5-2019

Prevalence of High-Frequency Notched Audiometric Configurations Among University Music Students and Faculty

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PREVALENCE OF HIGH-FREQUENCY NOTCHED AUDIOMETRIC CONFIGURATIONS AMONG UNIVERSITY MUSIC STUDENTS AND FACULTY

A Capstone Research Project Submitted in Partial Fulfillment
of the Requirements for the Degree of
Doctor of Audiology

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May 2019

This Capstone Project by: Chandra Maas

Entitled: *Prevalence of High-frequency Notched Audiometric Configurations Among University Music Students and Faculty*

has been approved as meeting the requirement for the Degree of Doctor of Audiology in College of Natural and Health Sciences in the Department of Audiology and Speech-Language Sciences.

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ABSTRACT

Maas, Chandra. *Prevalence of high-frequency notched audiograms among university music students and faculty*. Unpublished Doctor of Audiology capstone, University of Northern Colorado, 2019.

The present study determines the prevalence of audiometric notched configurations suggestive of noise-induced hearing loss (NIHL) among students and faculty at the University of Northern Colorado (UNC) School of Music. The prevalence of NIHL was determined by analyzing the results of 233 hearing evaluations that were administered during Fall semester music student orientation. High-frequency notches were characterized by evaluating the hearing thresholds at 3, 4, or 6 kHz being 10 dB or worse than the thresholds at 2 and 8 kHz, as defined by Wilson and McArdle, (2013). The prevalence of high-frequency audiometric notches was examined in terms of notch depth, notch frequency, and ear symmetry and how such prevalence varied as a function of sex and instrument type. Results indicated that an overall occurrence of notched high-frequency hearing loss was 56.7% (n = 132). Unilateral notches (65.9%) were more common than bilateral notches (34.1%), and notches occurred most frequently at 6 kHz amongst males. Vocalists (22.7%, n = 30) and woodwind instrument musicians (20.5%, n = 27) had the highest prevalence of notches. This study supports the need to implement a comprehensive hearing loss prevention program at the UNC School of Music and supports the continued provision of hi-fidelity hearing protection to incoming freshman students.

ACKNOWLEDGMENTS

To my amazing family and friends – this would not have been possible without your encouragement, belief in me, and undying support. Thank you from the bottom of my heart.

To my professors and research committee – thank you for encouraging me and challenging me throughout this journey.

Most of all, to my son, Greysen – in the struggles and trials throughout this achievement you have been my consistent source of joy. Thank you for your patience, your love, always making me smile, and for being my number one fan. I love you Grey.

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LIST OF ABBREVIATIONS

Abbreviation	
dB	Decibel
dB HL	Decibel hearing level
dB SPL	Decibel sound pressure level
DPOAE	Distortion product otoacoustic emissions
HCP	Hearing conservation program
HPD	Hearing protection device
Hz	Hertz
kHz	Kilohertz
NIHL	Noise-Induced hearing loss
OAE	Otoacoustic emissions
PEL	Permissible exposure level
PTS	Permanent threshold shift
REL	Recommended exposure level
TEOAE	Transient evoked otoacoustic emissions
TWA	Time weighted average

CHAPTER I

INTRODUCTION

Music students are at risk of noise-induced hearing loss (NIHL). The continuous exposure to sound pressure levels (SPLs) that exceed the known recommended daily amount contribute to NIHL (National Institute for Occupational Safety and Health (NIOSH), 1998). College music students and faculty are exposed to sound levels that range from 80 dBA to 104.5 dBA during individual and group rehearsal and performances (O’Brien, Driscoll, & Ackermann, 2013; Schmidt et al., 2011). These SPLs are generated by instruments, singers, and attendance at other musical-related activities. Orchestra performance peak SPLs are known to exceed 100 dBA; however, the musician’s instrument type and location during the performance may influence exposures related to the SPL that the instruments generate (Emmerich, Rudel, & Richter, 2008). Barlow (2010) reported mean SPLs of 98 dBA during rehearsal, recordings, and extracurricular activities.

The Prevalence of Noise-Induced Hearing Loss among Musicians

Noise-induced hearing loss is evident in musicians. Phillips, Henrich, and Mace, (2010) found that 45% (n = 148) of student musicians had audiometric notches of 15 dB or greater at 4 or 6 kHz, which was indicative of NIHL. In a study investigating symphony orchestra musicians, 52% (n = 128) had audiometric notches, which were defined as having a 10 dB difference in 3, 4, or 6 kHz when compared to 2 or 8 kHz (Jansen, Helleman, & Dreschler, 2009). The length of time spent as a musician has been linked to the decrease of hearing status. Emmerich et al. (2008) found that hearing status and otoacoustic emission amplitudes of orchestral musicians decreased with a function of age.

Noise-induced hearing loss is a permanent etiology and often occurs in conjunction with other auditory issues such as tinnitus, hyperacusis, diplacusis, and distortion. Tinnitus, the perception of sound when no outside sound equivalent is present, has been found to affect between 30-50% of the general population and 51% of musicians (Chasin, 2006; Jansen et al., 2009). Hyperacusis, the increased sensitivity to loud sounds, has been found to be prevalent among individuals with NIHL, and it has been a reported issue in 79% of musicians (Jansen et al., 2009). Noise-induced hearing loss and other auditory issues are known to affect an individual's ability to communicate, quality of life, and job performance (NIOSH, 2015).

Opportunities for Intervention

Hearing conservation programs (HCPs) can be adopted to provide education on hearing loss and hearing conservation strategies. Hearing conservation programs have been implemented among musicians. O'Brien, Driscoll, and Ackermann (2015) investigated the success, difficulties, and practical viability of an HCP in an Australian orchestra. The program incorporated multiple strategies for prevention of hearing loss including: (a) to maintain an ongoing noise exposure monitoring program, (b) to regularly review data and plot noise maps, (c) to supply the highest quality musician HPDs, (d) to implement engineering and administrative controls, (e) to form a noise committee, and (f) to continue hearing education for musicians. Difficulties included: (a) scheduling annual hearing education sessions, (b) implementing effective engineering controls due to inadequate financial funding, and (c) consistently using HPDs among musicians. Although practical and financial barriers were evident in this HCP, the approach has successfully become integrated into the orchestra.

The gold standard for diagnosing NIHL is pure tone audiometric results that include a notched configuration, which is a decline in hearing sensitivity at 3, 4, and 6 kHz when compared to 2 and 8 kHz (Wilson & McArdle, 2013). Table 1 includes various notched audiogram criteria. Baseline hearing thresholds and routine hearing tests should be administered to monitor hearing thresholds in musicians. This can provide information on hearing status and monitor thresholds for shifts in hearing sensitivity (Wilson & McArdle, 2013).

Table 1

Summary of Noise Notch Definitions Used in Research Studies of NIHL

Author(s)	Notch Definition
Agrawal, Platz, & Niparko (2008)	A high frequency pure tone average at 3, 4, and 6 kHz of 25 dB HL or more.
Bauch (1981); Chung (1980); Loch (1943)	A 15 dBHL decline in hearing sensitivity at both an octave above and below the hearing loss.
Coles, Lutman, & Buffin (2000)	A decline in hearing sensitivity of at least 10 dB at 3, 4, or 6 kHz when compared to those at 1 or 2 kHz and 6 or 8 kHz
Hsu, Wu, Chang, Lee, & Hsu (2013); Wilson & McArdle (2013);	The difference between threshold at the notch frequency (3 kHz, 4 kHz, or 6 kHz) and the threshold at 2 and 8 kHz are both greater than or equal to 10 dBHL.
Lees, Lees, Roberts, & Wald (1985)	A 10 dBHL or greater “notch” at 6 kHz.
McBride & Williams (2001)	Narrow or V-shaped notch: • Only one frequency in the depth of the notch and the depth is at least 15 dB. Wide or U-shaped notch: • More than one frequency in the depth of the notch, depth of 20 dB, thresholds better by at least 10 dB at the high frequency end.”
Niskar, Kieszak, Esteban, Rubin, Holmes, & Brody. (2001)	In at least one ear: • Hearing sensitivity at 500 and 1 kHz that are greater than or equal to 15 dBHL, and • The worst hearing threshold at 3, 4, or 6 kHz that are 15 dBHL or poorer than the worst threshold at 500 and 1 kHz, and • The hearing threshold at 8 kHz that are 10 dB HL or better than the poorest threshold value for 3, 4, or 6 kHz.
Phillips, Henrich & Mace (2010)	A 5 dBHL or more difference when comparing the thresholds at 3, 4, or 6 kHz to 2 and 8 kHz.
Phillips, Shoemaker, Mace, & Hodges (2008)	A decreased hearing threshold of at least 10 dBHL between 1000, 2000, or 3000 Hz when compared to 4000 Hz, or from 1000, 2000, 3000, or 4000, Hz to 6000 Hz, with at lobreast a 5 dBHL recovery at 8000 Hz.

The National Association of Schools of Music is responsible for the accreditation of the University of Northern Colorado School of Music. As part of this program, the accreditation recognizes the importance of hearing and promotes hearing health. Per the National Association of School of Music Handbook (2016), music majors, music faculty, and staff are to be provided information on hearing health and safety.

Study Rationale

Music students may be exposed to hazardous sound levels while studying, performing, and enjoying music. Monitoring their hearing provides an opportunity for early identification and intervention for NIHL. In 2016, the Audiology Program at UNC offered complimentary hearing testing and hearing protection to students and faculty in the School of Music for the first time. These tests may serve as baseline hearing tests for monitoring changes in hearing over time. This study was designed to describe the hearing status and the prevalence of audiometric notches in student musicians and faculty at UNC on baseline hearing tests.

Research Questions

Q1 What is the prevalence of high-frequency notched audiometric configurations, and how can notches be characterized in terms of depth, frequency, and ear asymmetry in university music students and faculty?

Q2 What is the prevalence of high-frequency notched audiometric configurations among students enrolled in the University of Northern Colorado School of Music on baseline hearing tests, and how does prevalence vary as a function of sex and instrument category?

CHAPTER II

REVIEW OF THE LITERATURE

Introduction

Noise-induced hearing loss (NIHL) is known to be the most common occupational "disease" and is the second most common self-reported illness or injury among workers in the United States. Research from the National Institute for Occupational Safety and Health (NIOSH) estimated that approximately 30 million Americans are at risk for hearing loss due to excessive exposure to noise levels on the job that exceed the recommended daily allowance (NIOSH, 1998). Some of these workers are musicians. For professional or student musicians, the sound source "music" is not considered noise. However, in the context of this manuscript, hearing loss from exposure to high-level music will be referred to as NIHL.

Audiometry

A hearing threshold is defined as the softest level a pure tone is identified at least 50% of the time. Test procedures for obtaining auditory thresholds should adhere to the standards of the American National Standard S3.21-2004 (ANSI-2004). This is a revision from the standard of American National Standard ANSI S3.21-1978. Jewelry and eyeglasses should be removed from the patient to ensure accurate placement of testing equipment and thorough instructions should be given. Earphones should be placed centered over the ear. The test tone should be presented for 3 seconds in duration, and the interval between tones should exceed the duration that the tone was presented. Varied presentations should be administered to avoid patient prediction. The American Speech-Language Hearing Association (ASHA) and NIOSH (1998) recommend obtaining hearing thresholds for 250, 500, 1k, 2k, 3k, 4k, 6k, and 8 kHz (ASHA, 2005). Occupational Safety and Health Administration (OSHA) (1983) requires 500, 1k, 2k, 3k, 4k, 6k, and 8 kHz to be tested and monitored. If it is known, the better ear should be tested first, and 1 kHz should be the first frequency that is measured, followed by the higher frequencies. After 2k through 6 kHz thresholds are established, 1 kHz should be rechecked to determine reliability. If there is a difference of more than 5 dB at 1 kHz, the lower threshold should be recorded, and at least one additional threshold should be rechecked for reliability. After a response to a tone, the presentation level should decrease by 10 dB. If a tone yields no response, it should increase by 5 dB until a response occurs at least 50% of the time.

Computerized audiometers establish threshold in the same way as described above using a programmed algorithm to guide stimulus presentations based upon listener responses. An advantage to computerized audiometry is that thresholds can be collected from several subjects at once. Large numbers of employees are tested during occupational hearing conservation programs using this technique. Another benefit of computer audiometry is the option to give instruction in several languages. In a study, Picard, Ilecki, & Baxter (1987) considered the reliability and validity of computerized audiometry by comparing the pure tone results among pediatric and geriatric groups to those gathered by a trained examiner. Researchers found computerized audiometry to be a reliable and valid means of assessing hearing sensitivity (Picard et al., 1987). Convey et al. (2013) measured the test reliability and validity of computerized audiometry among adults and found a strong correlation at all frequencies when compared to manual audiometry, which indicates that computerized audiometry is effective in obtaining audiometric hearing thresholds.

Test Environment

Audiometric testing should be administered in a sound-treated space to yield accurate hearing thresholds, especially for normal-hearing ears. Permissible ambient noise levels are specified by ANSI S3.1 (1999). Ambient noise levels are determined using a sound level meter that meets the requirements of ANSI 1999. Due to the difficulty in having a soundproof space for occupational audiometric monitoring, OSHA and other government agencies have specified more lenient sound pressure levels for test environments outside of the clinical setting. Audiometric testing should be conducted in a room that does not exceed the requirements listed in Table 2, depending on the clinical or regulatory circumstances. Audiometric equipment should be properly calibrated to ensure accurate results. Daily functional checks and annual exhaustive calibrations are standard practice.

Table 2

Maximum Acceptable/Permissible Sound Pressure Levels for Audiometric Test Rooms Assuming a Test Frequency Range of 500 to 8000 Hz

Supra-aural and Insert		Supra-aural Earphones ANSI S3.1-1999 (reaffirmed by ANSI, October 2008). If 250 Hz is included in the test frequency range, noise levels at 125 and 250 Hz should be 10 dB lower.	
Octave band center frequency (Hz)	OSHA (1983)	For 0 dB HL testing	For -10 dB HL testing
125		49	39
250		35	25
500	40	21	11
1000	40	26	16
2000	47	34	24
4000	57	37	27
8000	62	37	27

Note. Adapted from American National Standards Institute, Acoustic Society of America. (1999). ANSI/ASA S31-1999. (R 2008). *Maximum Permissible Ambient Noise Levels for Audiometric Test Rooms.* New York: American National Standards Society; Occupational Safety and Health Administration. (1983). 29 CFR 1910.95 OSHA. Occupational Noise Exposure; Hearing Conservation Amendment; Final Rule, effective 8 March 1983. *Federal Register*.48:9738-9785.

Audiogram

Hearing thresholds are recorded on a graph referred to as an audiogram. The horizontal axis of the audiogram represents frequency and ranges from 125 to 8000 Hz. The vertical axis of the audiogram represents intensity and ranges from -10 to 110-120 dBHL. Air conduction and bone conduction results for both ears are recorded on the audiogram. Air conduction tests the function of the outer ear, middle ear, and inner ear. Bone conduction testing bypasses the outer ear and middle ear and directly stimulates the inner ear.

Type, configuration, laterality, and symmetry of hearing status are recorded on an audiogram. In this context, a hearing loss can be classified as a conductive, sensorineural, or mixed. A conductive hearing loss is caused by pathologies in the middle and outer ear and can be temporary or permanent. A sensorineural hearing loss is caused by abnormalities in the inner ear or retrocochlear neural structures. Furthermore, sensorineural hearing loss can further be characterized by sensory or neural, respectively, when using additional diagnostic tests such as otoacoustic emissions. A mixed hearing loss is one that exhibits both conductive and sensorineural components.

The pattern of hearing loss can be found within the audiometric configuration. A “flat” audiometric configuration is a hearing loss that is of the same degree across all frequencies. A “sloping” audiogram is a hearing status that is best in low frequencies, then depicts poorer hearing sensitivity as the test frequency increases. An audiogram with a “rising” configuration is a hearing loss that is the poorest in the low frequencies, and improvements in hearing sensitivity are evident as the test frequencies increase. In “notched” configuration audiograms, hearing thresholds are poorest in a narrow test frequency region and better than that on the lower and upper side of the notch frequencies, which can occur at any frequency region. A “cookie-bite” configuration is a hearing loss that, when compared to the high and low frequencies, is poorest in the middle frequencies. A “reverse cookie bite” is a hearing loss that is best at the middle frequencies and poorer for the higher and lower frequencies.

The laterality of a hearing loss describes a hearing loss that is present in one ear or both ears. A hearing loss in only one ear is termed a unilateral hearing loss. A hearing loss in both ears is considered a bilateral loss. Hearing loss symmetry is also determined from the audiogram. A hearing loss can be symmetric, or the same in both ears, or asymmetric, or different in each ear. Classification of asymmetric hearing loss varies internationally (Rawool, 2012). The American Academy of Otolaryngology-Head and Neck Surgery (AAO-HNS) require a physician referral for asymmetric hearing losses, or an air-conduction pure tone average at 500, 1, 2, and 3 kHz that is 15 dB or more different between ears (AAO-HNS, 1994). Table 3 summarizes a criterion that has been used in various studies to classify asymmetric hearing loss.

Table 3

Summary of Asymmetric Audiogram Criteria

Source	Asymmetric Audiogram Criteria
Issam, Geneviève, & Miguel (2009)	15 dB or greater difference between ears at 1 or more frequencies or at least 15% difference in speech recognition scores
Leskowitz, Caruana, Siedlecki, Qian, Spitzer, & Lalwani (2016)	10 dB or greater difference at any two frequencies
Margolis & George (2008)	10 dB or greater difference between each ear at 1, 2, 4, and 8 kHz
Masaaki, Hashimoto, Shingeyuki, & Takuji (2010)	Greater than 15 dB HL difference at any frequency between ears
Vannson, James, Fraysse, Strelnikov, & Barone (2015)	15 dBHL difference in pure tone averages (500, 1-, 2-, and 4 kHz) between ears

Noise Induced Hearing Loss

Noise induced hearing loss is sensorineural, typically bilateral, and can be caused by prolonged exposure to high intensity stimulus or by a single traumatic impulse

(Kirchner et al., 2012). A "notched" audiogram in the high frequencies of 3000, 4000, or 6000 Hz with a recovery at 8000 Hz is an early indication of NIHL (McBride & Williams, 2001). Another early sign of NIHL is a better average hearing threshold of 500, 1000, and 2000 Hz when compared to the average of 3000, 4000, and 6000 Hz (Coles, Lutman, & Buffin, 2000). Intensity level and duration of the stimulus are factors that affect the amount of NIHL (Kirchner et al., 2012).

Notched Audiometric Configuration

Exposure to high-level noise causes the early damage at 4 kHz and often results in a notch at 3 kHz or 6 kHz (Coles et al., 2000). Several theories are in place regarding why the auditory damage is initially in this region of the cochlea including (a) reduced blood supply, or hypoxia, to the hair cells associated with 3 to 6 kHz; (b) a greater susceptibility to noise damage for the hair cells at this region; (c) damage due to the continual hydro-mechanical action of the stapes on the cochlea; and (d) the theory that NIHL does the most damage at one-half octave above the peak frequency of the noise spectrum. Any, or all, of these theories may explain why NIHL causes an audiometric notch (Bohne & Harding, 2000).

Several researchers (Gates, Schmid, Kujawa, Nam, & D'Agostino, 1999; McBride & Williams, 2001; Osei-Lah & Yeoh, 2010; Phillips et al., 2010) have concluded that unilateral high-frequency notches are more common than bilateral high-frequency notches. Notches are typically more severe in the left ear as compared to the right ear (McBride & Williams, 2001; Phillips, Shoemaker, Mace, & Hodges, 2008; Wilson, 2011). Additionally, audiometric notches are typically down-slopping with gradually worse thresholds in higher frequencies (Coles et al, 2000). Audiometric notches among musicians are primarily at 6000 Hz (Emmerich et al., 2008; Jansen et al., 2009), whereas audiometric notches among industrial workers has been observed primarily at 4000 Hz (McBride & Williams, 2001; Landen, Wilkins, Stephenson, & McWilliams, 2004). Table 2 provided a summary of noise-notch definitions used for research purposes as an indicator of NIHL. It is important to recognize that a comparison of studies reporting the prevalence of NIHL amongst noise exposed individuals may be confounded by the differences in notch criteria.

Permissible Noise Exposures

Along with the intensity, the duration of the time spent listening is known to contribute to the auditory damage associated with NIHL. Sound level and exposure time varies between musicians due to time spent practicing and performing. Typically, noise measurements and legislation are based on an A-weighted filter. Alternatively, a C-weighted filter, which specifically limits for noise exposure due to impulsive noise, is used by European regulations (Health and Safety Executive, 2005).

Since hazardous noise exposures are associated with NIHL, governmental agencies have established recommended guidelines and legal requirements to protect workers. The National Institute for Safety and Health (NIOSH) is the agency that is responsible for the research that guides occupational safety recommendations to U.S. governmental regulatory agencies. The NIOSH *Criteria for a Recommended Standard: Occupational Noise Exposure* (1998) is a “best practices” document and states that the recommended exposure levels (REL) should not exceed 85 dBA averaged over an 8-hour time period. The NIOSH estimates that the risk for workers developing NIHL over a 40-year timeframe is 8% when referencing an 85 dBA TWA and would increase to 25% for

90 dBA TWA exposures (NIOSH, 1998). The NIOSH guidelines are more conservative and measure noise exposure using a 3 dB exchange rate as opposed to the 5 dB exchange rate used by OSHA.

The Occupational Safety and Health Administration is the regulatory agency that is tasked with ensuring safety of U.S. workers. The Occupational Safety and Health Administration regulations set the legal requirements for employers to follow. The OSHA (1983) defined the permissible exposure level (PEL) as 90 dBA for an 8-hour time weighted average (TWA) period. For every 5 dB increase or decrease of exposure, the PEL is halved or doubled, respectively. Thus, if the sound pressure level is 95, 100 or 105 dB, the allowable time for each level is 4, 2, and 1 hours, respectively. The action level (85 dBA TWA) is the level at which the implementation of a hearing conservation program is required (OSHA, 1983). The Occupational Safety and Health Administration regulations cover general manufacturing and service industries in the U.S.

Specific regulations for sound exposure of musicians are in place by OSHA. When an employee is exposed to 8-hour TWA noise levels for 85 dB or above, OSHA requires the use of personal hearing protection devices. Annual hearing evaluations are obtained, and threshold shifts are monitored. Employers must keep exposure measurement records for two years and maintain the audiometric test results for the duration of each individual's employment (OSHA, 1910.95).

The European Union includes regulations that are similar to the recommendations of NIOSH. The daily noise exposure level is 87 dBA, and the action level, or the level at which a hearing conservation program must be in place, is 85 dBA. The European Union also adheres to the 3 dB exchange rate. The Code of Conduct specifies that employers in the music and entertainment sectors must meet obligations in the safety requirements (European Union, 2003). In 2008, the United Kingdom also adapted these regulations under the Control of Noise at Work regulations (2005).

Sound Exposure Studies

Barlow (2010) investigated whether college study and leisurely activities exceed the recommended daily noise dose in 100 undergraduate music students between the ages of 18-64 years, per ISO 9612:2009 with a 3 dB exchange rate. One hundred undergraduate music students were surveyed using a 30-point questionnaire to inquire about academic and leisure time exposure to music. Sound exposure measurements were gathered from rehearsal, performance, and concerts using calibrated personal noise dosimeters. Participants were exposed, on average, to 12 hours per week of lectures, tutorials, and seminars which ranged from 45 to 65 dBA. The mean amount of unsupervised activities, such as rehearsals or recordings, was 11.5 hours per week and was self-reported as being “loud” in 34% (n = 34) of the participants. Time spent in recording or rehearsal studios had a mean duration of 2 hours, 13 minutes and a mean exposure of 98 dBA. Both study and leisurely activities regularly caused the majority of students to exceed the recommended daily noise dose at least on some occasions, and in some cases, by extremely high levels, leading to a high degree of hazard of developing NIHL as defined by both the UK (Health and Safety Executive, 2005), EK (European Union, 2003), and NIOSH (1998), in which regular exposure levels in excess of 85 dBA LEP_d are considered hazardous. In conclusion, Barlow recommended that the students in this study undergo noise exposure education, and education on the use of HPDs as per adherence to European laws and regulations on noise exposure (ISO 9612:2009).

In Germany, Emmerich et al. (2008) collected noise dosimetry data using an A-weighted filter and sound level meter (Type 118, Class 1; Norsonic, Lierskog, Norway) for professional musicians performing in rehearsal rooms, orchestra pits, orchestra positions, and from the conductor. Researchers observed peak SPL to exceed 100 dBA from the whole orchestra and 109 dBA in front of the piccolos. All dosimetry data (Table 4) exceeded the German law regulations of 85 dBA.

Table 4

Summarized Data for $L_{p, A, eqT}$, $L_{p, Cpeak}$ and $L_{EX, 8h}$ by Instrument Type

	$L_{p, A, eqT}$ dB (A)				$L_{p, Cpeak}$ dB (C)				$L_{EX, 8h}$ dB (A)				
Instrument	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Number of Measure-ments
Strings	78.9	89.7	85.4	3.40	101.2	129.4	120.7	5.35	75.05	84.2	79.7	2.93	78
Woodwinds	84.9	96.8	90.5	3.45	115.4	131.1	122.6	4.30	80.29	91.9	85.0	3.25	42
Brass	87.0	97.4	92.7	2.77	120.1	133.4	128.2	4.44	82.29	92.6	87.7	2.97	40
Percussion & timpani	85.9	95.4	90.0	2.93	128.8	135.0	131.44	2.15	81.24	87.0	84.3	2.42	24
Conductor	77.2	86.3	82.1	2.56	107.7	120.4	114.5	3.92	72.07	81.6	76.5	2.67	24

Note. SD = Standard deviation. Adapted from Rodrigues et al. (2014). "Evaluation of the Noise Exposure of Symphonic Orchestra Musicians," by M. A Rodrigues, M. A. Freitas, M. P. Neves, and M. V. Silva, 2014, *Noise and Health, 16*(68), p. 42.

Rodrigues, Freitas, Neves, and Silva (2014) investigated noise exposure levels of Portuguese symphonic orchestral musicians and the conductor. Sound levels were measured during group and general rehearsals using Quest NoisePro and CESVA DC112 dosimeters and CESVA SC-310 sound level meters, per International Organization for Standardization (ISO) 9612:2009 standards. Musicians were divided into five groups: strings (violin), woodwinds (bassoon, saxophone, flute, clarinet, oboe, recorder, and piccolo), brass (trombone, tuba, trumpet, and French horn), and percussion and timpani. As shown in Table 4, brass instrument musicians were exposed to the highest noise levels, and noise exposure levels decreased as distance from the brass section increased. Peak sound level was the highest in the percussion and timpani. This study demonstrated that instrument type and musician position affect the amount of noise exposure and is an important factor for noise characterization for musicians.

In another study measuring noise levels of specific instruments, Schmidt et al. (2014) conducted pure tone audiometry and administered questionnaires amongst professional musicians. Pure tone audiometry was collected for 212 participants, questionnaires were administered to 337 participants, and noise dosimetry data were collected from 182 musicians. This study used dosimetry data from a previously conducted study (Schmidt et al., 2011) to analyze sound exposure. When compared to the other musicians, trumpet players had the highest exposure levels at 92.7 dBA TWA in each ear. Table 5 summarizes the sound levels for various instruments as reported across research studies of musicians. It is apparent that all the instruments have the potential to present a hazard to hearing, depending on the proximity of the ear to the sound source and the length of exposure.

Table 5

Sound Levels Generated by Instrument Type

Source	Strings		Woodwinds		Brass		Percussion and timpani	
	$L_{p, A, eqT}$ dB (A)	$L_{p, Cpeak}$ dB (C)	$L_{p, A, eqT}$ dB (A)	$L_{p, Cpeak}$ dB (C)	$L_{p, A, eqT}$ dB (A)	$L_{p, Cpeak}$ dB (C)	$L_{p, A, eqT}$ dB (A)	$L_{p, Cpeak}$ dB (C)
Dudarewicz, Pawlaczyk-Łuszczyńska, Zamojska-Daniszawska, & Zaborowski. (2015)	Harp: 83.3 Viola: 84.7 Violin: 84.6	*Harp: 110.0-125.1 *Viola: 104.4-120.8 *Violin: 106.6-131.8	Clarinet: 87.6 Oboe: 88.1	*Clarinet: 104.7-126.6 *Oboe: 112.5-124.7	Flute: 87.8 Trombone: 90.1	*Flute: 106.8-133.5 *Trombone: 115.7-128.3	Percussion: 87.1	*Percussion 105.0-135.5
Emmerich, Rudel, & Richter (2008)	Violin: 89.9		Bassoon: 91.0 Clarinet: 90.6		Contrabass: 91.6 French Horn: 90.7 Piccolo: 92.1 Trombone: 90.0			
O'Brien, Driscoll, & Ackermann (2013)	Cello: 80 (L) 80 (R) Harp: 82 (L) 84 (R) Viola: 88 (L) 83 (R) Violin: 86 (L) 89 (R)	Cello: 106(L) 108(R) Double Bass: 108(L) 109(R) Harp: 113(L) 116(R) Violin: 114(L) 111(R)	Bass Clarinet: 92 (L, R) Bb Clarinet: 92 (L, R) Eb Clarinet: 96 (L) 94 (R) Bassoon: 87 (L) 89 (R) Contra Bassoon: 86 (L) 85 (R) Oboe: 85 (L, R)	Bass Clarinet: 112(L) 112(R) Bassoon: 108(L) 109(R) Clarinet 111(L) 111 (R) Flute: 115(L) 117(R) Oboe: 103(L) 103(R) Piccolo: 117(L) 115(R)	Bass Trombone: 96 (L) 96 (R) Double Bass: 75 (L) 75 (R) Flute: 93(L) 95 (R) Horn: 92 (L) 95 (R) Piccolo: 94 (L) 94 (R) Trombone: 96 (L) 96 (R) Trumpet: 96 (L) 95 (R) Tuba: 95(L) 92 (R)	Bass Trombone: 122 (L) 121 (R) Horn: 115(L) 117(R) Trombone: 120(L) 117(R) Tuba: 124(L) 121 (R)	Side Drum: 97 (L) 98 (R)	Side Drum: 132 (L) 133 (R)

Table 5 (continued)

Source	Strings		Woodwinds		Brass		Percussion and timpani	
	$L_{p, A, eqT}$ dB (A)	$L_{p, Cpeak}$ dB (C)	$L_{p, A, eqT}$ dB (A)	$L_{p, Cpeak}$ dB (C)	$L_{p, A, eqT}$ dB (A)	$L_{p, Cpeak}$ dB (C)	$L_{p, A, eqT}$ dB (A)	$L_{p, Cpeak}$ dB (C)
Rodrigues, Freitas, Neves, & Silva (2014)	85.4	120.7	90.5	122.6	92.7	128.2	90.0	131.44
Schmidt, Pedersen, Juhl, Christensen-Dalsgaard, Andersen, & Poulsen (2011)	Cello: 83.4 (L) 85.5 (R) Double Bass: 76.4 (L) 74.8 (R) First Violin: 89.8 (L) 84.5 (R) Second Violin: 91.6 (L) 86.3 (R) Viola: 94.2 (L) 86.7 (R)	Cello: 116 (L) 117.3(R) Double Bass 113.2 (L) 113.8 (R) First Violin: 121.1 (L) 114.4 (R) Second Violin: 121.1(L) 117.9(R) Viola: 123.8(L) 115.2(R)	Bassoon: 87.9 (L) 88.9(R) Flute: 92.1 (L) 99.5 (R) Piccolo: 97.8 (L) 104.5 (R)	Bassoon: 121.6 (L) 123.1(R) Celeste 128.3 (L) 126.2 (R) Clarinet: 122 (L) 120.9(R) Flute/Piccolo: 122.1 (L) 123.3 (R) Oboe: 120.7(L) 121.4(R)	Barok Trombone: 88.4 (L) 88.2 (R) Trombone 1: 91.1(L) 87.3(R) Trombone 2: 98.9(L) 96.2(R) Trumpet: 91.6 (L) 90.2 (R)	French Horn: 124.5 (L) 125.3(R) Trombone: 123.6(L) 122.1 (R) Tuba: 124.2 (L) 123.5(R) Trumpet: 125.5(L) 126.4(R)		Timpani: 132 (L) 132.1 (R)

Note. (L) indicates Left ear, (R) indicates Right ear; * indicates a range.

Tufts and Skoe (2018) examined noise dosimetry levels among music and non-music college students at the University of Connecticut and found that, collectively, musicians are exposed to more noise than non-musicians. All students (n = 62) were divided into either “musicians” (n = 22; 4 males, 18 females) or “non-musicians” (n = 40; 14 males, 26 females), as determined by completing a survey. Of the 22 musicians, 9 played woodwind instruments, 6 played brass instruments, 4 were vocalists, 2 played percussion instruments, 2 played piano, and 1 musician reported playing a string instrument. All participants wore a dosimeter to collect noise exposure data during all waking hours for one week. Additionally, participants were instructed to maintain a journal to describe activities for all waking hours. Researchers found that 74% (n = 16) of musicians in this study exceeded the maximum daily exposure levels recommended by NIOSH in 3 of the 7 days of the week. This was compared to 13% (n = 5) of non-musicians who were over exposed in 3 out of the 7 days of the week. Additionally, researchers found that 9% (n = 2) of musicians and 70% (n = 28) of non-musicians did not exceed the daily dose of noise exposure during the 7 days. In addition to musicians having higher noise exposure levels than non-musicians, researchers also found that the average noise exposure level range was higher among musicians (19.2 dBA) when compared to non-musicians (7.1 dBA).

Hearing Loss in Musicians

Phillips et al. (2010) performed a study designed to evaluate the prevalence of NIHL among college aged classical musicians. The researchers investigated 329 university music students, aged 18-32 years, by analyzing questionnaire responses and measuring pure tone hearing thresholds at 1, 2, 3, 4, 6, and 8 kHz using the Hughson-

Westlake procedure, with a GSI-17 audiometer (Milford, NH) in a sound-treated room that met ANSI (1999) standards for ambient noise. Forty-five percent (n = 148) of the students had audiometric notches of 15 dB or greater at 4 or 6 kHz relative to the preceded frequency and with a recovery of at least 5 dB at a higher frequency in at least one ear. Of the 148 students with NIHL, as defined in Table 2, 76% (n = 112) had notches at 6 kHz. Twenty-two percent (n = 25) of the 112 students with notches at 6 kHz had bilateral notches, and the remaining 78% (n = 32) were unilateral. There was an increased prevalence of 6 kHz notches in the left ear (63%, n = 55) when compared to the right ear (37%, n = 32). When considering 4 kHz, researchers found 22% (n = 32) of the students with hearing loss had notches at 4 kHz, 9% (n = 3) were bilateral, and 14.8% (n = 10) were unilateral. The other 2% (n = 4) of students with hearing loss had notches at 3 kHz.

Jansen et al. (2009) investigated the hearing status among 241 musicians from five symphony orchestras. Pure tone thresholds for 250, 500, 1, 2, 3, 4, 6, and 8 kHz were obtained using an Interacoustics AC40 audiometer and TDH 39 headphones. Forty-eight percent (n = 118) of the participants had thresholds within normal limits, or thresholds equal to or better than 15 dB HL in all frequencies. A moderate notch, as defined by Niskar et al. (2001) in Table 2, was found in 11% (n = 27) of musicians. Nine percent (n = 22) of musicians had a profound notch, which is defined the same as moderate notches, except exceeded 25 dB at 3, 4, and 6 kHz instead of 20. Researchers found a sloping loss, which is defined as a "maximum threshold level of 3, 4, 6 kHz at least 5 dB poorer than the pure tone average of thresholds at 0.5, 1 and 2 kHz and the threshold level at 8 kHz at least 5 dB poorer than the maximum threshold level at 3, 4, and 6 kHz" (Jansen et al., 2009, p. 157), in 13% (n = 32) of the musicians, and a flat loss, or an audiogram that either is not considered to be in any other listed category or has thresholds that exceed 30 dB HL in all frequencies, in 12% (n = 29) of musicians.

Dudarewicz, Pawlaczyk-Łuszczyńska, Zamojska-Daniszawska, and Zaborowski (2015) considered temporary threshold changes in hearing status among 18 philharmonic orchestra musicians, aged 30-58 years, after group rehearsals and measured sound exposure during group rehearsals. Pure tone thresholds were obtained for 1, 2, 3, 4, 6, and 8 kHz using Traveler Audio Audiometer type 222 (Interacoustics). Of the 18 musicians, 28% (n = 5) had notched audiograms, as defined in Table 1, at 4 kHz. Transient-evoked otoacoustic emissions (TEOAE), using a Scout otoacoustic emission system version, 3.45.00 (Bio-logic System Corp.) were obtained at 1, 1.5, 2, 3, and 4 kHz pre-and post-rehearsal. Researchers observed a decrease in TEOAE amplitudes at all tested frequencies. Group rehearsal C-weighted peak SPL and A-weighted TWA sound exposure levels using a Svantek analyzer type SVAN 958 (prod. Svantek, Poland) are detailed in Table 5.

Audiometric hearing status and otoacoustic emissions (OAE) amplitudes of orchestral musicians have been found to decrease with the length of time spent as a professional musician. Emmerich et al. (2008) performed a study to determine whether the audiologic status of professional musicians reflects the sound exposure in classical orchestral music. Researchers obtained pure tone audiometric thresholds, distortion product otoacoustic emissions (DPOAE's), questionnaire responses, and noise dosimetry data for two groups of musicians. One group included 110 participants aged 11-19 years and was comprised of attendees of an academy of music with daily formal music training.

Another group consisted of 109 professional musicians from three of the major German orchestras, aged 30-69 years. The professional musicians were further divided in four age groups: 30-39 years, 40-49 years, 50-59 years, and 60-69 years. Permanent threshold shifts (PTS) of at least 15 dBSPL were evident in over 50% (n = 54.5) of the professional musicians and were found predominantly at 6 kHz. In all three orchestras, the most prevalent PTS occurrences was amongst string instruments. The researchers found PTS to be evident among professional musicians aged 30-39 years and to become larger with increasing age. Additionally, the smallest OAE amplitudes were found among string instrument musicians age 50-59 years. Fifty percent of survey respondents reported tinnitus after "loud" performances, and 60% of violinists reported tinnitus in their left ears.

Noise Notch Studies

In a longitudinal study, Phillips et al. (2008) considered the noise notch prevalence among undergraduate students. As shown in Table 6, in the first year of data collection, 110 undergraduate music students were involved in the study. In the second year, 50 more students volunteered, and in the third year, 178 students volunteered for a total of 338 participants. Students were recruited from the student body after attending a mandatory presentation about the study. Table 6 summarizes the number of participants and years of enrollment for clarity. Questionnaires were administered to participants at the time of obtaining pure tone thresholds. In Years 1 and 2, participants were asked about which instruments were played and ensemble involvement. Additionally, *yes* or *no* answers were obtained from questions about history of ear pathologies, tinnitus occurrences, use of HPDs, and exposure to loud stimuli. In Year 3, participants were asked to expand on tinnitus (never, occasionally for a few seconds, after practice, or after other noise), exposure to loud stimuli (firearms, power tools, recreational vehicle, or loud stereo music), and family history of musical ability and of hearing loss (specific to which family members). Pure tone thresholds for 250 Hz to 8000 Hz were gathered using a GSI 17 audiometer (Mitford, NH) in a sound-treated room following Occupational Noise Exposure Revised Criteria (NIOSH, 1998). Audiometric evaluations were administered using a GS 17 audiometer (Grason-Stadler, Mitford, NH) in the morning in an attempt to avoid sound exposure for 12 hours prior to the testing. Adequacy of the ambient noise levels within the testing rooms were determined by using the Quest 1700 (Oconomowoc, WI) sound level meter and met OSHA allowable values for all test frequencies. As shown in Table 6, researchers observed a notched audiometric configuration at 6000 Hz in at least one ear in 54% (n = 59) of the participants, in Year 1. Of these 59 participants with notches, 3% (n = 2) of these were bilateral notches. In Year 2, 50% (n = 25) of the participants tested had a notch at 6000 Hz, and 14% (n = 7) at 4000 Hz. In Year 3, 6000 Hz notches were observed in 52% (n = 93) of the participants, and researchers observed 4 kHz notches in 30% (n = 53) of the participants. Repeat volunteers were scarce in this study, but in Year 2, researchers had gathered data on 25 participants from Year 1. Notches had been observed in 48% (n = 12) of these 25 participants, and in Year 2, notches from 24% (n = 6) participants had worsened by 10 to 20 dB. Of this 24% (n = 6) of participants, 3 of them also showed notches at 4000 Hz by Year 2. Additionally, 3 students who had normal hearing in Year 1 were observed to have notches in Year 2. In Year 3, 13 students were repeat volunteers, and thresholds from Year 2 were compared. Researchers found notches in 61.5% (n = 8) of these 13 students in Year 2.

Table 6

Number of Students by Instrument Type and Year

Instrument	Year 1 (n = 110)	Year 2 (n = 50)	Year 3 (n = 178)
Voice	25.4% (n = 28)	24% (n = 12)	25.3% (n = 45)
Percussion	1.1% (n=20)	18% (n=9)	14% (n=25)
Brass	21.8% (n=24)	22% (n=11)	24.7% (n=44)
Wind	17.2% (n=19)	24% (n=12)	20.3% (n=36)
Strings	15.4% (n=17)	12% (n=6)	15.7% (n=28)

Note. "Environmental Factors in Susceptibility to Noise-Induced Hearing Loss in Student Musicians," by S. L. Phillips, V. C. Henrich, and S. T. Mace, 2008, *International Journal of Audiology*, *49*(4), p. 22.

Table 7

Number of Participants Showing 6 kHz Notches by Depth, Ear, and Year

Notch Depth (dB)	Year 1 (n = 110)		Year 2 (n = 50)		Year 3 (n = 178)	
	R	L	R	L	R	L
10	11	8	2	3	15	18
15	16	11	7	8	19	14
20	10	4	3	2	16	9
25	1	2	3	2	7	4
30	2	3	0	1	5	2
35	2	0	0	0	2	2
40	0	0	0	0	0	0
Total	42	28	15	16	65	49

Note. Adapted from "Environmental Factors in Susceptibility to Noise-Induced Hearing Loss in Student Musicians," by S. L. Phillips, V. C. Henrich, and S. T. Mace, 2008, *International Journal of Audiology*, *49*(4), p.22.

When considering symmetry and notch prevalence, studies have similar findings. Wilson (2011) considered 4 kHz notched audiograms in a retrospective study among 3,430 veterans evaluated at the Audiology Clinic at the Veteran's Assistance Medical Center Mountain Home in Tennessee. Exclusion criteria, as determined by Wilson, eliminated 35 left ears and 46 right ears from the study, leaving 3,349 left ears and 3,384 right ears to be analyzed. A notch was determined to be present when the difference between the 4 kHz threshold and the thresholds at 2 and 8 kHz were both greater than or equal to 10 dB. The veterans were categorized by the following age groups: 20s, 30s, 40s, 50s, 60s, 70s 80s and 20s-80s. Notched audiograms were prevalent in at least one ear among 40.6% (n = 1378) of veterans, and 37.5% (n = 517) of those notches were bilateral. Wilson found left unilateral notches among 28.8% (n = 978) and right unilateral notches among 27.1% (n = 917) of the veterans. Notch depth was considered in this study. Of the 517 bilateral notched audiograms, deeper notches were found in the left ear when compared to the right ear, and the mean notch depth was 26.9 dB and 26.1 dB for the left and right ears, respectively.

Head Trauma

Some studies considered causes, other than noise, for the presence of audiometric notches. Head trauma has been identified as a possible contributing factor. Head injuries in felines can cause cochlear damage from 3 to 8 kHz (Schuknecht, Neff, & Perham, 1951; Schuknecht & Davidson, 1956). In a follow-up study, researchers found head injury in humans to be damaging in the same frequency range (3 kHz to 8 kHz) of the cochlea (Hagan & Cole, 1964).

Bauch (1981) investigated head trauma and audiometric notches among 27 patients, aged 24 to 80 years, who reported head trauma, but had no history of significant noise exposure. Head trauma was characterized by the following: 15 falls, 7 automobile accidents, and 5 being stuck by foreign objects. Out of the 27 patients, 22% (n = 6) had unilateral double notched sensorineural hearing loss (SNHL). Several of these approximated bilateral involvement, however they did not meet the specific bilateral criteria. Of these 6 patients, 5 of them exhibited low-frequency notes at 1 kHz and a high-frequency notch at 4 kHz. Single notched audiometric configurations between 3 kHz and 6 kHz were found in the remaining 21 patients. Bauch observed unilateral or bilateral notches at 1 kHz in 33% (n = 9) and unilateral or bilateral notches at 2 kHz in 44% (n = 12) of these patients. It was concluded that cochlear damage among the patients in this study could not have been caused by hazardous noise exposure and was related to head trauma. In addition, state of consciousness, site of injury, or severity of the impact to the head was not found to be indicative or have a direct correlation with a specific notch configuration (Bauch, 1981). To date, there have been no studies differentiating a history of head trauma and noise exposure in terms of the presence of notched audiometric configurations among musicians.

Need for Early Detection of Noise-Induced Hearing Loss in Music Students

Noise-induced hearing loss is an avoidable pathology. If hearing loss is identified in the early stages, there is an opportunity to implement hearing protective strategies. Such strategies include specialized hi-fidelity hearing protectors, environmental sound treatments, physical location changes, and scheduling changes to minimize over-exposure. The National Association of Schools of Music (NASM) is responsible for the accreditation of schools of music. The NASM and Performing Arts Medicine Association (PAMA) accreditation handbook recognizes the importance of hearing health promotion as part of the accreditation process. The handbook states that music majors, music faculty, and staff with employment status are to be provided with basic information about the maintenance of health and safety. Brochures and advisory papers are included on the website, but the use of them is listed as "completely voluntary" on the NASM-PAMA Advisories on Hearing Health portion of the website. The online "tool kit" includes basic informational packets to be incorporated in an in-person orientation.

The effectiveness of any hearing loss prevention program or individual efforts can be determined by monitoring the hearing of musicians over time. The University of Northern Colorado School of Music offered complimentary hearing tests and hi-fidelity hearing protectors to music students enrolled in the 2016-17 academic year and to faculty. This was the first time these services and products were offered. This study proposed to evaluate the audiometric data set obtained during the initial year of implementation.

CHAPTER III

METHODOLOGY

The current study was designed to describe the hearing status and prevalence of notched audiograms among students and faculty on baseline audiograms. These audiograms were conducted at the University of Northern Colorado.

Data Set

The de-identified data set accessed for this study included music students and professors of the School of Music at the University of Northern Colorado who voluntarily participated in baseline hearing testing. The data set contained air conduction hearing thresholds obtained at .5, 1, 2, 3, 4, 6, and 8 kHz bilaterally for each participant. Computerized hearing testing was conducted with a calibrated Benson CCA-200 audiometer, with TDH-39 supra-aural earphones as the transducer. The stimuli were pulsed pure tones. Thresholds were obtained while participants were enclosed in one of three Acoustic Systems (RE-120) sound booths, which contained an in-line calibrated sound level meter and which recorded ambient noise. Ambient noise levels were in adherence to OSHA standards during data collection. Three Benson BAS 200 bioacoustic simulators were used for daily calibration prior to testing. All testing was completed using computerized audiometry.

Data Analysis

The audiological results were recorded in a secure software database. The de-identified data were exported to Excel to facilitate categorization and grouping as well as imported into Statistical Package for Social Sciences (SPSS) for descriptive reporting. The hearing status was described in terms of notch prevalence, notch depth (in decibels), notch frequency, and notch asymmetry. The noise-notch analysis categorized presence or absence of a noise notch and was characterized by the threshold of the notch frequency (3, 4, or 6 kHz) being 10 dB or worse than the thresholds at 2 and 8 kHz, as defined by Wilson and McArdle (2013), Coles et al. (2000), and Hsu, Wu, Chang, Lee and Hsu (2013). The criteria for an asymmetric hearing loss were defined as or an air-conduction pure tone average at 500, 1, 2, and 3 kHz that is 15 dB or more different between ears, as defined by the American Academy of Otolaryngology-Head and Neck Surgery (AAO-HNS, 1994). Classification of notch depth was considered in 5-dB step sizes. Further analysis described the prevalence of hearing loss as function of sex and instrument category.

CHAPTER IV

RESULTS

Study Population and Data Set

The dataset included audiograms from 233 students and faculty from the University of Northern Colorado (UNC) School of Music. Of the 233 musicians, 56.2% (n = 131) were male and 43.8% (n = 102) were female. When age information was available in the database (n = 232), the ages of musicians ranged from 17 to 69 years old, with a mean age of 26.4 years-old (±12.51 years). Of all the audiograms, 85.8% (n = 200) were obtained from students, and 14.2% (n = 33) were obtained from faculty members. Of the 200 students, 55.5% (n = 111) were male and 44.5% (n = 89) were female. The age range of the students was 17 to 59 years-old, with a mean age of 23.2 years-old (±7.22 years). Of the 33 faculty members, 60.6% (n = 20) were male and 39.4% (n = 13) were female. The age range of faculty data was 20 to 69 years, with a mean age of 45.6 years of age (±11.91). When information was available in the database, audiograms were further classified by the primary type of instrument played by the student or faculty member. The instrument categories included: brass, conductor, percussion, string, voice, and woodwind. Further detail regarding the classification of instruments is provided in Appendix B. The number of audiograms associated with each instrument type is summarized in Table 8.

Table 8

Audiograms Classified by Instrument Type Reported by Student or Faculty (n = 233)

Instrument	Males (n)	Females (n)	Total (n)
Brass	17	17	14.7% (n = 34)
Conductor	8	5	5.7% (n = 13)
Composition	4	0	1.8% (n = 4)
Music education	3	4	3.0% (n = 7)
Percussion	22	15	15.9% (n = 37)
String	22	19	17.7% (n = 41)
Voice	28	20	20.6% (n = 48)
Woodwind	26	22	20.6% (n = 48)
Total	131	102	233

Prevalence of Audiometric Notch

An overall prevalence of students and faculty with notched audiometric configurations was 56.7% (n = 132). Of these 132 audiograms, 65.9% (n = 87) had unilateral notches and 34.1% (n = 45) had bilateral notched audiometric configurations, suggestive of noise-induced hearing loss. Notched audiometric configurations were identified in one or both ears in 67.6% (n = 22) of faculty members and in 55.5% (n = 110) of students. The composite audiogram for all musicians with a notch is provided in Figure 1. Of the 233 musicians, none of them met The American Academy of Otolaryngology-Head and Neck Surgery (AAO—HNS, 1994) requirement for a physician referral for asymmetric hearing loss.

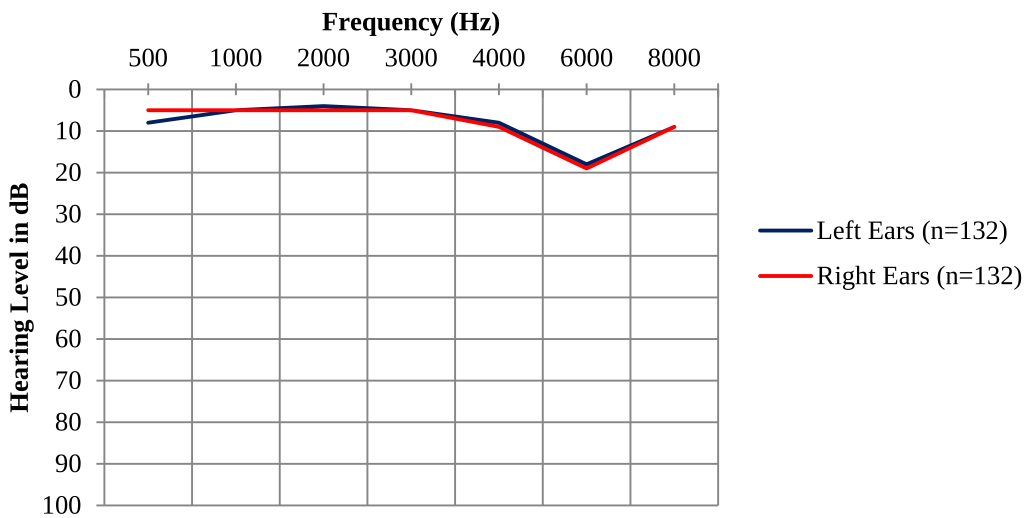

Figure 1. Mean audiogram of all participants who had notched audiometric configurations (n = 132).

When considering prevalence of notches across ears (n = 264), there was a prevalence of 67.0% (n = 177 ears). Of these 177 notches, 81.4% (n = 144 ears) occurred at 6 kHz, with 52.1% (n = 75 ears) occurring in the left ear and 47.9% (n = 69 ears) occurring in the right ear. The prevalence of notches at 4 kHz was 14.6% (n = 26 ears), with 38.5% occurring in the left ear and 61.5% in the right ear. At 3 kHz, there was a prevalence of notches of 4.0% (n = 7 ears). Of these 7 notches, 57.1% (n = 4 ears) were found in the left ear and 42.9% were found in the right ear. A summary of this information is included in Table 9. When considering referral criteria, none of the 233 participants had asymmetric hearing losses that would warrant a medical referral when considering the criteria from the American Academy of Otolaryngology-Head and Neck Surgery (AAO-HNS, 1994).

Table 9

Prevalence of Ears with Notched Audiometric Configurations

Ears	3 kHz		4 kHz		6 kHz		Total
	Left	Right	Left	Right	Left	Right	
Ears with notches	57.1% (n = 4)	42.9% (n = 3)	38.5% (n = 10)	61.5 % (n = 16)	52.1% (n = 75)	47.9% (n = 69)	
Total	4.0% (n = 7)		14.6% (n = 26)		81.4% (n = 144)		177

Notch depth at 3, 4, and 6 kHz was also calculated. Notch depth was conservatively characterized as the difference between the poorest threshold at each notch frequency and the poorest threshold at either 2 or 8 kHz for each ear tested. The prevalence of notch depth ranges from 10 dB to 70 dB. The deepest audiometric notches were found for right ears at 6 kHz. A summary of notch depth and frequency is provided in Table 10.

Table 10

Notch Depth by Frequency Counts for 3, 4, and 6 kHz

Notch Depth (dB)	3 kHz		4 kHz		6 kHz		Total
	Left Ear	Right Ear	Left Ear	Right Ear	Left Ear	Right Ear	Both Ears
10	2	1	2	2	9	11	29
15		1	3	8	29	17	55
20			2	2	11	16	32
25	1		1	3	12	12	28
30	1				8	3	13
35					3	4	8
40		1	1	1	1	1	5
45					1		1
50			1		1	1	3
55						1	1
60						2	2
65							
70						1	1
Number of Notches per Ear	4	3	10	16	75	69	177

Note. Notch depth was decided by the poorest threshold at 3-, 4-, or 6 kHz when compared to 2- or 8 kHz. Empty cells are equivalent to a count of zero.

Primary Instrument and Prevalence of Audiometric Notch

Notched audiometric configurations were further considered by the primary instrument type of the musician. Table 11 summarizes notch prevalence among males and females for each instrument group and frequency of occurrence. This table includes individuals with notches (n = 89) but is considered by ears with notches (n = 177). Notch prevalence among ears with audiometric notches (n = 177) is summarized in terms of instrument type in Figure 2. Males had a higher prevalence of audiometric notches at 3, 4, and 6 kHz than females.

Table 11

Audiometric Notch Counts Categorized by Sex, Instrument Type, and Frequency

Instrument	3 kHz L		4 kHz L		6 kHz L		3 kHz R		4 kHz R		6 kHz R		Sub-Total
	M	F	M	F	M	F	M	F	M	F	M	F	
Brass	0	0	0	0	4	5	0	0	1	0	7	6	23
Conducting	0	0	0	0	5	0	0	1	0	0	1	0	7
Composition	0	0	0	0	2	0	0	0	1	0	1	0	4
Music Education	1	0	0	0	1	3	1	0	0	1	1	0	8
Percussion	1	0	2	1	9	2	0	0	2	0	8	4	29
String	0	0	1	0	6	2	0	0	2	1	9	7	28
Voice	1	0	4	0	5	15	0	0	3	0	3	9	40
Woodwind	1	0	1	1	7	9	1	0	3	2	4	9	38
Sub Total	4	0	8	2	39	36	2	1	12	4	34	35	
TOTAL	4		10		75		3		16		69		177

Note. "M" indicates male musicians and "F" indicates female musicians. "R" indicates right ear and "L" ear indicates left ear.

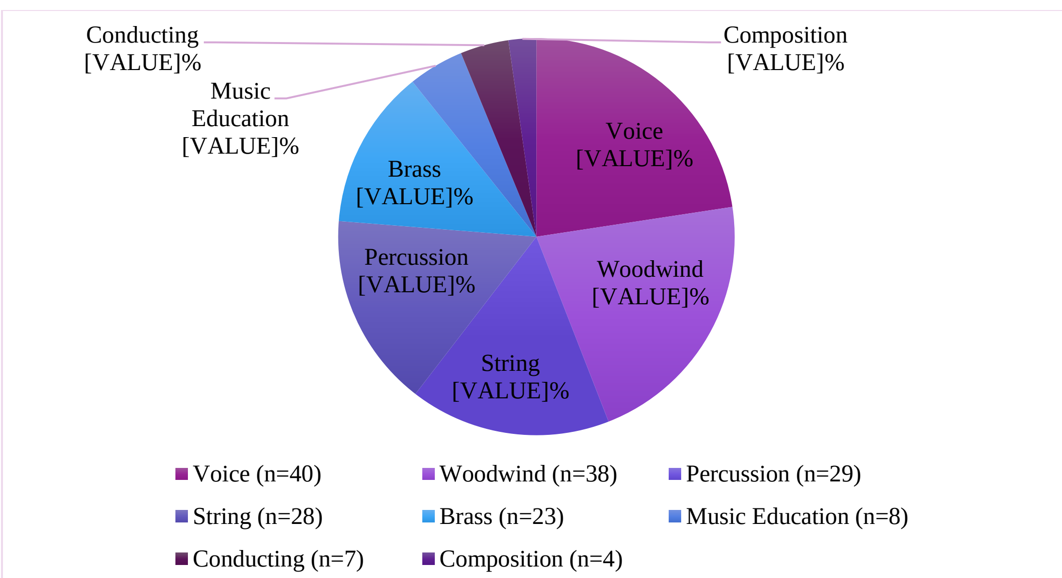

Figure 2. Ears with audiometric notches (n = 177) and instruments played.

Notch Prevalence Amongst Vocalists

Vocalists comprised a large portion of this study. Of the 233 musicians, 48 (20.6%) were singers. When considering the 132 musicians who had notched configurations, 22.7% (n =30) of them were vocalists. There were 40 notches present among these 30 singers. Eighty percent (n = 32 ears) were at 6 kHz. Notches at 3 kHz and 4 kHz were less prominent and accounted for 17.5% (n = 7 ears) and 2.5% (n = 1 ear), respectively. The majority of notched audiometric configurations in vocalists were unilateral (56.3%, n = 18 ears). Fourteen of these unilateral notches occurred in the left ear, and 4 occurred in the right ear.

Notch Prevalence Amongst Woodwind Musicians

Musicians who play woodwind instruments were the other one of the two largest groups of data that was analyzed in this study (vocalists being the other large group). Of the 233 musicians, 48 (20.6%) reported woodwind instruments as their primary instrument (see Appendix B for detailed instrument classification). Of these, 48 musicians (96 ears), 27 of them had notched audiometric configurations, and 38 notches were present among those 27 musicians. Of the 38 notches, 76.3% (n = 29 ears) were at 6 kHz, 18.4% (n = 7 ears) were at 4 kHz, and 5.3% (n = 2 ears) were at 3 kHz. Of these 38 musicians who had notched audiometric configurations and played woodwind instruments, 42.1% (n = 16) were unilateral notches, with 8 unilateral notches occurring in the left ear and 8 unilateral notches occurring in the right ear.

Notch Prevalence Amongst
String Musicians

There were 41 (17.7%), musicians in this study who reported that string instruments were their primary instrument. When considering the 132 musicians who had notched audiometric configurations, 18.2% (n=24) had configurations that were suggestive of NIHL, and there were 28 notches present among them. The majority of these notches (85.7%, n = 24) were at 6 kHz. There were no notches found at 3 kHz, and the other 4 notched configurations (14.3%) were at 4 kHz. For string instrument musicians, the majority of the notches (85.7%, n = 24 ears) were unilateral, with 6 being in the left ear and 13 in the right ear.

Notch Prevalence Amongst
Percussion Musicians

Percussion instruments were played by 15.9% (n = 37) of the 233 participants in this study. Of the 132 musicians with notched audiometric configurations, 15.9% (n=21) musicians who played string instruments , and there were 29 notches present among them. At 6 kHz, there were 23 (79.3%) notches at 6 kHz, 5 (17.2%) at 4 kHz, and 1 (3.5%) at 3 kHz. The prevalence of notched audiograms that were unilateral in nature was 18.9% (n = 14), and 7 notches were prevalent in each ear.

Notch Prevalence Amongst
Brass Musicians

There were 34 musicians (14.7%) who reported brass instruments as their primary instrument type. Among musicians who play brass instruments, 12.9% (n=17) of them had audiometric configurations that suggested NIHL, with 23 present notches among them. The frequency with the highest notch prevalence was 6 kHz (95.7%, n = 22 ears). The remaining notch was at 4 kHz. Unilateral notch prevalence among musicians who played brass instruments was 10.3% (n = 7), 3 occurred in the left ear, and 4 occurred in the right ear.

Notch Prevalence Amongst Conductors

There were 13 conductors who participated in this study, which made up 5.7% of the study population. Conductors had a prevalence of NIHL of 4.5% (n=6), and there were 7 present notches were found at either 3 or 6 kHz; however there were no notches evident at 4 kHz. Of the 7 audiometric notches, 5 (71.4%) were found to be unilateral in nature. Four of these unilateral notches occurred in the left ear, and 1 in the right ear.

Notch Prevalence Amongst Music Education Majors

Three percent (n = 7) of the participants were music education majors. The overall prevalence of audiometric notches among music education majors was 3.8% (n=5). There were 8 audiometric notches that were found among the 5 individuals. Five (35.7%) of these notches were found at 6 kHz, 1 notch was found at 4 kHz (7.1%), and 2 notches (14.3%) were found at 3 kHz. Fourteen percent (n = 2) of the notches were unilateral, and both unilateral notches occurred in left ears.

Notch Prevalence Amongst Composition Musicians

Four participants (1.7%) were composition musicians. Audiometric notches were prevalent among 1.5% (n=2), and there were 4 notches among the 2 composition musicians. Three of the notches (75%) were present at 6 kHz, and the other 1 (25%) was at 4 kHz. All notches were prevalent in both the left and right ears (bilateral). An averaged audiogram of all notched configurations in each ear among each instrument type is included in Figures 3 and 4 for the left and right ear, respectively.

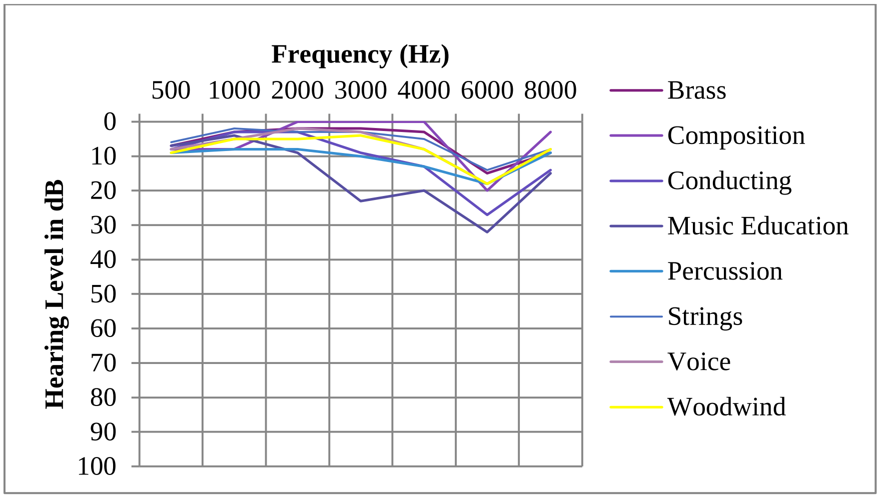

Figure 3. Mean left ear thresholds by instrument type.

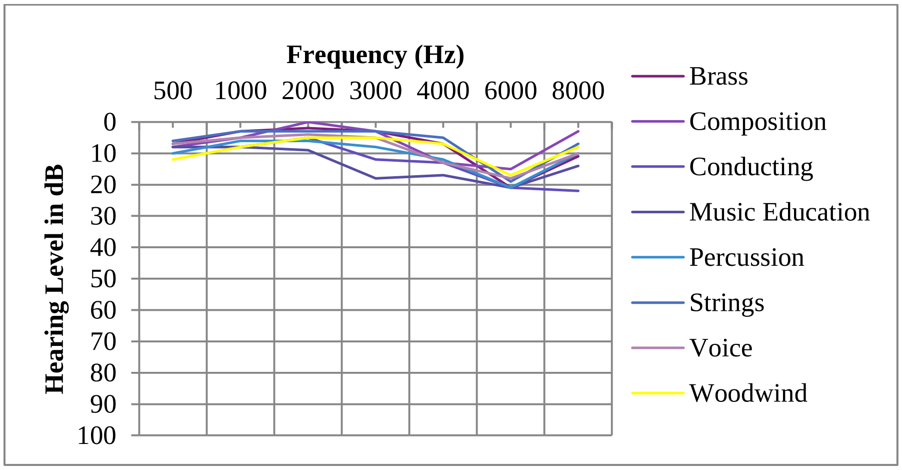

Figure 4. Mean right ear thresholds by instrument type.

Summary

This study was designed to examine the prevalence of audiometric notches suggestive of noise-induced hearing loss among student and faculty musicians at the University of Northern Colorado. This was accomplished by characterizing 233 audiograms from a hearing loss prevention database of baseline audiograms. The results indicated that the overall prevalence of high-frequency notched audiometric configurations (3, 4, or 6 kHz) was 56.7% (n = 132). Individuals had a higher prevalence of unilateral notches (65.9%) than bilateral (34.1%). These notches occurred most frequently at 6 kHz and amongst the male participants. Notch depth was deepest when it existed at 6 kHz. The highest prevalence of notched audiometric configurations was among vocalists and woodwind musicians.

CHAPTER V

DISCUSSION

This study further demonstrated the potential risk of auditory damage associated with high-level music exposures. The outcomes from the present study will be further explored in the context of previous studies in the literature.

Overall Prevalence of Notched Audiometric Configurations

The data analysis revealed that high-frequency notched audiometric configurations suggestive of noise-induced hearing loss is present in over half (56.7%, n = 132) of the musicians who participated in this study. These findings are similar to results indicated by Jansen et al. (2009), Phillips et al. (2008), and Phillips et al. (2010). Research performed by Dudarewicz et al. (2015) found a prevalence of 28% (n = 5) when NIHL was classified as a temporary threshold shift, as measured by TEOAEs following performance or rehearsal. This decreased prevalence could have been a result of how NIHL was classified. Table 12 includes a summary of audiometric notch prevalence as reported by previous research. The results that were obtained in this study were similar to previous research, which indicates that NIHL may be prevalent among approximately half music students and faculty.

Table 12

Comparison of Current Study to Literature on Prevalence of Audiometric Notches

	NIHL	Bilateral	Unilateral
		Previous Research	
Dudarewicz, Pawlaczyk-Łuszczyńska, Zamojska-Daniszawska, & Zaborowski. (2015)	28% (n=5)	Did not report	Did not report
Jansen Hellemen, & Dreschler (2009)	51% (n=123)	Did not report	Did not report
Phillips, Henrich, & Mace (2010)	45% (n=148)	11.5% (n=17)	67.6% (n=87) Left Ear: 63% (n=55) Right Ear: 37% (n=32)
Phillips, Shoemaker, Mace, & Hodges (2008)	Year 1: 55.5% (n=61)	Year 1: 0% (n=2)	Year 1: 100% (2/2)
	Year 2: 64% (n=32)	Year 2: 22.9% (n=11)	Year 2: 77.1% (n=37) Left Ear: 37.5% (n=18) Right Ear: 39.6% (n=19)
	Year 3: 82% (n=146)	Year 3: 15.8% (n=28)	Year 3: 84.2% (n=149) Left Ear: 39.0% (n=69) Right Ear: 45.2% (n=80)
Wilson (2011)	40.6% (n=1378)	37.5% (n=517)	Left: 28.8% (n=978) Right: 27.1% (917)
		Current Research	
Maas	56.7% (n=132)	34.1% (n=45)	65.9% (n=87)

Notch Depth and Frequency of Occurrence

Hearing loss was evident at 6 kHz, and the smallest portion was found at 3 kHz. These findings are similar to findings from previous research regarding the prevalence of notched audiometric configurations suggestive of NIHL among musicians. Audiometric notches occurring primarily at 6000 Hz is associated with hearing loss among musicians (Emmerich et al., 2008; Jansen et al., 2009), and notches occurring primarily at 4000 Hz has been associated with hearing loss among industrial workers (Landen et al., 2004; McBride & Williams, 2001). McBride and Williams (2001) concluded that 75% (n = 493) notches occurred at 6 kHz, while 6.9% (n = 45) occurred at 3 kHz. Phillips et al. (2010) found notch prevalence to be 2.7% (n = 4), 22% (n = 32), and 78% (n = 112) at 3, 4, and 6 kHz, respectively. This is similar to the results found in the current study of 4.4% (n = 7), 14.7% (n = 26), and 80.9% (n = 144) at 3, 4, and 6 kHz, respectively. Notch depth was deepest among right ears and at 6 kHz. When notch depth was considered, researchers indicated that notches were the most severe at 6 kHz (Jansen et al., 2009; McBride & Williams, 2001; Phillips et al., 2010).

Notch Symmetry

The current study indicated that more audiometric notches occurred in the left ear than the right ear. At 6 kHz, there was a higher prevalence of notches in the left ear (52.1%, n = 75) than in the right ear (47.9%, n = 69). Comparison of notch prevalence between ears is included in Table 12. Research in this study supports these findings of a higher prevalence of notches among musicians occurring in the right ear and are unilateral in nature. These findings are similar to those found in previous research studies (McBride & Williams, 2001; Phillips et al., 2008; Wilson, 2011).

Instrument Type

In the current study, the highest prevalence of notched audiometric configurations was among vocalists and musicians who played woodwind instruments. Sound exposure levels can be influenced by the type of instrument played and by the location of the musician in relation to other instruments. Studies have found that the musicians who are exposed to the highest levels of noise are musicians who play brass instruments (Emmerich et al., 2008; Rodrigues et al., 2014; Schmidt et al., 2014), percussion instruments (Dudarewicz et al., 2015; O'Brien et al., 2013, Schmidt et al., 2011), and woodwind instruments (Dudarewicz et al., 2015). The primary instrument played can influence the type of hearing loss that occurs when over exposed.

Study Limitations

Although musicians were advised to avoid noise and music for 14 hours prior to testing, it is possible that some of the participants may have been exposed prior to testing. This information, however, was not tracked in the database. It is possible that temporary threshold shifts were present in some individuals, which would result in elevated hearing thresholds and possibly result in an over-estimation of the prevalence of a notched audiometric configuration.

The current study did not include dosimetry data from the musicians at the University of Northern Colorado. This information would have contributed to a better understanding with regard to how an intense level sound exposure and hearing loss correlate in college student musicians and faculty members. It is also important to note that the assumption that the notch is related to music exposure is not able to be substantiated directly in a causal relationship. There are likely contributions from non-music hazardous noise sources. Some musicians may work in noise-hazardous jobs, but this information was unknown. Musicians who were concerned about their hearing status may have self-selected themselves for participating in the complimentary hearing test. This might contribute to a higher prevalence of notched audiometric configurations amongst UNC student musicians and faculty. Lastly, the use of hearing protection was not tracked in this data set. Therefore, it is unknown whether any of the musicians were protecting their hearing and how this related to the presence or absence of an audiometric notch. However, it was anecdotally reported that the majority of students received their first introduction to the use of hi-fidelity hearing protection when the devices were provided at the time of the hearing test. These musicians also received training in the proper use of hearing protection at this time.

Strengths

The data set that was analyzed for this research was vast and complete in terms of demographic information such as sex, age, and primary instrument type. The sample size for this study was 233 musicians. There are over 450 students enrolled and 60 faculty members employed at the University of Northern Colorado School of Music. With this number considered, this study represented 45.7% (n = 233/510), which allowed for a reasonable estimation of the hearing status of the UNC School of Music. The data set was collected uniformly, and the audiograms were valid.

Conclusion

Over half (56.7%, n = 132) of the students and faculty at the University of Northern Colorado School of Music have hearing losses that are suggestive of noise-induced hearing loss (or music-induced hearing loss in this context). Noise-induced hearing loss (typically found at 3, 4, or 6 kHz) was most prevalent at 6 kHz and amongst males. When NIHL was present, it occurred most often in the left ear. These results indicate that there is a need to implement a comprehensive hearing loss prevention program including: (a) sound exposure monitoring, (b) annual hearing tests, (c) hearing health education, (d) hearing protection device provision, and (e) training regarding the care and use of the devices. Best practice would also include attenuation fit-testing to assure adequate protection for UNC School of Music students and faculty. The continued distribution of hi-fidelity hearing protection for incoming freshman music students is warranted and should be continued.

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APPENDIX A

INSTITUTIONAL REVIEW BOARD APPROVAL

UNIVERSITY OF
NORTHERN COLORADO

Institutional Review Board

DATE:	April 24, 2017
TO:	Chandra Maas, Bachelor of Science
FROM:	University of Northern Colorado (UNCO) IRB
PROJECT TITLE:	[1059316-1] Prevalence of sound-induced hearing loss among university music students and faculty
SUBMISSION TYPE:	New Project
ACTION:	APPROVAL/VERIFICATION OF EXEMPT STATUS
DECISION DATE:	April 24, 2017
EXPIRATION DATE:	April 24, 2021

Thank you for your submission of New Project materials for this project. The University of Northern Colorado (UNCO) IRB approves this project and verifies its status as EXEMPT according to federal IRB regulations.

Hello Chandra,

I am the IRB reviewer of your proposed research. Congratulations on a well-prepared and clearly written IRB application. Your application is approved and good luck with your study.

Sincerely,
Nancy White, PhD, IRB Reviewer

We will retain a copy of this correspondence within our records for a duration of 4 years.

If you have any questions, please contact Sherry May at 970-351-1910 or Sherry.May@unco.edu. Please include your project title and reference number in all correspondence with this committee.

APPENDIX B

INSTRUMENT TYPE CATEGORIZATION

Instrument Type Categorization

Strings	**Woodwinds**	**Brass**	**Percussion**
Cello	Bassoon	Contrabass	Celeste
Double Bass	Clarinet	French Horn	Drums
Harp	Flute	Trombone	Timpani
Guitar	Oboe	Tuba	
Violin	Piccolo	Trumpet	
Viola	Saxophone		