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Audiometric Status, Self-Perception of Hearing Disorders, and Noise Dose in Audio Post-Production Engineers

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AUDIOMETRIC STATUS, SELF-PERCEPTION OF HEARING DISORDERS, AND NOISE DOSE IN AUDIO POST-PRODUCTION ENGINEERS

by

LAURA MARIE SINNOTT

A capstone research project submitted to the Graduate Faculty in Audiology in partial fulfillment of the requirements for the degree of Doctor of Audiology, The City University of New York

2018
Audiometric Status, Self-perception of Hearing Disorders, And Noise Dose In Audio Post-Production Engineers

by

Laura Marie Sinnott

This manuscript has been read and accepted for the Graduate Faculty in Audiology in satisfaction of the capstone project requirement for the degree of Au.D.

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ABSTRACT

Audiometric Status, Self-Perception of Hearing Disorders, And Noise Dose In Audio Post-Production Engineers

by

Laura Marie Sinnott

Advisor: Dr. Barbara Weinstein

Numerous studies have assessed the risk of hearing injury for musicians and other sound professionals due to excessive sound exposure, however no studies have investigated whether audio post-production engineers have this same risk. This preliminary study first measured 23 participants’ hearing thresholds and prevalence of audiometric notches. Second, a questionnaire, the Questionnaire for Sound Professionals (QUSP), was designed and administered to determine whether correlations between audiometric status and self-perception of hearing loss and hearing disorders existed. Third, sound dosimetry measurements were conducted at film audio post-production studios to assess whether this population is at risk for permanent hearing loss due to the level and duration of sound exposure. Results indicated that the majority of participants had at least one audiometric notch with normal hearing thresholds. No statistically significant correlations between QUSP scores and binaural mean hearing thresholds, age, years worked as an engineer or years as a musician were found. Dosimetry results were, overall, inconclusive due to the high variability of typical workday activities and small number of days surveyed (9 days). However, preliminary results suggest that there is a low risk of permanent hearing loss due to sound exposure for the specific activities that were performed (according to NIOSH criteria). Additionally, though personal dosimetry suggests these professionals are not at risk for permanent hearing loss, continuous equivalent average sound levels did exceed 85 dBA at times, and peaks, thought not formally measured in this study, are known in this industry to regularly
exceed 130 dB SPL, therefore all audio post-production engineers should undergo routine, audiometric evaluations and employ additional hearing conservation strategies such as hearing protection in order to prevent hearing loss and hearing disorders.
Acknowledgements

Conducting research parallels filmmaking in many ways: pre-production (IRB approvals, proposals and funding), to production (scheduling participants and trouble-shooting “on-set” equipment failures), post-production (data analysis) and distribution (publishing). In other words, it is impossible to do it alone. The following people and organizations were instrumental to completing the project: Dr. Barbara Weinstein, my capstone advisor, provided enthusiastic support, guidance, and was also instrumental in the production stage by organizing equipment pickups at all hours. Drs. Michael Santucci and Heather Malyuk, my externship mentors from Sensaphonics Hearing Wellness, provided encouragement, equipment, and connections that helped with participant recruitment in Chicago. Etymotic Research provided a generous grant in the form of dosimeters. The CUNY Graduate Center provided clinical resources and equipment for the NYC portion of research.

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INTRODUCTION

Certain populations, including musicians and sound professionals, rely heavily on their hearing abilities in order to perform their day-to-day job activities. A great deal of studies has assessed the risk of hearing injury for musicians due to excessive sound exposure (Emmerich, 2008; Kähäri et al., 2001; Luders et al., 2016; O’Brien et al., 2013; Philips et al., 2010; Royster et al., 1999; Samelli et al., 2012; Schmidt et al., 2011). A few studies have assessed risk for studio and live music engineers (Bulla and Hall, 1998; Fortin and Hetu, 1994; Järvinen et al., 2004). However, no studies have investigated whether film and television sound engineers, which include re-recording mixers and sound editors and often all under the umbrella term audio post-production engineers (APPEs), have the same risk. Furthermore, theatrical film soundtracks presented in movie theaters can exceed recommended daily noise doses (Warszawa and Sataloff, 2010), and film sound engineers work long hours on these soundtracks. This population is deeply concerned that they may be at risk for hearing loss and hearing disorders by working in the studio all day with high sound levels, and then exposing themselves to additional noise while commuting, dining out, concert-going and engaging in other recreational activities. Additionally, while talking amongst each other, members of this population report disorders such as tinnitus and auditory processing difficulties such as difficulty understanding speech in loud environments.

The purpose of this preliminary research is trifold. First, to measure hearing thresholds and determine the prevalence of hearing loss in APPEs. Second, to design and assess the reliability of a questionnaire for sound professionals that measures self-perception of hearing loss/disorders and determine whether correlations between audiometric status and self-perception of hearing loss/disorders exist. Third, conduct sound dosimetry measurements at the workplace
to assess whether this population is at risk for permanent hearing loss due to the level and duration of sound exposure.

Noise induced hearing loss (NIHL) refers to permanent hearing threshold shifts that occur with cumulative exposure to high intensity sound for long durations (Niquette, 2009). This term implies that the sonic culprits are characterized by noise, like industrial machines or gunfire. Music induced hearing loss (MIHL) refers to similar consequences of loud and long sound exposure on hearing sensitivity but with music being the offending sound (Chesky, 2008). Music induced hearing disorders (MIHD) (Santucci, 2009), or sound induced hearing disorders (Moore, 2015), reflects the bigger picture of the consequences of loud and long, non-noise-like sound exposure. MIHDs include elevated hearing thresholds but also tinnitus (perceived ringing or noises in the ears without a sound source), hyperacusis (extreme sensitivity to high intensity sound), diplacusis (abnormal pitch perception) and distortions of sound. Various people are affected from concert-goers to composers and conductors. Anecdotally, patients at Sensaphonics Hearing Wellness, a musician’s audiology clinic commonly report feeling vertigo during extremely loud amplified music exposure.

No data exist on audio post-production engineers, but this population arguably relies on their hearing more than musicians - Beethoven could compose and perform while deaf, however a sound engineer is unable to manipulate sound or identify soft, subtle imperfections of sound if they cannot hear. Damage-risk criteria does not exist for non-noise-like sound, but, though some feel are outdated and too lenient (Suter, 2009), the Occupational Safety and Health Administration (OSHA) and the National Institute for Occupational Safety and Health (NIOSH) have developed criteria to assess risk for NIHL (OSHA, 1983; Rosenstock, 1998) that has been widely used by previous researchers to draw conclusions about movie theater sound levels for
audience members (Ferguson et al., 2000; Huth et al., 2014; Ihne et al., 1999; Warzsawa and Sataloff, 2010; Mullen, 2003; Rao et al., 2003), and risk for MIHL and MIHD for musicians (Royster et al., 1999; Emmerich, 2008; Russell and Yamaguchi, 2018; Schmidt et al., 2011) and live sound and music engineers (Bulla and Hall, 1998; 1994; Järvinen et al., 2004). Key terms used in noise dosimeter studies include (Casella, 2010):

**Leq:** Continuous equivalent average sound levels in dB SPL, A-weighted. It is the average sound level calculated over a period of time and represented as a single number even though the actual sound fluctuates. A-weighted places less importance on low frequency sounds, i.e. low frequencies are attenuated and the reading will be less than a C-weighted measurement.

**Noise dose (%)**: The amount of sound exposure an individual has experienced, expressed as a percentage, and based on specific criterion level and exchange rate.

**Criterion level:** the level at which exposure to a continuous sound will result in a 100% noise dose for an 8-hour period. NIOSH uses 85 dBA, OSHA uses 90 dBA.

**Exchange rate:** The rate (in dB) at which an increase of sound intensity will result in a doubling of risk or noise dose. NIOSH uses 3 dB, OSHA uses 5 dB. For example, if NIOSH criteria says that exposure to 85 dBA of continuous sound for 8 hours results in a 100% noise dose, 88 dBA for 8 hours results in a 200% noise dose etc. Also, at 85 dBA a person has 8 hours of safe exposure time before risk for hearing loss, but at 88 dBA they have half the amount, or 4 hours. NIOSH is more protective compared to OSHA.

**Cinema Sound: Standards and Risks**

Mainstream audiences vocalize annoyance at loudness levels of films; newspapers and other media frequently discuss the issue (Clark, 2001; Barron, 1998, Guardian, cited by
Ferguson, 2000; Rossen and Bomnin, 2016). A historical journey into the annals of film sound standards explains why.

Contrary to many assumptions, cinema sound standards exist both for theaters and film sound engineers (SMPTE, 2013; Newell et al., 2016). They are *recommended* standards, however, and not government regulations. Stakeholders (theater owners, film studios, post-production members) are not motivated to fix the problem for numerous reasons. For example, small, independent theater owners may be unable to afford to upgrade to speakers that meet standards (Newell et al., 2016) and may actually *lower* the sound levels to avoid distorting their speakers. On the other hand, directors may push sound levels higher than the recommended standards because they believe the audience prefers loud sound (Hanson, 2003; Newell et al., 2016).

Sound can easily reach dangerous levels in movie theaters. In the analog days, dialogue was mixed to a reference of 85 dBC with 20 dB of headroom. Analog headroom is the audio space reserved for peaks and transients, not for sustained sounds because they could distort due to the integrity of the circuits used\(^1\). Sound effects such as gunshots or *forte* sections of musical score would occasionally surpass 85 dBC, close to the 85 dBA which NIOSH recommends wearing hearing protection (Rosenstock, 1998). When the digital revolution happened, the analog standards did not change and this resulted in the ability for all sound to continuously live in headroom, not just transients and peaks. Directors began pushing re-recording mixers to design longer and louder action sequences. Audience members would regularly complain about the sound being too loud, and projectionists would therefore lower the sound from the Dolby standard “7” to about “5.” When lowered, often the dialogue became difficult to hear, and so

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\(^1\) Analog circuits will often start to break down when they cannot handle the audio signal level (i.e. when the signal enters “headroom”). These circuit issues cause distorted audio but are typically imperceptible with peaks and transients. This is a non-issue when working in the digital realm.
film-makers would push the engineers to increase the dialogue levels. Dialogue would then be combined with sound effects and music, and a blanket of loud movie sound would ensue. The resultant soundtrack can be annoying for the listener with normal hearing and difficult or near impossible for the hearing impaired listener to make sense of.

Movie theater speakers should each be able to reproduce sound up to 105 dBC (the reference 85 dBC plus 20 dB headroom) without distortion. In a typical 6-speaker, 5.1 surround sound theater, this means the sound can potentially reach levels of 140 dBC. OSHA and NIOSH both agree that impulse sounds over 140 dB SPL are unsafe (US Department of Health and Human Services, 1998). Indeed, a handful of studies investigated whether attending a movie is dangerous for hearing health as will be discussed. However, what about the professionals creating the soundtrack? They work long hours and often spend weeks on a single action scene. Concern is warranted for potential consequences on hearing health.

The Audio Post Production Engineer

There are an estimated 4,500 professional “Sound engineering technicians” in the motion picture and video industries according to the Bureau of Labor Statistics (2017). The number is likely greater due to the high number of freelance engineers, actual number unknown. Sound engineers usually work either at live concert venues or in studio settings. Many work exclusively in the music industry, but many also work in the film, broadcast and online industries and these are called audio post-production engineers (APPEs). APPEs are distinct from film scoring composers, who write music for film. They may or may not be distinct from video game and virtual or augmented reality audio engineers and sound designers. The APPE is responsible for producing a final cinematic or broadcast soundtrack after the initial production phase. They

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2 Within the industry, sound editors are distinct from an engineer however for this project the term will encompass editors and engineers.
edit and mix dialogue, music, and sound effects. Some are highly specialized and tend to focus on one element, like a dialogue editor. Others perform a variety of duties including recording background dialogue, editing sound effects or managing a team of many APPEs. Some APPEs have less exposure to high sound levels than others. For example, the assistant sound editor may spend a lot of time organizing sessions and searching for alternate takes of audio which is a relatively quiet task. Independent APPEs may spend a significant amount of time on administrative duties, another quiet task. The re-recording mixer, on the other hand, is regularly exposed to loud sound for long durations. They tweak, balance, and add effects to the sound editorial. They may play back action scenes involving dozens of layers of explosions, dinosaur roars, or transforming robots countless numbers of times for weeks. Overall, APPE tasks are varied in terms of activity and sound exposure.

Hearing Questionnaire for Sound Professionals (QUSP): Background and Motivation

Musicians and sound engineers are a special population whose listening needs and therefore level of audiologic care can be “drastically different” compared to non-musician populations (Fligor, 2015). Thus, we explored availability and applicability of tools to assess their needs. It is widely accepted knowledge that the audiogram does not correlate well with measures of self-perceived hearing difficulties (Weinstein, 2015). Numerous questionnaires, outcome measures and intervention tools currently abound in the audiology community including the internationally recognized Hearing Handicap Inventory for the Elderly (HHIE) developed by Ventry and Weinstein (1982), the Client Oriented Scale of Improvement (COSI) (Dillon et al., 1999) and the Abbreviate Profile for Hearing Aid Benefit (APHAB) (Cox and Alexander, 1995). Clinicians and researchers have made calls to action to create questionnaires that assess musical needs for individuals with hearing loss (Chasin and Hockley, 2009; Rutledge,
2009; Uys and van Dijk, 2011) because nothing exists that measures these individuals’ self-perceived effects of hearing loss or disorders on sound perception. Chicago-based Sensaphonics Hearing Wellness, one of the only dedicated musicians’ and sound engineers’ audiology clinic in the world, has an extensive case history form, however it does not quantify self-perception of hearing difficulties. Researchers and clinicians at the University of Melbourne Audiology Clinic (Beach et al., 2018) are developing the Musician Oriented Scale of Improvement (MOSI), a goal-setting and intervention tool that audiologists employ to help musicians maintain hearing health, much like the COSI. However, the MOSI does is not a measurement-oriented questionnaire. Thus, the “Questionnaire for Sound Professionals” was developed. Originally titled “Musician’s Hearing Handicap Inventory” after the HHIE, “sound professional” was deemed more appropriate since the term encompasses not only musicians but sound editors and engineers (Santucci & Malyuk, 2016).

**RELEVANT LITERATURE**

**Audio Engineers and Noise Dose**

Bull and Hall (1998) authored the lone study investigating sound exposure levels of 7 music studio audio engineers in the Nashville area. Sound levels were recorded with dosimeters utilizing both OSHA and Department of Defense (DOD) criteria (DOD uses an 84 dB criterion level with a 4 dB exchange rate). Each participant recorded sound levels for 5 workdays; no audiometric measurements were performed. The overall results show that levels are hazardous according to DOD criteria but not according to OSHA. The authors point out that when averaging the data, results become skewed and suggest that sound engineers work in “conservative” environments. However, when looking more deeply, data shows that this is not
the case: one engineer experienced a 290% noise dose (DOD) on day 4 but only 70% on day 3. Another even exceeded OSHA criteria (125%) on one long work day. Overall, Lavg ranged from 68 - 87 dBA, noise dose ranged from 12% - 57% for OSHA and 23 - 290% for DOD, and peaks from 123 - 146 dBA. Typically, these engineers worked 50 hour work weeks, which increased the chance of higher noise doses, but is typical in this industry. The authors concluded that levels are between safe and potentially dangerous, however with long term exposure their hearing mechanism is likely to suffer some kind of damage.

**Broadcast and Production Personnel**

One study that reported sound exposures for broadcast sound engineers who worked on live television sets, concerts or sports productions and not in a studio, revealed that sound engineers’ LEP,d ranged from, 66 - 94 dB(A) with an average of 81 dB(A) (Järvinen et al. 2004). The average level did not pose a threat for permanent threshold shift (PTA), however the higher end of the range, 94 dB(A) did indicate risk for permanent hearing loss.

Though inconclusive due to the small N, a small study by Fortin and Hetu (1994) with 3 live sound engineers and 2 studio sound technicians found that the exposure levels predicted a permanent threshold shift after 10 years of working at these levels at 4 kHz from 18 - 29 dB for sound engineers and 11 dB for sound technicians. They concluded that these professionals work “in a paradoxical situation where hearing acuity is both highly solicited and deteriorated by the very signals that are being processed.”

**Rock Musicians and Hearing Status**

Perhaps the focus of concern should shift towards prevalence of other MIHD such as tinnitus. Stromer et al. (2017) compared 111 performing Norwegian rock musicians to 40
controls and found 20% reported permanent tinnitus compared to 0% of controls. 38% of these musicians displayed hearing loss compared to 2.5% of controls. Luders et al. (2016) surveyed 100 college musicians, full and part time, and found that 72% experience tinnitus (although only 5% reported permanent tinnitus).

Samelli et al. (2012) compared 16 professional rock/pop musicians to 16 controls and found that the musicians had significantly worse hearing thresholds at 2 and 3 kHz and 12.5 - 18 kHz and smaller transient evoked otoacoustic emissions (TEOAE) amplitudes compared to controls. However, auditory brainstem response (ABR) Wave V and the P300 cortical potential latencies were shorter compared to controls, which suggests that while musicians have more prevalence of hearing loss, their central auditory processing abilities are not necessarily compromised and in fact may be stronger, possibly due to musical training.

Though most of these types of studies conclude that some musicians are at risk for NIHL, Gez Saperstein (2017) points out in her systematic review of occupational MIHL that most studies are limited in their design, and longitudinal studies do not exist, so it is difficult to truly know whether music exposure causes hearing loss. Additionally, the criteria for presence of a hearing loss differs between studies (e.g. distortion product otoacoustic emissions (DPOAE) amplitude decrease, pure-tone average (PTA) loss versus extended high frequency loss).

**Classical Musicians, Hearing Status and Noise Dosimetry**

Studies also abound on sound exposure levels and audiometric status of classical musicians. Speculation as to why is that these musicians may be able to pursue compensation from their employer whereas a freelance musician is unable, and lawyers need to present evidence to support claims, so there is simply more interest. In fact, in March 2018, a British symphonic viola player won an unprecedented lawsuit against the Royal Opera House for
hearing damage while performing Wagner’s notoriously loud “Ride of the Valkyries” (Gayle, 2018). Research typically indicates that some but not all orchestral musicians display hearing thresholds that are worse than age matched non-musicians (Royster et al., 1991), and musicians that are regularly exposed to Lavg levels > 85 dBA tend to play specific instruments (e.g., violin or percussion), or sit in front of or near more powerful instruments such as the brass section (O’Brien, 2013).

One of the stronger study designs was by Royster, Roster and Killion (1991). They obtained 68 dosimeter readings on 44 Chicago Symphony Orchestra musicians for two different rehearsal repertoires comprising of a variety of works. They also measured 59 musician’s hearing thresholds and compared them to data from the International Standards Organization (ISO) 7029, a screened population with non-hazardous occupations. Leq ranged from 79 - 99 dBA with an 8-hour daily Leq of 85.5 dBA. Brass and percussion players, and those sitting in front of them, experienced the highest sound levels. Audiometrically, 52% showed notched thresholds at 3 - 6 kHz consistent with NIHL. Violinists and violists had statistically significantly worse thresholds at 4 kHz in their left ear compared to their right (by 5.74 dB), and sound levels were on average 6-8 dB lower on the right side due to proximity to the violin body and the head shadow effect. They concluded that the most susceptible musicians experiencing higher sound levels would incur 28 dB of PTS at 3-4 kHz after 30 years of playing, and the average musician would incur about 18 dB (according to ISO 1999 standards). We must also consider the after-work sound exposure of a typical musician, they practice solo, and often gig after hours. These additional sound exposures imply that the musician is actually at greater risk than these data might imply.
An additional study of three German orchestras support the prevalence of PTS in the musicians that exceed age-matched controls (Emmerich et al., 2008) however a study on a Swedish orchestra resulted in the opposite; any hearing loss found could not be explained by music exposure (Emmerich et al., 2008).

Additional studies on orchestras support the prevalence of potentially dangerous sound exposure levels (Schmidt et al. 2011). O’Brien, Driscoll and Ackermann (2013) found that 52% of classical musicians practicing on their own exceed recommended daily noise exposure (NIOSH), and specific instrumentalists such as violinists showed statistically significant interaural differences in exposure levels between ears (left ear with higher intensities than right for violinists). However, Emmerich et al. (2008) shows conflicting results between violinists from different orchestras; some had differences between ears others did not.

Studies also suggest that band instructors and music students have the highest risk for PTS due to sound exposure (O’Shea, 2018) and have the highest prevalence of NIHL (Philips et al., 2010).

**Sound Levels in Cinemas**

Mainstream audiences vocalize annoyance at loudness levels of films; newspapers frequently discuss the issue from the New York Times (Barron, 1998) to The Guardian (Hanson, 2003). Studies, however, mostly indicate that according to OSHA criteria, attending one film alone does not pose any risks for hearing health (see below). Film sound engineers presumably are exposed to cinematic sound levels for entire working days however, not only 110 minutes (the average length of a feature film (Follows, 2016)). Thus, it is possible that professionals working on cinematic soundtracks are working with harmful levels due to the duration of exposure.
Huth, Popelka and Blevins (2014) measured Leq sound levels for 2 different films, 6 times in 10 different theaters (117 measurements) utilizing calibrated smart phone sound level meters. Average levels were between 70 - 76 dBA with an Lmax of 92 dBA during an action movie. Up to 3.3 dB differences were found between SLMs positioned in the center of the theater versus the last row (no SLMs were placed in the front row). There were no statistically significant differences in sound levels between weekend/evening showings and afternoon/weekday showings, or between the genres.

Warszawa and Sataloff (2010) measured Lavg, Lpk and noise doses in 25 different films at a single multiplex cinema. Lavg ranged from 52 - 80 dBA, Lpks between 120 - 144 dBA, and noise doses were all below 5% using OSHA criteria. However, they measured sound levels of > 100 dBA for > 15 minutes and up to 55 minutes (the movie-musical *Hairspray*) for numerous films. Using NIOSH criteria, these exposures would result in over 100% noise dose. This study was a preliminary study and the authors state that these data should be used as support for support for further investigations.

Mullen (2003) conducted a study for her master’s thesis that utilized a dosimeter to measure sound levels during 11 different movies. Leq ranged from 70 - 77 dBA with peaks of 140 dBA concluding that levels are not hazardous to audiences’ hearing (although OSHA (1983) does state that impulse sounds reaching 140 dB SPL are potentially harmful). No significant differences were found between genres.

Ferguson, David and Lovell (2000) measured sound levels and noise doses for 7 showings of 4 action films from the center of the theater. Leq ranged from 73 - 79 dB(A) with peaks between 90 - 110 dBA. They concluded that attending movies are safe and will not
contribute to hearing damage, even considering cumulative effects of moviegoing with other daily activities.

A study on 20 different films in 20 theaters India (Rao et al., 2015) showed Lavg between 79 - 93 dBA suggesting that some showings may be hazardous for hearing health. The authors noted that these theaters used generators for air conditioners that could be heard through the theater walls, and the audience at times cheers loudly as is customary in India.

Other reports, both informal studies and conference presentations, confirm that cinema sound levels do not pose risks for hearing loss (Ellerton, 2000; Scholte Lubberink, 2013; Ihne, 1999).

RESEARCH QUESTIONS
1. What are the audiometric characteristics of audio post-production engineers (APPEs)? Specifically, what is the prevalence of audiometric notches and sound-induced hearing disorders in the population?
2. Is the Questionnaire for Sound Professionals (QUSP) a reliable tool to use for measurement of self-perception of hearing difficulties among Sound Professionals?
3. What is the correlation between the QUSP scores and participants’ hearing thresholds?
4. What is the relation between noise dosimetry readings and hearing status in APPEs?
5. Are APPEs at risk for permanent hearing thresholds shifts due to sound exposure as indicated by dosimetry?

METHODOLOGY
Participants
Participants were recruited through word of mouth and professional associations by the principle investigator. No formal sampling procedure was used, and participation was completely voluntary. This study was approved by the CUNY Graduate Center Institutional Review Board and all participants signed an informed consent form.

Locations

Data were collected at audio post-production facilities where the participants regularly work in New York City and Chicago, IL as well as the CUNY Graduate Center Hearing Clinic. Audiometry was conducted in sound-treated audio studios designed for film sound mixing or in a sound-treated room at the CUNY Clinic that met ANSI S3.1-1999 standards for Maximum Permissible Ambient Noise Levels. Dosimetry was conducted in 3 different Dolby-certified re-recording mix stages in New York City.

Materials

The following three audiometers were used to measure pure-tone hearing thresholds: GSI 17 portable audiometer using Etymotic Research ER-3A insert earphones with calibration performed 2 months prior to data collection, GSI Audiostar Pro with ER-3A insert earphones with calibration performed within 6 months of data collection, and Interacoustic AA Traveler portable audiometer with Interacoustics supra-aural headphones (last calibration unknown). The Amplivox Otowave Tympanometer was used to gather data on status of the middle ear.

Hearing Questionnaire for Sound Professionals (QUSP): Development

The QUSP was developed to gather information on the self-perceived hearing status of sound professionals. Initial development was based on Hearing Handicap Inventory for the Elderly (HHIE) (Ventry and Weinstein, 1982). First, specific problems were identified including
consequences of hearing loss or disorders on music perception. An extensive article on said topic by Moore (2015) presented at the Music Induced Hearing Disorders conference was consulted. Moore concisely discussed specific auditory problems from loss of frequency selectivity to recruitment on music perception and a series of questions were composed assessing impairment. Here are three examples of the questionnaire-in-development:

**Dynamic range** (assessing loss of OHC/reduced sensitivity and dynamic range)
- Do you have difficulties hearing pianissimo (quiet) passages in music?
- Do you have difficulties hearing fortissimo (loud) passages in music?

**Tinnitus**
- If you experience tinnitus, does this tinnitus cause difficulty when listening to or practicing music? (tinnitus sufferers often cannot enjoy music played at pianissimo levels, and most musicians have tinnitus, audiologists should treat the tinnitus first (Fligor, 2015)).

**Distortion** (assessing dead regions or diplacusis)
- Does music sound distorted or noise-like?
- Does music sound like “there is no clear pitch?”

Next, informal interviews with a handful of NYC-based musicians, composers and audio engineers were conducted to develop questions that identified activity limitations and participant restrictions. As shown by the HHIE, emotional impacts of hearing impairment have higher intersubject variability and lower correlations with pure tone averages compared to situational impacts, and so questions assessing emotional impact were composed. Finally, one question on hearing protection was added. Goals were clearly outlined for the QUSP:

- Identify problems: impairments, activity limitations and participant restrictions.
- Measure direct effects of hearing loss and/or hearing disorders (e.g. tinnitus) on music listening, rehearsing, composing, and sound editing, recording and mixing.
- Facilitate shared decision making between audiologist and patient, and prioritize problems.
  
  Audiologist together with patient design treatment focusing on issues that are treatable.
• Increase patient satisfaction since the audiologist will have tailored questions that may help build rapport.

• Audiologist should “counsel, counsel, counsel” on areas that are not treatable (Blum, 2016). However, the audiologist cannot be expected to counsel properly if they do not understand the specific issues these patients face. The final goal is to produce supplementary materials for audiologists, such as tutorials, so audiologists can increase awareness, knowledge and understanding of musicians’ issues and needs by using the QUSP. Perhaps musician patients will not be a “nightmare” (Fligor, 2009) anymore.

Additional informal interviews were conducted and informal feedback gathered from audiologists, advisors and other doctorate students of audiology. Revisions were made to shorten the length, and one question specific for post-production engineers was added.

Participants answer “yes,” “sometimes,” or “no.” A three-point scale was chosen for scoring with “yes” = 4, “sometimes” = 2 and “no” = 0. Maximum total score is 56, a higher score indicating a more severe self-perceived impairment. Questions based on tinnitus and hyperacusis had follow-up questions if the participant answered “yes” to help identify appropriate medical referrals, however the answers were not incorporated into the final score.

When this research project started, there were 19 questions. Throughout administering the QUSP, however, some questions were clearly irrelevant to participants and were eventually omitted. By the end of the data collection phase 15 questions remained, and one that asked if the participant used hearing protection was not scored as this was not necessarily a reflection of self-perceived difficulties. The final version can be found in Appendix A.

Procedures

Case History
Participants completed a brief, interview-style, case history including years worked, specific engineer type, musician/non-musician and instrument played, history of loud sound exposure, hearing protection use and presence of tinnitus as defined by a constant ringing, hissing, buzzing in one or both ears.

Hearing Questionnaire for Sound Professionals (HQSP)

The investigator administered a questionnaire, face-face, which assessed the self-perceived difficulties of hearing loss and hearing disorders on music and sound perception.

Audiometry, Tympanometry and Otoscopy

Pure tone thresholds at octave frequencies of 250 - 8000 Hz and inter-octave frequencies 3000 and 6000 Hz were measured utilizing the modified Hughson-Westlake procedure for each participant. Extended high frequencies from 9 - 18 kHz were measured for the Chicago participants however not New York City participant due to equipment limitations. All participants had an otoscopic examination and tympanometry performed prior to audiometry to ensure absence of any obstructions or significant middle ear pathologies that might affect threshold testing. The investigator provided an interpretation of the results and informational counseling immediately after testing. All questions were answered by the investigator.

Personal Noise Dosimetry

Three Etymotic Research ER200DW8 Personal Noise Dosimeters were used. While not a Class 2 or 1 device, the settings of this low-cost dosimeter are consistent with ANSI S1.25–1991 (R2002) and NIOSH Criteria for a Recommended Standard (NIOSH, 1998). Additionally, results from a peer-reviewed study by Cook-Cunningham (2014) assessed the accuracy and
reliability of this device by comparing it to two Type 2 dosimeters with pink noise and collegiate music settings as the sound sources.

The ER200DW8 can record the following noise exposure criteria:

- Real-time and final noise dosage with respect to NIOSH criteria and exchange rate. Expressed in a percentage.
- Real-time Leq (equivalent continuous sound level) in dBA, sampled every 220 ms then averaged over a 3.75-minute period. I.e., the final data output reports one number every 3.75 minutes.

Specifications include:
- Criterion level: 85 dBA (NIOSH)
- Exchange rate: 3 dB
- Threshold level: 75 dBA (NIOSH)
- Frequency weighting: A weighted
- Response: slow
- 16 hours of continuous run time, then automatic shut-off
- Unable to measure peak SPL

Additional technical specs:
- Microphone Specs: 100 Hz - 15000 Hz, 70 - 130 dB RMS

Three participants wore the dosimeter for a total of 9 days from morning until night. They were provided written and video instructions on use, and clipped the device either to a breast pocket or the center of the chest. The dosimeters were factory calibrated by Etymotic Research prior to each participants’ measurements and for each run was between 0.0 to -2.4 dB accuracy as automatically reported at the end of each run.

Hearing injury due to loud sound exposure is cumulative; it does not distinguish between work or after-work exposure, so the participants wore the dosimeter for an entire day including commutes to and from work as well as activities after work to better estimate a daily noise dose. This approach was utilized in the study of music recording engineers by Bulla and Hall (1998). Each participant maintained a brief journal where they recorded the day’s activity including whether they rode a subway to work or watched a movie at home. The journal was
used for reference purposes to determine whether extra-curricular activities contributed to the overall noise dose.

**RESULTS**

**Demographic Information**

Participants were 19 males and 4 females (N = 23) audio post-production sound recordists, editors and re-recording mixers between the ages of 23 - 62 (M = 38.8 years). All worked full time (M = 14 years worked). 16 (70%) had been past or current musicians for at least 7 years. Instruments ranged from violin to club DJs and percussionists in marching bands; genres from rock and electronic to jazz and classical. All performed a variety of duties as is typical of this occupation, including re-recording mixing on a dub stage (a small movie theater), sound design (creating sound effects), assistant sound editing (organizing audio software sessions), dialogue editing with headphones and recording foley and additional dialogue replacement (ADR). None were solely music engineers although 3 (13%) occasionally recorded and mixed music. All reported some additional history of loud sound exposure from concert-going to gunfire.

**Audiometric Status**

Table 1 presents the binaural mean hearing thresholds with standard deviations for all participants, different age ranges, years worked, musicians or non-musicians, males/females. 17% of participants (N = 4) had unilateral mild hearing loss for 1 - 2 thresholds, and 4% (N = 1) had bilateral mild to moderate hearing loss for most 2 - 8 kHz. Table 2 shows the percentage of Hoffman and Coles audiometric notches (as described by Lie, A., Engdahl, B.,
Table 1. Audiometric status for participants broken down by groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>Statistic</th>
<th>500</th>
<th>1000</th>
<th>2000</th>
<th>3000</th>
<th>4000</th>
<th>6000</th>
<th>8000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>Mean</td>
<td>16.7</td>
<td>15.9</td>
<td>15.4</td>
<td>18.7</td>
<td>28.3</td>
<td>20.9</td>
<td>13.7</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>(8.9 )</td>
<td>(9.6 )</td>
<td>(14.6)</td>
<td>(17.9)</td>
<td>(26.1)</td>
<td>(20.3)</td>
<td>(22.0)</td>
</tr>
<tr>
<td>Males</td>
<td>Mean</td>
<td>8.3</td>
<td>7.9</td>
<td>7.5</td>
<td>9.5</td>
<td>14.6</td>
<td>10.1</td>
<td>5.1</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>(4.7 )</td>
<td>(5.1 )</td>
<td>(8.0 )</td>
<td>(9.7 )</td>
<td>(13.5)</td>
<td>(11.0)</td>
<td>(11.0)</td>
</tr>
<tr>
<td>Females</td>
<td>Mean</td>
<td>8.8</td>
<td>8.1</td>
<td>8.8</td>
<td>8.8</td>
<td>11.9</td>
<td>11.9</td>
<td>15.0</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>(3.2 )</td>
<td>(3.8 )</td>
<td>(2.5 )</td>
<td>(5.2 )</td>
<td>(12.1)</td>
<td>(5.5 )</td>
<td>(7.4 )</td>
</tr>
<tr>
<td>Ages 23 - 29</td>
<td>Mean</td>
<td>7.5</td>
<td>8.8</td>
<td>5.6</td>
<td>5.0</td>
<td>5.0</td>
<td>1.9</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>(1.8 )</td>
<td>(2.2 )</td>
<td>(2.7 )</td>
<td>(1.8 )</td>
<td>(1.8 )</td>
<td>(5.4 )</td>
<td>(4.1 )</td>
</tr>
<tr>
<td>Ages 30 - 39</td>
<td>Mean</td>
<td>7.1</td>
<td>6.0</td>
<td>5.8</td>
<td>8.1</td>
<td>9.6</td>
<td>8.5</td>
<td>3.1</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>(4.2 )</td>
<td>(2.8 )</td>
<td>(4.2 )</td>
<td>(7.8 )</td>
<td>(7.3 )</td>
<td>(7.0 )</td>
<td>(4.3 )</td>
</tr>
<tr>
<td>Ages 40 - 49</td>
<td>Mean</td>
<td>9.2</td>
<td>6.7</td>
<td>5.8</td>
<td>5.8</td>
<td>23.3</td>
<td>15.0</td>
<td>3.3</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>(5.1 )</td>
<td>(3.1 )</td>
<td>(5.1 )</td>
<td>(3.1 )</td>
<td>(10.5)</td>
<td>(4.1 )</td>
<td>(2.4 )</td>
</tr>
<tr>
<td>Ages 50-62</td>
<td>Mean</td>
<td>12.5</td>
<td>13.8</td>
<td>16.9</td>
<td>20.0</td>
<td>30.0</td>
<td>21.3</td>
<td>26.3</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>(3.1 )</td>
<td>(6.7 )</td>
<td>(10.5)</td>
<td>(10.2)</td>
<td>(15.1)</td>
<td>(12.8)</td>
<td>(11.4)</td>
</tr>
<tr>
<td>Years worked:</td>
<td>Mean</td>
<td>8.4</td>
<td>7.8</td>
<td>6.3</td>
<td>8.8</td>
<td>8.1</td>
<td>9.4</td>
<td>3.1</td>
</tr>
<tr>
<td>5 - 10</td>
<td>SD</td>
<td>(3.9 )</td>
<td>(2.6 )</td>
<td>(3.8 )</td>
<td>(8.3 )</td>
<td>(7.7 )</td>
<td>(7.2 )</td>
<td>(4.3 )</td>
</tr>
<tr>
<td>Years worked:</td>
<td>Mean</td>
<td>7.1</td>
<td>6.7</td>
<td>5.0</td>
<td>4.6</td>
<td>14.6</td>
<td>10.0</td>
<td>2.5</td>
</tr>
<tr>
<td>11 - 20</td>
<td>SD</td>
<td>(4.4 )</td>
<td>(2.4 )</td>
<td>(5.0 )</td>
<td>(5.3 )</td>
<td>(11.9)</td>
<td>(6.9 )</td>
<td>(2.5 )</td>
</tr>
<tr>
<td>Years worked:</td>
<td>Mean</td>
<td>12.5</td>
<td>13.8</td>
<td>16.9</td>
<td>20.0</td>
<td>30.0</td>
<td>21.3</td>
<td>26.3</td>
</tr>
<tr>
<td>21 - 40</td>
<td>SD</td>
<td>(3.1 )</td>
<td>(6.7 )</td>
<td>(10.5)</td>
<td>(10.2)</td>
<td>(15.1)</td>
<td>(12.8)</td>
<td>(11.4)</td>
</tr>
<tr>
<td>Musician &gt; 7 years</td>
<td>Mean</td>
<td>7.2</td>
<td>6.4</td>
<td>5.9</td>
<td>7.7</td>
<td>10.6</td>
<td>7.7</td>
<td>2.7</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>(3.7 )</td>
<td>(3.1 )</td>
<td>(3.6 )</td>
<td>(6.6 )</td>
<td>(9.5 )</td>
<td>(7.4 )</td>
<td>(4.4 )</td>
</tr>
</tbody>
</table>

Hoffman, H. J., Li, C., & Tambs, K. (2017)\(^3\) found in at least one ear for each group. The Coles criteria was used for most of the analyses since it identifies more notches. A higher prevalence

---

\(^3\) The Hoffman notch has stricter criteria than Coles: at least one threshold at 3, 4, or 6 kHz exceeds the average threshold of 0.5 and 1 kHz by 15 dB and is lower (better) than the threshold at 8 kHz by at least 5 dB. The Coles notch criteria: at least one threshold at 3, 4 or 6 kHz is lower (worse) than thresholds at 1 or 2 kHz and at 6 or 8 kHz by at least 10 dB.
of Coles notches was found in left ears compared to right (14 left ear notches, 8 right) but the
difference was not statistically significant. Note that a presence of a notch does not necessarily
prove hearing injury due to loud sound exposure.

Table 2. Prevalence in % of audiometric notches for participants broken down into age, years worked and
years as a musician.

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Mean age, years</th>
<th>Hoffman Notch (Uni or Bilateral)</th>
<th>Coles Notch (Uni or Bilateral)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>23</td>
<td>38</td>
<td>26%</td>
<td>61%</td>
</tr>
<tr>
<td>Males</td>
<td>19</td>
<td>37</td>
<td>26%</td>
<td>68%</td>
</tr>
<tr>
<td>Females</td>
<td>4</td>
<td>43</td>
<td>25%</td>
<td>25%</td>
</tr>
<tr>
<td>Ages 23 - 29</td>
<td>4</td>
<td>25</td>
<td>0%</td>
<td>25%</td>
</tr>
<tr>
<td>Ages 30 - 39</td>
<td>12</td>
<td>34</td>
<td>17%</td>
<td>58%</td>
</tr>
<tr>
<td>Ages 40 - 49</td>
<td>3</td>
<td>44</td>
<td>33%</td>
<td>100%</td>
</tr>
<tr>
<td>Ages 50-62</td>
<td>4</td>
<td>58</td>
<td>75%</td>
<td>75%</td>
</tr>
<tr>
<td>Years worked:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 - 10</td>
<td>8</td>
<td>30</td>
<td>13%</td>
<td>38%</td>
</tr>
<tr>
<td>11 - 20</td>
<td>6</td>
<td>40</td>
<td>17%</td>
<td>84%</td>
</tr>
<tr>
<td>21 - 40</td>
<td>4</td>
<td>58</td>
<td>75%</td>
<td>75%</td>
</tr>
<tr>
<td>Musician &gt; 7 years</td>
<td>16</td>
<td>32</td>
<td>31%</td>
<td>50%</td>
</tr>
</tbody>
</table>

Figure 1 shown below reveals the mean hearing thresholds for all participants with
standard deviations by ear. A slight notched pattern emerged. Mean thresholds were not
significantly different between ears.

Tympanometry revealed normal tympanometric peak pressure, static acoustic
compliance, and ear canal volume for of 96% (N = 22) participants. One patient showed
significant negative pressure in the left ear. Tympanic membranes were fully visualized via otoscopy with no gross abnormalities noted in 91% ($N = 21$). Two participants had non-occluding cerumen in the left ear with tympanic membranes partially visualized.

![Mean Thresholds All Participants](image)

*Figure 1. Mean and SD hearing thresholds for all participants by ear.*

**Hearing Questionnaire for Sound Professionals (QUSP)**

Cronbach’s *alpha* was calculated to measure the overall internal consistency of the QUSP (i.e. is the questionnaire an internally consistent and reliable measure of related variables)? The QUSP’s Cronbach *alpha* was 0.87 indicating good internal consistency and reliability.

The mean total QUSP score was 13.2 (SD = 7.6). 25% ($N = 13$) scored between 2 - 14, 39% ($N = 9$) scored between 15 - 28, 4% ($N = 1$) scored between 29 - 42 and 0% between 43 - 56. Correlation coefficients were calculated between total QUSP scores and participant variables including binaural mean hearing thresholds, age, total years worked, and years as a musician.
None of the correlations reached statistical significance. We found two questions that did not assess what they intended to assess. One question attempted to assess hyperacusis. For “Do you feel like you are especially sensitive to loud sound?” 74% responded “yes” or “sometimes.” However, when the follow-up question was asked, “do sounds ever cause you pain or extreme discomfort, more than a typical person?”, answers varied. The other question attempted to assess an emotional consequence of hearing impairment. For “Do you worry that your hearing negatively affects your ability to work properly?” 30% responded “yes” or “sometimes,” however 100% further commented something like, “not now, but in the future,” so the question was not necessarily assessing a current emotional problem. Eliminating these questions resulted in a significant correlation (Table 4) between QUSH scores and binaural mean hearing thresholds ($0.373, p = 0.05$) and age ($0.374, p = 0.05$).

### Table 3. Correlation coefficients between total QUSH scores and participant variables.

<table>
<thead>
<tr>
<th>Correlation of Variables</th>
<th>Pearson Product Moment Correlation Coefficient ($p &lt; 0.05^{*}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total QUSH scores and mean binaural thresholds (n = 23)</td>
<td>0.322</td>
</tr>
<tr>
<td>Total QUSH scores and age (n = 23)</td>
<td>0.297</td>
</tr>
<tr>
<td>Total QUSH scores and years worked as an engineer (n = 23)</td>
<td>0.226</td>
</tr>
<tr>
<td>Total QUSH scores and years as a musician (n = 17)</td>
<td>0.310</td>
</tr>
</tbody>
</table>
Table 4. Correlation coefficients between modified QUSP scores and participant variables.

<table>
<thead>
<tr>
<th>Correlation of Variables, 2 Questions Eliminated</th>
<th>Pearson Product Moment Correlation Coefficient (p &lt; 0.05*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total QUSP scores and mean binaural thresholds (n = 23)</td>
<td>0.373*</td>
</tr>
<tr>
<td>Total QUSP scores and age (n = 23)</td>
<td>0.374*</td>
</tr>
<tr>
<td>Total QUSP scores and years worked as an engineer (n = 23)</td>
<td>0.267</td>
</tr>
<tr>
<td>Total QUSP scores and years as a musician (n = 17)</td>
<td>0.305</td>
</tr>
</tbody>
</table>

Figure 2 (following page) shows the correlations of each individual participant’s QUSP scores plotted against mean binaural hearing thresholds, age, years as a musician and years worked as an audio engineer. (continued on following page)
Fisher’s exact test was used to find associations between participant history of being a musician, how many years the participant worked as an audio engineer, and presence of an audiometric notch with both reports of tinnitus (Table 5, following page) and loud sound sensitivity (Table 6, following page). No statistically significant associations were found. (continued on following page)
Tinnitus was reported by participants by case history and by answering “yes” or “sometimes” to the question: “Does ringing or any noise in your ears cause you to feel frustrated or stressed?” If the participant answered “yes” or “sometimes,” further clarification was made as to whether it was continuous as opposed to occasional, and unilateral or bilateral. 48% (N = 11) participants reported continuous tinnitus in at least one ear. Loud sound sensitivity was reported by participants by answering “yes” or “sometimes” to the question: Do you feel like you are especially sensitive to loud sounds?” 70% (N = 16) participants reported “yes” or “sometimes.”

Readability was assessed using the Flesch–Kincaid Grade Level Formula. The QUSP level was 7.7 which indicates an eighth grade reading level is required to ensure proper readability and increase the validity of the results (Douglas and Kelly-Campbell, 2018).

**Personal Dosimetry**
Participant journals revealed that participants spent between 6 - 11 hours performing audio post-production tasks (mean = 8.7, SD = 1.6), an average of 1.5 hrs/day commuting on the NYC subway, and a variety of other activities such as “Watch movie at home.” Daily doses using NIOSH criteria ranged from 12% - 76% (mean = 33%, SD = 22%) and overall continuous equivalent sound levels (Leq) for the entire day ranged from 73 - 81 dBA (mean = 76 dBA, SD = 3 dBA). Figure 3 shows the breakdown of noise dose by activity. The specific post-production engineering task that resulted in the most intense Leq levels (78 - 86 dBA) was “Mix review, playback and punching,” roughly hours 1 - 5 in Figure 4. The task resulting in the lowest Leq levels (0 - 71 dBA) was “Sound editing, emails, prepping,” roughly hours 5 - 8.5 in Figure 4.

Figure 3. Daily noise dose by activity.
DISCUSSION

The purpose of this preliminary study was to provide information about the hearing status of APPEs, to develop and assess a questionnaire that reflects the self-perceived hearing status of APPEs, and to measure the daily noise dose for an APPE’s typical work day and assess whether they are at risk for permanent hearing loss due to sound exposure.

Audiometric Status

Hearing threshold results of this study were both similar and different compared to results from other studies. Mean hearing thresholds for all participants for 3, 4, 6 and 8 kHz were 9, 14, 10 and 6 dB HL respectively with large standard deviations (> 10 dB HL). A survey by Martinez and Gilman (1987) reported thresholds of 100 audio recording engineers were 7, 12, 14 and 12 dB HL with large standard deviations as well. Participants included all audio engineer types, music and film, ages < 30 - 60 utilizing an on-location test truck with an up and down test method. Mean thresholds for 3, 4, 6 and 8 kHz of 59 musicians aged 30 - > 70 from the Chicago
Symphony, as measured by Royster et al. (1991) were lower (better) with 6, 5, 1 and -4 dB HL respectively with large standard deviations. 14 rock/pop musicians had mean thresholds of 8, 11, 9 and 5 dB HL with standard deviations under 10 dB HL (Samelli et al., 2012).

Also, it is unlikely that occupational sound exposure alone can account for all of the audiometric notches and hearing losses. Other analyses of classical musicians, as reviewed by Woolford et al. (1998), reported that though hearing loss exists for a percentage of musicians, hearing loss due to music alone is “very small indeed” (p. 274), as other etiologies included gunfire, conductive hearing loss, machine noise and Meniere’s disease. Similarly, participants in this current study reported additional loud sound exposure that may contribute to hearing status. Almost all (N = 16) reported regular attendance at nightclubs and live music venues. One participant worked in a “loud” coffee truck for 5 years, one regularly rides a motorcycle, one had a history of mandibulectomy with partial facial paralysis, and another with a recent viral infection affecting his hearing. All were urban dwellers exposed regularly to subway noise.

Though hearing thresholds were mostly in the normal hearing range, 5 participants did show mild to moderate hearing losses, many had audiometric notches and most reported tinnitus and/or loud sound sensitivity. Whether reports of loud sound sensitivity was truly hyperacusis was somewhat unknown, as loudness discomfort levels were not tested. Participants were asked if loud sound ever caused pain or extreme discomfort, and answers varied. Although we cannot realistically pinpoint what, exactly, caused the notches, losses or hearing disorders given the varied backgrounds, it is likely that regular exposure to amplified sound during work, often above 85 dBA, is one of the many, though not the exclusive, contributing factors.

Participants were volunteers, and most verbalized a good deal of interest and concern in their hearing status. Some audio post-production engineers who were contacted adamantly
expressed disinterest in participating; a common reply being, “I don’t want to know [if I have hearing loss].” The majority were relieved to know that though they might have had a notch (which was explained in full), they did not have, or had a mild, diagnosable hearing loss.

**QUSP**

A reliable test will have consistent results over multiple administrations. Initial evaluation of the QUSP revealed that the questionnaire has good internal consistency or reliability \( (\alpha = 0.87) \)^4. However, test-retest reliability has not yet been measured. Test validity was not measured at this time as it is complex and often ignored, but reliability is a prerequisite to validity (Ventry and Weinstein, 1982). Validity indicates that the tool measures what it purports to measure. In other words, does a high score on the QUSP actually indicate that the person perceives significant impairments, activity limitations, participation restrictions and emotional frustrations due to hearing difficulties or are they just picky, critical audiophiles? The QUSP is being revised, and validity will be addressed during a future study.

One of the purposes of the QUSP is to obtain information about the patient that more objective measurements are unable to do. It is well known that the “gold standard” test, pure tone thresholds, is inadequate for painting the whole picture of the consequences of hearing impairment (Alpiner and McCarthy, 2000, Ventry and Weinstein, 1984). Self-reported questionnaires can reflect more subjective experiences like depression, fatigue, or inabilities to socialize (Weinstein, 2015). For sound engineers and musicians, the audiogram can be even less relevant compared to a non-musician, as simply having a +/- 10 or 5 dB of test-retest reliability often leads them to question the efficacy of the results for their personal benefit. Sound engineers work in increments of 1 dB, often a difference of 0 and 10 dB on an audiogram is

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4 Excellent is > 0.90, unacceptable > 0.65 (DeVellis, 2012).
alarming regardless of the degree or ear. There were little to no correlations between QUSP scores and audiometric status, years worked as an engineer, years as a musician and age, indicating that the QUSP provides information that cannot be extracted from pure tone threshold results, age or experience alone. Many of the questions address issues that may not result from loss of hearing sensitivity such as tinnitus or diplacusis, so the lack of significant correlations to mean pure-tone thresholds is unsurprising and provides support for using the tool in the clinic.

Regarding revisions, one question consistently needed clarification: “Do you have difficulty understanding dialogue in film or TV shows?” Many people, especially dialogue editors, responded, “Yes, but that’s because it’s probably not mixed well.” So the question was lengthened to, “Do you have difficulty picking out dialogue in film or tv shows due to hearing difficulties?

Participants had numerous follow-up questions during the QUSP. Overall, it may be most useful as a counseling tool; a way to educate engineers about additional disorders that can result from cumulative loud sound exposure (e.g., diplacusis or distortions) that most were previously unaware of. If the patient has high scores, the QUSP could be used in combination with the MOSI (Beach et al., 2018) to help provide more extensive, tailored recommendations, goals and strategies for hearing loss prevention strategies.

**Dosimetry and Sound Exposure**

Personal noise dosimeters using NIOSH criteria were used by audio post-production engineers for a total of 9 days at 3 different film sound studios in New York City. Results were all well under a 100% dose, 5 out of 9 were even under a 25% dose. The measurements were made from morning until night and included typical daily life activities such as commutes on the New York City subway and watching movies at home. Overall Leq levels were 72 - 80 dBA.
Though not a direct comparison since these were for 8 - 14 hours days, they are consistent with the Leq levels for feature films in the theater reported in previous literature (73 - 79, 70 - 77, 52 - 80 and 70 - 75 Leq by Ferguson et al., 2000; Mullen, 2003; Warszawa and Sataloff. 2010; and Huth et al., 2014, respectively). It is important to point out that these Leq values used with noise dosimetry can present skewed results and may not accurately represent whether or not damage risk criteria has been met. For example, you can be exposed to 55 minutes of sound > 100 dBA but the with overall Leq = 78 dBA like the measurements for the movie musical *Hairspray* showed by Warszawa and Sataloff (2010).

Compared to the study on studio music engineers by Bulla and Hall (1998), the overall noise doses in our study (12% - 76% using NIOSH criteria) were lower than their 23% - 290% Department of Defense criteria (which is similar to NIOSH) or 12% - 57% OSHA dose. This could be due to film sound engineering activities having a greater dynamic range, from quiet dialogue editing sessions to the heavy sound effects and music scenes. Additionally, activities varied from quiet business emailing to setting up a mix session (sound may not even be played). The loudest part of an audio post-production engineer’s schedule is typically the re-recording mix, or dubbing. This is one of the final steps, where the director and re-recording mixer, and then often assistants, producers and other team members, are in a studio with audio and acoustic specifications that resemble a movie theater. Loud scenes will be played back and tweaked repeatedly. While there were re-recording mix sessions during some of the dosimetry measurements in this study, most days were *not exclusively* mix sessions. Furthermore, the industry standard is for mix rooms to be calibrated to 85 dBC SPL, however some engineers mix at 82 or even 78 dBC to avoid ear fatigue (a positive by-product of which may be hearing loss
prevention). For 4 of the 9 days measured, the engineers monitored at 78 dB, the other days were unknown.

**Limitations of OSHA and NIOSH Criteria**

Dosimetry results should be interpreted with caution because they potentially downplay the importance of hearing conservation needs. Noise dosimetry is based on A-weighted sound level measurement that OSHA developed decades ago to predict whether industrial workers were at risk for permanent thresholds shifts (PTS) as described by a 10 dB decrease in the average threshold at 2, 3 and 4 kHz. I.e., these criteria are sensitive for significant hearing loss and do not predict smaller changes. NIOSH is more conservative with a decrease by 15 dB in any threshold up to 6 kHz. With both criteria, some audiometric notches may not be considered a PTS. Additionally, OSHA is only protective for 75% of the population, so 1 in 4 people may still develop hearing loss while adhering to their permissible exposure limits (Niquette, 2009). NIOSH criteria still allows 8% of the population to slip through the cracks. Additionally, PTSs are assessed with pure tone audiology. However, pure tone audiometry is not sensitive for hearing disorders such as tinnitus and cochlear synaptopathy (Liberman and Kujawa, 2017). Finally, research contributing to the criteria are based on continuous, steady, noise-like sound over a 40-hour work week, not including weekends or after-work activities (Kardous et al., 2016) thus not perfectly appropriate for people who engage in loud recreational activities. Also, dosimetry is not accurate for impulse sound (Woolford et al., 1988, p. 271). In this study, we can assume that peaks and transients regularly reached over 105 dBC (the maximum headroom of each individual speaker in a properly calibrated studio) and in a surround sound studio or theater, combined speakers output transients that reach up to 140 dBC, deemed unsafe.
even by OSHA. Thus, NIOSH recommends hearing protection for any sound that reaches 85
dBA (Kardous et al., 2016). Though noise doses are low and Leqs conservative, levels did
consistently surpass 85 dB, therefore audio post-production engineers should still incorporate
hearing conservation strategies into their daily lives.

**Recommendations**

The strongest recommendations for APPEs are regular hearing evaluations to monitor
any gradual changes in hearing status. If threshold shifts are noted, the audiologist can discuss
hearing conservation strategies with the patient.

Formally, it is unknown whether editors or mixers have ever been fired or not hired due
to hearing impairments. Veteran sound mixers still regularly work, and although their hearing
status is not public knowledge, this study implies that many likely have at least mild impairments
or hearing disorders. They are still performing their jobs quite spectacularly as any Academy-
Award Winner list will show. If some over-compensate, for example by increasing the level of
the high frequencies to compensate for loss of high frequency sensitivity, visual tools such as
real-time spectral analyzers can help keep the mix balanced. Dialogue editors can use
spectrograms to help identify soft, unwanted, high-frequency noises. Unlike live musicians who
require quick temporal reactions and the need to constantly adjust their intonation, audio post-
production engineers work in steps. They start and stop constantly, revise and refine, and team
members check each other’s work. The process is more akin to an orchestral rehearsal. The
“performance” happens in the movie theater. Thus, hearing impairments and hearing disorders
may not actually have dire consequences on the ability to perform their job activities.
We do not expect and will not encourage sound engineers to start wearing hearing protection at all times. It is unnecessary given the low noise dose and overall low-risk sound exposure levels. Audiologists can recommend a personal, low cost dosimeter like the Etymotic Research ER200 for re-recording mixers. If a 50% dose is reached, they can choose to then use hearing protection. However, the audiologist should recommend a low attenuation, high fidelity custom silicone earplug when they are unable to turn the level down for particularly long and loud scenes. Etymotic Research developed an earplug filter that attenuates sound by 9 or 15 dB with a relatively flat frequency response up to 8 kHz (above which the sound is attenuated by > 15 dB) (Etymotic Research Inc., 2016). Between colleagues, it is known in the film sound industry that engineers in one of the most renowned studios, Skywalker Sound in Northern California, regularly wear earplugs during mix sessions. Many companies manufacture custom silicone earplugs using Etymotic filters. However, Sensaphonics Hearing Wellness earplugs are crafted with a sound bore that is shaped to resonate 2700 Hz, the natural resonance of the human ear canal (Etymotic Research Inc., 2016; Miskowicz, 2017). The ear canal portion reaches the second bend, which is helpful for reducing the occlusion effect, and ear impression technique is detailed and specific for optimizing the seal, even for professional vocalists who move their mouth to extreme positions. All of these carefully designed features contribute to a more natural sound quality that even professional musicians will accept, so engineers may, too.
APPEs incorporate visual tools to carefully monitor sound, but if they are aware of their hearing status, they may utilize the tools more regularly or differently. Audiologists can counsel patients on these strategies. Audiologists are also strongly encouraged to test extended high frequencies with this population. One of a APPE’s daily task is to pick out extended high frequency noises in original production audio such as a buzzing fluorescent light and eliminate it. Many anecdotes exist about the young intern walking into the studio and asking the veteran sound mixer, “what’s that high pitched noise?” If the APPE has poor extended high frequency thresholds, the audiologist can recommend that they compensate by relying more heavily on visual tools like spectrograms (Figure 6), which all APPEs have at hand. Perhaps the veteran will not be caught off guard by the young intern.

![Spectrogram from iZotope’s RX 6 Noise Reduction and Audio Repair software showing dialogue with a 15 kHz noise.](image)

Figure 6. Spectrogram from iZotope’s RX 6 Noise Reduction and Audio Repair software showing dialogue with a 15 kHz noise.

Loss of frequency selectivity and widening of critical bands can lead to a signal-to-noise ratio (SNR) loss (Moore, 2015). This may cause an action scene with a pounding musical score to sound muddy, and a mixer may over-compensate by increasing the SNR of the
dialogue. Though a higher SNR will likely be appreciated by audience members with hearing impairment, the engineer should still be aware of the overall, aesthetic impact of this approach. If speech-in-noise tests are performed, like the QuickSIN (Killion et al., 2014), and an engineer is found to have a significant signal-to-noise ratio loss, the audiologist can counsel the patient about the natural inclination he or she might have to mix the dialogue at a higher SNR and to rely more heavily on their sound level meter or loudness meter tools, which all mixers have.

Finally, though this study does not explore distortion product otoacoustic emissions (DPAOEs), this test may show outer hair cell loss before the conventional audiogram (Spankovich and LePrell, 2017) and accordingly is recommended when testing hearing of APPEs. Additionally, it can increase patient satisfaction and patient-clinician rapport, as APPEs seem to be personally fascinated by this test.

LIMITATIONS

Equipment limitations could decrease external validity of the audiometric results, as three different audiometers were used in multiple locations. Though all were calibrated, the times between the most recent calibration varied. Both insert earphones and supra-aural headphones were used which could result in elevated low frequency thresholds for participants using inserts but not for patients using supra-aural headphones.

The study did not use random sampling, and there was a small sample size of only 23 participants. Between these participants, their professional, recreational and occupational history

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5 Engineers and researchers connected with the BBC in the UK are working on implementing object-based audio broadcasts so that hearing impaired listeners can independently control levels of dialogue, music and sound effects (Shirely et al., 2017). Results showed improvements for many of the hearing impaired participants.
of sound exposure varied significantly and so it is impossible to know the exact etiology of audiometric notches, reports of tinnitus and reports of loud sound sensitivity.

The QUSP has an eighth grade readability level. Although many of the participants in this study had college level degrees, the education level was not known for every single participant and so low readability could be a potential limitation.

**RECOMMENDATIONS FOR FUTURE RESEARCH**

Future studies with more participants are warranted and including extended high frequency audiometry is crucial. DPOAEs should also be measured. The principal investigator plans on following the current participants to see if their hearing status changes over time. Validity and test-retest reliability of QUSP should be assessed. The QUSP is a tool designed for audiologists to administer, however those unfamiliar with APPE activities may not fully know how to interpret the QUSP, so educational materials for audiologists should be designed.

Though preliminary dosimetry provided some information that will be sure to ease some APPE fears, more dosimetry for longer periods of time, especially for all day re-recording mix sessions, should be conducted to get a better idea of the noise dose during the most extreme work days and to more accurately provide appropriate recommendations.

On the patient side, outreach should be done to increase awareness of audiological services for APPEs. Organizations such as the Sound Editors Guild, sound editor unions and audio post-production houses in Hollywood and New York City, then nationally and globally, can be contacted as well as university programs, by local audiologists for care and education.
CONCLUSIONS

The majority of 23 audio post production engineers from a variety of ages, backgrounds and history of sound exposure, were found to have some indication of hearing loss or hearing disorders including audiometric notches, tinnitus and loud sound sensitivity. The QUSP was administered and showed to have good internal consistency. Scores mostly did not correlate with pure tone threshold results, indicating that the questionnaire is a valuable tool for further assessing these engineers’ hearing needs. Noise dosimetry results indicated that these engineers are not at risk for permanent threshold shifts due to occupational sound exposure alone, however noise dosimetry should not be the sole approach for assessing risk, especially since hearing difficulties that arise prior to threshold shifts can affect how the engineers work. Many participants with notches and tinnitus were under 40 years old, with potentially 25+ years left of their careers. Whether occupational sound exposure is significantly contributing or not, all audio post-production engineers should undergo routine, audiometric evaluations in order to prevent permanent hearing injury due to occupational, recreational and urban sound exposure. Additional hearing conservation practices such as utilizing a personal noise dosimeter and wearing appropriate hearing protection when necessary should be considered.
**APPENDIX A**

**Questionnaire for Sound Professionals (QUSP)**

<table>
<thead>
<tr>
<th>Question</th>
<th>Definitely</th>
<th>Maybe</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do you believe that you have experienced any permanent hearing injuries?</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>I Do you feel like you’re missing brightness, clarity or presence of sound?</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>I Do you have difficulty hearing warmth or fullness of sound?</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>I Do you strain to hear quiet passages in music or film?</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>I Is it difficult to understand speech when there’s a lot of background noise, like in a loud restaurant?</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>I Is it difficult for you to identify individual instruments in a musical performance?</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>PR Do hearing difficulties ever prevent you from attending concerts, theatrical events or films?</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>I Do pitches sound out of tune or sound like different pitches in each ear?</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>I Do you feel like you are especially sensitive to loud sounds?</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>I Do you ever hear distortions in sound like buzzing or squeaking?</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>AL Do you rely on visual cues, like spectrograms, when sound editing due to concerns with hearing?</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>I Do you have difficulty understanding dialogue in films or TV shows due to hearing difficulties?</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>E Does ringing or any noise in your ears cause you to feel frustrated or stressed?</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>E Do you worry if hearing problems are negatively impacting your work?</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>E Do difficulties listening to music or sound design as an audience member cause frustration or stress?</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>HC Do you wear earplugs in loud environments? (do not score this question)</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
</tbody>
</table>

Yes = 4, Sometimes = 2, No = 0  
Score (to be tallied by the interviewer): __________________

Please list further concerns you may have about your hearing needs, sound engineering abilities or music and sound design enjoyment on the following page:
APPENDIX B

Example of the report from the Etymotic ER-200DRW dosimeter.

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**ETYMÔTIC RESEARCH**

ER-200D Report

<table>
<thead>
<tr>
<th>Report Date</th>
<th>Tue, Apr 17, 2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>Report Time</td>
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</tr>
<tr>
<td>Serial Number</td>
<td>40531</td>
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<tr>
<td>Run</td>
<td>010</td>
</tr>
<tr>
<td>Run Type</td>
<td>Normal Run</td>
</tr>
<tr>
<td>Final Dose %</td>
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</tr>
<tr>
<td>Overall LEQ (dB)</td>
<td>81.40</td>
</tr>
<tr>
<td>Run Description</td>
<td>ES_03</td>
</tr>
<tr>
<td>Run Length (DD:HH:MM:SS)</td>
<td>00:13:41:19</td>
</tr>
<tr>
<td>Max Run Length (DD:HH:MM:SS)</td>
<td>00:16:00:00</td>
</tr>
<tr>
<td>Exchange Rate (dB)</td>
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</tr>
<tr>
<td>Criterion (dB)</td>
<td>85</td>
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<tr>
<td>Threshold (dB)</td>
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<tr>
<td>Signal Source</td>
<td>Microphone</td>
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<tr>
<td>Calibration (dB)</td>
<td>-0.0</td>
</tr>
<tr>
<td>Run Termination</td>
<td>Run ended due to manual shutdown.</td>
</tr>
<tr>
<td>Warnings</td>
<td>none</td>
</tr>
<tr>
<td>Software Version</td>
<td>4.04</td>
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</table>
REFERENCES


http://digitalcommons.wustl.edu/pacs_capstones/272


http://www.canadianaudiologist.ca/movies-too-loud/


