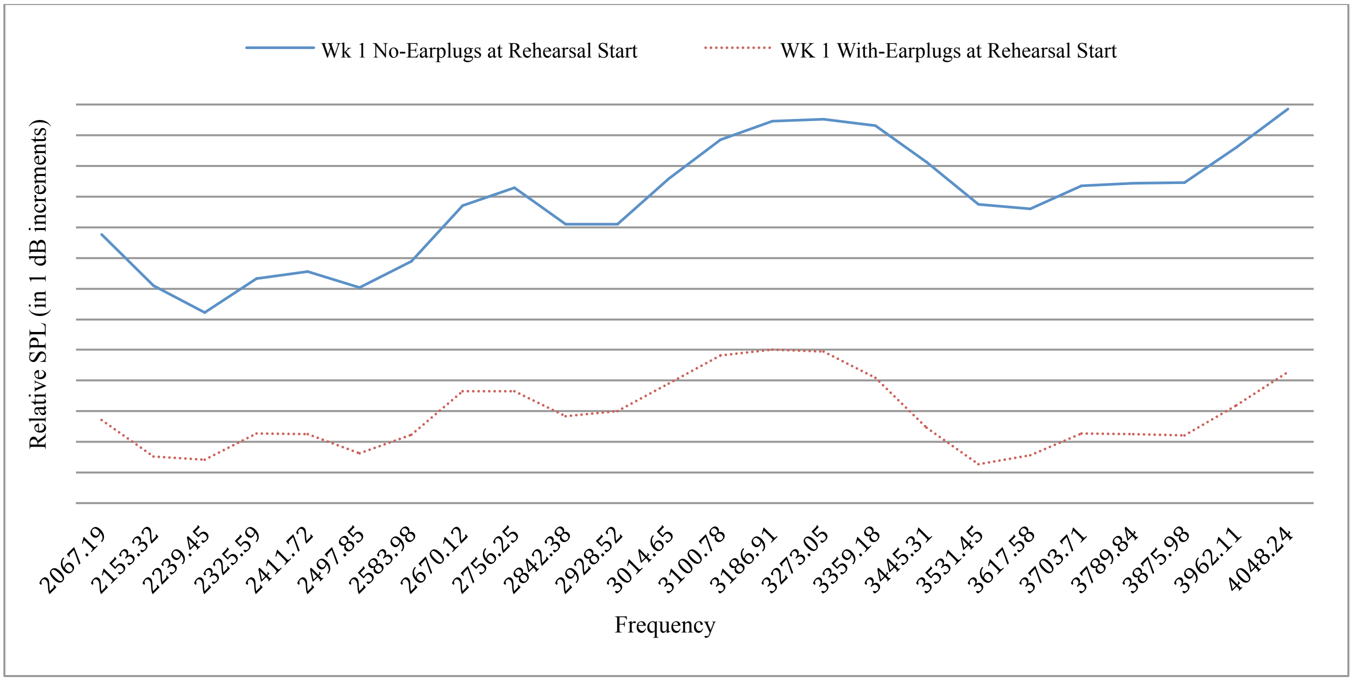

Figure J-2. Week one Group A: LTAS contours in the 2 – 4 kHz region of performances of no-earplugs and with-earplugs at rehearsal start.

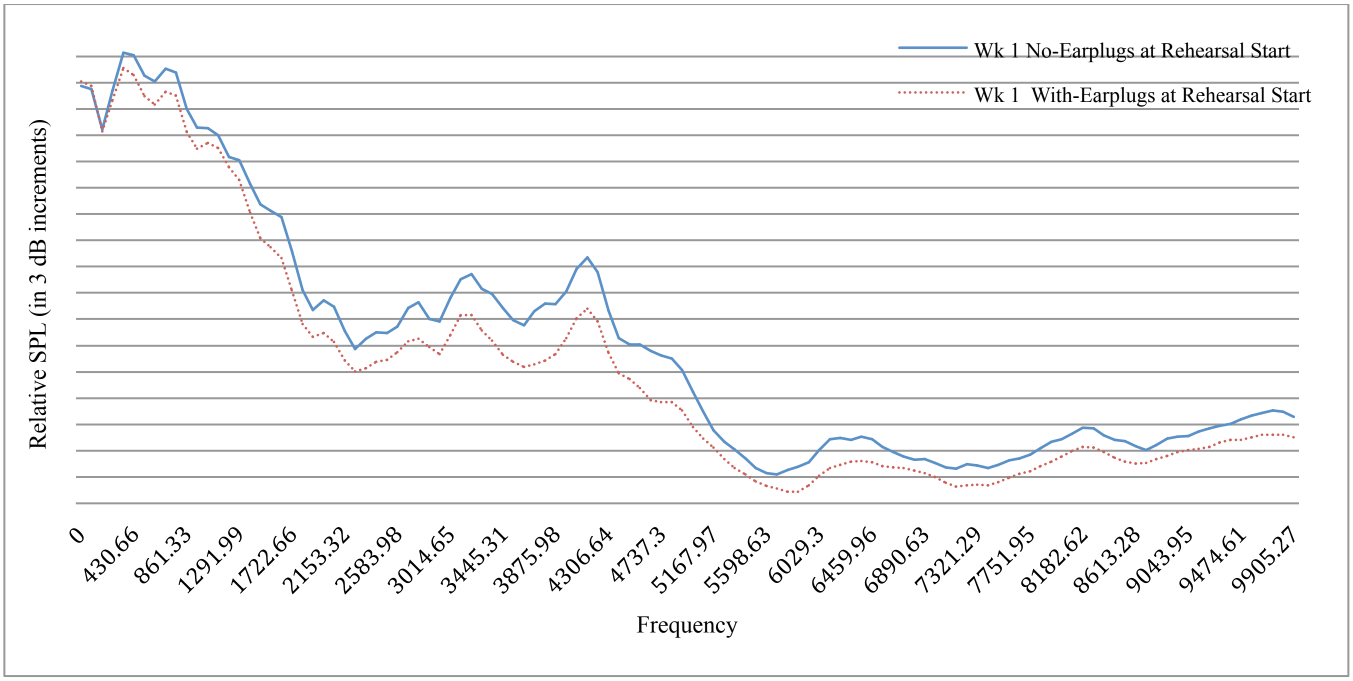

Figure J-3. Week one Group B: LTAS contours in the 0 – 10 kHz region of performances of no-earplugs and with-earplugs at rehearsal start.

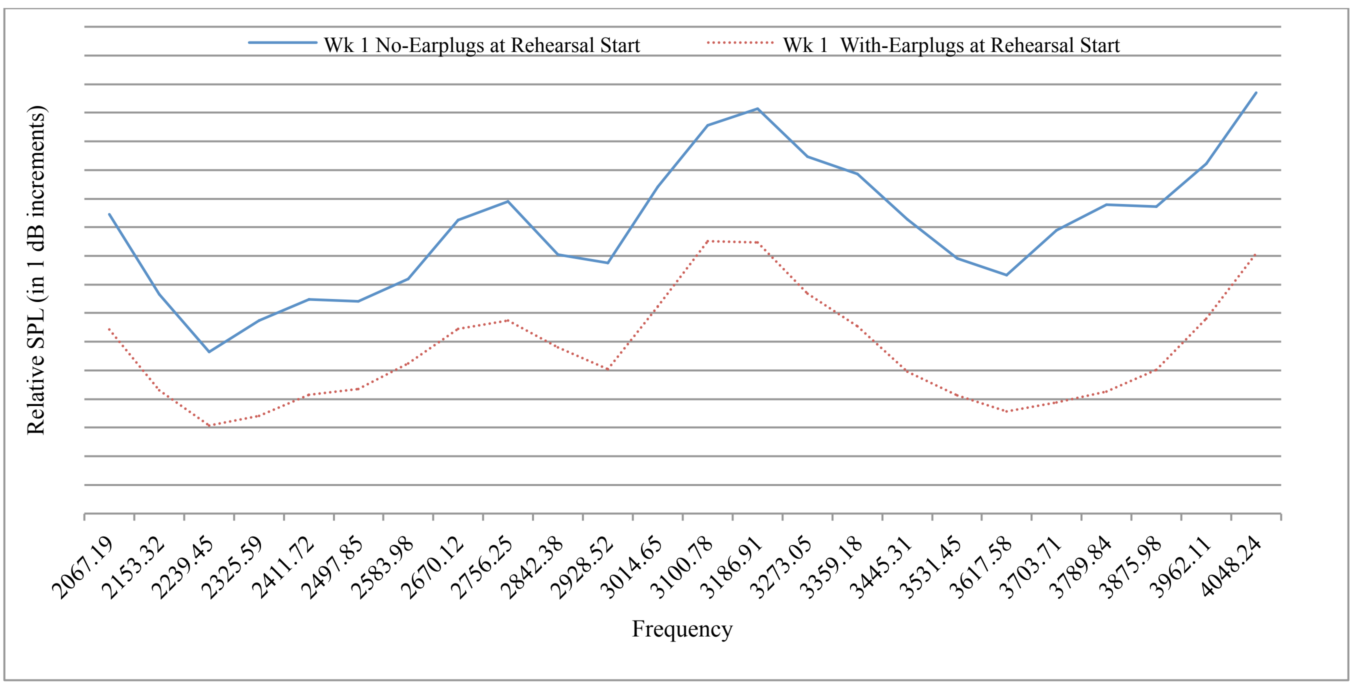

Figure J-4. Week one Group B: LTAS contours in the 2 – 4 kHz region of performances of no-earplugs and with-earplugs at rehearsal start.

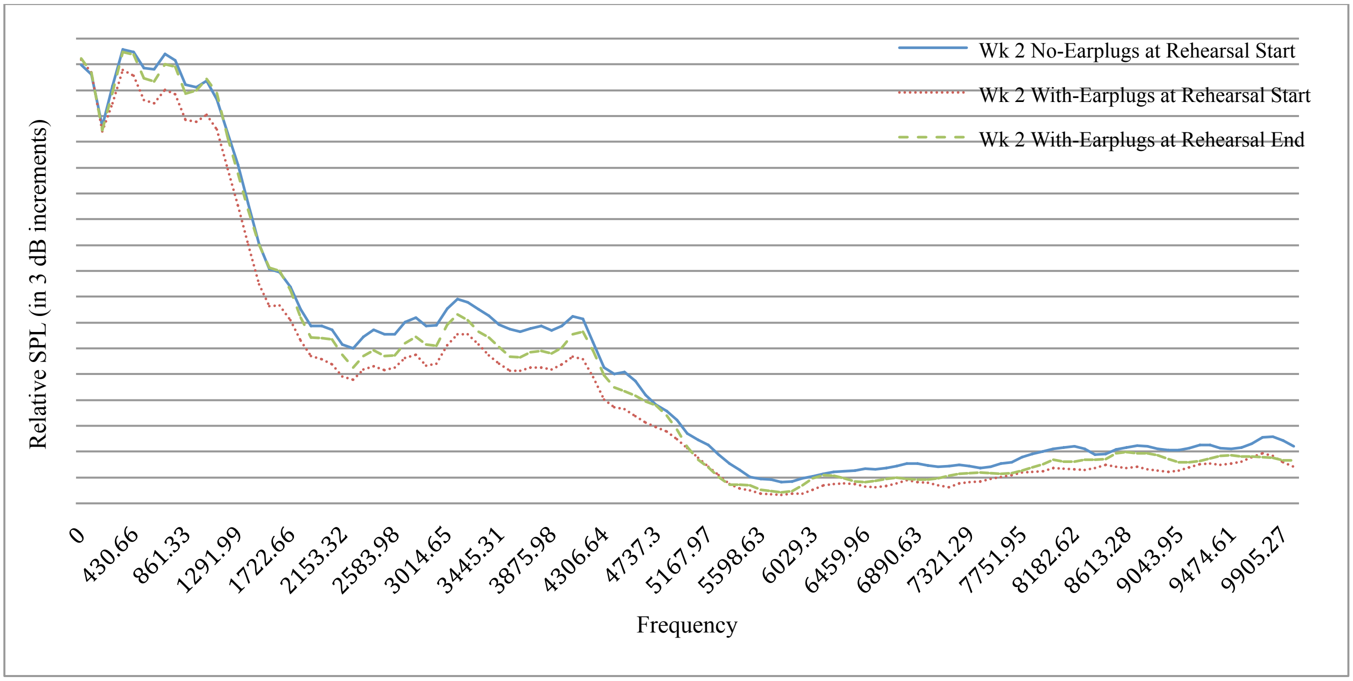

Figure J-5. Week 2 Group A: LTAS contours of performances in the 0 – 10 kHz region under 3 conditions, no-earplugs at rehearsal start, with-earplugs at rehearsal start and with-earplugs at rehearsal end.

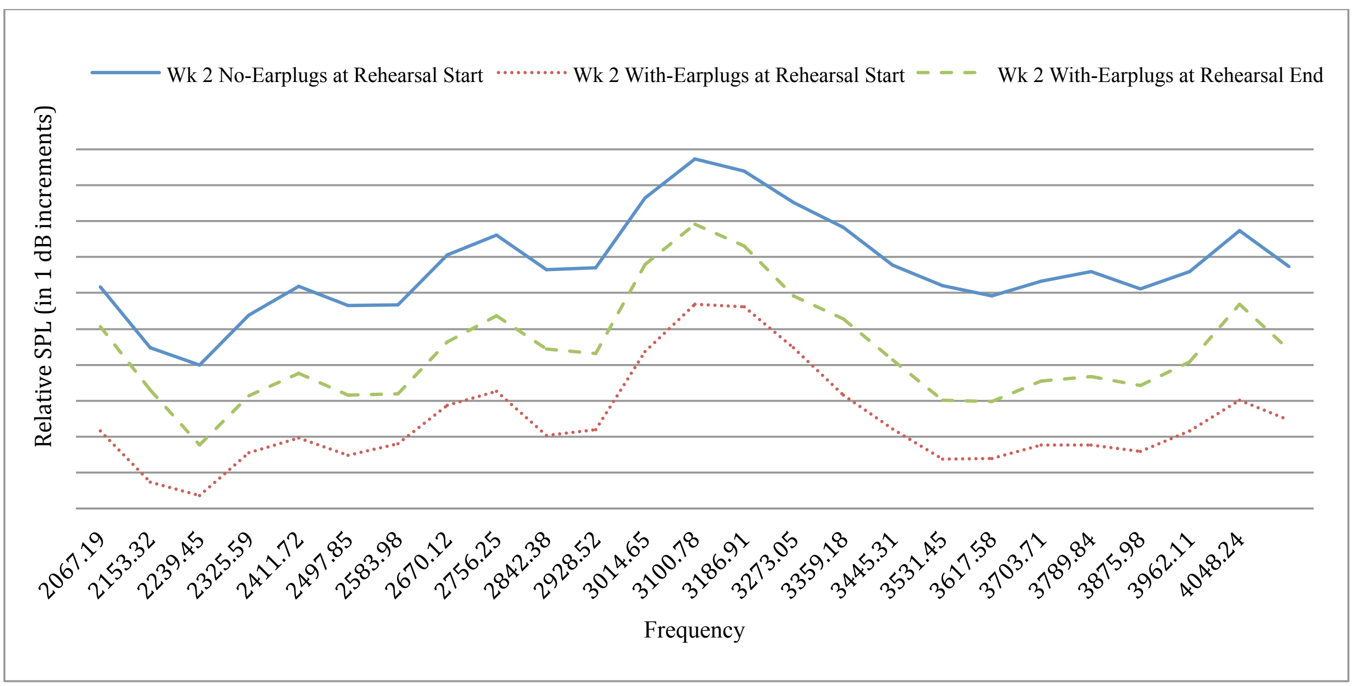

Figure J-6. Week two Group A: LTAS contours in the 2 – 4 kHz region of performances under 3 conditions, no-earplugs at rehearsal start, with-earplugs at rehearsal start and with-earplugs at rehearsal end.

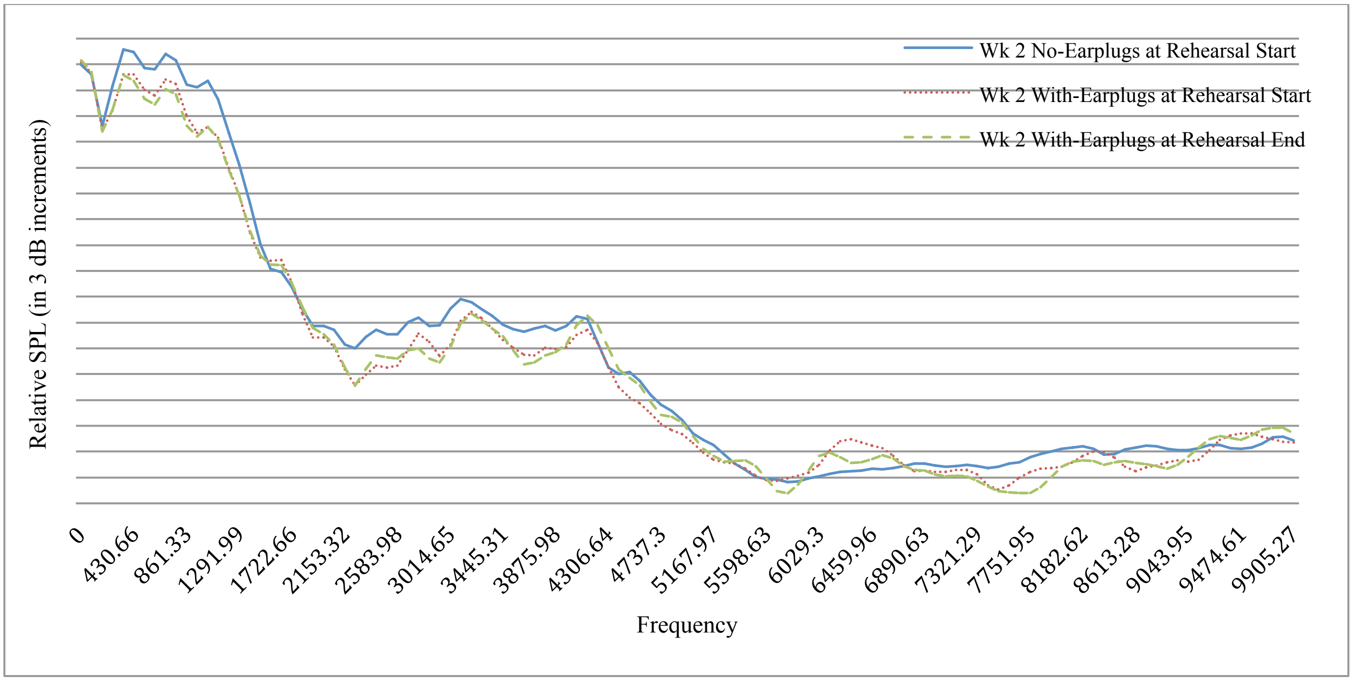

Figure J-7. Week two Group B: LTAS contours in the 0 – 10 kHz region of performances under 3 conditions, no-earplugs at rehearsal start, with-earplugs at rehearsal start and with-earplugs at rehearsal end.

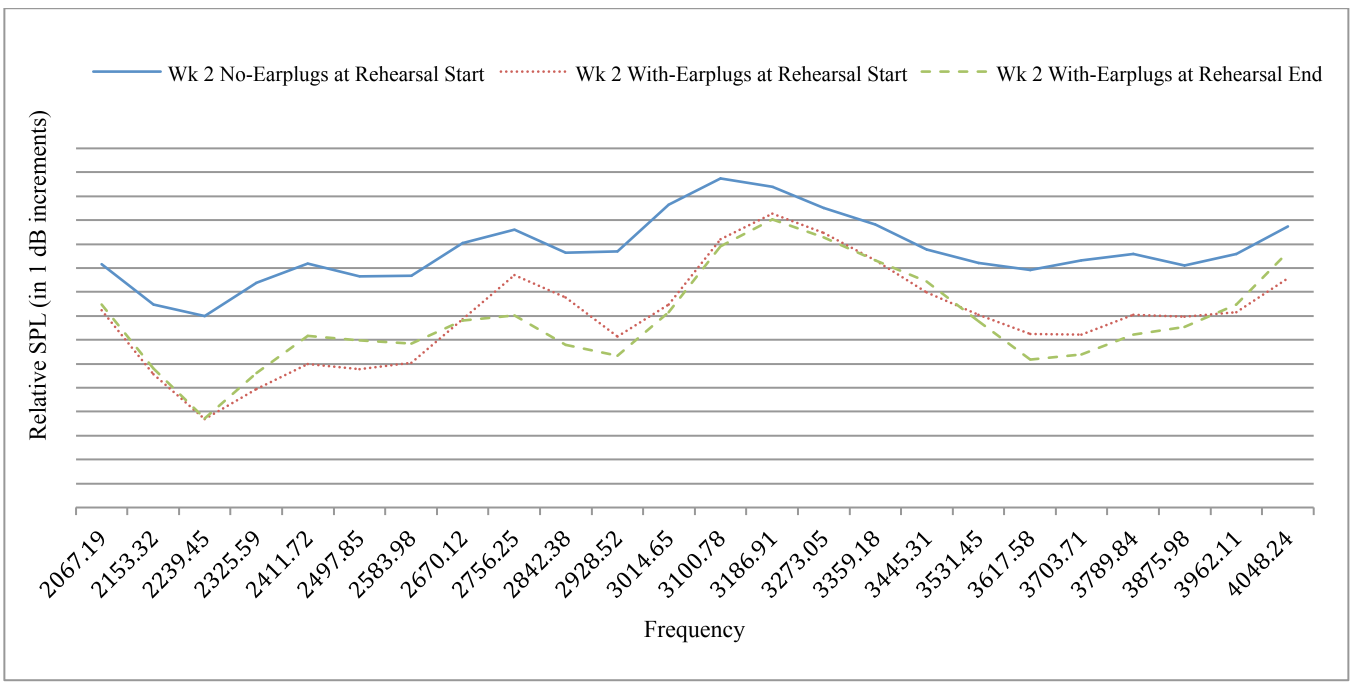

*Figure J-8***.** Week two Group B: LTAS contours in the 2 – 4 kHz region of performances under 3 conditions, no-earplugs at rehearsal start, with-earplugs at rehearsal start and with-earplugs at rehearsal end.

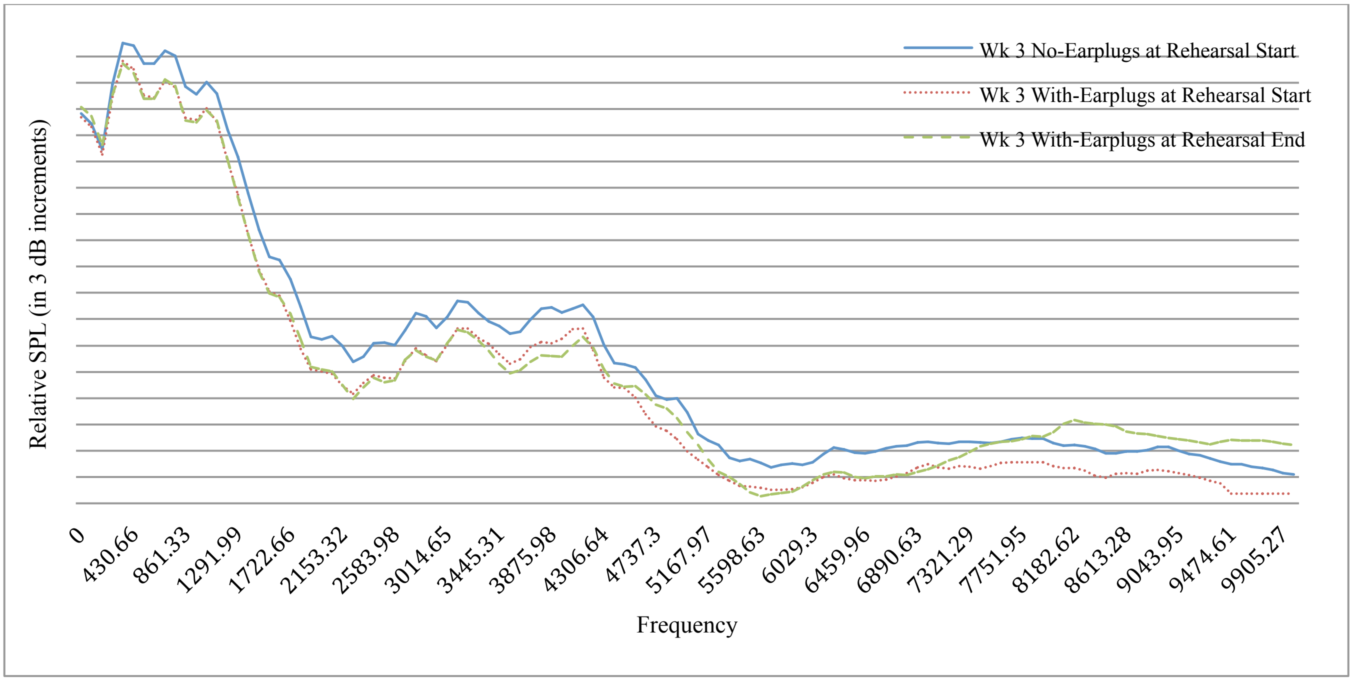

Figure J-9. Week three Group A: LTAS contours in the 0 – 10 kHz region of performances under three conditions; no-earplugs at rehearsal start, with-earplugs at rehearsal start and with-earplugs at rehearsal end.

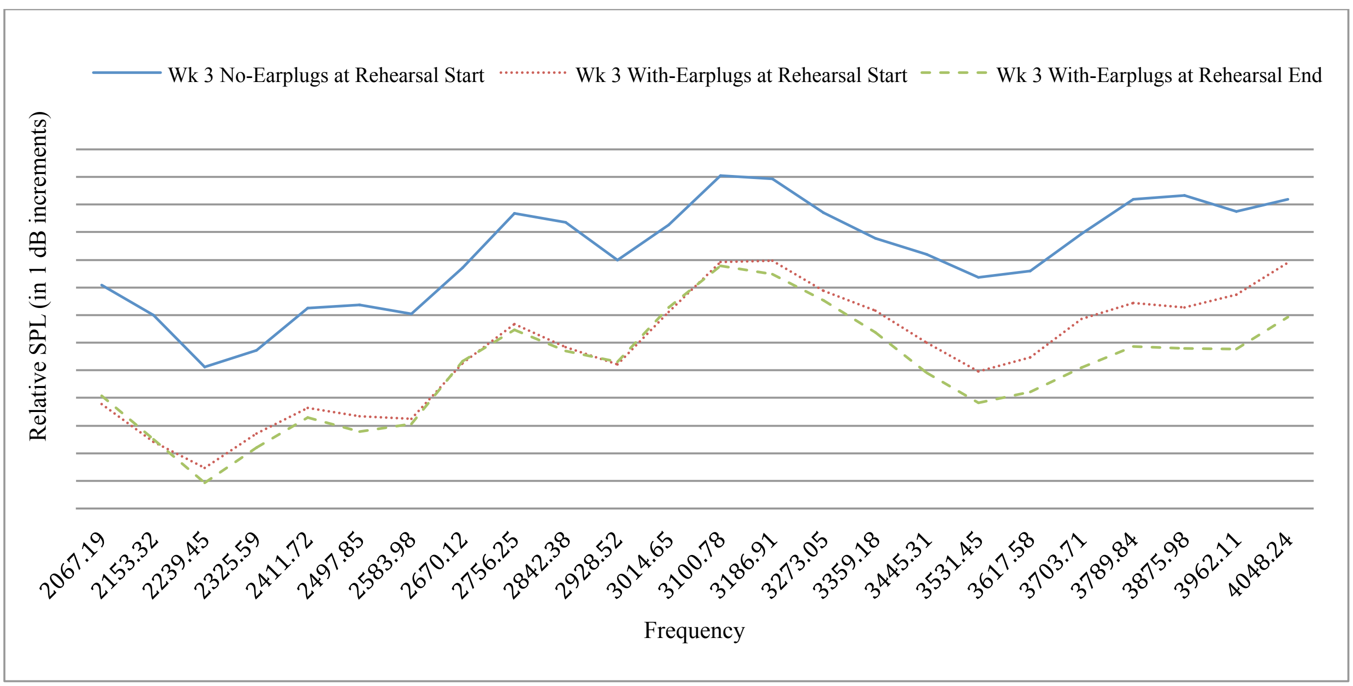

Figure J-10. Week three Group A: LTAS contours in the 2 – 4 kHz region of performances under 3 conditions, no-earplugs at rehearsal start, with-earplugs at rehearsal start and with-earplugs at rehearsal end.

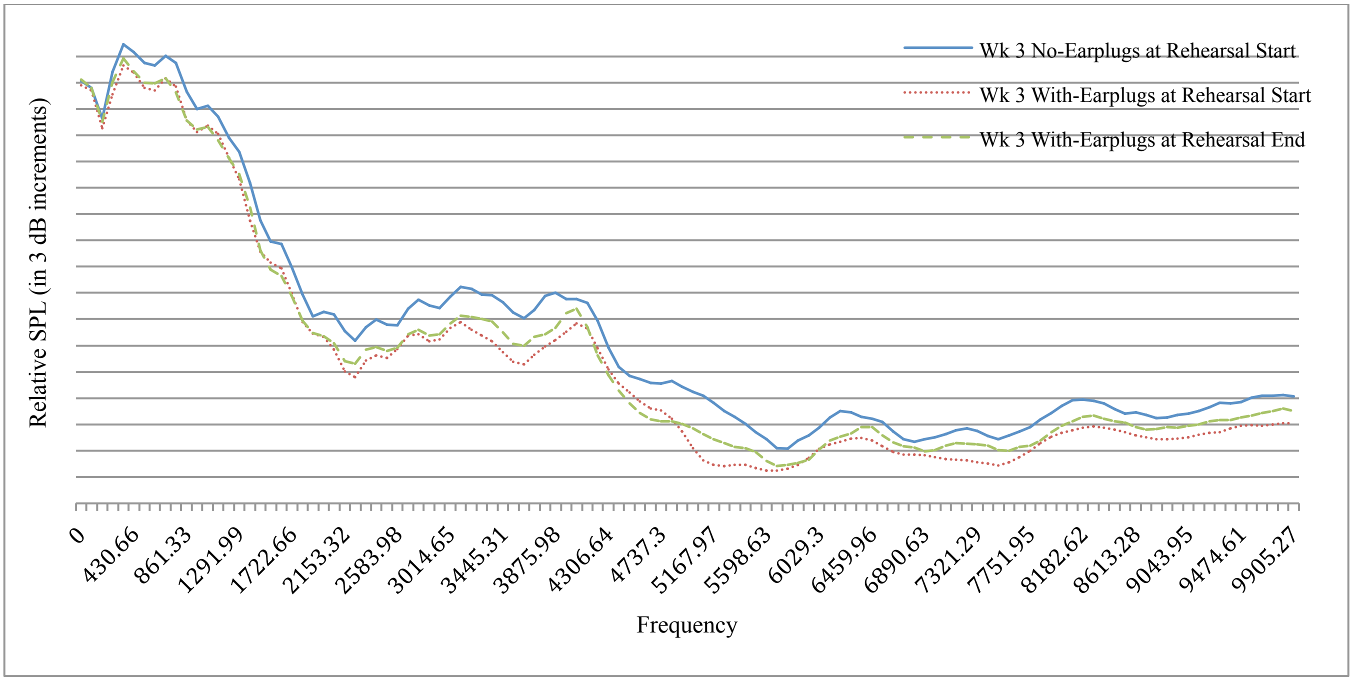

Figure J-11. Week three Group B: LTAS contours in the 0 – 10 kHz region of performances under three conditions; no-earplugs at rehearsal start, with-earplugs at rehearsal start and with-earplugs at rehearsal end.

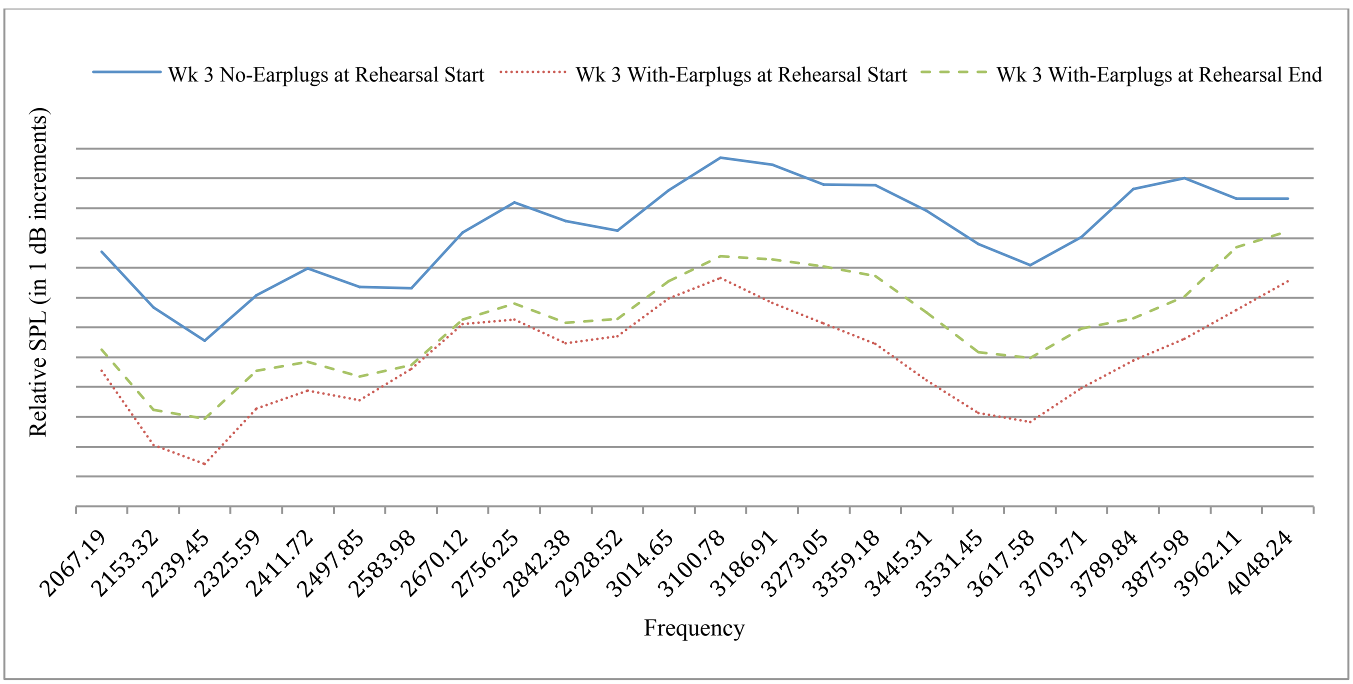

Figure J-12. Week three Group B: LTAS contours in the 2 – 4 kHz region of performances under 3 conditions, no-earplugs at rehearsal start, with-earplugs at rehearsal start and with-earplugs at rehearsal end.

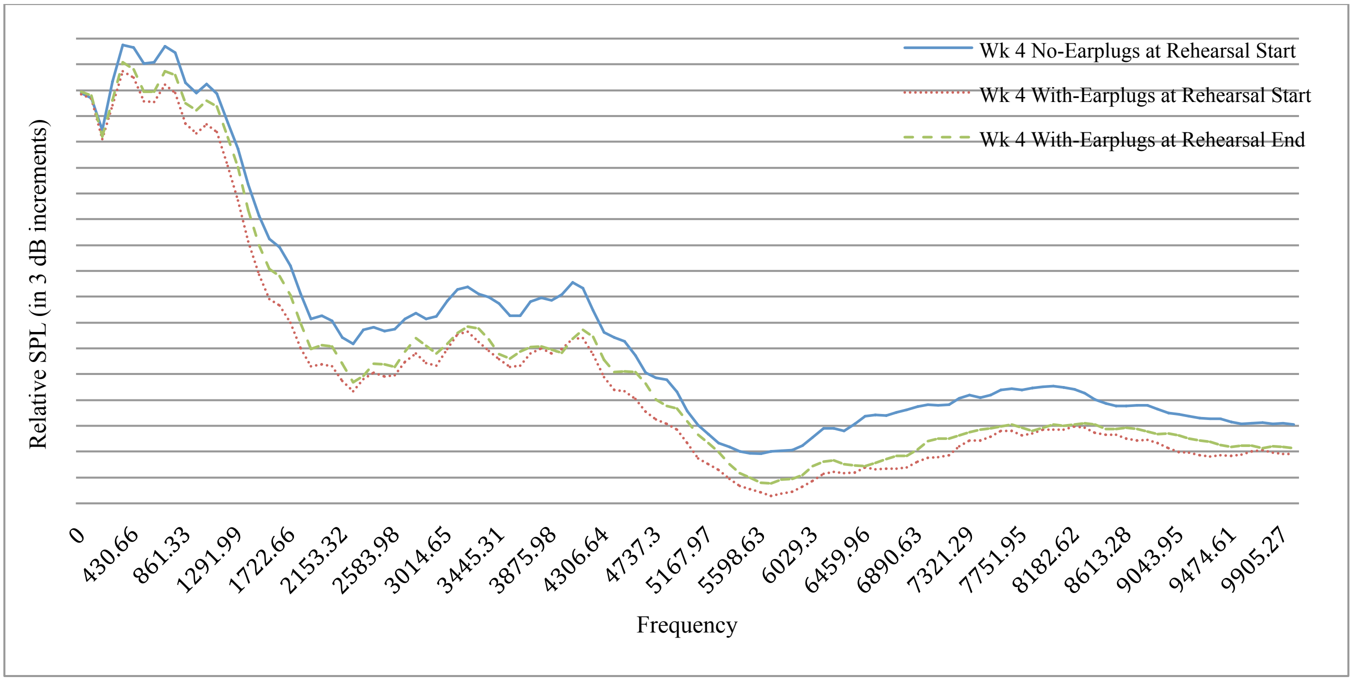

Figure J-13. Week four Group A: LTAS contours in the 0 – 10 kHz region of performances under three conditions; no-earplugs at rehearsal start, with-earplugs at rehearsal start and with-earplugs at rehearsal end.

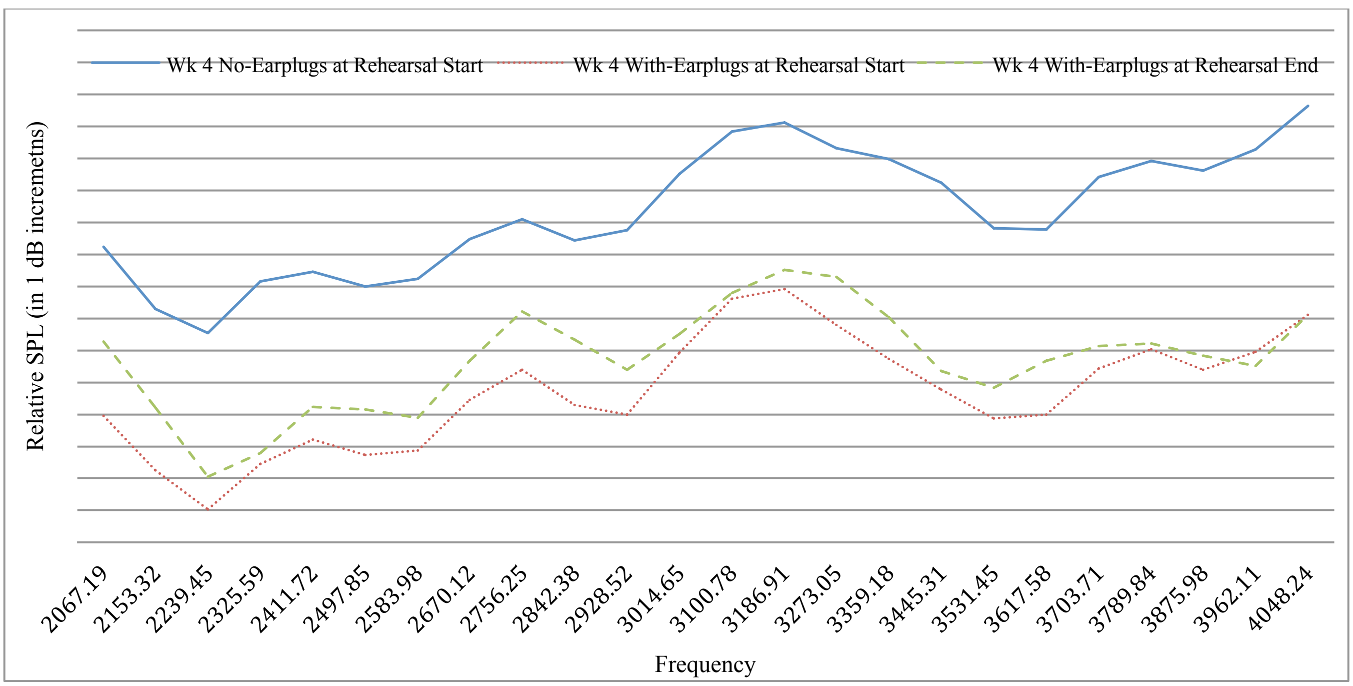

*Figure J-14***.** Week four Group A: LTAS contours in the 2 – 4 kHz region of performances under 3 conditions, no-earplugs at rehearsal start, with-earplugs at rehearsal start and with-earplugs at rehearsal end.

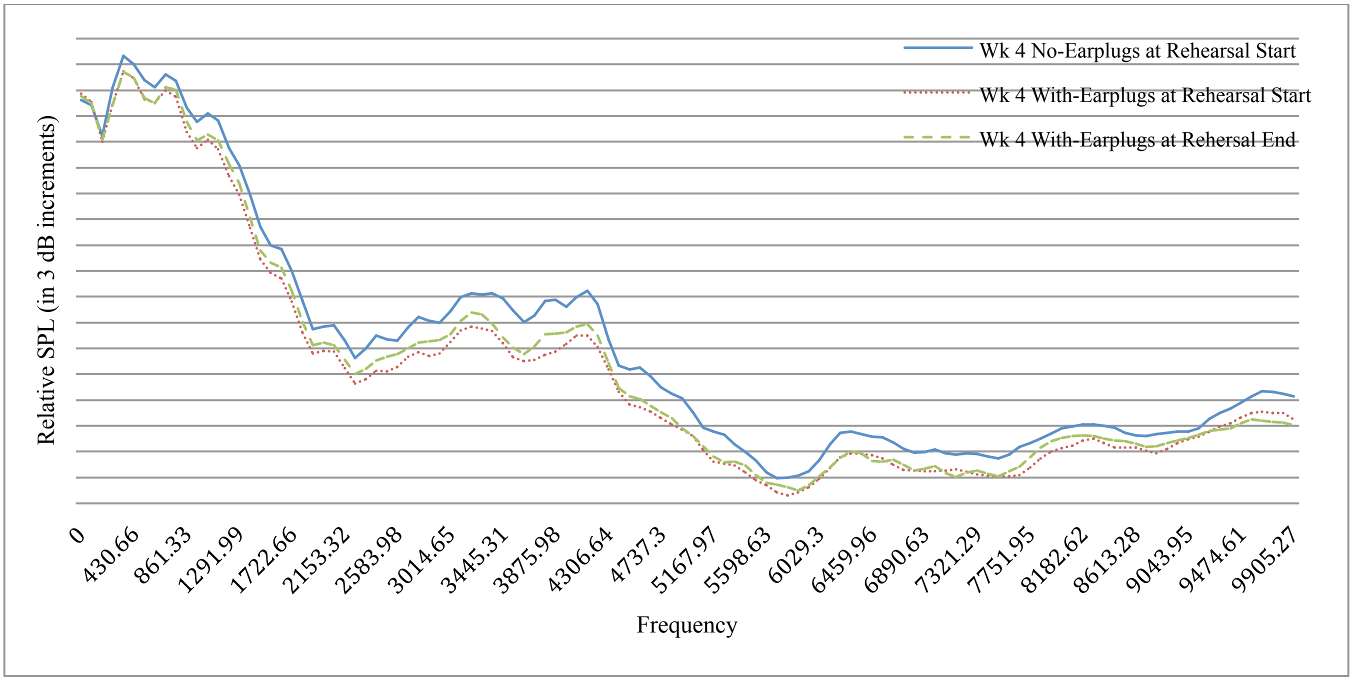

Figure J-15. Week four Group B: LTAS contours in the 0 – 10 kHz region of performances under three conditions; no-earplugs at rehearsal start, with-earplugs at rehearsal start and with-earplugs at rehearsal end.

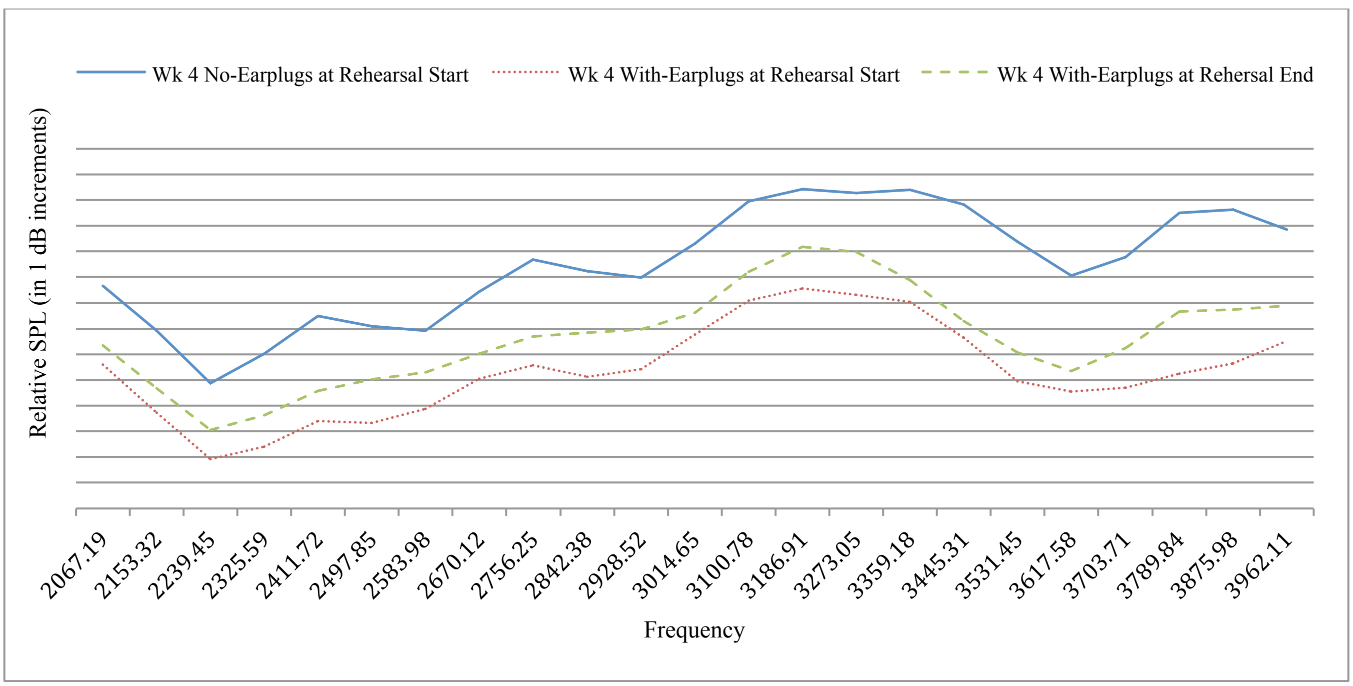

Figure J-16. Week four Group B: LTAS contours in the 2 – 4 kHz region of performances under 3 conditions, no-earplugs at rehearsal start, with-earplugs at rehearsal start and with-earplugs at rehearsal end.

Appendix K

Choral Pitch Analyses for Weeks One – Four

Table K-1. *Deviation in cents from Scored Pitch for Group A and Group B, Week 1.*

Scored Pitch	A♭$_4$			F$_4$			C$_4$		
	No-Earplugs at Rehearsal Start	With-Earplugs at Rehearsal Start	With-Earplugs at Rehearsal End	No-Earplugs at Rehearsal Start	With-Earplugs at Rehearsal Start	With-Earplugs at Rehearsal End	No-Earplugs at Rehearsal Start	With-Earplugs at Rehearsal Start	With-Earplugs at Rehearsal End
Group A	-16.77	-16.77	U/A	-19.96	-24.98	U/A	-47.07	-33.49	U/A
Group B	-29.45	-25.21	U/A	-35.08	-40.15	U/A	-20.01	-53.89	U/A

Table K-2. *Deviation in cents from Scored Pitch for Group A and Group B, Week 2.*

Scored Pitch	A♭$_4$			F$_4$			C$_4$		
	No-Earplugs at Rehearsal Start	With-Earplugs at Rehearsal Start	With-Earplugs at Rehearsal End	No-Earplugs at Rehearsal Start	With-Earplugs at Rehearsal Start	With-Earplugs at Rehearsal End	No-Earplugs at Rehearsal Start	With-Earplugs at Rehearsal Start	With-Earplugs at Rehearsal End
Group A	-16.77	-29.45	-16.77	-35.08	-24.98	-19.96	-33.49	-33.49	-26.74
Group B	-8.36	-20.99	-12.56	-14.95	-19.96	-19.96	-40.26	-26.74	-26.74

Table K-3. *Deviation in cents from Scored Pitch for Group A and Group B, Week 3.*

Scored Pitch	A♭$_4$			F$_4$			C$_4$		
	No-Earplugs at Rehearsal Start	With-Earplugs at Rehearsal Start	With-Earplugs at Rehearsal End	No-Earplugs at Rehearsal Start	With-Earplugs at Rehearsal Start	With-Earplugs at Rehearsal End	No-Earplugs at Rehearsal Start	With-Earplugs at Rehearsal Start	With-Earplugs at Rehearsal End
Group A	-8.36	8.32	24.85	-14.95	9.89	9.89	-13.32	-6.65	-26.74
Group B	-12.56	-12.56	8.32	-24.89	-14.95	9.89	-53.89	-47.07	-26.74

Table K-4. *Deviation in cents from Scored Pitch for Group A and Group B, Week 4.*

Scored Pitch	$A\flat_4$			F_4			C_4		
	No-Earplugs at Rehearsal Start	With-Earplugs at Rehearsal Start	With-Earplugs at Rehearsal End	No-Earplugs at Rehearsal Start	With-Earplugs at Rehearsal Start	With-Earplugs at Rehearsal End	No-Earplugs at Rehearsal Start	With-Earplugs at Rehearsal Start	With-Earplugs at Rehearsal End
Group A	-12.56	-16.77	-12.56	-8.32	-14.95	-8.32	-20.01	-20.01	-26.74
Group B	-12.56	-16.77	-8.36	-19.96	-14.95	-9.95	-13.32	-33.49	-47.07

Appendix L

LTAS Solo Charts from Weeks One - Four

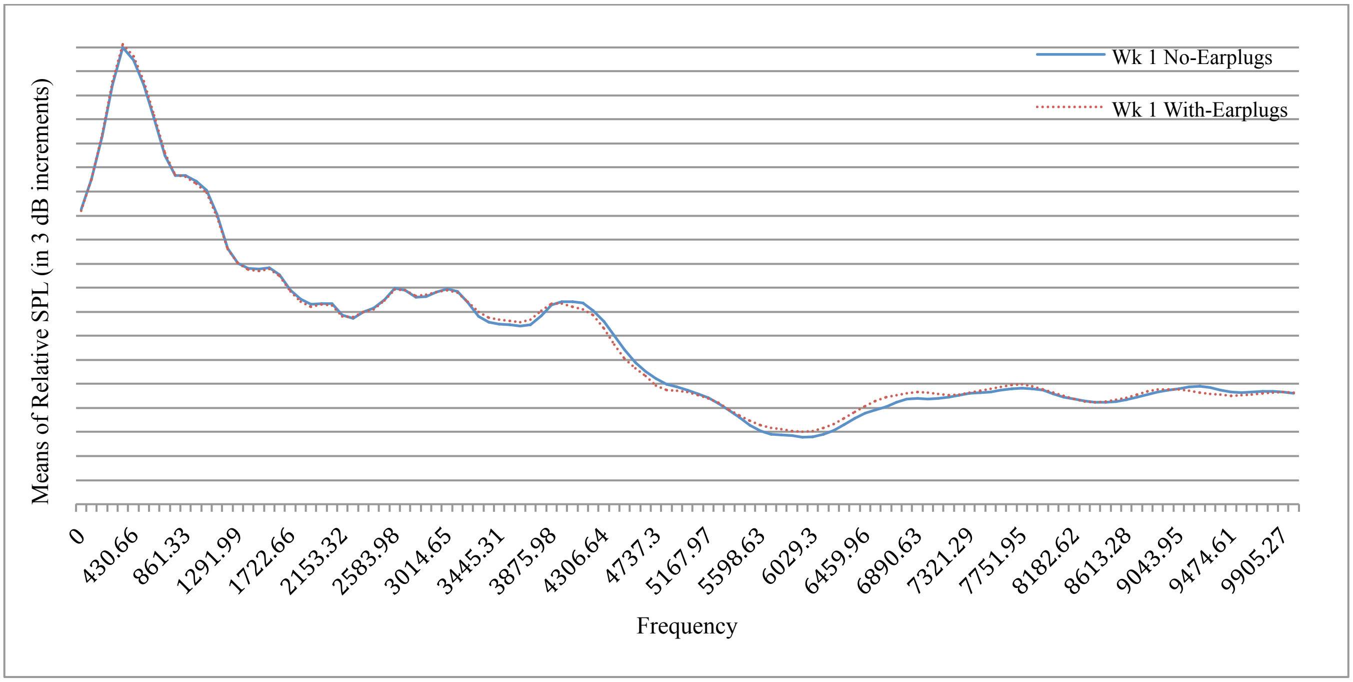

Figure L-1. Week one Group A: LTAS contours of performances in the 0 – 10 kHz region of mean solo performances under two conditions, no-earplugs and with-earplugs.

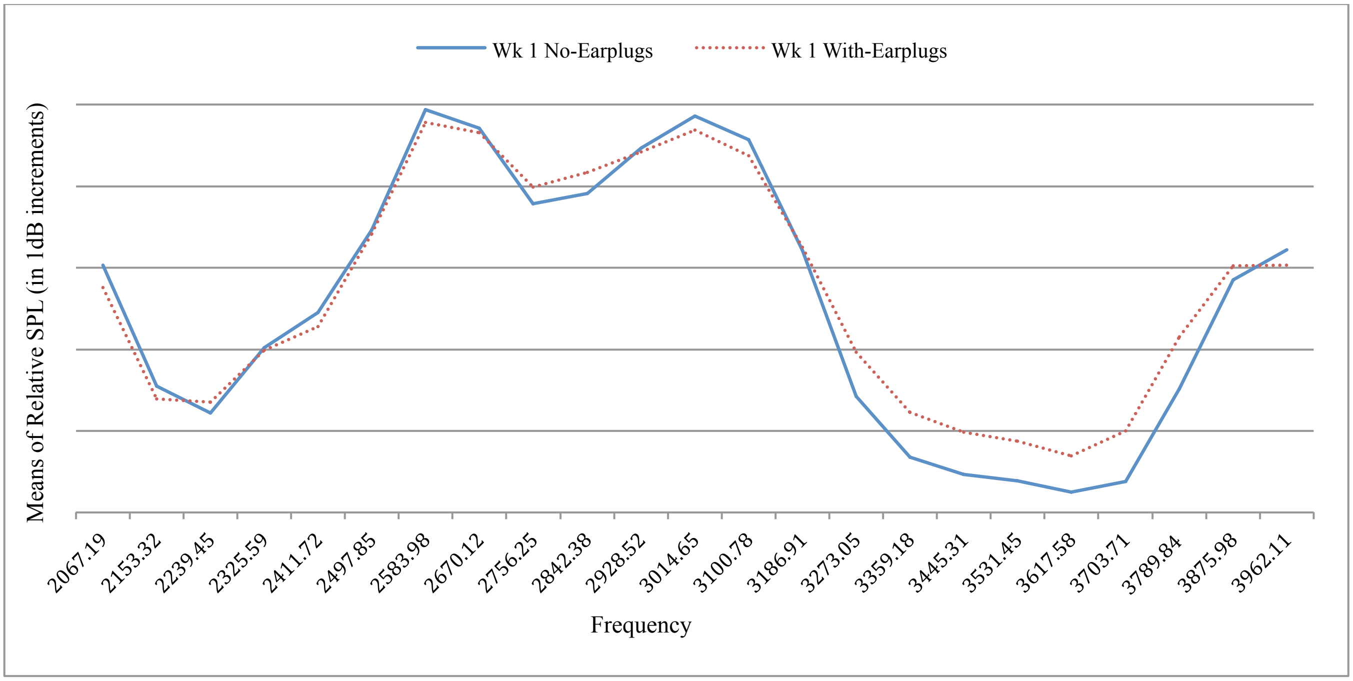

Figure L-2. Week one Group A: LTAS contours in the 2 – 4 kHz region of mean solo performances under two conditions, no-earplugs and with-earplugs.

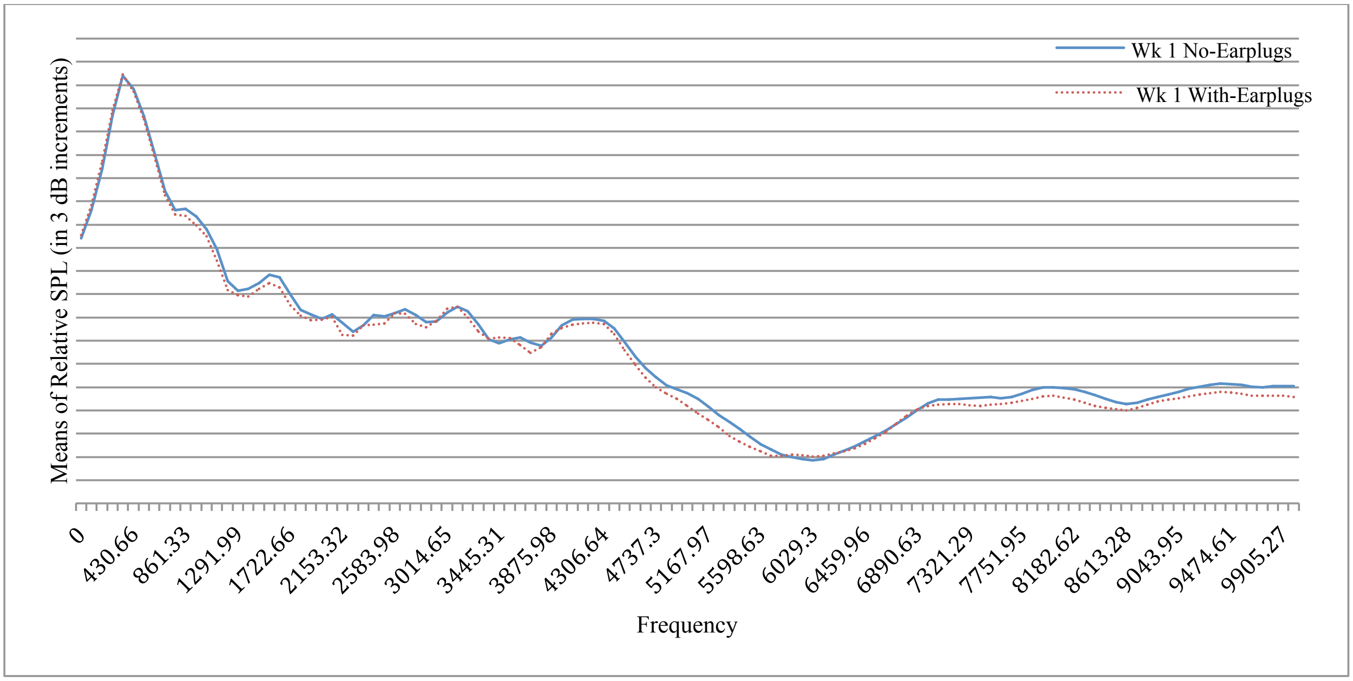

Figure L-3. Week one Group B: LTAS contours of performances in the 0 – 10 kHz region of mean solo performances under two conditions, no-earplugs and with-earplugs.

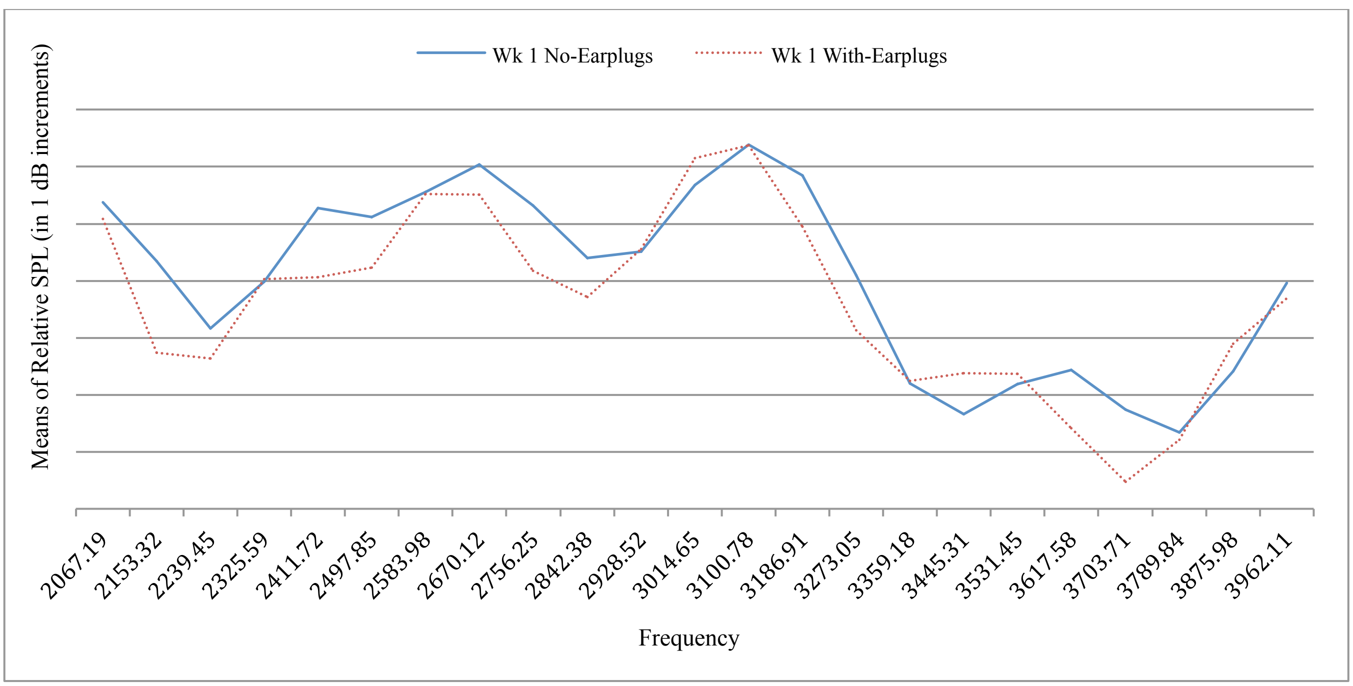

Figure L-4. Week one Group B: LTAS contours in the 2 – 4 kHz region of mean solo performances under two conditions, no-earplugs and with-earplugs.

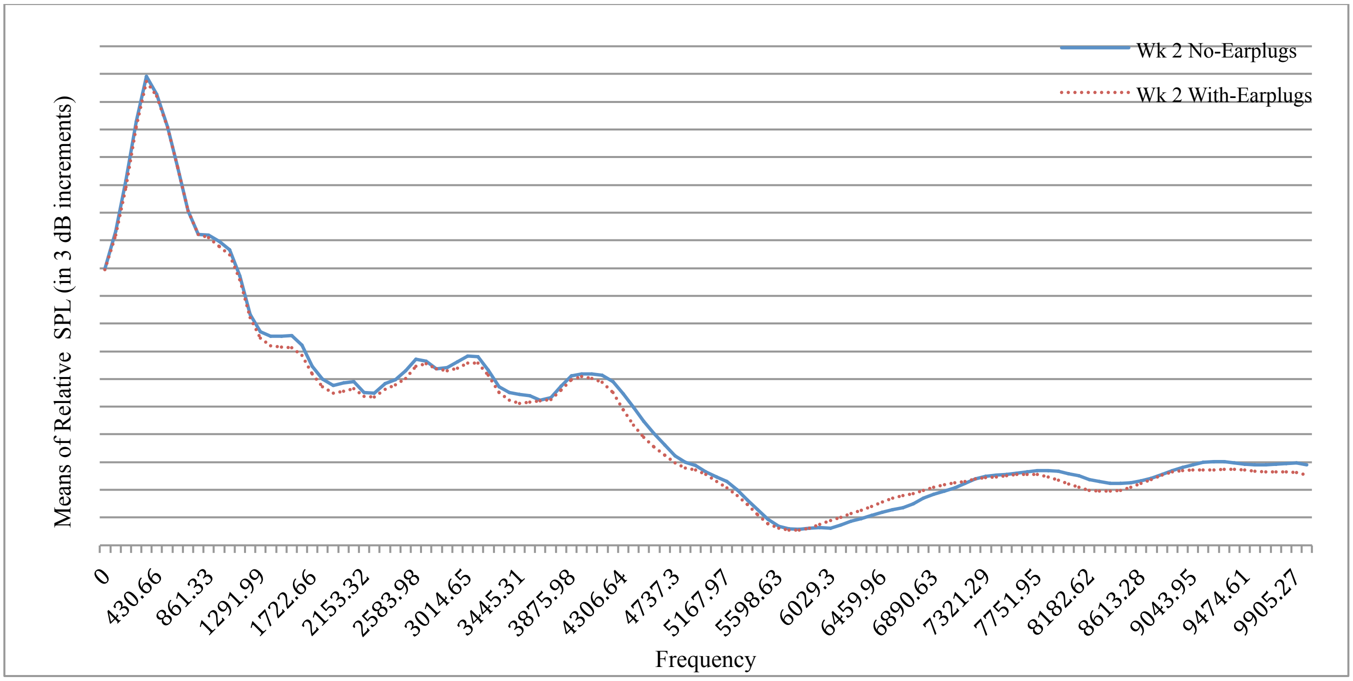

Figure L-5. Week two Group A: LTAS contours in the 0 - 10 kHz region of mean solo performances under two conditions, no-earplugs and with-earplugs.

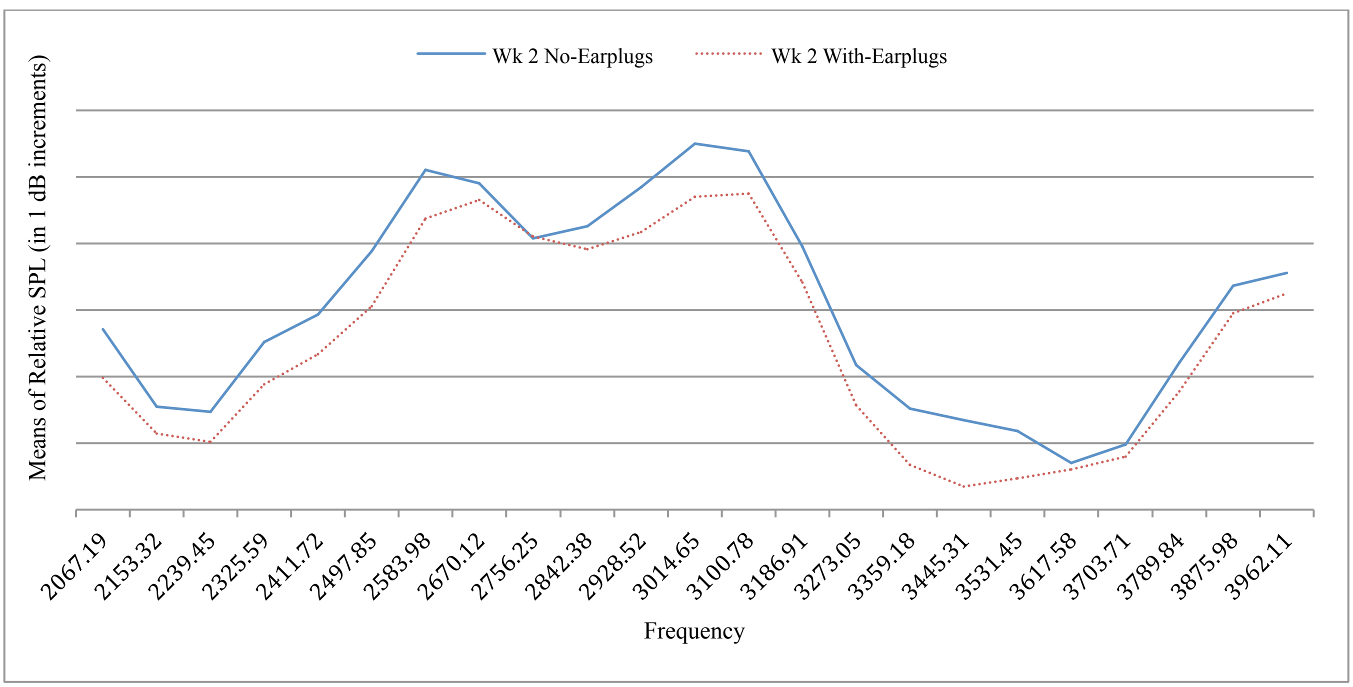

Figure L-6. Week two Group A: LTAS contours in the 2 – 4 kHz region of mean solo performances under two conditions, no-earplugs and with-earplugs.

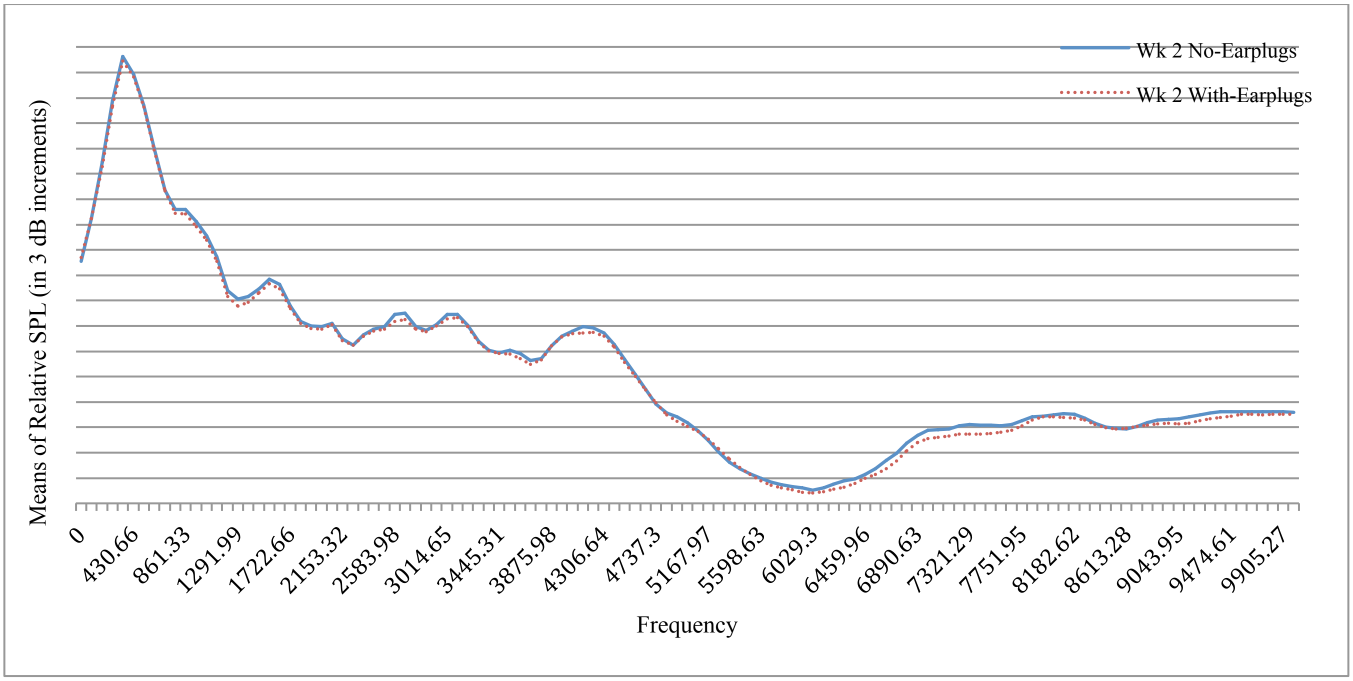

Figure L-7. Week two Group B: LTAS contours in the 0 – 10 kHz region of mean solo performances under two conditions, no-earplugs and with-earplugs.

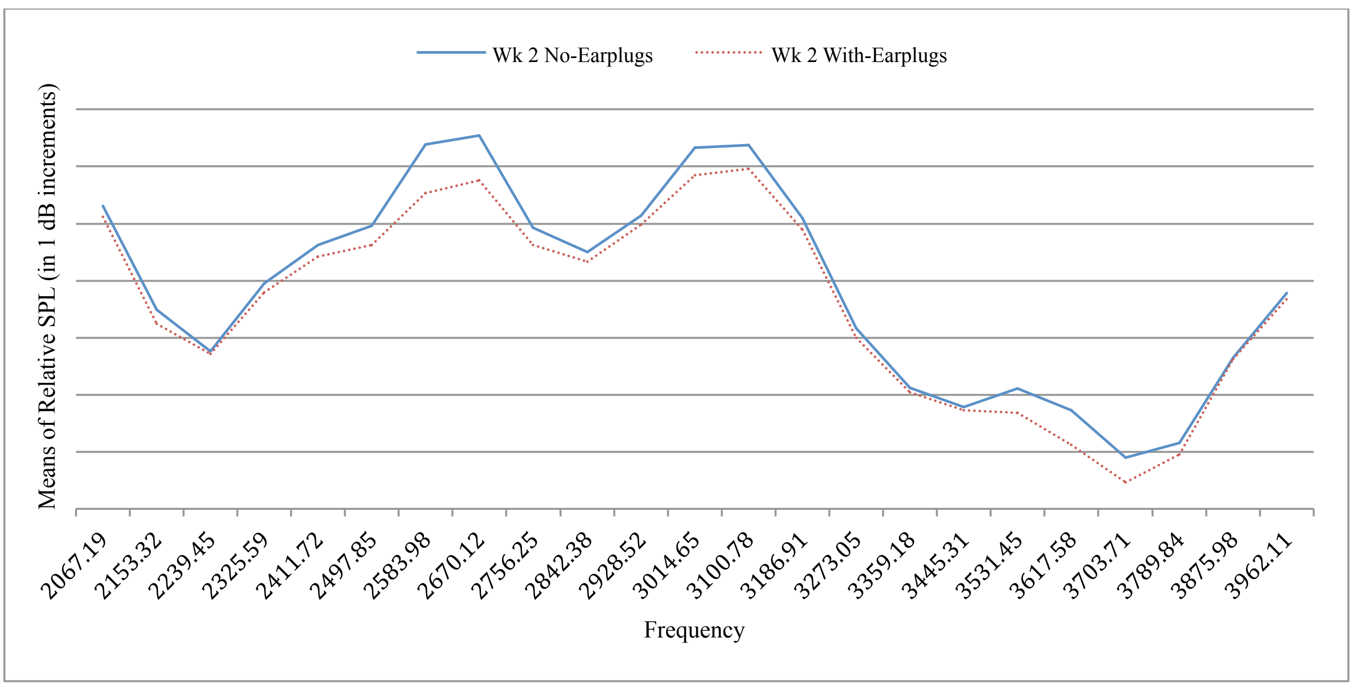

Figure L-8. Week two Group B: LTAS contours in the 2 – 4 kHz region of mean solo performances under two conditions, no-earplugs and with-earplugs.

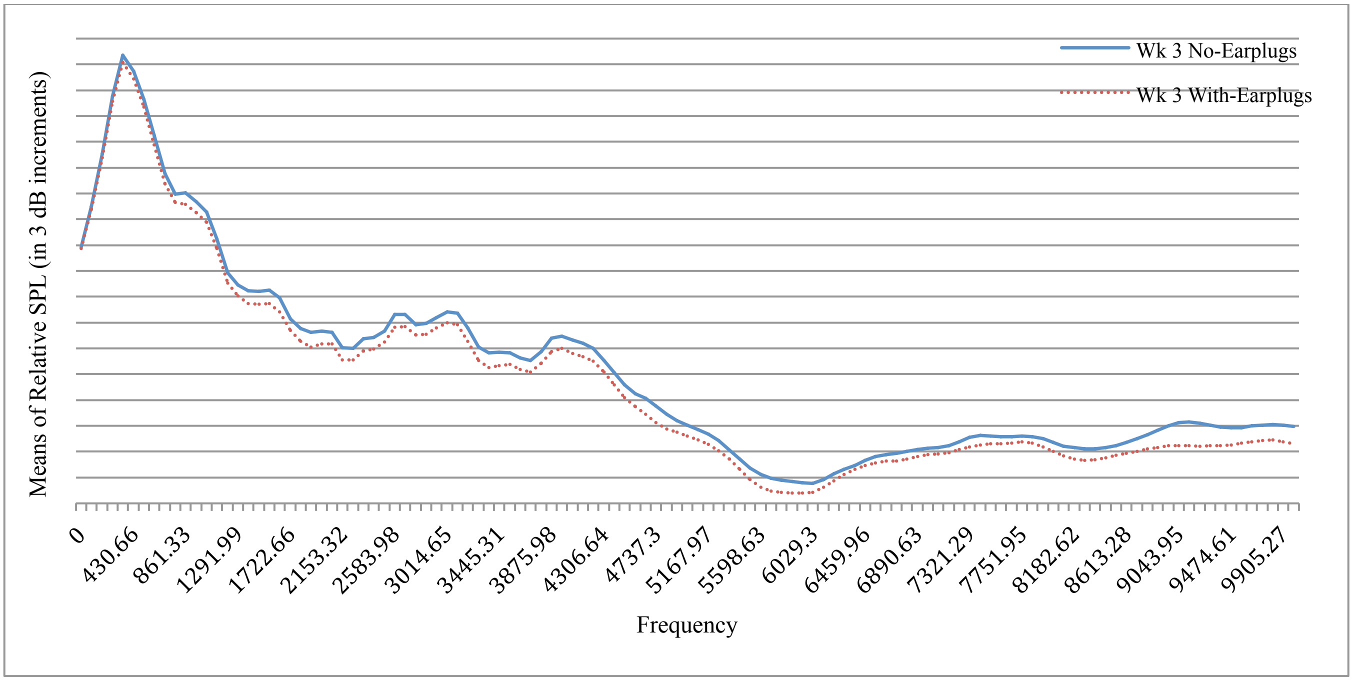

Figure L-9. Week three Group A: LTAS contours in the 0 – 10 kHz region of mean solo performances under two conditions, no-earplugs and with-earplugs.

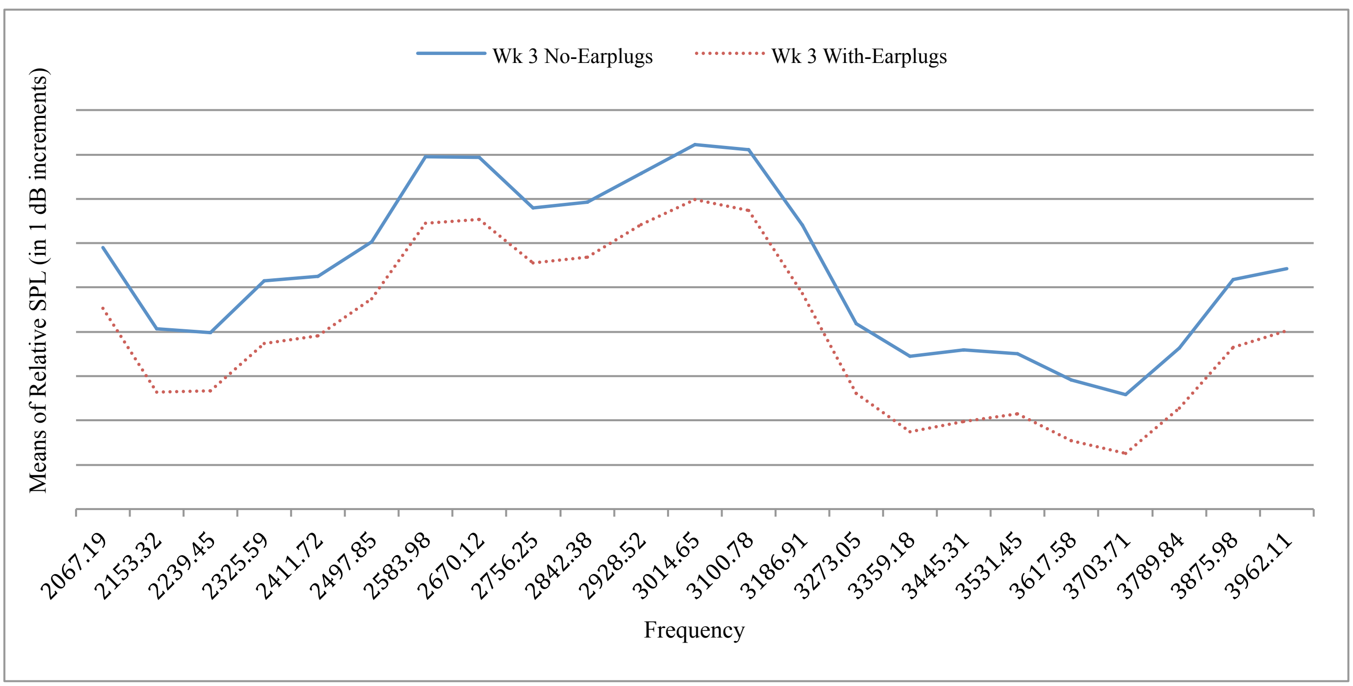

Figure L-10. Week three Group A: LTAS contours in the 2 – 4 kHz region of mean solo performances under two conditions, no-earplugs and with-earplugs.

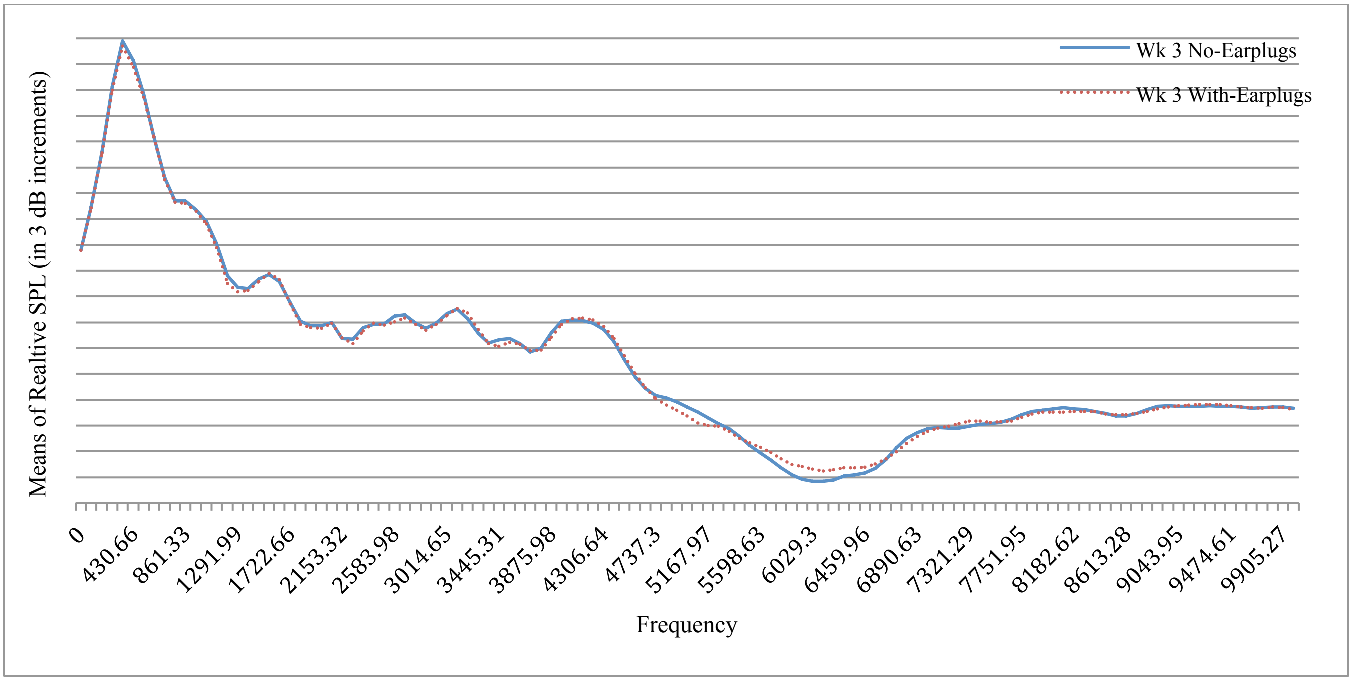

Figure L-11. Week three Group B: LTAS contours in the 0 – 10 kHz region of mean solo performances under two conditions, no-earplugs and with-earplugs.

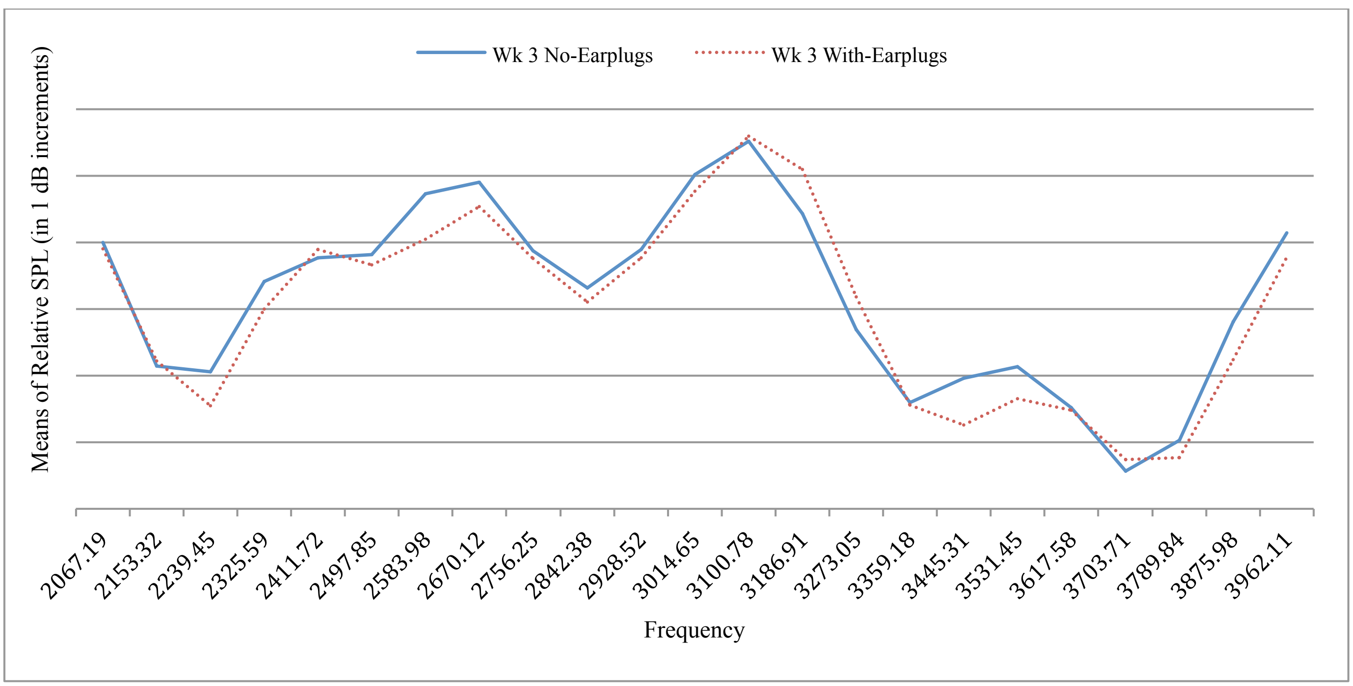

Figure L-12. Week three Group B: LTAS contours in the 2 – 4 kHz region of mean solo performances under two conditions, no-earplugs and with-earplugs.

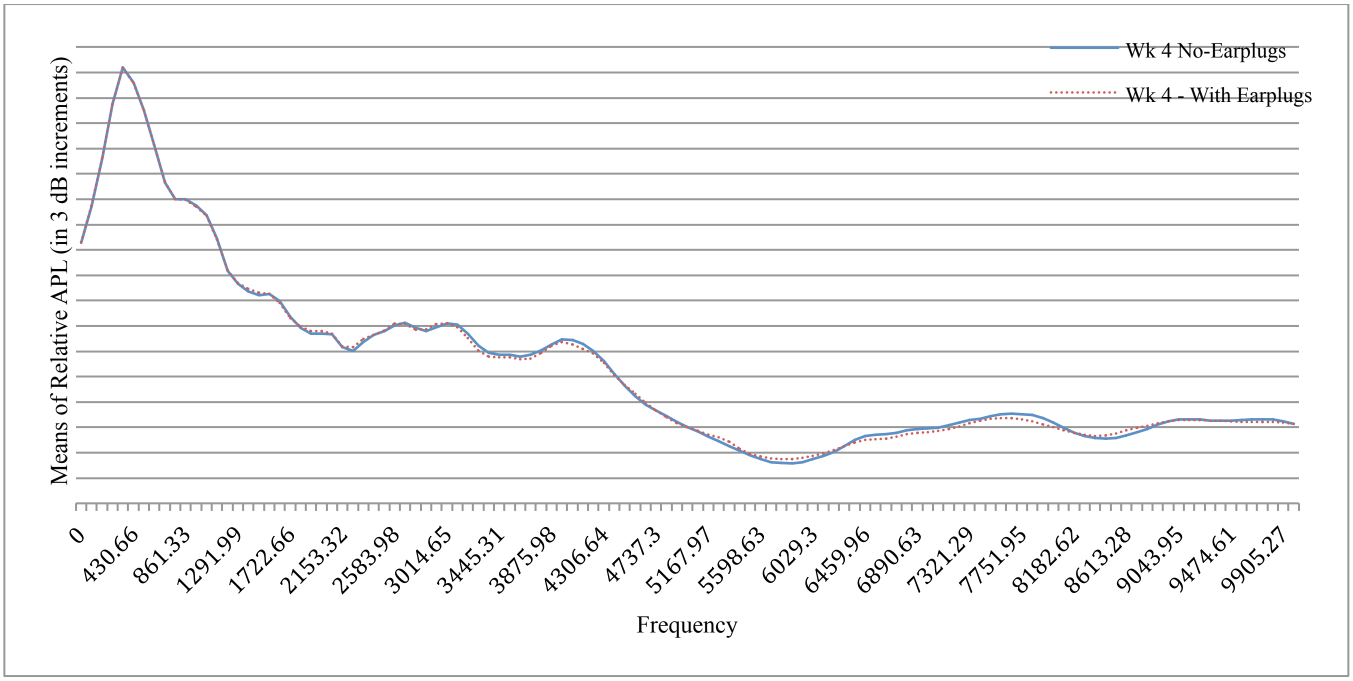

Figure L-13. Week four Group A: LTAS contours in the 0 – 10 kHz region of mean solo performances under two conditions, no-earplugs and with-earplugs.

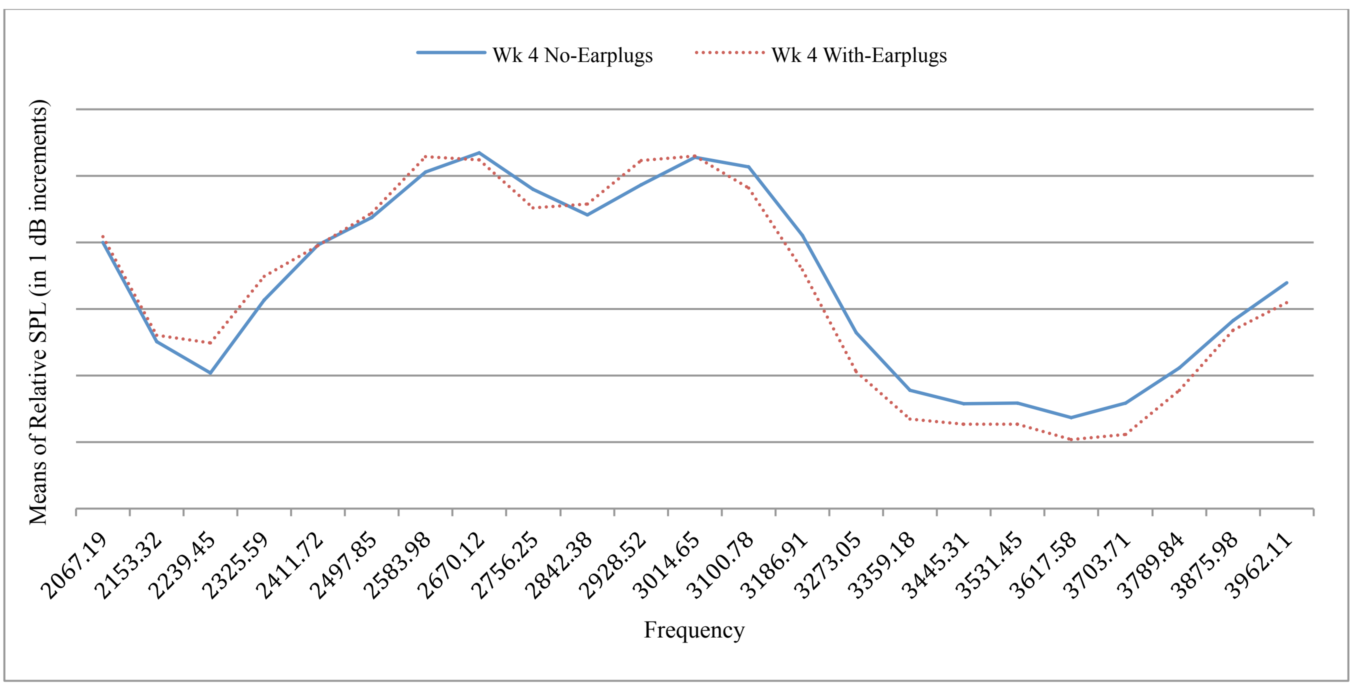

Figure L-14. Week four Group A: LTAS contours in the 2 – 4 kHz region of mean solo performances under two conditions, no-earplugs and with-earplugs.

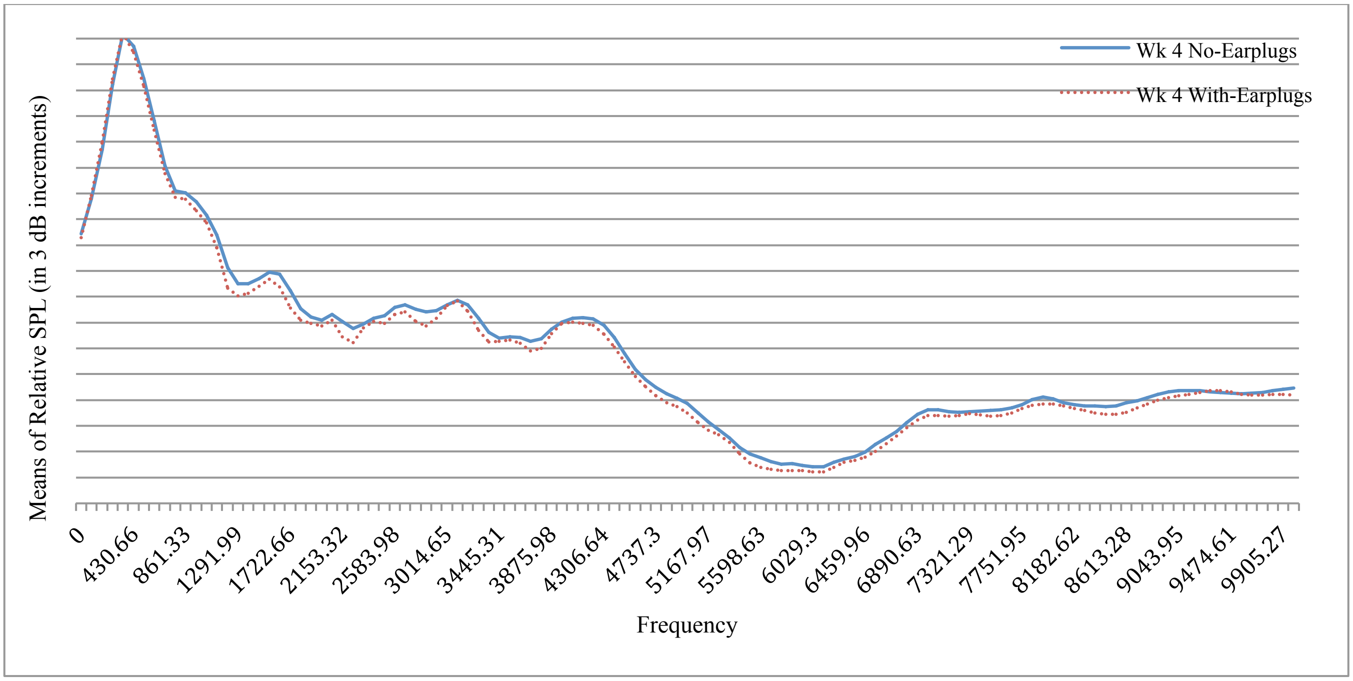

Figure L-15. Week four Group B: LTAS contours in the 0 – 10 kHz region of mean solo performances under two conditions, no-earplugs and with-earplugs.

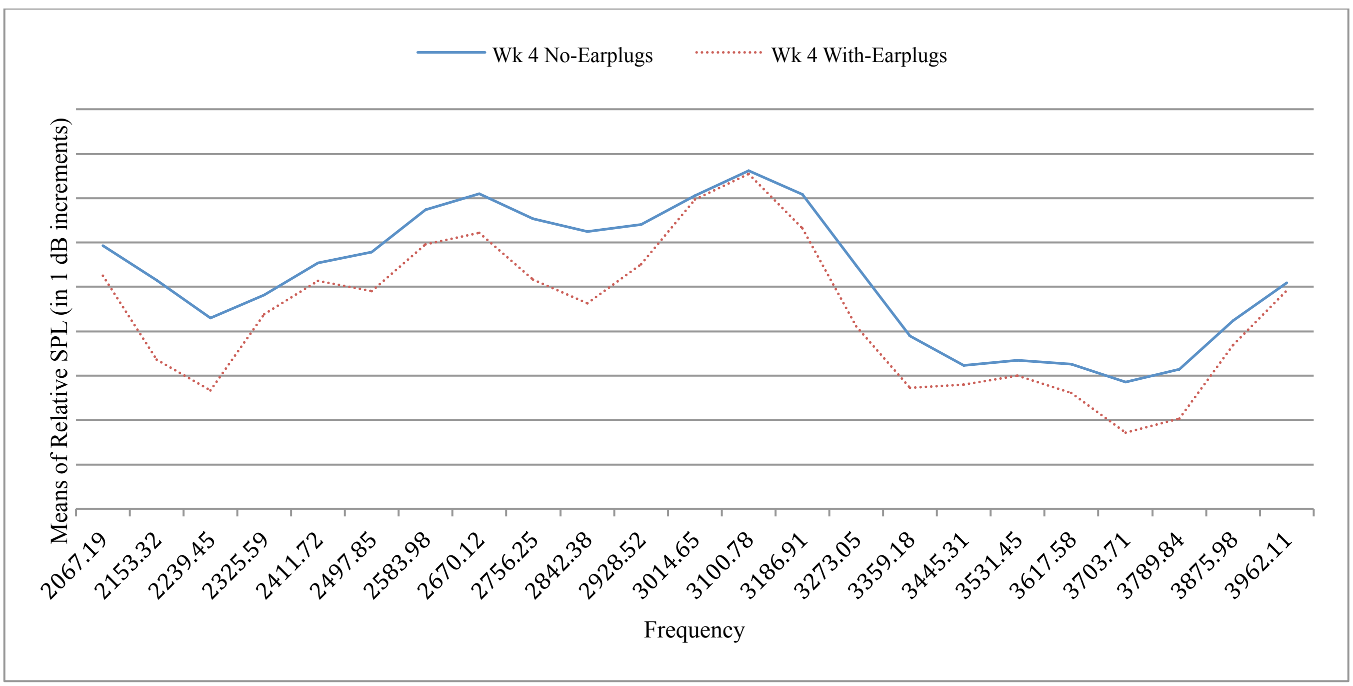

Figure L-16. Week four Group B: LTAS contours in the 2 – 4 kHz region of mean solo performances under two conditions, no-earplugs and with-earplugs.

Appendix M

Solo Fundamental Frequency Analyses

Table M-1. *Group A Soloists, Week One: Deviation from Notated Pitch in Cents*

Soloist	C_4-No-Earplugs	C_4 With-Earplugs	G_4-No-Earplugs	G_4-With Earplugs
A1	55	99	-37	84
A2	-35	-4	-50	33
A3	3	-60	-47	-65
A4	-23	-33	-5	-5
A5	127	9	-30	9
A6	-49	9	5	31
A7	50	26	59	61
A8	-8	15	36	63
A9	13	47	53	-26
A10	1	17	11	80
A11	25	17	-10	48

Table M-2. *Group B Soloists, Week One: Deviation from Notated Pitch in Cents*

Soloist	C_4-No-Earplugs	C_4 With-Earplugs	G_4-No-Earplugs	G_4-With Earplugs
B1	25	17	-10	48
B2	15	-2	15	-39
B3	16	32	-24	34
B4	-76	15	-73	37
B5	15	97	15	51

Table M-3. *Group A Soloists, Week Two: Deviation from Notated Pitch in Cents*

Soloist	C_4-No-Earplugs	C_4 With-Earplugs	G_4-No-Earplugs	G_4-With Earplugs
A1	-19	45	-55	-93
A2	-15	-6	-16	26
A3	-27	-5	-75	-39
A4	10	19	-11	16
A5	60	32	35	51
A6	-10	-47	37	2
A7	13	34	42	7
A8	-11	27	67	53
A9	59	-88	130	-30
A10	-9	14	24	10
A11	19	8	-109	-6

Table M-4. *Group B Soloists, Week Two: Deviation from Notated Pitch in Cents*

Soloist	C_4-No-Earplugs	C_4 With-Earplugs	G_4-No-Earplugs	G_4-With Earplugs
B1	9	14	-4	32
B2	11	24	-89	-47
B3	49	-9	71	77
B4	18	5*	-30	-31
B5	20	12	-1	20

Table M-5. *Group A Soloists, Week Three: Deviation from Notated Pitch in Cents*

Soloist	C_4-No-Earplugs	C_4 With-Earplugs	G_4-No-Earplugs	G_4-With Earplugs
A1	17	-19	88	50
A2	37	-38	-31	20
A3	-17	-15	-37	-12
A4	17	5	40	46
A5	21	29	18	12
A6	-21	-4	47	10
A7	16	51	33	30
A8	11	17	19	58
A9	114	-55	76	60
A10	48	-8	32	-21
A11	28	12	5	10

Table M-6. *Group B Soloists, Week Three: Deviation from Notated Pitch in Cents*

Soloist	C_4-No-Earplugs	C_4 With-Earplugs	G_4-No-Earplugs	G_4-With Earplugs
B1	-17	1	-31	54
B2	-4	-6	-44	3
B3	-7	-24	77	34
B4	-2	2*	8	-38
B5	1	46	6	85

Table M-7. *Group A Soloists, Week Four: Deviation from Notated Pitch in Cents*

Soloist	C_4-No-Earplugs	C_4 With-Earplugs	G_4-No-Earplugs	G_4-With Earplugs
A1	21	15	-40	31
A2	12	-81	21	-28
A3	-56	-62	-79	-94
A4	U/A	U/A	U/A	U/A
A5	11	30	26	-5
A6	-2	-27	0	-4
A7	-6	53	12	29
A8	-23	11	23	81
A9	-5	15	63	58
A10	-13	16	55	41
A11	-6	1	-17	30

Note: U/A indicates corrupted recording data

Table M-8. *Group B Soloists, Week Four: Deviation from Notated Pitch in Cents*

Soloist	C_4-No-Earplugs	C_4 With-Earplugs	G_4-No-Earplugs	G_4-With Earplugs
B1	17	54	34	-71
B2	40	14	-54	-39
B3	6	76	19	5
B4	7	55	-98	-61
B5	12	40	0	51