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Hearing Loss and Hearing Protection Use Among Midwestern Farmers

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HEARING LOSS AND HEARING PROTECTION USE AMONG MIDWESTERN FARMERS

by

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ABSTRACT

HEARING LOSS AND HEARING PROTECTION USE AMONG MIDWESTERN FARMERS

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Many farmers have noise-induced hearing loss, yet few use hearing protection when working around loud noise. A point source intervention (storing hearing protection devices near sources of noise) was implemented to help farmers overcome accessibility barriers related to using hearing protection. Intervention farmers (n=53) received education and the point source intervention; control farmers (n=36) received education only. During each year of the study, all farmers completed a questionnaire about their perceptions of hearing protection and participated in an audiometric test at their farm. Ambient sound pressure levels were taken during tests. The main objectives of this dissertation were to evaluate if the point source intervention improved farmers' perceptions about hearing protection and prevented hearing loss. The onsite audiometric test environments were also assessed.

The first study evaluated factors that influence farmers' perceptions about hearing protection. These perceptions improved during the study, specifically those related to barriers, self-efficacy, and intent. Older age was associated with positive perceptions of barriers concerning communication and intention to use hearing protection. Having hearing loss (both perceived and measured) was associated with lower intention of using hearing protection. These findings were similar for both intervention and control groups.

The second study, conducting audiometric testing on farms, showed that in most cases ambient noise levels exceeded the American National Institute Standard for audiometric test

rooms. Exceedances occurred commonly at lower frequencies, but rarely at high frequencies, which could compromise the reliability of the audiometric test data. Though unconventional, audiometric testing in nonstandard audiometric test environments can detect noise-induced hearing loss.

The final study revealed that a high percentage of farmers have audiograms indicative of noise-induced hearing loss. After adjusting for covariates, farmers' low-frequency hearing improved over the duration of the study. Farmers that were older had worse low-frequency hearing than younger farmers, and farmers in the control group had worse low-frequency hearing than intervention farmers. Older farmers had worse high-frequency hearing than younger farmers, and left ears had poorer hearing acuity than right ears. The point source intervention did not change the effect from education alone on farmers' perceptions or their hearing acuity.

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Hazardous Noise in the Work Environment

Widely recognized as one of the most common occupational hazards, each year 22 million American workers are exposed to hazardous noise.[1-3] Hazardous noise, defined as noise greater than 85 decibels, can be found in many work environments. Exposures may result from the operation of industrial machinery or heavy equipment. However, even the most benign sounds can become hazardous if they are loud enough and occur over an extended period. Environments where workers must shout to be heard less than 3-feet away, can be hazardous; this is often referred to as the 'three-foot rule'.[4] Short-term exposures to hazardous noise can cause temporary hearing impairment and tinnitus; repeated exposures can lead to permanent noise-induced hearing loss (NIHL).[1,3] It has been estimated that almost one-third of all cases of NIHL in the United States can be attributed to noise exposures at work.[5]

A Brief Overview of Sound and Hearing

The noises we hear are the direct result of sound waves created by pressure variations induced by a vibrating source.[4] The sound waves propagate through the air and are received by our outer ears and funneled into our inner ears, where they induce vibrations of the small organs in the middle ear through the resonance effect.[4] These oscillations are then translated by the brain into sounds that we recognize.[4] The characteristics of the sound depend on the initial force, the medium through which it travels, and properties of the vibrating source. The greater the displacement of the initial vibration; the louder the sound. Loudness is typically measured by sound pressure level in decibels (dB), which is analogous to the pressure exerted by the sound wave.[4] Sound pressure levels can be weighted to better represent the ear's response to noise. For instance, A-weighting adjusts sounds to better represent the human ear's response to sound.[4] Higher decibel sound pressure levels correspond to higher pressure impacts by the sound wave. For this reason, loudness is often referred to as the intensity of sound.[4] Most sounds that we hear travel through the air. However, sounds can travel through medium, such as water. The medium through which sound travels can affect the propagation of the sound wave causing it to lose (or gain) energy.[4] This property of sound is essential in designing acoustic environments to enhance sound, like in an auditorium, or to dampen sound, such as concrete sound walls near roadways.

The pitch of sound can be high or low; it is the frequency of the vibration, usually measured in Hertz (Hz).[4] High pitch sounds, such as sounds from a whistle or tea kettle, correspond to high-frequency vibrations. Low pitch sounds, like sounds from a tuba or thunder, correspond to lower frequency vibrations. Most sounds are not constant at a single frequency or result from a single sound wave.[4,6] In fact, sounds that we perceive, from a sole source, are a conglomeration of sound waves at several different frequencies.[6] Even within a single frequency, sound is rarely constant.

Sounds can be intermittent, or impulse sounds, such as the impact caused by a mechanical die or gunfire; sounds can also be steady-state, or continuous, like the steady hum from a radiator or a pneumatic conveyor.[3,4] Both types of sound can cause hearing loss. Constant sounds are thought to be more dangerous since they do not afford the ear any recovery time.[4] Nevertheless, high and low pitch sounds, and impulse and steady-state sounds can all be hazardous. Ultimately, the risk of hearing loss is determined by both the sound pressure level and the duration of the exposure.

Hearing Loss

Hearing declines naturally as we age in a phenomenon known as presbycusis.[4,7] As with other parts of our body, the small organs within our ears tend to degrade naturally over time.[4,7] Hazardous noise can greatly expedite this process by causing injury to these organs resulting in irreparable damage known as noise-induced hearing loss (NIHL). NIHL is a permanent and untreatable disease; it is the direct result of exposure to hazardous noise and can take years to develop to the point of recognition. Unfortunately, this can leave it undetected until later in life causing it to be masked by presbycusis.

Audiometric Testing

NIHL is identified on an audiogram through audiometric testing. The two types of audiometric testing involve air-conduction and bone-conduction.[8,9] Air-conduction tests assess an individual's subjective hearing sensitivity.[9,10] These tests are typically performed in a quiet location using an audiometer equipped with headphones.[10] During an air-conduction audiometric test, an individual is asked to listen for tones and to respond using an arm gesticulation when the tone is heard. The individual proctoring the test, tests for the pure tone hearing threshold levels at 500 – 8000 Hz in each ear. The hearing threshold level is the faintest sound pressure level that can be heard at a specific frequency. Bone-conduction tests are typically done using a vibrating source placed on the mastoid bone behind the ear.[8,9] The vibrating source induces vibrations along the skull and ossicular chain, which directly stimulate the cochlea and auditory nerve.[8,9] These tests are performed in a clinical setting; they are primarily used to validate air-conduction tests and further diagnose hearing loss.[8] The results from both tests are presented in an audiogram.

Interpreting an Audiogram

An audiogram displays an individual's pure tone hearing threshold levels (HTL) in each ear at 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz. Although humans can hear sounds ranging from 20-20,000 Hz, HTLs are usually tested from 500-8000 Hz.[4] Hearing at these frequencies is important, because hearing is most sensitive between 1000-4000 Hz and hearing loss often presents between 3000-6000 Hz.[4] Moreover, speech ranges from 250-4000 Hz, which means that hearing loss below 4000 Hz can impede communication.[4] Hearing threshold levels on the audiogram are usually categorized into different gradations of hearing loss to make them easier to understand.[8] The gradations for hearing loss are as follows:[8]

- Normal hearing – hearing threshold levels less than or equal to 25 dB
- Mild loss – hearing threshold levels between 26-40 dB

- Moderate loss – hearing threshold levels between 41-55 dB
- Moderate/severe loss – hearing threshold levels between 56-70 dB
- Severe loss – hearing threshold levels between 71-90 dB
- Profound loss – hearing threshold levels exceed 90 dB

Types of Hearing Loss

The two main types of NIHL are conductive and sensorineural.[8,11] Conductive hearing loss is usually associated with stifled sounds and low- to mid-frequency hearing loss. It can be a temporary and reversible condition caused by an obstruction in the ear canal, such as a build-up of cerumen (earwax); or it can be a more permanent condition caused by a congenital disorder, such as a shortened ear canal.[11] Sensorineural hearing loss, on the other hand, is a more permanent, acquired type of hearing loss.[8] It is typically associated with the inability to recognize speech; this type of hearing loss is frequently attributed to damage to the small organs in the inner ear, such as injury to the hair cells on the cochlea or presbycusis.[8] Most common treatment for hearing loss is symptom management. Hearing aids, for instance, can amplify noises and improve auditory detection of noise. However, there is no cure for hearing loss; thus, prevention is critical.

Social and Psychological Effects

Hearing loss alone can be socially isolating and frustrating for both individuals with hearing loss and those without hearing loss. In addition to NIHL, exposure to hazardous noise has been associated with tinnitus, physical pain, and psychological distress.[12,13] Research has shown that it may also reduce cognitive function and response time.[14] Hearing problems can contribute to accidents and injuries on the job and lower productivity, as hearing impairment and hazardous noise inhibit an individual's ability to hear warning signals and effectively communicate with others.[15-18] It has been estimated that a mere 5 dB increase in noise increases the risk of severe injury by 21%.[18]

Regulating Noise in the Work Environment

The Occupational Safety and Health Act

In 1970, the federal government promulgated a key piece of legislation, the Occupational Safety and Health Act (OSH Act).[19,20] This act gave rise to the Occupational Safety and Health Administration (OSHA), the National Institute of Occupational Safety and Health (NIOSH), and the workplace injury regulations and exposure standards that we follow today. During this same period, OSHA promulged the 'Noise Exposure Regulation' geared to address the hazard of occupationally-acquired hearing loss.[20] The first regulations were geared toward the elimination of hazardous noise in the work environment.[20] However, elimination was impractical for most workplaces; consequently, OSHA amended these regulations in 1981 to implement hearing conservation instead. These regulations were promulgated in 1983 and are still followed today.[19,20]

The regulations specific to noise can be found in 29 Code of Federal Regulations (CFR) 1910.95, *Occupational Noise Exposure.*[19,21] OSHA uses a time-weighted average (TWA) and exchange rate to determine an employees' exposure. The TWA considers the variability of noise over a certain time frame; it is the average noise exposure over a given period, usually 8-hours. The exchange rate describes the relationship between the noise exposure and the duration of the exposure to meet specific dose (in most cases 100%); OSHA uses an exchange rate of 5-dB in determining the appropriate duration of the exposure to meet the regulatory limits.[21] For instance, for every 5-dB increase in noise, the duration an employee can endure the noise is decreased by 50%. Though this method is not scientifically accurate, it is easy to remember on the job.

According to the OSH Act, workplaces that exceed a TWA of 85 dB must implement a hearing conservation program for employees; this value is considered OSHA's Action Level (AL).[21] Under these same regulations, employees can experience a TWA of 90 dB over 8-hours, which is OSHA's Permissible Exposure Limit (PEL).[19,21] Any exposures that exceed this limit initiate further interventions by the employer to reduce the exposures. These can include methods to reduce the intensity of sounds, such as retrofitting equipment with noise-dampening material, or reducing the duration of exposure for employees.[22] Either way, if the PEL is exceeded – the employer must act to reduce, prevent, or eliminate the exposure.

Hearing Conservation Programs

In addition to establishing acceptable exposure limits for hazardous noise, the OSH Act also describes the requirements for hearing conservation programs in the work environment. Under the OSH Act, hearing conservation programs must include: noise monitoring in the work environment; annual audiometric screening for employees; provision of hearing protection at no cost to the employee; and worker training and continuing education.[19] Employers must keep detailed records of all these activities to demonstrate compliance.[19] In addition, employers must keep records of each employee's baseline audiogram, usually conducted within the first year of employment, as well as records of their annual audiometric tests throughout their employment.[19,21] They also must monitor employees' hearing over the course of their employment and report any standard threshold shifts (STS) that may occur. An STS is defined as an average change of 10 dB or more in the hearing threshold level at 2000, 3000, and 4000 Hz relative to the baseline audiogram.[19,21] If an STS is detected, employers must notify the employee of the STS in writing within 21-days of the test; refit the employee for hearing protectors; retrain the employee about hearing conservation, and; refer the employee out for further care if warranted.[21] If an STS is proven, and the average decline in hearing level at 2000, 3000, and 4000 Hz is 25 dB or greater, then the STS must be recorded in the OSHA 300 Log of Work-Related Injuries and Illnesses.[21]

While OSHA's regulations are effective in protecting most workers, employers with fewer than ten employees are expected to self-regulate and implement the OSH Act at their discretion. They are not evaluated by OSHA, nor are they required to keep records or report injuries.

Consequently, the only incentive to comply with the OSH Act for these unique work environments is to protect one's health. This creates a precarious environment for workers in these enforcement-exempt workplaces, such as agriculture.

Farming in the United States

Agriculture represents a modest share of the United States' total gross domestic product at 5.5%, contributing nearly $992 billion to the economy in 2015.[23] Data from United States Department of Agriculture (USDA) 2012 Census showed that there were 3.2 million farmers operating 2.1 million farms.[24] The major commodities of American farms are cattle (and calves), corn, and soybeans.[25] Most principal farm operators in the United States are white men, aged 55-years or older, and they farm on average about 434 acres.[24] Many farms are family-owned and operated, which means most employ fewer than ten employees making them OSHA enforcement exempt workplaces.[24]

Farming is a dangerous, dirty, and time-consuming occupation. Farmers often work independently; their job is highly affected by the weather, determining when they can get crops planted or harvested. Farmers can be in the field for 12-hours or more per day during these times of the year; often, they usually stay in the field until the job is complete. Farmers are resilient, self-motivated, and fiercely independent workers. While they are the hard-working, blue-collar workforce that drives and feeds the American population; these admirable traits can instill feelings of hardiness and invincibility in farmers. Fortunately, modern farming has helped to minimize some of the risks associated with farming through the advent of safer equipment. For instance, today's tractor cabs are enclosed and automated with technology that farmers can use to program the till depth, seed drop rate, and map the planting area. Older equipment certainly didn't afford these luxuries; most didn't even have an enclosed cab.

Although farming equipment has advanced greatly over the years, farmers still have high rates of fatalities (21.4 per 100,000 worker-years)[26] and injuries (5.0 per 100 worker-years).[27] In addition, farmers are also highly affected by work-related illnesses, such as respiratory disease, cancer, musculoskeletal disorders, and pesticide toxicity.[28] Yet, another work-related health ailment that disproportionally affects farmers and often gets overlooked is noise-induced hearing loss (NIHL).

Hearing Loss Among Farmers

Workers in agriculture have been shown to have the second highest prevalence of hearing impairment out of the entire American workforce.[29] Research has estimated that anywhere between 20% to 80% of farmers have hearing loss in at least one ear.[12,15,30-32] The CDC reported that 11% of all American farmers that have participated in an audiometric test and shared the results of their audiogram have some degree of hearing loss, and that these losses equate to about 2.2 healthy years lost for every 1,000 farmers.[2] NIHL is not just a health problem for older farmers either, it has been suggested that at least 25% of all farmers will have difficulty communicating due to acquired hearing loss by the time they reach the age of 30[33] and more than half will have issues by the age of 50.[33,34] Moreover, 50-76% of farm youth have been shown to have hearing loss, likely due to helping with labor on farms.[31,35] Additionally, numerous studies have documented high rates of hearing impairment or other indicators of hearing loss, such as tinnitus, among workers in the agriculture.[12,15,30,31,36]

Farmers' Exposures to Hazardous Noise

Farmers are routinely exposed to hazardous noise over the course of the workday. Exposures occur through the operation of traditional farm equipment, such as tractors (exposures range between 82-92 dBA [A-weighted decibels]),[37-39] combines (90+ dBA),[37,39] or all-terrain vehicles (ATV) (83-85 dBA).[39,40] They are also exposed through their normal interaction with livestock (85-115 dB).[41] In addition to their work-related exposures, farmers have significant recreational exposures through the operation of firearms and self-propelled equipment.[15,31,42] Many farmers are aware of their exposure to hazardous noise.[12,15,30,31,35,36,43] Yet, few take precautions to protect themselves.[12,15,30,31,36,44-51]

Challenges for Researchers

Several studies have attempted to identify the burden of hearing loss among farmers. However, many of these studies only provide a snapshot of the true burden of hearing loss among this population. As shown previously, estimates of the magnitude of hearing loss within the farming community ranges widely.[12,15,30-32] Unfortunately, many of these studies may be biased, relying on self-identification of hearing loss. National studies are even further limited because they only provide an estimate of hearing loss among farmers that have previously had an audiometric test and volunteered to share that information. Regrettably, this is one of the biggest challenges with researching farmers. We are limited by the fact that farmers' health and safety is virtually self-regulated and only voluntarily disclosed. The true magnitude of hearing loss among farmers will likely be unknown; however, we can provide better estimates by continuing to research this topic.

Preventing Hearing Loss

There is no cure for hearing loss, which places a great emphasis on preventive measures. In the hierarchy of hazardous controls, the best approach would be to eliminate the source of hazardous noise altogether, followed by substitution, engineering controls, and administrative controls. However, these approaches are not only unaffordable, but most are also impractical for farmers. Many farmers lack the resources to retrofit or replace equipment. Furthermore, farms are primarily operated by 1- or 2- farmers and work is ultimately governed by the weather, which means that time is a critical resource that most farmers are unwilling to sacrifice. Though not the best approach in protecting workers against hazardous noise in the work environment, hearing protection, when used properly, are accessible, cheap, and effective in protecting hearing. However, hearing protection is not widely used among farmers.[12,15,30,31,36,44-51]

Personal Protective Equipment Use Among Farmers

Farmers are concerned about their health. Many have reported a concern about hearing loss;[48] others have reported feeling that they already had hearing loss.[12,15,32,46,47,49,52,53] Even more reported routine exposures to hazardous noise while on the job.[12,15,30,47,49] Yet, hearing protection use has consistently been low, ranging from 9-50% of farmers reporting its use.[12,15,30,31,35,36,42-49,54,55] Risk factors for non-use of hearing protection include: involvement in grain production,[36,54] gender,[45,54] and age.[36,45-47] Factors explaining hearing protection use have varied. Farmers report exposure avoidance,[48,49] warning labels,[48] social support,[48,49] comfort,[46,48,49] and cost[48,49], as determining factors for its use. Others have felt that hearing protection would interfere with communication[15] or cause discomfort; others simply reported forgetting to use it.[46]

Understanding Motivating Factors for Using Hearing Protection

There have been several studies evaluating the psychosomatic determinants for hearing protection use among workers across a variety of industries. One of the first studies evaluated the factors influencing hearing protection use among factory workers.[56] Researchers found that workers' self-efficacy, definition of health, perceived health status, job classification, and onsite situational factors were all associated with hearing protection use.[56] Follow-up studies using a cohort of construction workers demonstrated the impact of workers' demographic characteristics, work history, interpersonal relationships, and exposure patterns on their use of hearing protection.[57] In general, workers that used hearing protection felt that they would benefit from its use; did not feel that there were many barriers to using it; felt confident in how to use it; reported being exposed to noise; and had observed their peers using it.[56,57] These results were used to develop a targeted intervention geared to improve the use of hearing protection using a video as an educational platform to dispel some of the misconceptions about hearing protection and educate viewers about hearing loss.[58] The intervention itself was moderately successful in doing so.[58,59]

Other studies have evaluated the psychological factors associated with hearing protection use using a variety of different models and industries. One particular study evaluated the environmental and individual barriers to using hearing protection perceived by Appalachian coal miners.[60] The researchers found that environmental barriers were associated with job security, hygiene, regulatory requirements, and physical constraints; individual barriers included: concerns about communication and lack of social support/modeling.[60] Another study evaluated use among Latinos working in garment manufacturing plants.[61] It was noted that adherence to hearing protection practices was strongly influenced by social de-stigmatization of hearing protection by promoting the benefits of them; reducing the number of barriers or perception of barriers; improving workers' self-confidence; and modifying workers' perception of good health to include using hearing protection.[61]

Some found that adherence to hearing protection practices was heavily influenced by the safety culture promoted by the employer and that worksites with a high degree of support for safety and hearing protection use, also had a greater number of workers that used hearing protection.[62] A study evaluating hearing protection use among firefighters found that firefighters that had more exposure to noise, higher social and organizational support for hearing protection, fewer perceptions of barriers, and more feelings of susceptibility to hearing loss were more likely to use hearing protection than firefighters who didn't.[63] Few studies evaluate the factors associated with hearing protection use among farmers.

McCullagh, Lusk, and Ronis used the Pender Health Promotion Model to evaluate the primary factors affecting farmers' use of hearing protection.[50] Farmers were requested to respond to statements in a questionnaire that elucidated their perceptions about the barriers and benefits of using hearing protection, and the effect of self-efficacy, situational influences, and interpersonal influences in predicting its hearing protection.[50] They were also asked to report whether they used hearing protection.[50] Then, researchers used farmers' responses to the questionnaire to predict hearing protection use in a logistic model.[50] In the end, they found that farmers' perceptions of barriers, as well as their feelings of social and interpersonal support were all determining factors for hearing protection use.[50] Not surprisingly, use of hearing protection was associated with having fewer barriers, high accessibility to hearing protection, and a having communal support for hearing protection.[50]

In a similar study using a larger cohort, farmers' perceptions of barriers, gender, situational influences were associated with hearing protection use.[51] Farmers that felt that hearing protection would affect their performance, communication, or comfort were less likely to use hearing protection.[51] Likewise, farmers that felt that hearing protection was accessible and convenient were more likely to use them.[51] Interestingly, female farmers were almost 60% less likely to use hearing protection than male farmers.[51]

Interventions to Improve Hearing Protection Use

Methods used to improve hearing protection use rates among farmers have been employed in the past. One of the first studies was the implementation of a hearing conservation program by Knoboch and Broste.[36] In this study, researchers assigned Wisconsin students working in agriculture into two study group, a control group and an intervention group, and followed them over a 4-year period.[36] During the first year of the study, both groups participated in an audiometric test and completed a survey that asked questions about participants' hearing, past exposures, and tested some of their knowledge about hearing loss.[36] Beginning in the first year and in each proceeding year, farm students assigned to the intervention group participated in a hearing conservation program which included: education about hearing loss; visual cues to action at school and home; direct measurement of noise sources; provision of multiple types of hearing protection; and annual audiometric tests.[36] At the end of the study, both groups participated in an audiometric test and completed a final survey.[36]

Researchers found evidence of hearing loss among both groups, including tinnitus and feeling stuffy following exposure.[36] They also found that hearing protection use improved by almost 64 percentage points for students in the intervention group, and by nearly 20 percentage points in the control group;[36] reanalysis of the data confirmed these findings.[35] The top three aspects of the intervention that influenced their hearing protection use were (in descending order): provision of hearing protection; annual audiometric test; and visual cues to action.[36] Unfortunately, the hearing conservation program intervention was unsuccessful in preventing hearing loss over the course of the study[35] and in the long-run.[55] However, long-term follow-up of the study found that hearing protection use was consistently higher among the intervention groups after a 16-year follow up period, though still relatively low at about 26% compared to 20%.[55]

Another intervention involving farm youth was the AgDARE education intervention.[64,65] In this study, researchers tested the AgDARE educational program's effectiveness at modifying behaviors.[64,65] AgDARE (Agricultural Disability Awareness and Risk Education) is a learning course developed for agriculture students; in the AgDARE program, students listen to stories and participate in simulations detailing disabling, disfiguring, and life-changing injuries resulting from poor decision-making on the farm.[64,65] Students from 21 high schools from Iowa, Kentucky, and Mississippi participated in the study.[64,65] Researchers found that the AgDARE program was effective in changing students' readiness to engage in protective behaviors; students in the program changed their attitudes about working smart on the farm and expressed a stronger intent to use personal protective equipment while on the job. [64,65] Follow up of this study demonstrated farm youth were receptive to the AgDARE curriculum as hearing protection use rates increased modestly from 18.5% to 36.0% a year after the study.[65]

McCullagh implemented a variety of different techniques to improve hearing protection use among farm operators.[45] In this study, farmers were assigned to one of six intervention groups.[45] The first intervention group were mailed a variety of different types of hearing protection.[45] The second group participated in an interactive web-based intervention, where users were given a chance to explore noise exposures on a farm in a virtual environment and given a chance to learn about the benefits and types of hearing protection.[45] Other interactive approaches included testimonials by other farmers with hearing loss.[45] The third intervention was generic web-based information, which provided farmers access to the standard informational brochures about hearing protection.[45] The other interventions were combinations of the three primary interventions and included: mailed hearing protection and the interactive web-based intervention; mailed hearing protection and the generic web-based information, and the interactive web-based intervention and generic web-based information.[45] Hearing protection use improved with all study groups, as did farmers' attitudes about hearing protection.[45] Farmers that received an assortment of hearing protection in the mail had higher patterns of use than those who did not.[45] Farmers that had the interactive web-based intervention had a different outlook of situational influences than farmers in the generic web-based group.[45] Farmers that received mailed hearing protection felt that they better access to hearing protection than those that didn't.[45] In general, farmers were fairly happy with the interactive model.[45] The researchers suggested that most farmers are interested in hearing protection, and that providing hearing protection helped to overcome some of the accessibility barriers and misconceptions that farmers had about hearing protection.[45]

In an intervention pilot study, Gates and Jones assigned farmers (n=25) to intervention and control arms and followed them over short (~4 month) period.[47] Both groups completed baseline surveys that collected demographic data, as well as information about their previous exposures, hearing protection use, and attitudes about hearing loss and hearing protection use.[47] Farmers from both groups were also asked to complete two additional surveys that gathered information about their perceptions about susceptibility to hearing loss, severity of hearing loss, barriers to using hearing protection, and current use practices.[47] In addition to completing the surveys, farmers in the intervention arm were educated about hearing and hearing loss, educated on their specific exposures, provided hearing protection at sources of hazardous noise, and mailed a visual cues to action.[47] Farmers in the control group were not given the intervention, they were only requested to participate in the surveys. Gates and Jones found that farmers are exposed to significant levels of noise.[47] They also found that hearing protection use improved for the intervention group.[47] However, they did not find that use was correlated with susceptibility, severity, barriers or knowledge.[47]

Another intervention study evaluated hearing protection and other personal protective equipment (PPE) use among farmers in the Certified Farm Safe (CFS) Program.[44] Farmers from Iowa were either assigned to control and intervention groups, where the intervention group participated in the CFS program and the control group did not.[44] The CFS program consisted of: wellness and occupational health screenings; on the farm safety and exposure risk assessments; one-on-one meetings with CFS staff, where CFS staff explained personalized risk assessments and provided PPE demonstrations; and monetary incentives to implement safe practices.[44] PPE use was markedly higher in the CFS farmers (23% higher for hearing protection).[44] Moreover, the research demonstrated that farmers that used hearing protection were more likely to be injury free, and that farmers that felt that they were of good health were more likely to use hearing protection than farmers that did not have a positive outlook of their health status.[44]

Overall, these interventions were effective at increasing hearing protection use among farmers, though the long-term effectiveness of each intervention is debatable. Nevertheless, results from all these studies demonstrate several key points: 1) use of hearing protection is heavily influenced by one’s confidence in the hearing protection and in themselves; 2) people are observant of behavioral modeling at work, as such hearing protection must be normalized and destigmatized in the work environment; 3) perceptions of barriers and actual experiences with barriers must be addressed to improve protective practices; and 4) the mere provision of hearing protection improves usage rates.

Specific Aims

Previous research has demonstrated that farmers don't regularly use hearing protection and have a high degree of hearing loss. While several studies have identified psychological factors that influence farmers' protective behaviors, few studies have employed methods to improve hearing protection usage rates. The purpose of this dissertation was to evaluate the effect of a point source intervention on improving farmers' perceptions about hearing protection and preventing further hearing loss. In addition, we also wanted to evaluate the audiometric testing environments, which were often farmers' homes, to validate our methodology. To accomplish these goals, three studies were conducted:

Study 1 Objective: Evaluate factors that influence farmers' perceptions about hearing protection and evaluate if a point source hearing protection intervention changed these perceptions over time.

Study 2 Objective: Describe and evaluate the audiometric test environments used to test farmers' hearing.

Study 3 Objective: Describe farmers' hearing loss and evaluate if a point source hearing protection intervention changed their hearing over time.

Significance of Research

The dissertation will provide valuable information for farm workers, agricultural health and safety professionals, industrial hygienists, and occupational hearing conservationists. Health and safety professionals and industrial hygienists will be able to use our methodology as a basis of execution for other point-source interventions to improve personal protective equipment accessibility across a variety of industries. Moreover, they will be able to use our results in tailoring programs to address the individual cognitive issues that arise with the implementation of personal protective equipment initiatives. Our results will also provide valuable information about unique audiometric testing environments, which will be useful for hearing conservationists restricted by logistic and accessibility barriers. This will broaden the scope for practice of audiometry and help hearing conservationists be cognizant of the challenges and benefits of performing audiometric tests without a sound-treated enclosure. We hope our results will help to challenge the practice of adjusting hearing loss for age. This practice diminishes the extent of occupational hearing loss and may cause workers to underestimate and minimize their hearing impairment. Finally, our results will provide vital information for farmers concerned about their auditory health. We hope our results will improve farmers' adhesion to hearing protective behaviors.

CHAPTER 2: PREDICTORS OF FARMERS' PERCEPTIONS ABOUT HEARING PROTECTION

Abstract

Objectives: Hearing protection devices (HPDs) can be effective in preventing hearing loss. However, they are not widely used by farmers. This study explored factors that influence farmers' perceptions about hearing protection and evaluated if a point source hearing protection intervention changed these perceptions over time.

Methods: Intervention farmers (n=53) received education and the point source intervention (storing HPDs near major sources of noise). Control farmers (n=36) received education only. Annually, farmers from both groups were asked to complete a questionnaire about their perceptions of hearing protection.

Results: Over the course of the multi-year study, farmers' perceptions about hearing protection became more positive regarding comfort (OR = 1.65; 95% CI, 1.14-2.37), self-efficacy (OR = 2.05; 95% CI, 1.37-3.07) and intention to use hearing protection (OR = 1.58; 95% CI, 1.26-1.98). Older farmers were less concerned about limited communication when wearing hearing protection (OR = 1.04; 95% CI, 1.01-1.06), and expressed greater intention to change their behaviors related to hearing protection (OR = 1.05; 95% CI, 1.02-1.08) than younger farmers. Those with perceived (OR = 0.32; 95% CI, 0.12-0.92) and measured (OR = 0.37; 95% CI, 0.17-0.80) hearing loss showed less intention to use hearing protection in the future. These differences were similar in the intervention and control groups.

Conclusion: Intervention and control groups showed improvements in their perceptions, intentions, and self-efficacy about hearing protection over time. The point source intervention did not significantly add to the effect from education alone.

Key Words: hearing; noise; personal protective equipment; agriculture; farmer

Introduction

Hazardous noise, defined as noise greater than 85 decibels (dB), is a common occupational hazard that can lead to noise-induced hearing loss (NIHL).[2,3] Almost 25% of American adults have audiograms indicative of NIHL.[5] Industries particularly affected by hazardous noise include mining, construction, and manufacturing.[2] Workers in agriculture are also affected by hearing loss.[29] Recent estimates indicated that about 11% of U.S. hired agricultural workers have hearing loss in at least one ear, equating to about 2.2 healthy years lost for every 1,000 workers.[2] This estimate may not represent the true prevalence among all workers in agriculture as other estimates have ranged widely from less than 20% to nearly 80%.[2,15,30-32,66] Some studies indicate the prevalence of hearing loss is higher in self-employed farmers compared to workers in most other occupations[32]; second highest in the entire American workforce according to one study.[29]

Farmers are exposed to hazardous noise from tractors (82-92 dBA),[37,38] combines (90+ dBA),[37] all-terrain vehicles (ATV) (83-85 dBA),[40] and livestock (85-115 dBA).[41] In addition to work-related exposures, farmers may have recreational exposures from firearms and equipment.[15,31,42] Many farmers are aware of their exposure to hazardous noise.[12,15,30,31,43] Yet, few take precautions to protect themselves.[12,15,44,45,48,49] The Occupational Safety and Health Act (OSH Act), which includes provisions for audiometric testing and hearing conservation, is not enforced on small family farming operations.[44,45,67,68]

Several studies have applied the health belief model (HBM) to investigate psychological factors that influence the decision to wear hearing protection.[47,50,51,57,63] The HBM uses individuals' behavioral constructs (their perceptions of severity, susceptibility, barriers, benefits, self-efficacy, and cues to action), as well as their personal characteristics to predict the likelihood that a person will engage in a certain activity.[57,69] Some behavioral constructs that influence the use of hearing protection among farmers have been identified in previous studies. Barriers related to communication,[47,51,57,70] comfort,[51,62,63,71,72] and accessibility[48,51,73] have been associated with hearing protective behaviors. Other constructs related to hearing protection use include perceived susceptibility to hearing loss,[47,60,63,72,74] perceived severity of hearing loss;[47,60,72] and interpersonal influences.[45,47,58]

Successful interventions to improve hearing protection use have included education about hearing conservation,[36,45,47,64,74] the provision of multiple types of hearing protection,[45,47] personalized noise exposure measurements on the farm,[47] and the provision of routine audiometric tests.[36,58] The purpose of this study was to identify factors that influence farmers' perceptions about hearing protection, and to evaluate if the point source hearing protection intervention contributed to changes in farmers' perceptions about hearing protection.

Methods

Study Population and Design

The study population was derived from the Farm Market iD's database of farm operations. Farm Market iD is a private company that provides a service for marketing and research organizations, with ability to draw samples of farm operations based on selected production, location, and operator characteristics.[75] Principal farm operators managing farms located within a 100-mile radius of Omaha, Nebraska, were selected for the study from the Farm Market iD database. Full-time principal farm operators aged 19-years and older that intended to continue to farm for the duration of the study were eligible to participate. Other farm operators or hired workers involved in agricultural work (up to five from the same farm) were also invited to participate if they were at least 14 years or older.

Principal farm operators (n=3,962) were contacted by mail about their potential eligibility and willingness to participate in the study. Farms of eligible responding principal operators were included in the study and randomly assigned to either control or intervention arms (1:1 allocation ratio) using a computer-based random number generator. This process was repeated during year 2 of the study to reach the recruitment target. Family members and workers who requested to join were added to the study. The study participation selection strategy is illustrated in Figure 2.1. After randomization, one intervention farm withdrew from the study before any data were collected, and two farms (one control and one intervention) withdrew from the study after the first visit. The final study population consisted of 89 farmers and farm workers representing 51 farms that were randomly assigned into either control (n=26) or intervention arms (n=25) for up to four years, depending on the year in which they enrolled. All study participants are herein referred to as farmers for brevity.

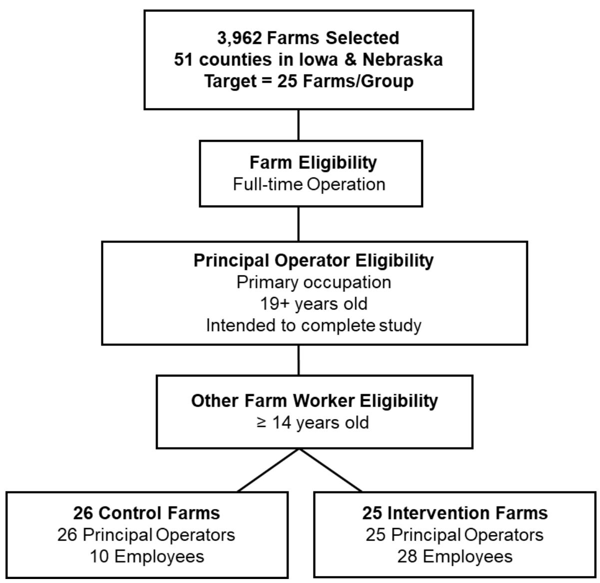


Figure 2.1 – Flow chart of study participation selection strategy.

Point Source Hearing Protection Intervention

Farmers in the intervention group received the point source intervention, which consisted of up to four weatherproof boxes containing a pair of ear muffs and 30 sets of earplugs placed in areas of the farm identified to have loud noise. Details of this intervention are described elsewhere.[76] In addition, farmers in both the intervention and control groups were taught how to insert earplugs properly and educated one-on-one on the importance of wearing hearing protection devices, as well as the ramifications of hearing loss.

Collection of Demographic, Audiometric, and Hearing Protection Perception Data

We requested each farmer to complete a standardized baseline demographic and medical history form, which provided information regarding their gender, age, state of residence, self-reported hearing health, and perceived hearing acuity. We also gathered information describing their farming operation and farm activities. In each year of the study, all farmers were asked to participate in an audiometric test and complete the complete the Beliefs about Hearing Protection and Hearing Loss (BHPHL) Questionnaire.

The BHPHL questionnaire, developed by researchers at NIOSH,[77,78] was used to gauge farmers' perceptions about hearing loss and hearing protection. Farmers reviewed 19 different statements corresponding to five different constructs (barriers of comfort and muffling, self-efficacy, intention, and benefits) within the health belief model. Respondents indicated whether they strongly agreed, agreed, disagreed, or strongly disagreed with each statement (Table 2.1). When the statement was inversely worded, we reversed the weights in analyses. Within each year, we summed each farmer's responses to the statements within each construct. Farmers that did not respond to all statements within each construct were excluded from analysis of that construct for the year that was missed. For analysis, we dichotomized each construct at the median response at baseline.

Positive perceptions were defined as having a score that was equal to or less than the median; negative perceptions were defined as having a score that was greater than the median. The partitioning of the BHPHL questionnaire and the statements related to each behavioral construct are summarized in Table 2.1. Positive perception of comfort meant that comfort was not a barrier to using hearing protection. Positive perception of self-efficacy corresponded to high self-efficacy in using hearing protection. Farmers that had a positive perception of intent expressed a strong intention to wear hearing protection. Positive perception of benefits meant that farmers felt confident that hearing protectors would protect their hearing. Positive perceptions of communication meant that farmers did not think hearing protection would hinder their ability to hear important sounds. Each construct was evaluated at the end of the study with the median response at baseline as the referent value.

All data were manually entered into a Microsoft Excel database and then imported into SAS® (Version 9.4; SAS Institute Inc.; Cary, NC) for data management and analysis. Random checks of data were performed to identify and correct any errors.

Statistical Analysis

Descriptive statistics were used to describe the study population and define baseline values for farmers' perceptions about hearing protection. Cronbach's alpha coefficient was calculated to measure the internal consistency of the statements used within each construct. Alpha coefficient values greater than 0.70 demonstrated high internal consistency between the statements. Generalized estimating equations (GEE) were used to model the probability of farmers having a positive perception to each behavioral construct. The GEE models were designed to account for correlation among farmers from the same farm, and data collected year-to-year from the same farmer. Tests for interactions between all the pair-wise combinations of variables used in the GEE models were conducted and did not yield any significant interactions. Accordingly, these interaction terms were not included in the GEE models. The GEE models were built using farmers' duration participation, group assignment, age, state of residence, perception of hearing loss, and measured hearing loss. The significance level was set at two-sided alpha=0.05. The study protocol was approved by the University of Nebraska Medical Center's Institutional Review Board (263-12-EP).

Results

Baseline descriptive statistics of both study arms are displayed in Table 2.1. Eighty-nine farmers, mostly male, from Nebraska and Western Iowa participated in the study for an average of 2.2 years. Thirty-two participated for four years, 48 for three years, four for two years, and five for one year. Many were lifelong farmers reporting an average of 35 years in the farming occupation. Nearly all reported that they cultivated crops, predominantly corn and soybeans; about half also reported that they raised livestock. Over three-quarters reported previous exposure to loud noise. Sixty-seven percent reported that they had previously used hearing protection, and just under 40% reported that they currently used hearing protection. Farmers in the control group were an average of about 12 years older than farmers in the intervention group. They also had poorer hearing than farmers in the intervention group.

Table 2.1 – Baseline demographic and exposure characteristics of study farmers (n=89)

Characteristics	Control n	(%)	Intervention n	(%)
Farms	26	(51.0)	25	(49.0)
Farmers	36	(40.5)	53	(59.5)
Employment Status				
Principal Operator	26	(72.2)	25	(47.2)
Employee	10	(27.8)	28	(52.8)
Gender				
Male	33	(91.7)	46	(86.8)
Female	3	(8.3)	7	(13.2)
Duration of Participation				
Mean (±SD; Years)	2.3	(0.7)	2.2	(0.9)
Range	1 day–3.6 years		1 day–3.4 years	
Age (Years)				
Mean (±SD)	56.9	(15.3)	45.0	(15.8)
Range	22–90		17–73	
Years Farming				
Mean (±SD)	42.4	(14.1)	29.8	(19.1)
Range	10–70		0.2–68.4	
Crop Producer	35	(97.2)	50	(94.3)
Corn	33	(94.3)	44	(88.0)
Soybeans	33	(94.3)	44	(88.0)
Other [a]	15	(42.9)	18	(36.0)
Livestock Producer	19	(47.5)	21	(52.5)
Cattle	14	(73.7)	9	(42.9)
Other [b]	5	(26.3)	12	(57.1)
State				
Nebraska	24	(66.7)	40	(75.5)
Iowa	12	(33.3)	13	(24.5)
Perceived Hearing Loss [c]				
Perfect to Mild	25	(69.4)	46	(88.5)
Moderate to Profound	11	(30.6)	6	(11.5)
Measured Hearing Loss [d]				
Normal – Mild in Both Ears	15	(42.9)	31	(59.6)
Moderate – Profound ≥ 1 Ear	20	(57.1)	21	(40.4)

[a] Other subcategory includes hay, alfalfa, rye, wheat, oats, and yeast.
[b] Other reported livestock exposures included hogs, chickens, horses, sheep, and transporting livestock.
[c] One intervention farmer did not provide information about their self-perceived hearing ability.
[d] Audiometric testing was not included for one intervention farmer and one control farmer; these farmers already had profound hearing loss and used hearing aids.

Most farmers were healthy adults reporting few health maladies related to impaired auditory function such as chronic ear infections, measles, or mumps. Roughly 25% reported that they experienced tinnitus. Most reported occasional or rare issues with their hearing; 19% reported hearing loss. Hearing tests showed that roughly 46% had moderate or worse hearing loss in at least one ear between 2000-6000 Hertz.

Table 2.2 describes the partitioning of the BHPHL questionnaire into the behavioral constructs. In general, the raw unstandardized Cronbach's alpha coefficients indicated that responses were consistent within each construct across all years of the study.

Table 2.2 – Behavioral construct summary including BHPHL statements, response scores, and Cronbach's alpha coefficients

Construct	Statements [a]	Sum of Response Scores at Baseline [b] Median (Range)	All Years Cronbach's α [c]
Barriers: Comfort (4 items)	*I think earmuffs put too much pressure on my ears.* *I think earmuffs make my head sweat too much.* *Hearing protectors are uncomfortable to wear.* *Wearing hearing protection is annoying.*	10 (4-16)	0.77
Self-Efficacy (5 items)	I believe I know how to fit and wear earplugs. *I'm not sure how to tell when earplugs need to be replaced.* I know when I should use hearing protectors. I know how to tell when an earmuff needs to be replaced. If co-workers asked me, I would be able to help them wear hearing protectors correctly.	12 (5-20)	0.76
Intent (4 items)	*I do not intend to wear hearing protectors when I am around loud tools or equipment.* I wear hearing protectors whenever I work around loud noise. I plan to wear hearing protection when I work near loud noises and on my current job. *I seldom wear hearing protectors when I work around loud noises.*	9 (4-16)	0.84
Benefits (3 items)	I think wearing hearing protectors every time I am working in loud noise is important. I am convinced I can prevent hearing loss by wearing hearing protectors whenever I work in loud noise. If I wear hearing protection, I can protect my hearing.	6 (3-12)	0.65
Barriers: Muffling (3 items)	*I think it will be hard to hear warning signals (like backup beeps) if I am wearing hearing protectors.* *Hearing protectors limit my ability to hear problems on the job site.* *I can't hear problems with my tools and machinery if I wear hearing protectors.*	7 (3-12)	0.78

[a] 4-point Scale: 1=Strongly Agree; 2=Agree; 3=Disagree; 4=Strongly Disagree; *italicized* statements indicate reversal of scale.
[b] Positive perceptions correspond to response scores less than or equal to the median response at baseline; negative perceptions correspond to response scores greater than the median response at baseline.
[c] Cronbach's alpha coefficient based on current study, all years combined, n=285, missing responses excluded.

Findings from the GEE models for each behavioral construct are summarized in Table 2.3. Farmers' perceptions about comfort, self-efficacy, and their intention to use hearing protection improved over the course of the study. Farmers' age was positively associated with their intention to use hearing protection and their perception of communication. Also, farmers' intent to use hearing protection was associated with their perception of their hearing and their degree of hearing loss. These results are described below.

Table 2.3 – Summary of generalized estimating equation (GEE) models of positive perceptions to each behavioral construct related to hearing protection

	Barriers: Comfort Adjusted OR [a] (95% CI)	Self-Efficacy Adjusted OR [a] (95% CI)	Intent Adjusted OR [a] (95% CI)	Benefits Adjusted OR [a] (95% CI)	Barriers: Muffling Adjusted OR [a] (95% CI)
GEE Model					
Duration (1-4 Years)	**1.65** (1.14-2.37)	**2.05** (1.37-3.07)	**1.58** (1.26-1.98)	1.06 (0.68-1.67)	1.15 (0.97-1.36)
Group (Intervention)	0.92 (0.40-2.10)	0.80 (0.32-1.97)	0.47 (0.20-1.08)	1.86 (0.47-7.37)	0.70 (0.30-1.62)
Age	1.01 (0.98-1.03)	0.99 (0.97-1.02)	**1.05** (1.02-1.08)	1.02 (0.96-1.07)	**1.04** (1.01-1.06)
State (Iowa)	1.28 (0.53-3.10)	0.62 (0.27-1.46)	0.53 (0.23-1.21)	0.45 (0.08-2.52)	1.11 (0.50-2.46)
Perceived Loss (Yes)	0.46 (0.16-1.34)	0.61 (0.21-1.72)	**0.32** (0.12-0.92)	0.32 (0.04-2.88)	0.52 (0.17-1.65)
Measured Loss (Yes)	0.74 (0.26-2.11)	1.22 (0.55-2.72)	**0.37** (0.17-0.80)	2.66 (0.89-7.96)	0.98 (0.54-1.80)

[a] Adjusted OR (95% CI): Adjusted Odds Ratio (95% Confidence Interval). Odds ratio adjusted for duration of participation, group assignment, age, state of residence, perceived loss, and measured loss. Bold **OR**s indicate significance at $p < 0.05$.

Barriers: Comfort

Perceptions of barriers related to comfort changed for both groups over the course of the study with most farmers having a positive perception that lack of comfort was *not* a barrier to using hearing protection (Table 2.3). At the beginning of the study, 62% of all farmers had positive perceptions about comfort. By the end of the study, 85% of all farmers had positive perceptions of comfort. In particular, 21 farmers (9 control and 12 intervention) changed their perception that lack of comfort was a barrier to using hearing protection over the course of the study. After adjusting for farmers' group assignment, measured and perceived hearing loss, age, and state of residence, each additional year of participation was associated with 1.65 higher adjusted odds of having a positive perception of barriers related to comfort (95% CI, 1.14-2.37).

Self-Efficacy

Overall, farmers in both groups appeared to become increasingly more confident in their ability to properly use hearing protection over the course of the study (Table 2.3). At the beginning of the study, 63% had positive perceptions of self-efficacy, and by the end of the study 88% had positive perceptions of self-efficacy. Specifically, 26 farmers (11 control and 15 intervention) changed their negative perception of self-efficacy over the course of the study. After adjusting for farmers' group assignment, measured and perceived hearing loss, age, and state of residence, farmers that participated for one year longer had twice the adjusted odds of having a positive perception of self-efficacy than farmers that participated for fewer years (OR = 2.05; 95% CI, 1.37-3.07).

Intent

Farmers in both groups expressed a stronger intention to wear hearing protection as the study progressed. At the beginning of the study, 52% had positive perceptions of intent. By the end of the study, 80% had a positive perception of intent. Twenty-seven farmers (11 control and 16 intervention) experienced a positive change in their intention over the course of the study. Duration of study participation, measured and perceived hearing loss, and age were all significantly associated with farmers' perception of intent after adjusting for all other covariates.

After adjusting for group assignment, measured and perceived hearing loss, age, and state of residence, farmers that participated for one-year longer had 1.58 higher adjusted odds of having a positive perception of intent than farmers that participated for fewer years (95% CI, 1.26-1.98). Measured hearing loss was negatively associated with the probability of having a positive perception of intent after adjusting for duration of participation, group assignment, perceived hearing loss, age, and state of residence (OR = 0.37; 95% CI, 0.17-0.80). Farmers that had measurable hearing loss had 63% less adjusted odds of having a positive perception of intent than farmers that had no detectable hearing loss. Similarly, perceived hearing loss was also negatively associated with the probability of having a positive perception of intent after adjusting for duration of participation, group assignment, measured hearing loss, age, and state of residence (OR = 0.32; 95% CI, 0.12-0.92). Farmers that felt that they had hearing loss had 68% less adjusted odds of having a positive perception of intent than farmers that had no self-identified hearing loss.

Older age was associated with having a positive perception of intent after adjusting for duration of participation, group assignment, measured and perceived hearing loss, and state of residence. Farmers that were one year older had 1.05 times higher adjusted odds of having a positive perception of intention than younger farmers (95% CI, 1.02-1.08).

Benefits

Over the course of the study, there was no significant difference between the two intervention arms in the number of farmers that felt that wearing hearing protection was important to prevent hearing loss (Table 2.3). At the beginning of the study, 91% had positive perceptions of benefits, and by the end of the study, 94% had positive perceptions of benefits. Only six intervention farmers experienced a change in their negative perceptions about the benefits of using hearing protection over time; most felt positively about the benefits of hearing protection. None of the covariates were associated with a positive perception of the benefits of wearing hearing protection.

Barriers: Muffling

Farmers in both groups experienced moderate changes in their perceptions about earmuffs disrupting their ability to communicate (Table 2.3). At the beginning of the study, 52% had positive perceptions about communication, and 64% had positive perceptions about communication by the end of the study. Older age was associated with having a positive perception of barriers related to communication. After adjusting for duration of participation, group assignment, measured and perceived hearing loss, and state of residence, farmers that were one year older had 1.04 higher adjusted odds of having a positive perception of barriers related to communication than younger farmers (95% CI, 1.01-1.06). Farmers that were older did not feel that using hearing protection would hinder their ability to effectively communicate with others.

Discussion

Low perceptions of barriers, high self-efficacy, and positive views of the benefits of using hearing protection, have previously been linked to greater hearing protection use.[50,51,57,63] We assessed the demographic and physical factors, as well as the study intervention effects contributing to farmers' perceptions about hearing protection. Farmers who participated in the study for a longer period had higher adjusted odds of having positive perceptions of barriers related to comfort, self-efficacy, and intent to use hearing protection. Also, farmers' age was associated with their perceptions of barriers and intention to use hearing protection. Older farmers had higher adjusted odds of having positive perceptions of barriers and intent to use hearing protection than younger farmers. It was also noted that farmers' hearing loss (measured and perceived) was associated with their intention to use hearing protection. Farmers that had measured and perceived hearing loss had lower adjusted odds of having a positive perception of their intention to use hearing protection than farmers without measured or perceived hearing loss. Overall, farmers agreed that hearing protection is important to prevent hearing loss, which is consistent with findings from other studies.[45,61]

Farmers were trained about the effects of hazardous noise and the long-term consequences of hearing loss. They also received training on how and when to use hearing protection; how hearing protection works; and given a chance to observe and test hearing protection in a setting outside of their work environment. While farmers from both groups were given the same education about hearing loss, farmers that had participated for longer had more opportunity to interact with the research team and have the key points of the educational component reinforced. Farmers that participated in the study for a longer period had more positive perceptions about lack of comfort as a barrier to using hearing protection, self-efficacy to using hearing protection, and intentions of using hearing protection than farmers that participated for fewer years.

Barriers to using hearing protection have consistently been identified as significant factors for their use.[51,57,62,70-72] Many have felt that comfort was a barrier to using hearing protection,[62,63,71,72] as was the potential for the muffling of important sounds.[47,57,62,70-72] Farmers from both groups experienced a positive change in their perceptions about barriers to using hearing protection as the study progressed. Similarly, one's self-efficacy has been implicated as a key predictor for hearing protection use; individuals that feel more confident in their ability to use hearing protection are more likely to use them.[57,58,71] Farmers felt more confident in their ability to properly use hearing protection as the study advanced. The increase in the number of farmers that experienced a positive change in their perception of barriers and self-efficacy may be attributed to the educational component of the intervention, as education has consistently shown to improve hearing protection use.[45,47,58,74,79]

The effects of perceived hearing loss and measurable hearing loss were also evaluated. Several studies have found that self-reported hearing loss is a good indicator for measured hearing loss.[17,31,61,74] This was inconsistent with our findings. Almost 46% of farmers had measured moderate or worse hearing in at least one ear, but only 20% acknowledged having hearing loss. Farmers that had self-reported or measured hearing loss had lower adjusted odds of intending to use hearing protection. It is possible that this observation could be due to the ceiling effect, where farmers that have a hearing impairment may not believe that hearing protection will do much to protect their already damaged hearing.[72,74] In any case, it is important to note that most farmers with hearing loss (both perceived and measured) don't use hearing protection at all.[12,44,45,48,49]

Farmers' age was linked to their perceptions about their intentions of using hearing protection and their beliefs about the barriers to using hearing protection. Older farmers had a stronger intention to use hearing protection and not perceive communication as a barrier to using hearing protection. Published studies on the effect of age have mixed results. In several studies, older age was associated with greater hearing protection use,[45,57,61] while others did not find age to be influential.[47,50,51,62] Most agree that age affects hearing protection use as a moderating variable through different pathways. For instance, researchers have speculated that years of employment (used in lieu of age) negatively affect workers' self-efficacy, which in turn resulted in a negative perception of barriers surrounding hearing protection use and ultimately resulted in low adhesion to hearing protection practices.[71,72]

Age has been closely tied to experience and linked to a greater intention to wear hearing protection,[57,58] which is consistent with our findings. This relationship could be explained by the finding that older farmers have hearing loss and are more likely to use hearing protection to preserve their remaining hearing. Older farmers may also have more experience, causing them to recognize and anticipate the risk with noise.[57,58] Older age was also related to not perceiving fear of limited communication as a barrier to using hearing protection. Older farmers may simply have more experience with hearing protection and value the benefits of hearing protection more than their younger counterparts.

Although the effect of the intervention was negligible in our study, the point source intervention still may be an invaluable tool to improve hearing protection use among farmers. Studies have shown that the mere provision of hearing protection on farms have improved their use.[45,47] Also, farmers from Nebraska and Western Iowa shared similar patterns of their perceptions to all constructs. This finding, though seemingly small, is important, because it shows that farmers are receiving similar information across the two-state region. Many farmers receive training about personal protective equipment through their local extension offices, farmer co-ops, agricultural safety and health specialists, and articles in the media.[48,49] Consequently, it is critical that these sources continue to provide information and access to resources for all farmers, as they are a trusted, and effective point of outreach for farmers.[47-49]

Strengths and Limitations

This study had several strengths. First, it was one of few that has evaluated the psychological factors that influence an individual's engagement in a preventive action in an occupational setting. Second, it linked each farmer's personal characteristics to their individual beliefs about hearing protection. Using the data collected during this study, we were able to link intervention data, audiometric data, questionnaire data, and health data across the same group of farmers. Though there were missing data, we had a robust dataset for each year of the study, which enabled us to evaluate the same group of farmers over time and draw conclusions about the effectiveness of our intervention in changing farmers' perceptions about hearing protection.

One limitation was that the control group of farmers was older than the intervention group of farmers in our study. Farms, not farmers, were allocated into each of the study arms. We also allowed others (n=7) from the same farm to join over the course of the study. One oversight to this approach was that many of these unsolicited participants were from intervention farms. It is possible that the new participants volunteered to join, because they were interested in the point source intervention and wanted to use the hearing protection. Many of these farm employees were also younger than the principal operator. Consequently, this skewed the age and sample size distributions between the groups. As a post hoc sensitivity analysis, the seven unsolicited participants were excluded from each of the GEE models and the conclusions from the models remained the same.

Although there was bias in the way that the study groups were formed, the bias introduced was negligible, because we did not see any effect of group assignment to any of the behavioral constructs in any of the GEE models. Farmers from both groups responded similarly. However, the models were adjusted for hearing loss (perceived and measurable) and age when appropriate. An unexpected benefit from this approach was that the unsolicited study participants (n=7) in the intervention group inadvertently demonstrated that the point source intervention was generating an interest in hearing conservation on intervention farms.

Also, our study population at year four was less than half of the population sizes for years one, two, and three due to our staggered enrollment. We had two farms drop out of the study (one control and one intervention) and three farmers (all from the intervention arm) withdraw from the study population completely after the first year. In year two, we had four farmers from the intervention arm withdraw from the study. We minimized selection bias due to uneven sample sizes by using duration of participation as a continuous variable. However, an analysis using year of participation as a categorical variable could have produced different results. Most farmers experienced a change in their perceptions after the first year of the study. Graphically, the proportion of farmers that had positive perceptions did not appear to change substantially after year two. A different analysis evaluating the change in farmers' perceptions between years of the study could have provided valuable insights about the critical time necessary to change farmers' perceptions and engage in protective behaviors. Another limitation was that we invited members from the same farm to participate in the study. This also introduced selection bias into our study because it is very likely that members from the same farm shared similar exposures to hazardous noise. This would have caused us to overestimate the degree of hearing loss or the effect of the intervention. We attempted to minimize the bias due to the clustering effect of farms by using a GEE model with random and fixed effects to account for the within-cluster and between cluster variations.

Yet, another limitation is related to the internal validity of the study due to the Hawthorne effect.[80,81] This phenomenon occurs when study participants alter their responses due to their awareness of being observed. The Hawthorne effect is common with self-reported data, and it should be noted that farmers' answers to the questionnaires in this study could be misrepresented, causing overestimation of the effect of the intervention. Finally, farmers were only asked about their perceived hearing ability at the beginning of the study. Their responses may have changed as the study progressed and they became more aware of their hearing acuity. This would have caused us to underestimate the effect of perceived hearing loss on farmers' perceptions. However, these data were not available. Future studies should evaluate the effect of perceived hearing loss and how it changes over time.

Conclusion

The study findings show that the point source intervention alone did not significantly contribute to changes in farmers' perceptions of barriers, self-efficacy, or intent. Education about hearing loss and hearing protection should continue to be an integral component of interventions aimed at improving hearing protection usage rates.

CHAPTER 3: PURE-TONE AUDIOMETRY ON FARMS: MOBILE TESTING WITHOUT A SOUND-TREATED ENVIRONMENT

Abstract

Objectives: Audiometric testing is an integral component of a hearing conservation program. Best practices indicate that audiometric testing should be conducted inside a sound-treated environment. However, this is not always feasible, especially when working with farmers. The purpose of this study was to describe and evaluate the onsite audiometric test environment used to test farmers' hearing.

Methods: We tested 87 farmers' pure-tone hearing thresholds at their primary residence (275 tests at 50 different farms) or at the principle investigator's laboratory (3 tests). Prior to testing, we minimized ambient noises to the extent possible. We also measured ambient sound pressure levels during the tests.

Results: Ambient noise levels exceeded the American National Standard Institute (ANSI) standard for audiometric test rooms at all tested frequencies. Ninety percent of the test rooms exceeded the standard at 500 Hertz (Hz) and 78% exceeded it at 1000 Hz. Less than 5% of the rooms exceeded the standard at 2000, 4000, and 8000 Hz. Fewer ambient noise levels exceeded the Occupational Safety and Health Administration (OSHA) limit for audiometric test rooms. These exceedances compromised the reliability of the audiometric test data, particularly at low frequencies.

Conclusion: Audiometric testing in nonstandard test environments can be a practical strategy to detect noise-induced hearing loss among hard-to-reach populations. However, researchers should be cognizant that ambient noise can interfere with the reliability of audiometric test results, especially at low frequencies. Researchers should ensure that test environments meet the background noise limits before administration of audiometric tests.

Key Words: audiometry; ambient noise; farmers; test environment

Introduction

Nearly one out of ten American farmers have noise-induced hearing loss (NIHL).[2] NIHL is caused by exposure to hazardous noise (defined as sounds greater than 85 dB). Farmers are routinely exposed to hazardous noise through the operation of heavy equipment, interaction with livestock, and recreational activities. Although farmers are astute at recognizing hazardous noise, few protect themselves around such exposures.[30,36,48,49]

American farmers are largely unregulated by occupational safety and health standards, which include provisions for audiometric testing and hearing conservation. Consequently, farmers are left on their own to apply occupational health and safety best practices.[44,45] One shortcoming to this approach is that farmers do not have the same resources used to evaluate, implement, and revisit safety and health protocols as employers in general industry. For hearing conservation, these limitations are profound, because NIHL is entirely preventable. Just one successful feature of hearing conservation programs is the early detection and identification of hearing loss through annual audiometric testing. During an audiometric test, an individual's threshold hearing sensitivity is measured at a range of frequencies. The tests are usually conducted in an audiometric test room or preselected quiet room where background noise is minimized, and sound is attenuated. However, due to the labor demands and logistic challenges of farmers, most do not participate in routine audiometric testing.

Beginning in 2012, we conducted a cluster-randomized controlled trial to evaluate the effect of a point-source hearing protection intervention on improving hearing protection usage rates among farmers in Western Iowa and Eastern Nebraska. As part of this study, researchers provided annual audiometric tests onsite at each farm to assess farmers' hearing over time. Although best practices indicate that hearing tests are to be provided in sound-treated audiometric test rooms,[10,82,83] this was not a practical solution for our study population. The purpose of this study was to evaluate the onsite audiometric test environment used to test farmers' hearing and to understand limitations introduced by this approach.

Methods

Study Population

The study population was derived from the Farm Market iD database. Farm Market iD is a private company that provides a service for marketing and research organizations, by drawing samples of farm operations based on selected farm production, location, and operator characteristics.[75] Principal farm operators managing farms located within a 100-mile radius of Omaha, Nebraska, were selected for the study from the Farm Market iD database.[75] Full-time principal farm operators aged 19-years and older that intended to continue to farm for the duration of the study were eligible to participate. Other farm operators or hired workers involved in agricultural work (up to five from the same farm) were also invited to participate if they were at least 14 years or older.

Principal farm operators (n=3,962) were contacted by mail about their potential eligibility to participate in the study and requested to respond to the research team. Farms of eligible responding principal operators were included in the study and randomly assigned to either control or intervention arms (1:1 allocation ratio) using a computer-based random number generator. This process was repeated during year 2 of the study. After installation of the intervention on some farms, others from the same farm requested to join, and they were added to the study. After randomization, one intervention farm withdrew from the study before any data were collected, and two farms (one control and one intervention) withdrew from the study after the first visit.

Farmers that had profound hearing loss were excluded from analysis (n=2), which included a principle operator from the control group and a farm employee from the intervention group. The final study population consisted of 87 farmers and farm workers representing 50 farms that were randomly assigned into either control (n=25) or intervention arms (n=25) for up to four years, depending on the year in which they enrolled. The study participation selection strategy and final sample sizes are illustrated in Figure 3.1. For succinctness, all study participants are referred to as farmers.

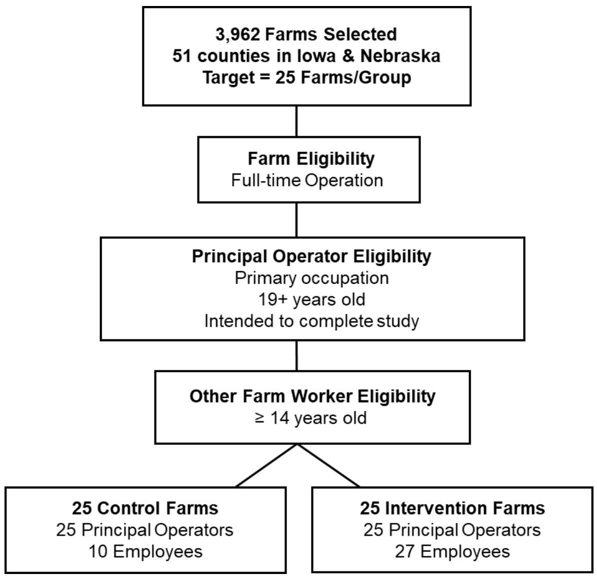


Figure 3.1 – Flow chart of study participation selection strategy.

Onsite Audiometric Testing

Two-hundred seventy-eight (n=278) audiometric tests were administered by a certified occupational hearing conservationist using a portable audiometer (Model: Monitor MI-5000B, Cherry Valley, IL) equipped with TDH 49-P earphones (Model: Telephonics 296-D100-1, Farmingdale, NY). Most (275/278) audiometric tests were conducted at each farm; three tests were conducted in the PI's research laboratory. For each test, researchers attempted to minimize low-frequency noises by turning off lights or unplugging appliances. These modifications to the test environment were only implemented under the consent of the farmer. The pure-tone frequencies of 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hertz (Hz) in each ear of each farmer were evaluated in accordance with the ANSI S3.6-1996 Specifications for Audiometers.[82]

Hearing thresholds (HT) in decibels (dB) were recorded for each ear of each farmer at each tested frequency. Hearing loss was defined as having mild or worse hearing in at least one ear.

Ambient Noise

Ambient noises were noted, and sound pressure levels in 196 test environments were evaluated using a Larson Davis Sound Level Meter (Depew, NY) during audiometric tests beginning in April 2014. Sound pressure levels across the octave band at 125, 250, 500, 1000, 2000, 4000, and 8000 Hertz (Hz) were taken in the 'A' weighted sound exposure setting and were recorded in decibels (dB). These values were compared to the American National Standard Institute (ANSI) Maximum Permissible Ambient Noise Levels for Audiometric Test Rooms (MPANL) and the Occupational Safety and Health Administration (OSHA) Maximum Allowable Octave-Band Sound Pressure Level (MAOSPL) for audiometric test rooms. Ambient noise levels that exceeded each respective standard were identified. Ambient noise measurements were not taken at 3000 or 6000 Hz, because these frequencies are mid-octave band measurements. To understand the effect of the exceedances on the reliability of the audiometric test data, we collated the audiometric test data with the ambient noise data taken during each test. We compared ambient noise readings to the ANSI MPANL to gauge the suitability of the test environment. Then, we identified cases where the audiometric test data was likely compromised due to an unfavorable test environment.

Data Analysis

Descriptive statistics were used to describe the study population, report average ambient sound pressure levels (SPL), and to enumerate exceedances of the ANSI MPANL and OSHA MAOSPL. We used SAS® (Version 9.4; SAS Institute, Cary, NC) for all analyses. The study protocol was approved by the University of Nebraska Medical Center's Institutional Review Board.

Results

Eighty-seven farmers representing 50 farms were included in this analysis. The mean duration of study participation was 2.2-years. The subjects were 77 men and 10 women, aged 17-90 years (mean 49.3 years, SD 16.4 years). Most audiometric testing was conducted onsite at each farm (~99%); however, three audiometric tests were conducted in a research laboratory. The location of audiometric tests at each farm changed according to the standard requirements for audiometric test environments. Most tests were conducted in the kitchen or dining area of the farmer's house. Other notable testing environments included: utility rooms, home offices, basements, workshops, and farm buildings.

Ambient noises varied within each test environment. Common ambient noises included: normal sounds caused by kitchen appliances; air movement through the air ducts; furnace or air conditioner blowers; cars; sounds caused by other occupants (talking and walking); animals (birds chirping and dog barking/moving); weather (wind and rain); the ticking of clocks; and the low-frequency hum of light sources. Most noises were unavoidable, such as sounds caused by passing vehicles or barking dogs; however, researchers attempted to minimize low-frequency noises during audiometric tests by unplugging appliances, turning off unnecessary lights, or waiting until the noise had ceased before starting the test.

Table 3.1 illustrates the average sound pressure levels at each frequency for all tested audiometric test environments. Average sound pressure levels were higher at higher frequencies. None of the audiometric test environments exceeded ANSI MPANL or OSHA MAOSPL at all frequencies. Most exceedances for both standards occurred at 500 and 1000 Hz, though exceedances were also noted between 250–2000 Hz. ANSI MPANL were exceeded more frequently than OSHA MAOSPL.

Table 3.1 – Average sound pressure levels (SPL) at each tested frequency compared to the ANSI MPANL and the OSHA MAOSPL (n=196)

Frequency (Hertz)	Average Ambient SPL (Range) (A-weighted decibels)	ANSI MPANL [a]	n Exceeded [b]	OSHA MAOSPL [c]	n Exceeded [d]
125	20.9 (15.3-49.5)	49	1	--	--
250	22.6 (15.5-50.1)	35	20	--	--
500	25.9 (20.2-49.1)	21	177	40	11
1000	28.0 (23.9-43.5)	26	153	40	7
2000	30.6 (26.4-47.1)	34	8	47	6
4000	32.7 (29.2-40.2)	37	6	57	0
8000	34.1 (32.5-37.2)	37	2	62	0

[a] Octave Band ANSI MPANL (American National Standard for Maximum Permissible Ambient Noise Levels for Audiometric Test Rooms) for ears covered with supra-aural earphones at each respective frequency.
[b] Number of samples taken at that frequency that exceeded the ANSI MPANL.
[c] OSHA MAOSPL (Occupational Safety and Health Administration Maximum Allowable Octave-Band Sound Pressure Level for Audiometric Test Rooms) at each respective frequency.
[d] Number of samples taken at that frequency that exceeded the OSHA MAOSPL.

Table 3.2 describes the magnitude of the exceedances of each standard. None of the 196 tested audiometric environments exceeded the ANSI MPANL for 125, 4000, or 8000 Hz by more than 5 dB. About 6% of the audiometric environments exceeded the ANSI MPANL for 250 Hz by more than 5 dB, and 1% exceeded by more than 10 dB; nearly 23% of the audiometric environments exceeded the ANSI MPANL for 500 Hz by more than 5 dB, and just under 12% exceeded by more than 10 dB. Six-percent of the audiometric environments exceeded the ANSI MPANL for 1000 Hz by more than 5 dB, and 4% exceeded by more than 10 dB. Less than 1% of the audiometric environments exceeded the ANSI MPANL for 2000 Hz by more than 5 dB, and about 3% exceeded by more than 10 dB. None of the audiometric environments exceeded the OSHA MAOSPL for 1000, 2000, 4000, or 8000 Hz by more than 5 dB. Only 4% of the audiometric environments exceeded the OSHA MAOSPL for 500 Hz by more than 5 dB; none exceeded by more than 10 dB.

Table 3.2 – Distribution of exceedances of the MPANL and MAOSPL

Frequency	MPANL			MAOSPL		
	<5 dB	5-9 dB	≥10 dB	<5 dB	5-9 dB	≥10 dB
125	1	--	--	--	--	--
250	6	12	2	--	--	--
500	109	45	23	4	7	--
1000	134	11	8	7	--	--
2000	1	1	6	6	--	--
4000	6	--	--	--	--	--
8000	2	--	--	--	--	--

The average ambient SPL exceeded the ANSI MPANL at all frequencies with most exceedances occurring at the 500 and 1000 Hz. At 500 Hz, 90% of the audiometric data was compromised by the test environment. For both ears, all suspected cases of hearing loss were identified in test environments unsuitable for tests. Likewise, at 1000 Hz, 78% of the audiometric data was compromised by the test environment. Most suspected cases of hearing loss were identified in test environments unsuitable for tests (8/11 for left ears and 6/7 for right ears). At higher frequencies, 4% were unsuitable for tests at 2000 Hz, 3% at 4000 Hz, and 1% at 8000 Hz. At both 2000 and 8000 Hz, all suspected cases of hearing loss in both ears were identified in test environments below the ANSI MPANL. While, at 4000 Hz, only one out of 108 (<1%) suspected cases of hearing loss in the left ear and two out of 89 (~2%) suspected cases of hearing loss in the right ear were identified in unsuitable test environments.

Discussion

Audiometric testing in nonstandard audiometric test environments can detect hearing loss.[84-87] Admittedly, it is not the best practice for audiometric testing purposes. Sound-treated environments are specifically engineered to minimize background noises across all frequencies and diagnose hearing loss. Yet, in a research capacity, it can be advantageous to conduct audiometric testing without a sound-treated environment as it can help researchers estimate the magnitude of high-frequency hearing loss in an otherwise unreachable population. However, this approach cannot produce diagnostic results, and it is imperative that researchers monitor ambient noise levels and minimize background noise.

The average sound pressure levels (SPL) of the test rooms used in our study ranged from 24.4-41.9 dBA. In other studies, the average SPL from ambient noises in quiet, *not* sound-treated, test rooms have ranged from 29.8-47.8 dB.[84,87-90] Our results are consistent with these results. It should be noted that ambient SPL in sound-treated test rooms have ranged from 11.9-37.0 dB,[87-89,91] which is comparable to SPL measured in not sound-treated rooms. Moreover, audiometric test results measured in both sound-treated and not sound-treated test environments have produced similar results,[85-88] which may undermine the need to 'sound-treat' rooms at all.

Few studies enumerate the magnitude of the difference of treated and untreated test rooms from the ANSI MPANL or the OSHA MAOSPL. Of the studies available, most exceedances occur at lower frequencies.[86,89-92] For sound-treated test rooms, all exceedances at 125, 250, and 500 Hz were less than 5 dB.[91] For quiet, not sound-treated test rooms, exceedances ranged between 1-8.5 dB at 250 Hz, 1-16.3 dB at 500 Hz,[89,92] and by 10 dB at 1000 Hz.[92] In agreement with our findings, the MAOSPL is not exceeded as often as the MPANL; this is probably because the OSHA MAOSPL is less stringent than the ANSI MPANL.[91] Most exceedances of the ANSI MPANL occurred between 250-1000 Hz. One possible explanation for the low-frequency exceedance of the MPANL is due to the normal transient noises experienced in any uncontrolled environment.[89,91] Transient noises have been described elsewhere and include: noises generated by living organisms; weather; HVAC processes; and electrical equipment.[89,91] Outside of a vacuum, noise from these sources are unavoidable, even within a sound-treated environment.

Many test environments exceeded the ANSI MPANL at 500 Hz and 1000 Hz, which likely compromised the reliability of the audiometric data gathered at those frequencies. Hearing thresholds at lower frequencies are highly affected by transient noises.[89,91] Previous studies have indicated that hearing thresholds at 500 Hz can be artificially inflated due to noise in the test environment.[90] As a result, it has been recommended that hearing conservationists initiate testing at 1000 Hz instead of 500 Hz to acclimate the testee to the protocol.[82,90] Only six test environments exceeded the ANSI MPANL at 4000 Hz. When collated with the audiometric test data at 4000 Hz, only three ears (left and right combined) suspected of having hearing loss were tested in unsuitable test environments. None of the suspected cases of hearing loss at 2000 or 8000 Hz were tested in unsuitable test environments.

Sound-treated environments are the optimal environment for audiometric tests. They are specifically designed to control for background noise and improve the validity of audiometric tests. They are also relatively isolated reducing the distractibility of their occupants.[89] Moreover, the equipment necessary for audiometric tests, which can sometimes create noise or distractions, can be removed entirely from the environment. For clinical purposes, audiometric testing should be conducted in a sound-treated environment. Yet, they are expensive, difficult to transport, and do not appear to guarantee an error-proof audiometric test.[87,89,91] It is entirely reasonable to perform audiometric testing in any environment that meets the ANSI MPANL and the OSHA MAOSPL for background noises.[84-87] Individuals that have audiograms indicative of hearing loss can be referred outward to physicians for more diagnostic procedures.

Strengths and Limitations

There are few studies that describe not sound-treated audiometric testing environments. This study is one of the very few that describes the challenges and environments of mobile audiometric testing inside people’s homes. Though not the conventional approach to administering an audiometric test, we were able to identify potential hearing losses among an otherwise underserved population. Our efforts helped detect early stages of hearing loss and could prevent future hearing losses. Also, our tests were administered over a 3-4-year period. Hearing loss can take years to develop, which makes it challenging to diagnose, treat, and prevent. A drastic change in hearing is unlikely to occur in the short term. Consequently, our annual audiometric test ultimately helped to authenticate our testing methods at 2000, 4000, and 8000 Hz. One limitation was that ambient sound pressure level monitoring was initiated in the middle of the study, which meant the ambient noise levels in test environments prior to April 2014 were not measured. However, most tests occurred in the same general vicinity over the course of the study, so it is unlikely that the environment would change drastically.

Conclusion

Onsite audiometric testing is a practical way to administer audiometric tests; however, ambient sound pressure level monitoring should be conducted in tandem to ensure that the test environment is within the accepted ambient noise standards for audiometric test rooms.

CHAPTER 4: EFFECT OF A POINT SOURCE INTERVENTION ON FARMERS' HEARING

Abstract

Objectives: Hearing protection, if worn properly in the presence of excessive noise, can prevent hearing loss. However, farmers rarely use hearing protection. This study characterized hearing loss among farmers and assessed changes in their hearing following implementation of a point source hearing protection intervention.

Methods: Intervention farmers (n=52) received education and the point source intervention (storing hearing protection devices near major sources of noise). Control farmers (n=35) only received education. Farmers from both groups participated in annual audiometric tests for the duration of the study.

Results: High-frequency hearing loss was prevalent among farmers. Standard threshold shifts, and high-frequency notches were identified, primarily affecting left ears. Farmers' low-frequency hearing improved over the duration of the multi-year study ($p<0.01$). No significant changes in farmers' high-frequency hearing were observed for the same period. Control farmers had worse low-frequency hearing than intervention farmers ($p=0.04$) even after adjusting for the effects of age, year of participation, and tested ear. Farmers' age was positively associated with both low- and high-frequency hearing thresholds ($p<0.01$ for both). Left ears had more high-frequency hearing loss than right ears after adjusting for year of participation, group assignment, and age ($p<0.01$).

Conclusion: Characteristics indicative of noise-induced hearing loss were common, especially in the left ear. The point source intervention may have prevented further high-frequency hearing loss in the short-term; however, long-term follow-up is warranted.

Key Words: farmers, hearing loss, standard threshold shift, notch, pure tone average

Introduction

Noise-induced hearing loss (NIHL) is permanent, irreversible, and entirely preventable; it affects nearly a quarter of all Americans.[5] About 30% of all cases of NIHL can be attributed to noise exposures at work making it the most common work-related illness in the United States.[2,5] Workers in the agricultural industry have been shown to have the second highest prevalence of NIHL out of the entire American workforce.[29] A recent study indicated that one out of ten American farmers has hearing loss in at least one ear.[2]

There are many contributing factors to the high rate of hearing loss among farmers. Numerous studies indicate workers in agriculture are routinely exposed to hazardous noise.[35,41,93,94] In addition, farmers appear oblivious and complacent to hearing loss, as many incorrectly perceive their own hearing loss[12,15,36,49,53] and even less routinely use hearing protection.[30,36,48,49] Moreover, farmers are expected to implement and oversee their own hearing conservation programs,[44,67,68] many of which are not evaluated by the Occupational Safety and Health Administration (OSHA).

Hearing conservation programs are critical in the work environment and help to prevent work-related hearing loss through noise control, audiometric testing, and worker training.[95] One successful feature of hearing conservation programs is the early detection and identification of hearing loss through annual audiometric testing. Audiometric testing measures an individual's threshold hearing sensitivity at specific frequencies; the results are presented in an audiogram. Audiograms allow employers monitor employees' hearing health; these results provide valuable information that can aid in the diagnosis of hearing loss, describe the type of hearing loss, and help to predict future hearing losses.

In the Occupational Safety and Health Act, hearing losses are identified as standard threshold shifts (STS); an STS is defined as a 10 dB increase in the average hearing threshold at the frequencies of 2000, 3000, and 4000 hertz (Hz) in any ear over time relative to the original audiogram.[21,95] Evaluating the shape of hearing thresholds across increasing frequencies can also help to identify and describe hearing loss. NIHL typically presents a notched (V- or U-shaped) pattern in the audiogram anywhere between 2-6 kHz;[8] whereas presbycusis (age-related hearing loss) can be indicated in a perpetually downward sloped audiogram.[8] presbycusis (age-related hearing loss) can be indicated in a perpetually downward sloped audiogram Flat audiograms can either show profound hearing loss or deafness (at high hearing thresholds) or perfect hearing (at lower hearing thresholds).[8]

Hearing conservation programs are hardly implemented on small scale farming operations. Most farmers have access to hearing protection, but few use them, even when recognizing the risk.[30,36,48,49] Previous studies have identified farmers' perceptions of barriers,[47,48,70,96] susceptibility,[47,74] and severity[47] of hearing loss as determinants for hearing protection use; others have found that use was influenced by self-efficacy[57,71] and social support for hearing protection.[45,47] Interventions designed to increase hearing protection use among farmers have used a variety of methods to engage farmers and improve protective behaviors. The mere provision of hearing protection to farmers has improved hearing protection use,[45,47] as have targeted interventions that enhanced farmers knowledge.[36,45,47,64,74] Simply enabling farmers to recognize their own hearing deficiencies have also improved hearing protection use.[36,79] This current study aims to improve farmers' protective behaviors using a combination of audiometric monitoring, education, and the provision of hearing protection at sources of hazardous noise.

Methods

The overall objective of this study was to analyze the audiograms of 87 different farmers involved in a point source intervention study designed to improve hearing protection use. We aimed to describe farmers' baseline hearing acuity, to identify raw and age-adjusted STS among farmers, and to identify notches indicative of noise-induced hearing loss (NIHL) within the farmers' audiograms. We also explored the change in low and high-frequency pure tone averages

(PTA) over time due to a point-source intervention and evaluated the differences between left and right ears.

Study Population

The study population was derived from the Farm Market iD database. Farm Market iD is a private company that provides a service for marketing and research organizations, by drawing samples of farm operations based on selected farm production, location, and operator characteristics.[75] Principal farm operators managing farms located within a 100-mile radius of Omaha, Nebraska, were selected for the study from the Farm Market iD database.[75] Full-time principal farm operators aged 19-years and older that intended to continue to farm for the duration of the study were eligible to participate. Other farm operators or hired workers involved in agricultural work (up to five from the same farm) were also invited to participate if they were at least 14 years or older. The study participation selection strategy is illustrated in Figure 4.1.

Principal farm operators (n=3,962) were contacted by mail about their potential eligibility to participate in the study and requested to respond to the research team. Farms of eligible responding principal operators were included in the study and randomly assigned to either control or intervention arms (1:1 allocation ratio) using a computer-based random number generator. This process was repeated during year 2 of the study. After installation of the intervention on some farms, others from the same farm requested to join, and they were added to the study. After randomization, one intervention farm withdrew from the study before any data were collected, and two farms (one control and one intervention) withdrew from the study after the first visit.

Farmers that had profound hearing loss were excluded from analysis (n=2), which included a principle operator from the control group and a farm employee from the intervention group. The final study population consisted of 87 farmers and farm workers representing 50 farms that were randomly assigned into either control (n=25) or intervention arms (n=25) for up to four years, depending on the year in which they enrolled. For succinctness, all study participants are referred to as farmers.

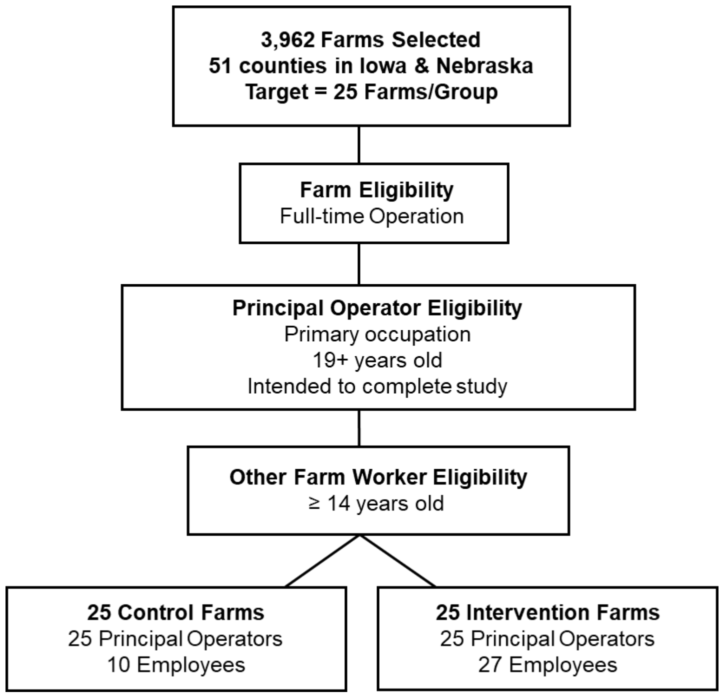


Figure 4.1 – Flow chart of study participation selection strategy.

Point Source Hearing Protection Intervention

Farmers in the intervention group received the point source intervention, which consisted of up to four weatherproof boxes containing a pair of ear muffs and 30 sets of earplugs placed in areas of the farm identified to have loud noise. Details of this intervention are described elsewhere.[76] In addition, farmers in both the intervention and control groups were taught how to insert earplugs properly and educated one-on-one on the importance of wearing hearing protection devices, as well as the ramifications of hearing loss.

Audiometric Testing Procedures and Audiometric Data

Audiometric tests were administered by a certified occupational hearing conservationist onsite at each farm using a portable audiometer (Model: Monitor MI-5000B, Cherry Valley, IL) equipped with TDH 49-P earphones (Model: Telephonics 296-D100-1, Farmingdale, NY). The pure-tone frequencies of 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz in each ear of each farmer were evaluated in accordance with the American National Standards Institute (ANSI) S3.6-1996 Specifications for Audiometers.[82] Hearing threshold in decibels (dB) were recorded for each ear of each farmer at each tested frequency.

The high and low pure tone averages (PTA) were calculated for each ear of each farmer for each year of the study. High-frequency PTA were the average hearing thresholds at 3000, 4000, and 6000 Hertz (Hz); low-frequency PTA were the average hearing thresholds at 500, 1000, and 2000 Hz.[12,15] Hearing loss was defined as: normal (PTA ≤ 25 dB); mild (25 dB < PTA ≤ 40 dB); moderate (40 dB < PTA ≤ 55 dB); moderate/severe (55 dB < PTA ≤ 70 dB); severe (70 dB < PTA ≤ 90 dB); and profound (PTA > 90 dB). Using each farmers' age and gender, we applied OSHA's allowances for age and adjusted all audiometric profiles for hearing loss due to presbycusis. Raw and age-adjusted standard threshold shifts (STS) were calculated following the requirements set forth by OSHA.[21]

Notches were identified as positions within the audiogram where the hearing threshold at 3000, 4000, or 6000 Hz was at least 10 dB greater than the hearing threshold at 1000 or 2000 Hz and at 6000 or 8000 Hz.[97] Instances where these conditions were satisfied were indicative of an audiometric notch. Notches were described as either monaural (affecting one ear only) or binaural (affecting both ears simultaneously). They were classified as either V-shaped or U-shaped. V-shaped, or narrow, notches involved notches at only one frequency, while U-shaped, or wide, notches involved notches at more than one consecutive frequency.

To estimate notch depths, we first calculated the average hearing threshold at 1000 and 2000 Hz (the upper boundary – the depression), and the average hearing threshold at 6000 and 8000 Hz (the lower boundary – the rebound). Then we subtracted the average upper boundary hearing threshold from the hearing threshold at the notch, and the average lower boundary hearing threshold from hearing threshold at the notch; the average estimated notches depth was the average of those two differences. This allowed us to conservatively approximate the depth using both the notch depression and the rebound. Persistent notches were defined as notches that were identified in each ear at each frequency in each proceeding year thereafter. Notches that did not consistently persist after recognition over the study were not classified as persistent notches.

All data were manually entered into a Microsoft Excel database and then imported into SAS® (Version 9.4; SAS Institute Inc.; Cary, NC) for data management and analysis. Random checks of data were performed to identify and correct any errors.

Statistical Analysis

Descriptive statistics were used to summarize hearing loss, standard threshold shifts (STS), and notches within the study population. Generalized linear mixed models (GLMM) were built to model the effects of year of participation, group assignment, farmers' age (in years), and tested ear on farmers' low and high-frequency pure-tone average (PTA). The GLMM were designed to account for possible correlation among farmers from the same farm, and data collected from each ear from the same farmer. After testing for interactions between group assignment and ear, and group assignment and age and determining there were no statistically significant interactions, we built GLMM using farmers' year of participation, group assignment, and age. The significance level was set at two-sided alpha=0.05. The study protocol was approved by the University of Nebraska Medical Center's Institutional Review Board (263-12-EP).

Results

Eight-seven farmers representing 50 farms participated in the study. Farmers' baseline characteristics are summarized in Table 4.1. The mean duration of study participation across all farmers was 2.2-years. The subjects were 77 men and 10 women, aged 17-90 years (mean 49.3 years, SD 16.4 years). Farmers in the control group were about 12-years older than farmers in the intervention group, and they had also been farming almost 13-years longer than farmers in the intervention group. Despite these differences, most were lifelong crop farmers, with about half reporting current animal husbandry operations. The average low and high PTA across both ears for control farmers was 15.4 dB and 33.9 dB, respectively. Similarly, the average low and high PTA across both ears for intervention farmers was 10.6 dB and 23.6 dB, respectively

Table 4.1 – Farmers' baseline characteristics (n=87)

	Control		Intervention	
	n	(%)	n	(%)
Farms	25	(50.0)	25	(50.0)
Farmers	35	(40.2)	52	(59.8)
Employment Status				
Principal Operator	25	(71.4)	25	(48.1)
Employee	10	(28.6)	27	(51.9)
Gender				
Male	32	(91.4)	45	(86.5)
Female	3	(8.6)	7	(13.5)
Age (Years)				
Mean (±SD)	56.5 (15.3)		44.5 (15.4)	
Range	22–90		17–73	
Years Farming				
Mean (±SD)	41.9 (13.9)		29.2 (18.8)	
Range	10–70		0.2–68.4	
Duration of Participation				
Mean (±SD; Years)	2.2 (0.7)		2.2 (0.9)	
Range	1 day–3.3 years		1 day–3.4 years	
Crop Producer	34	(97.1)	49	(94.2)
Corn	32	(94.1)	43	(87.8)
Soybeans	32	(94.1)	43	(87.8)
Other [a]	15	(44.1)	18	(36.7)
Livestock Producer	19	(54.3)	21	(42.0)
Cattle	14	(73.7)	9	(42.9)
Other [b]	5	(26.3)	9	(42.9)
Low-frequency PTA [c]				
Mean (±SD)	15.4 (7.5)		10.6 (6.0)	
Range	0–33.3		0–36.7	
High-frequency PTA [c]				
Mean (±SD)	33.9 (18.7)		23.6 (16.4)	
Range	3.3–70.0		0–73.3	

[a] Other subcategory includes hay, alfalfa, rye, wheat, oats, and yeast.
[b] Other reported livestock exposures included hogs, chickens, horses, sheep, and transporting livestock.
[c] Pure Tone Average (PTA) for both ears combined.

A description of the distribution of farmers' baseline hearing sensitivities for low- and high-frequency PTA for each ear is summarized in Table 4.2. Most farmers had normal hearing in both ears at lower frequencies; however, high-frequency hearing loss in both ears was observed.

Table 4.2 – Distribution of hearing loss at baseline by pure tone average (n=87)

	Low PTA[a]				High PTA[b]			
Hearing Loss	Left		Right		Left		Right	
	n	(%)	n	(%)	n	(%)	n	(%)
None	82	(94.3)	80	(91.9)	39	(44.8)	51	(58.6)
Mild	5	(5.7)	7	(8.1)	23	(26.4)	21	(24.1)
Moderate	--	--	--	--	17	(19.5)	8	(9.2)
Moderate/Severe	--	--	--	--	8	(9.2)	6	(6.9)
Severe	--	--	--	--	--	--	1	(1.2)

[a] Low-frequency Pure Tone Average (PTA) is the average hearing thresholds at 500, 1000, and 2000 Hz (Hertz).

[b] High-frequency Pure Tone Average (PTA) is the average hearing thresholds at 3000, 4000, and 6000 Hz.

Figure 4.1 depicts the distribution of hearing thresholds and the interquartile range (IQR) for right and left ears for the entire study population at baseline. Hearing thresholds were mostly normal (≤ 25 dB) for both ears at low frequencies (Figure 4.1 and Table 4.2). However, high-frequency loss was noted in both ears and appeared to range from mild to severe loss. Median hearing thresholds were higher in the left ear compared to the right ear at 3000, 4000, and 6000 Hz.

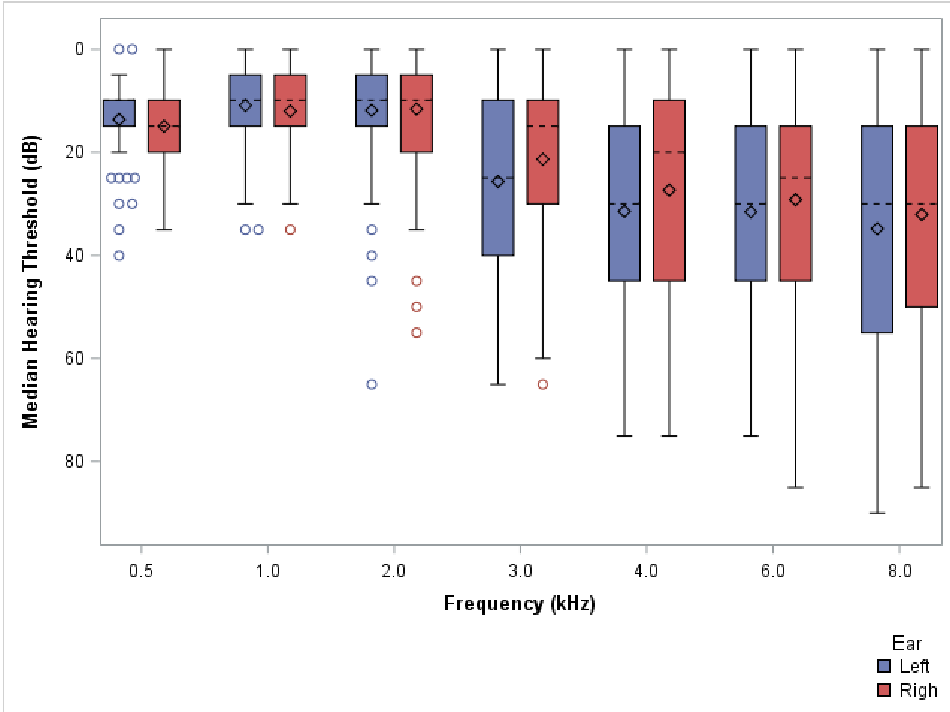


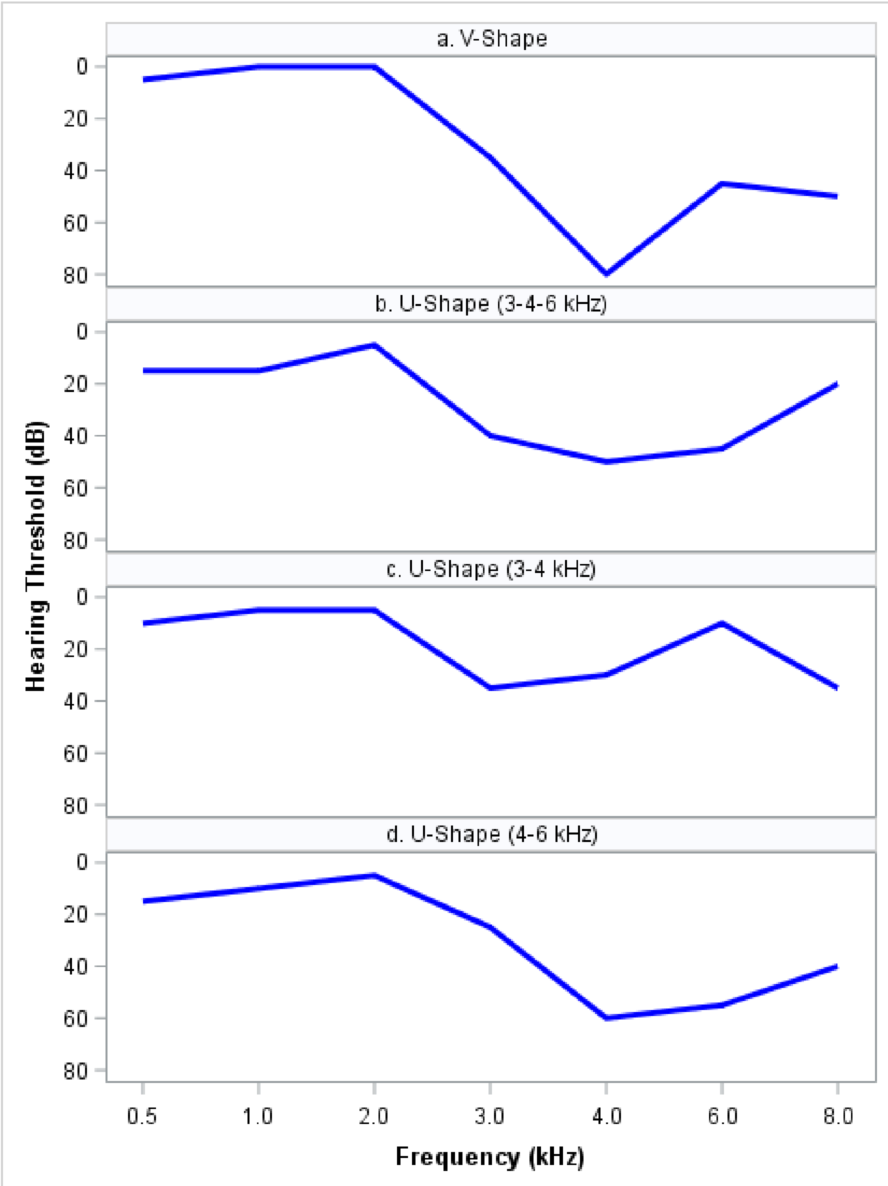
Figure 4.2 – Distribution of hearing thresholds by ear and frequency for both groups at baseline

Seven standard threshold shifts (STS) were identified over the 4-year period. Five of the STS occurred in the left ear, and two occurred in the right ear. After adjusting for presbycusis, only one STS remained in the right ear. The distribution and frequency of notches identified over the course of the study are summarized in Table 4.3. Selected audiometric graphs illustrating the different shapes of notches are identified in Figure 4.2.

Table 4.3 – Distribution, average depth, and shape of audiometric notches at 3, 4, and 6 kHz

	3 kHz		4 kHz		6 kHz	
	Left	Right	Left	Right	Left	Right
Frequency [a]	58	38	93	69	54	42
Average Depth (±SD) [b]	22.7 (10.9)	21.4 (9.8)	25.1 (13.5)	22.2 (10.8)	19.6 (7.5)	14.9 (7.9)
<10 dB	9	2	9	7	4	7
10-19 dB	15	17	25	26	25	23
20-29 dB	14	10	25	15	19	8
≥ 30 dB	20	9	34	21	6	3
Shape						
Narrow [c]	4	12	31	31	22	21
Wide [d]	54	26	62	38	32	21
3-4	30	17	30	17	--	--
4-6	--	--	8	12	8	12
3-4-6	24	9	24	9	24	9

[a] Notches identified over study duration (n=278).
[b] Average depth of notch and standard deviation. Notch depth stratified by 10-decibel increments.
[c] Narrow, V-shaped, pattern involving notch at one frequency.
[d] Broad, U-shaped pattern involving notch at more than one frequency. Notch shape stratified across consecutive frequencies.



† Audiometric graphs selected from individual study participants.

Figure 4.3 – V-and U-shaped notches within the audiogram. (a) V-shaped notch at 4 kHz. (b) U-shaped notch involving notches at 3, 4, and 6 kHz. (c) U-shaped notch involving notches at 3 and 4 kHz. (d) U-shaped notch involving notches at 4 and 6 kHz.

Audiometric notches were identified at 3, 4, and 6 kHz, with most occurring at 4 kHz. Of all the notches identified at 3 kHz over the course of the study, 20 were binaural or occurring in both ears simultaneously for the same participant. Forty-three of the notches identified at 4 kHz were binaural, and 36 of the notches identified at 6 kHz were binaural. Left ears had more notches than right ears, and most notches occurred at 4 kHz. The average depth of notches varied. Most were around 20 dB deep in both ears and left ears had deeper notches than right ears. Notches were deepest at 4 kHz, and shallowest at 6 kHz. They were classified as either narrow (V-shaped [Figure 4.2a]), or wide (U-shaped) [Figure 4.2b-c]. Most notches were wide, involving notches at more than one-frequency, especially those identified in the left ear. Notches at 3 kHz tended to be wide, while notches at 4 and 6 kHz were both wide and narrow. Most wide notches at 3 and 4 kHz involved consecutive notches at both 3 and 4 kHz, though wide notches across all three frequencies were identified. Wide notches at 6 kHz were variable. At 6 kHz, left ears tended to have the widest notches involving all three frequencies, while right ears tended to have wide notches that involved 4 and 6 kHz.

Some notches identified at the beginning of the study persisted over the duration of the study, others developed at some point and persisted for the remaining duration. However, most notches did not persist consistently over the study. Many were sporadic - meeting the definition of a notch inconsistently over the duration of the study. Of the notches that developed and persisted, most had a slight depression in the hearing threshold level at that particular frequency in the years preceding (and proceeding) their transition into meeting the actual definition of a notch.[97]

Results from the generalized linear mixed models (GLMM) are summarized in Table 4.4. Farmers' low-frequency PTA were related to their year of participation, group assignment, and age. Farmers' model adjusted low-frequency PTA decreased for each year of the study after adjusting for farmers' group assignment, age, and tested ear ($p<0.01$). Specifically, the model adjusted mean low-frequency PTA at year one was 13.04 dB (SE=0.66); at years two and three 11.74 (SE=0.67) and 10.54 dB (SE=0.67) respectively; and at year four, the model adjusted mean low-frequency PTA was 10.95 dB (SE=0.79). Farmers from the two study groups had different low-frequency PTA even after adjusting for year of participation, age, and tested ear ($p=0.04$). Control farmers had worse low-frequency hearing than intervention farmers. Specifically, the model adjusted mean low-frequency PTA for control farmers was 12.96 dB (SE=1.02), while the model adjusted mean low-frequency PTA for intervention farmers was 10.19 dB (SE=0.82). Farmers' age was positively associated with their low-frequency PTA after adjusting for year of participation, group assignment, and tested ear (p<0.01). As farmers' aged, their low-frequency PTA hearing thresholds also increased.

Farmers' high-frequency hearing thresholds were affected differently. In the GLMM, farmers' high-frequency PTA was related to their age and tested ear. After adjusting for farmers' year of participation, group assignment, and tested ear, farmers' age was positively associated with their high-frequency PTA (p<0.01). As observed with low-frequency hearing, as farmers' aged, their high-frequency PTA hearing thresholds increased. Left ears had worse high-frequency PTA than right ears after adjusting for year of participation, group assignment, and age (p<0.01). Specifically, the model adjusted mean high-frequency PTA for left ears was 30.35 dB (SE=1.44), while the model adjusted mean high-frequency PTA for right ears was 26.38 dB (SE=1.44).

Table 4.4 – Summary of generalized linear mixed models (GLMM) of low- and high-frequency pure tone averages (PTA)

	Low-frequency PTA		High-frequency PTA	
Covariates	β Estimate (± SE)	p-value	β Estimate (± SE)	p-value
Intercept	5.05 (2.50)	0.05	-4.01 (5.55)	0.47
Year of Participation				
Year 1	Ref.	--	Ref.	--
Year 2	-1.30 (0.39)	**<0.01**	-0.47 (0.79)	0.56
Year 3	-2.50 (0.40)	**<0.01**	-1.26 (0.82)	0.12
Year 4	-2.09 (0.57)	**<0.01**	-0.05 (1.17)	0.97
Group				
Control	Ref.	--	Ref.	--
Intervention	-2.77 (1.34)	**0.04**	-1.85 (2.99)	0.54
Age	0.18 (0.04)	**<0.01**	0.71 (0.09)	**<0.01**
Ear				
Left	Ref.	--	Ref.	--
Right	0.10 (0.30)	0.73	-3.97 (0.61)	**<0.01**

Bolded p-values considered statistically significant.
Model adjusted for duration of participation, group assignment, age, and measured ear.
Negative β estimates indicate lower hearing thresholds, which correspond to better hearing.

Discussion

The results of this study confirm previous reports that farmers have substantial hearing loss.[29,32,53,54,98] We identified standard threshold shifts (STS) among this group of farmers and observed the effect of age adjustment on STS. We also identified audiometric notches indicative of NIHL. Control farmers had significantly worse low-frequency hearing than intervention farmers after adjusting for year of participation, age, and tested ear. Left ears had significantly worse high-frequency hearing than right ears after adjusting for age, and group assignment. Low-frequency hearing improved over the course of the study after adjusting for all other covariates. We also found that age was positively associated with both low- and high-frequency PTA.

Our results are consistent with patterns of hearing loss among farmers in other studies. Research has universally found that farmers have high-frequency hearing loss.[12,32,35,43,53] Most high-frequency hearing loss appears to be mild or moderate and heavily influenced by age;[15,32,43,93] this agrees with our findings. Almost 80% of high-frequency hearing loss in left and right ears was mild or moderate. Only a handful of farmers had evidence of low-frequency hearing loss, all of which was classified as mild. Mild low-frequency hearing loss has been widely reported.[15,31,32,52,53,98]

Few studies have identified the presence of STS among farmers and fewer have reported the effect of age-adjustment on STS. About 8% of our study population experienced an STS over the course of the study, which is consistent with other reports. Reported STS among farmers has ranged from 2-5%.[35,54] One study found farm youth had almost twice the number of noise-induced threshold shifts as the national average.[98] Few studies evaluate the distribution of STS; most STS were evident in the left ear, which could be expected as left ears tend to have poorer hearing sensitivity than right ears.[15,31,32,43,53] Age-adjustment minimized noise-induced hearing loss by decreasing the number of identifiable STS. Although this practice is widely accepted, it may not afford employers the ability to detect early signs of hearing loss, which would hinder preventative intervention efforts.

Audiometric notches were identified among farmers in this study. Most notches were monaural, affecting left ears more often than right ears; however, binaural notches were also commonly identified. This is consistent with other findings of the distribution of notches across ears.[99-101] The ratio of monaural to binaural notches has been reported to be about 3:1.[99,100] Previous research has also demonstrated that left ears have more notches at all frequencies than right ears.[99-102] The asymmetric distribution of hearing loss is common and explained in depth later.

The frequency at which notches tend to occur is varied. In agreement with another study,[99] notches were most common at 4 kHz. Several studies have found notches predominantly occur at 6 kHz in both ears,[99,102] while others found ears were dissimilar in the frequency where notches were indicated.[100,102] For example, left ears have been indicated to have more notches at 6 kHz, while right ears had more at 4 kHz,[100] conversely this trend was reversed for individuals exposed to high impulse sounds.[102] It has been suggested that the high prevalence of notches at 6 kHz could be attributed to the progression of notches at 4 kHz into notches at 6 kHz.[102] Nevertheless, it is important to note, notches at 6 kHz can form even in the absence of hearing loss due to the standardization of hearing threshold sensitivities.[102,103]

The shape of audiometric notches was also examined. At 3 kHz, most notches were wide, or U-shaped, involving 3 and 4 kHz. Narrow, or V-shaped, notches were more commonly identified at 4 kHz and 6 kHz. At 4 kHz, wide notches mostly involved notches at 3 and 4 kHz or across all three frequencies; wide notches involving just 4 and 6 kHz were less frequent. At 6 kHz, wide notches typically involve all three frequencies, with fewer farmers having wide notches involving 4 and 6 kHz. The shape of notches has rarely been studied among noise-exposed workers. The shape of notches (not specific to a frequency) has been reported with narrower notches occurring more frequently than wide notches.[99,102] This is inconsistent with our findings. Researchers have studied notches shape as a function of depth. Deeper notches corresponded to wider notches, which makes sense as the depression and rebound of the notch would span more than one-frequency.[102] Most wide notches involved 3 and 4 kHz, which conflict with other reports.[99] Contrary to our findings, notches spanning 4 and 6 kHz have been reported to occur more frequently than notches spanning 3 and 4 kHz.[99] As mentioned earlier, the depression at 6 kHz could be attributed to the standardization at notches at higher frequencies, or it could also be attributed to progressive hearing loss across frequencies.[102]

Our calculation of notches depths differs from calculations used in other studies, yet our calculations produced comparable results. One study calculated depths of notches by calculating the average notches at the adjacent frequencies surrounding the notch, and then subtracted this value from the notches at the notch.[102] Results from this study indicated that most notches (49%) were between 16-30 dB deep.[102] The remaining percentage was equally distributed between 15 dB or less deep or greater than 30 dB deep.[102] Similarly, most notches depths were between 10-29 dB at all frequencies. At all frequencies, especially at 3 and 4 kHz, notch depths exceeded 30 dB, which agrees with previous findings.[102] Another study calculated depth by averaging the differences between the notch relative to 2 and 8 kHz.[99] Results indicated that most depths at 3 kHz were between 10-18 dB; at 4 kHz, most were between 15-23 dB, and most were between 15-18 at 6 kHz for both ears.[99] We observed a similar trend; notches appeared to be slightly deeper at 4 kHz relative to 3 kHz and 6 kHz.

Hearing capabilities appeared to behave differently between left and right ears. In general, left ears farmers had poorer hearing in the left ears than in their right ears. We also observed differences in the declination rate at higher frequencies between ears. Hearing thresholds in the right ear appeared to gradually decline in the higher frequencies, while left ears experienced a sharper decline followed by a plateau between 4-8 kHz. Upon analysis, there was a significant difference in model adjusted mean high-frequency PTA between left and right ears even after adjusting for year of participation, group assignment, and age. Left ears had a greater model adjusted mean high-frequency PTA than right ears. The asymmetric left-sided distribution of hearing loss among farmers is common.[15,31,32,43,53] There are competing theories to explain this phenomenon. One theory is that one ear may be more directed to the source of noise causing more injury relative to the other ear; this phenomenon has been described as head shadowing.[31,104] The other theory is that one ear is simply more physiologically predisposed to damage.[104] Unfortunately, the causal pathway remains undefined and further examination of this topic is warranted.

Farmers' age was significantly related to both low and high-frequency PTA ($p<0.01$ for both) after adjusting for year of participation, group assignment, and tested ear. As the study progressed, individuals aged and hearing naturally declined. Age is known to be associated with hearing loss, and numerous studies have found this effect among farmers. Moreover, the gradual decline of hearing thresholds over high frequencies in the audiogram is indicative of presbycusis.[8] This general trend was observed upon examination of the shapes of hearing thresholds across the audiogram; many farmers had perpetually downward sloped audiograms indicative of presbycusis. We also found that many of these farmers also had audiograms with a characteristic notch indicative of noise-induced hearing loss. It is possible that there could be a synergistic effect between noise-induced hearing loss and presbycusis for farmers with notches spanning across consecutive frequencies.[97]

Farmers' low-frequency PTA differed between the study groups, even after adjusting for age, year of participation, and tested ear. Farmers in the control group had almost a 3 dB higher model adjusted mean low-frequency PTA than farmers in the intervention group. Other studies have also observed an improvement in hearing, but this observation is atypical since hearing loss is irreversible.[30] In the same model, we also found that year of participants was significantly associated with farmers' low-frequency PTA, where farmers' farmers' model adjusted mean low-frequency PTA slightly improved over the four-year period. Both of these observations could be related to low-frequency transient noise interference in the background ambient testing environment. Transient noises have been described elsewhere and include noises HVAC processes and electrical equipment.[89,91] Many of these noises occur at low-frequencies and it is possible that these noises could have interfered with the reliability of our low-frequency test results over the course of the study.

Farmers' high-frequency PTA did not differ between groups or change over the course of the study, even after adjusting for all other covariates. This observation could indicate that the educational component of the intervention helped to prevent hearing loss, especially since there was no decline in hearing for either study group. However, previous research has not found any notable change in hearing over a three-year follow-up period[35] and it has been suggested that NIHL can take up to 10-years to develop.[35,105]

Strengths and Limitations

This study is one of the few that evaluates farmers' hearing using audiometric testing over time. Most studies on this topic are cross-sectional, and few pertain to adult farmers. Another strength is the same cohort of farmers were followed over the course of the study. Although there were different endpoints for farmers, we applied audiometric monitoring practices for this group and evaluated the change in their hearing over time and the asymmetric distribution of hearing loss. Also, this is one of the few studies that enumerates STS among farmers and describes the distribution of STS between ears. Furthermore, it one of the very few that describes audiometric notches based on their depth and shape for farmers.

One limitation was that audiometric monitoring was not performed in a standard audiometric enclosure. Standard audiometric enclosures are soundproof enclosures that control background ambient noise and improve the reliability of the audiometric monitoring. The alternative approach used in our study may have compromised the reliability and validity of our low-frequency hearing threshold data. However, we could solicit farmers and follow them over time, because we were able to meet them at their convenience. Another limitation is related to our methodology. In addition to supplying farmers with hearing protection, we also provided a recessed counter to track the number of times hearing protection were used. This metric would have been valuable to correlate hearing protection use to a change in hearing. Unfortunately, the recessed meter was too sensitive and resulted in an unusually large frequency of hearing protection uses. For this reason, we excluded this data from analysis.

Yet another limitation was related to our staggered enrollment, which resulted in uneven sample size endpoints for our groups. Our study population at year four was less than half of the population sizes for years one, two, and three due to our staggered enrollment. We had two farms drop out of the study (one from each study arm) and three farmers from the intervention group withdraw from the study population completely after the first year. In year two, we had four farmers from the intervention group withdraw from the study. We minimized selection bias due to uneven sample sizes by using duration of participation as a continuous variable.

We introduced another form of selection bias into our study by inviting others involved in farm work from the same farm (n=7) to join over the course of the study. One oversight to this approach was that many of these unsolicited participants were from intervention farms, and likely volunteered, because they were interested in the intervention and wanted to use the hearing protection. Many of these farm employees were younger than the principal operator, which skewed the age and sample size distributions between the groups. We attempted to account for the clustering effect of farms by using a generalized linear mixed model with random and fixed effects. As a post hoc sensitivity analysis, we removed the seven unsolicited participants from each of the GLMM models. The post hoc sensitivity analyses showed that the exclusion of the seven unsolicited participants did not change the conclusions from the GLMM models.

Conclusion

Farmers have a substantial amount of high-frequency hearing loss and audiograms indicative of noise-induced hearing loss. The point source intervention may have prevented further high-frequency hearing loss in the short-term; however, long-term follow-up is warranted.

CHAPTER 5: CONCLUSION

Hearing protection is not widely used among farmers. It has been speculated that this is largely due to the limited availability of hearing protection in noisy work areas on farms. Aiming to resolve barriers to accessibility, a point source randomized control trial was initiated onsite at 51 farms in Eastern Nebraska and Western Iowa. Farms in the intervention arm were given a point source hearing intervention, featuring a pair of noise attenuating earmuffs and 30-sets of earplugs, at locations on the farm where hazardous noise had previously been identified. In addition, farmers on intervention farms were educated about hazardous noise and the long-term consequences of hearing loss. Also, they received training on hearing protection. Farmers on farms in the control arm were only given education about hearing loss and hearing protection; they did not receive the point source hearing protection intervention. Both farms were visited at baseline and annually for the duration of the study. During each visit, farmers were asked to participate in an audiometric test and complete the Beliefs about Hearing Protection and Hearing Loss (BHPHL) questionnaire.

The main objective of this dissertation was to evaluate the effect of the point source intervention on improving farmers' perceptions about hearing protection and preventing further hearing loss. We also wanted to evaluate the onsite audiometric test environment used as part of this study and comment on the feasibility of this approach for future practice. As such, three distinct studies were conducted to achieve these objectives. The first study "*Predictors of Farmers' Perceptions about Hearing Protection*" evaluated the factors that influence farmers' perceptions of barriers, self-efficacy, intention, and benefits of using hearing protection. It also evaluated the changes in farmers' perceptions due to the point source intervention. The second study "*Pure-Tone Audiometry on Farms: Mobile Testing Without a Sound-Treated Environment*" examined the onsite ambient testing environments used to perform audiometric tests. The third study "*Effect of a Point Source Intervention on Farmers' Hearing*" described the magnitude of hearing loss among the cohort of farmers' and evaluated the change in farmers' hearing due to the point source intervention.

Predictors of Farmers' Perceptions about Hearing Protection

In this study, farmers all seemed to agree that hearing protection was important to prevent hearing loss. Also, all farmers regardless of group assignment expressed a stronger intention to use hearing protection over the course of the study. We also found that farmers from Nebraska and Iowa shared consistent patterns in their perceptions, which indicates farmer outreach initiatives are delivering a consistent message across the area. We did not find that the point source intervention alone created a substantial difference in farmers' protective behaviors or attitudes because we did not see any difference farmers' perceptions of barriers, benefits, self-efficacy, or intentions between study groups. It is more likely that the educational component of the intervention resulted in the observed differences.

The intervention and control study arms shared similar patterns in their responses over time. For both groups, farmers that participated in the study for a longer period were more likely to have better perceptions about hearing protection. For instance, farmers that were involved in the study for longer did not feel that lack of comfort was a barrier to using hearing protection. Similarly, farmers that were in the study for longer had a better sense of self-efficacy and expressed a stronger intention to use hearing protection than farmers that were in the study for a shorter period. These observations could be attributed to the fact that farmers that had participated for longer simply had more opportunity to interact with the research team and have the key points of the educational component reinforced.

Older farmers were less likely to view communication as a barrier to using hearing protection than younger farmers. They also expressed a stronger intention to use hearing protection in the future even after adjusting for both measured and perceived hearing loss. It is possible that these findings could be related to older farmers having more experience with hearing loss. Hearing naturally declines as one ages, so much so that the farmers in this study simply could have been affected more by hearing loss and may lament their past behaviors. They may be more inclined to change their behaviors reactively now, and rather than proactively when they were younger. To add to that, the effect of perceiving one's own hearing loss was not associated with having a stronger intention to use hearing protection, neither was having measurable hearing loss. On the contrary, farmers' that perceived themselves as having hearing loss had lower odds of using hearing protection, as were farmers' that had physical evidence of hearing loss. It could be these observations are due to the ceiling effect, where farmers that already perceive their own hearing loss may not feel that there is much they can do to prevent further loss. Overall, educating farmers about hearing protection and hearing loss appeared to change their perceptions about barriers to using hearing protection, improved their self-efficacy, and altered their behavioral practices. The point source intervention did not significantly contribute to these changes.

Pure-Tone Audiometry on Farms: Mobile Testing Without a Sound-Treated Environment

In this study, the ANSI MPANL was exceeded more often than the Occupational Safety and Health Administration's (OSHA) Maximum Allowable Octave-Band Sound Pressure Level for audiometric test rooms (MAOSPL). This is because the ambient noise thresholds of the OSHA MAOSPL are less stringent than those for the ANSI MPANL. For example, at 500 Hz, OSHA's MAOSPL is 40 dB, while ANSI's MPANL is 21 dB. Ninety-percent (177/196) of the audiometric testing environments used in this study exceeded the ANSI MPANL at 500 Hz, while just over 5% (11/196) exceeded the OSHA MAOPLS at the same frequency. The ANSI MPANL was exceeded at all frequencies with most exceedances occurring at lower frequencies (250-1000 Hz). Most exceedances were less than 5 dB; however, some exceeded the MPANL by more than 5 dB, a few exceeded the MPANL by more than 10 dB.

The audiometric test data was collated with the ambient SPL data to determine if the suspected cases of hearing loss were identified in test environments suitable for tests. It is likely that the exceedances of the ANSI MPANL corrupted the reliability of the audiometric test results. At 500 Hz, all suspected cases of hearing loss for both ears were identified in test environments unsuitable for tests. Likewise, at 1000 Hz, 73% of left ears and 86% of right ears suspected of having hearing loss were identified in test environments unsuitable for tests. At 4000 Hz, only one out of 108 suspected cases of hearing loss in the left ear and two out of 89 suspected cases of hearing loss in the right ear were identified in unsuitable test environments. At both 2000 and 8000 Hz, all suspected cases of hearing loss in both ears were identified in test environments below the ANSI MPANL. Overall, audiometric testing in nonstandard audiometric test environments can detect high-frequency hearing loss, but it is imperative that researchers monitor ambient noise levels and minimize background noise.

Effect of a Point Source Intervention on Farmers' Hearing

In this study, almost half of the farmers had high-frequency hearing loss in both ears. Although most was mild or moderate, seven standard threshold shifts (STS) (five in the right ear and two in the left ear) were identified among this group of farmers over the course of the study. Only one of which remained in the right ear after adjusting for age-related hearing loss. High-frequency notches at 3, 4 and 6 kHz were identified in both ears and described in terms of their shape and depth. Most notches were monaural, affecting left ears more than right ears; binaural notches were also common among this group of farmers. Most notches were identified at 4 kHz, and most notch depths were about 20 dB at all frequencies. Only a few notches exceeded 30 dB, and the deepest notches tended to occur around 4 kHz. The shape of notches varied by frequency. Notches at 3 kHz tended to be wide, or U-shaped, while notches at 4 and 6 kHz tended to be both narrow and wide.

The generalized linear mixed models (GLMM) were built to model the effects of year of participation, group assignment, farmers' age (in years), and tested ear on farmers' low and high-frequency pure-tone average (PTA). Farmers' low-frequency PTA was associated with their duration of participation, year of participation, age, and group assignment. Specifically, farmers' low-frequency hearing improved over the course of the study and although these changes were modest (±2 dB), they were significant after adjusting for all other covariates. Also, older farmers had poorer low-frequency PTAs than younger farmers, and farmers in the control group had significantly worse low-frequency PTAs than farmers in the intervention group, even after adjusting for other covariates. There was no difference observed in low-frequency PTA between left and right ears.

Similar associations were found for farmers' high-frequency PTAs, but with age and ear. Farmers' age was positively associated with high-frequency PTAs after adjusting for all other covariates, where older farmers had greater high-frequency PTAs than younger farmers. Significant differences in high-frequency PTAs between left and right ears were also observed, with left ears having a greater model adjusted mean high-frequency PTA than right ears. There was no significant difference in farmers' high-frequency PTA between control and intervention farmers or over the duration of the study. The point source intervention may have prevented further high-frequency hearing loss in the short-term; however, long-term follow-up is warranted.

Together these studies demonstrated that farmers that are educated about hearing protection are more likely to use it. Although it is uncertain if the intervention itself was successful at changing farmers' perceptions, it is probable that the educational component of the study was highly effective at changing farmers' perceptions about hearing protection, most notably those related to self-efficacy, barriers, and intent. Farmers' hearing acuity was measured through audiometric testing onsite at each farm, which circumvented logistic barriers for farmers. Audiometric testing in nonstandard audiometric test environments can detect hearing loss; however, researchers should monitor ambient noise levels and minimize background noises, especially at lower frequencies. Since most noise-induced hearing loss occurs at higher frequencies, this approach may be useful for researchers aiming to detect high-frequency hearing loss in an otherwise unreachable population. The intervention may have been successful at preventing hearing loss, but more time was needed to appreciate those changes fully.

Strengths and Limitations

There are some clear strengths about the studies conducted in this dissertation. For starters, all these studies pertain to the agricultural work-environment, which is largely misunderstood. Most farmers are apprehensive about participating in research that involves occupational health and safety; many may be concerned that research will turn into policy and direct efforts to complicate their practices. In addition, many are strapped for time and simply cannot afford the added stress of participating in research. Consequently, many of the studies surrounding the agricultural work-environment are outdated and may not be relevant for today's farmers. Farming itself has changed drastically with the advent of modern technology and safer practices. The health status of today's farmers reflects their previous exposures, but assessments of their current exposures will need to be done to predict the health of tomorrow's farmers.

Our first study evaluated the demographic, physical, and study effects that influence farmers' adhesion to personal protective behaviors. We were able to correlate farmers' hearing acuity and their unique personal characteristics to their personal beliefs about hearing protection. We were also able to see if (and how) the point source intervention helped to modify farmers' perceptions. Our second study evaluated an unconventional approach to audiometric testing and described the challenges of mobile audiometric testing inside people's homes. Though our methodology introduced bias into our study, our efforts helped detect hearing loss among farmers and may broaden the scope of audiometric testing. Our final study evaluated the audiological health of farmers. Research describing farmers' hearing is limited, and most of the keystone articles evaluate adolescents. We were not able to definitively conclude that the point source intervention prevented hearing loss. However, we were able to monitor farmers' hearing over time and describe their audiograms in conventional audiometric terms.

There are weaknesses about each of these studies, most have been described previously, but a few will be highlighted. First, our enrollment was poor, so we modified our approach after the second year and extended our target region. We also allowed for other farm workers to participate. Initially, we expected to do simple analyses on independent variables and draw clear conclusions from clear relationships. We also initially expected most to participate in the study for the same amount of time. However, this was not the case. Since we opened enrollment again in the second year of the study, we had a substantial proportion of our study population with different endpoints. This made it difficult to describe the final effects of the study because each farmer had different length of participation. Moreover, since we allowed for multiple farmers to participate from the same farm, our approach had to be adjusted to evaluate repeated measures on clustered data. Also, our alternative approach to audiometric testing introduced bias into our study. Unfortunately, we only had background noise measurements after April 2014, which meant that we couldn't comment on the adequacy of the test environments used prior to that point. Luckily, most tests occurred in the same general vicinity each year, so we didn't expect the ambient noise in the environment to change much over time. A final limitation was that we excluded data from a recessed counter that was supposed to track the number of times hearing protection were used. Regrettably, the recessed meter was too sensitive and resulted in an unusually large frequency of hearing protection use.

Directions for Future Research

Several things could have been done differently. First, it would be interesting to correlate hearing protection usage to each of the constructs. As mentioned previously, the metric used to evaluate hearing protection usage (the recessed counter) produced unreliable data, so that data was not available for use. But we could have overcome this shortcoming by using a surrogate variable to estimate hearing protection use. In the questionnaire, question 8, pertained to current hearing protection usage. In hindsight, we could have excluded the behavioral intent construct altogether and focused on responses to question 8. Then, we could have expanded our analyses to evaluate which constructs contributed to reporting current hearing protection use. These results, coupled with our current results, could have allowed us to see pathways through which the intervention affected constructs related to current hearing protection use. Our current analysis is still relevant, but this alternate approach would have expanded our previous findings.

Also, it would have been interesting to compare the high-frequency notches according to different definitions of notches. Currently, there are three different working definitions audiometric notches. We focused on notches as defined by Coles, Lutman, and Buffin.[97] These notches are specific and focus on three different points within the audiogram where a notch can occur (3, 4, and 6 kHz). In the other two definitions of notches, one definition focuses on the existence of a notch across the average hearing thresholds at 2, 3, and 4 kHz relative to the average of hearing thresholds at 1 and 8 kHz;[106] the other definition focuses on any position in the audiogram where the hearing threshold decreases by 10 dB and then increases by 5 dB.[107] It would be interesting to observe how the definitions of notches vary, and how much agreement exists between the different definitions.

Beyond our study, there are still gaps in knowledge about hearing loss among farmers. Little is known about the true extent of hearing loss among this population. Current estimates vary considerably; most data are voluntarily disclosed and may only represent the hearing status of farmers already self-identified to be affected by hearing loss. Also, most studies about hearing loss reflect damage from past exposures. Consequently, it is imperative to continue surveillance efforts in the farming community. This will allow us to add to the body of research that exists about the magnitude of hearing loss among this population, and it will help us to evaluate and continually improve our approaches to tackle hearing loss.

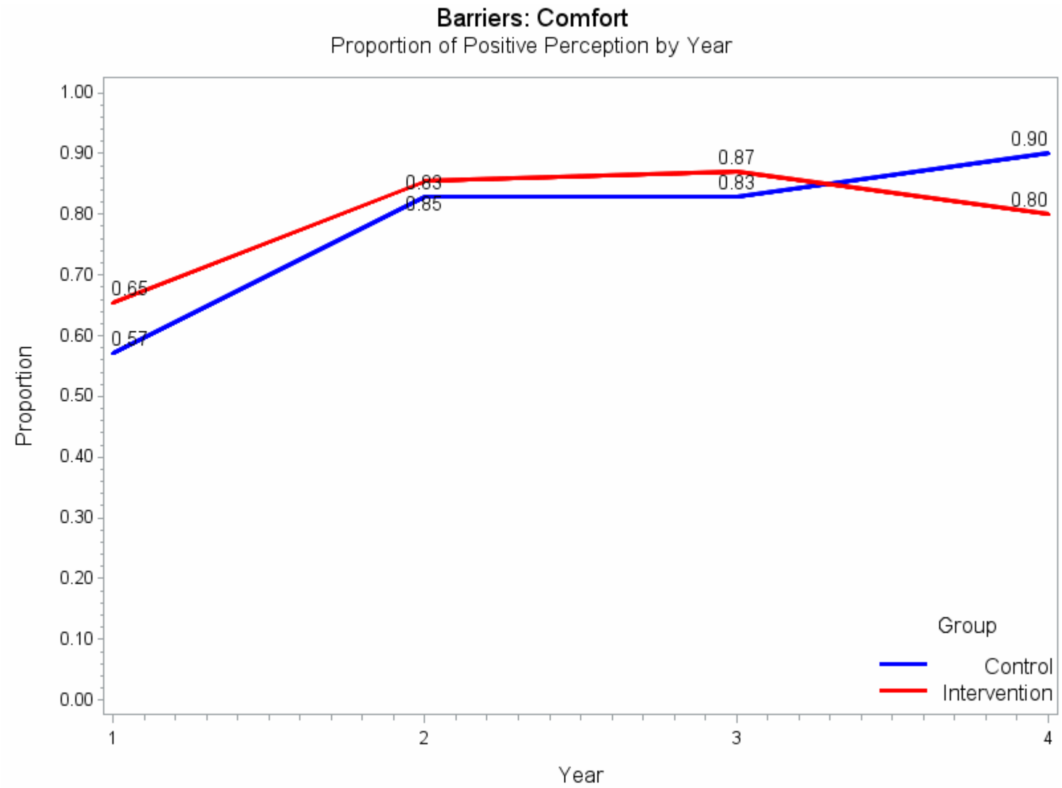
Also, there are huge gaps in knowledge about audiometric notches. Though there are different definitions of notches, there are clear differences in how a notch is defined. Similarly, there are different ways to calculate notch depth and shape. While it is beneficial to have several different working definitions and theories as to how to describe audiometric notches, we need to establish single definitions to improve the vocabulary of audiometry. Positions within the audiogram that may turn into audiometric notches can be identified, but until we establish a unified definition for audiometric notches, we can only retroactively identify early signs of notches.

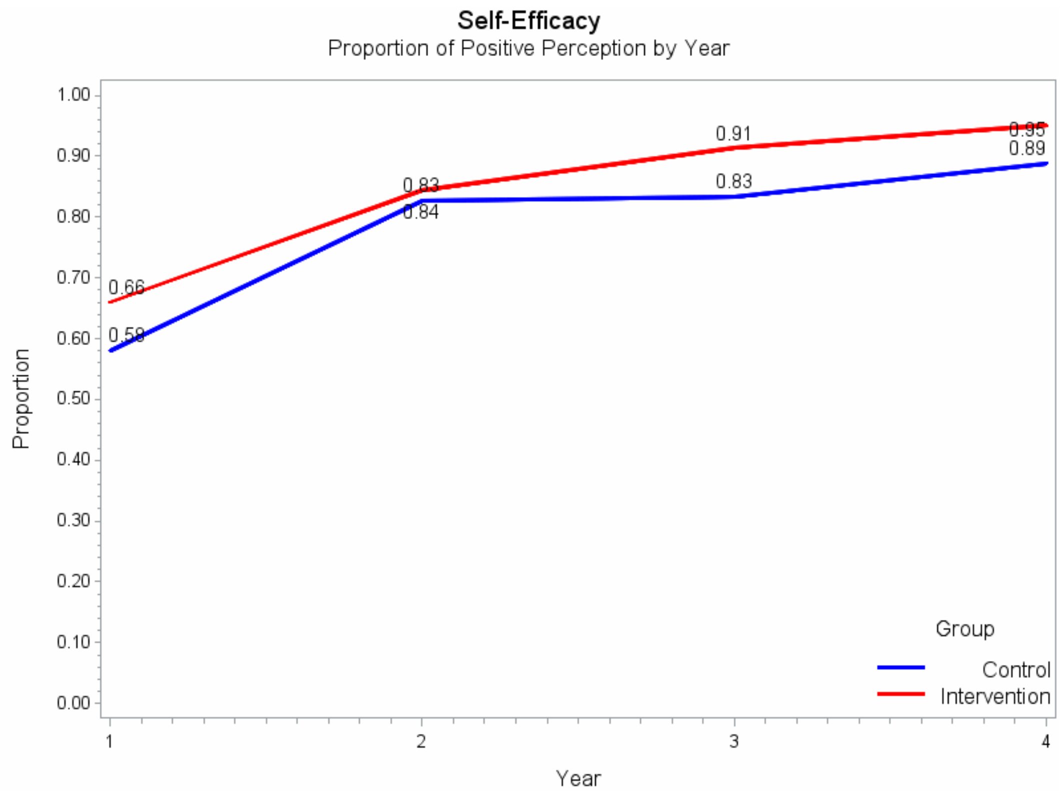
APPENDIX A – BELIEFS ABOUT HEARING PROTECTION AND HEARING LOSS QUESTIONNAIRE

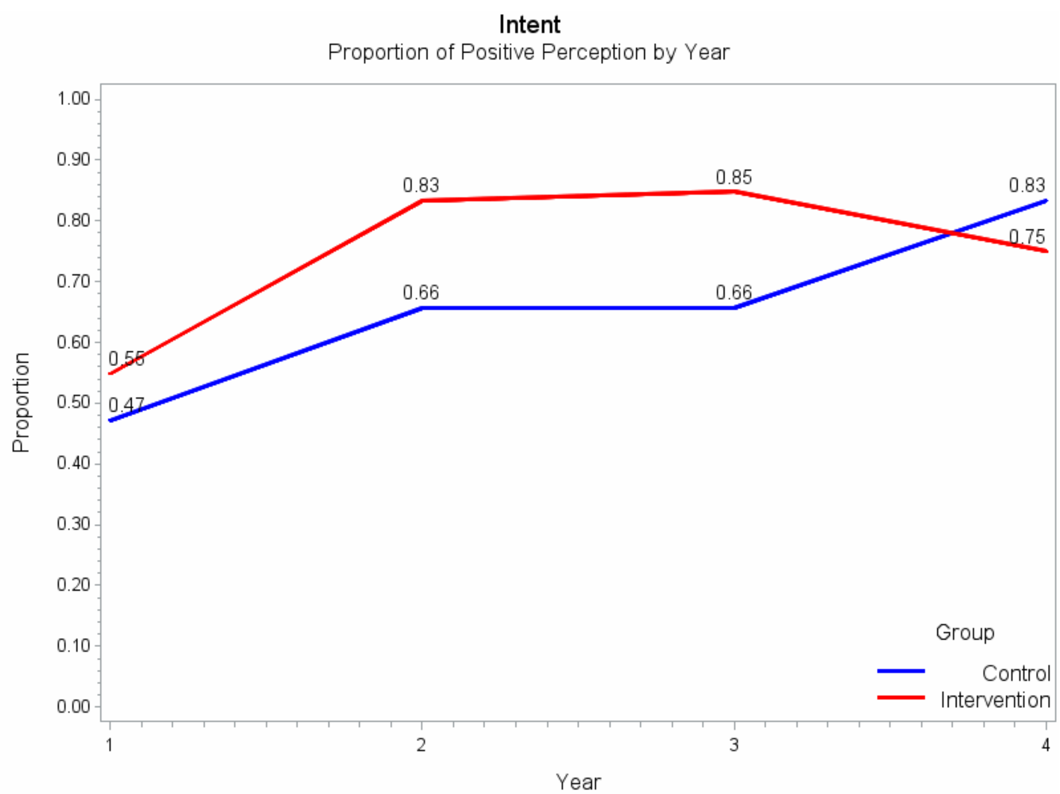
	Statement	Strongly Agree	Agree	Disagree	Strongly Disagree	Content Area
1.	I think earmuffs put too much pressure on my ears.	1	2	3	4	Perceived barriers to preventive actions: comfort
2.	I believe I know how to fit and wear earplugs.	1	2	3	4	Self-efficacy
3.	I do *not* intend to wear hearing protectors when I am around loud tools or equipment.	1	2	3	4	Behavioral intentions; future behaviors
4.	Most of my co-workers wear hearing protectors when they work around loud noise.	1	2	3	4	Social norms
5.	I think I can work around loud noise without it hurting my hearing.	1	2	3	4	Perceived susceptibility to hearing loss.
6.	I think wearing hearing protectors every time I am working in loud noise is important.	1	2	3	4	Perceived benefits of preventive action.
7.	I think earmuffs make my head sweat too much.	1	2	3	4	Perceived barriers to preventive action: comfort
8.	I wear hearing protectors whenever I work around loud noise.	1	2	3	4	Behavioral intentions: present behaviors
9.	Hearing protectors are uncomfortable to wear.	1	2	3	4	Perceived barriers to preventive action: comfort
10.	My co-workers don't wear hearing protectors when they work in loud noise.	1	2	3	4	Social norms
11.	I'm not sure how to tell when earplugs need to be replaced.	1	2	3	4	Self-efficacy
12.	Losing my hearing would make it hard for people to talk to me.	1	2	3	4	Perceived severity of consequences of hearing loss
13.	I believe that my ears can eventually 'get toughened' to noise, so they are less likely to be damaged by it.	1	2	3	4	Perceived susceptibility to hearing loss
14.	I know when I should use hearing protectors.	1	2	3	4	Self-efficacy
15.	I think it will be hard to hear warning signals (like backup beeps) if I am wearing hearing protectors.	1	2	3	4	Perceived barriers to preventive action: muffle important sounds.

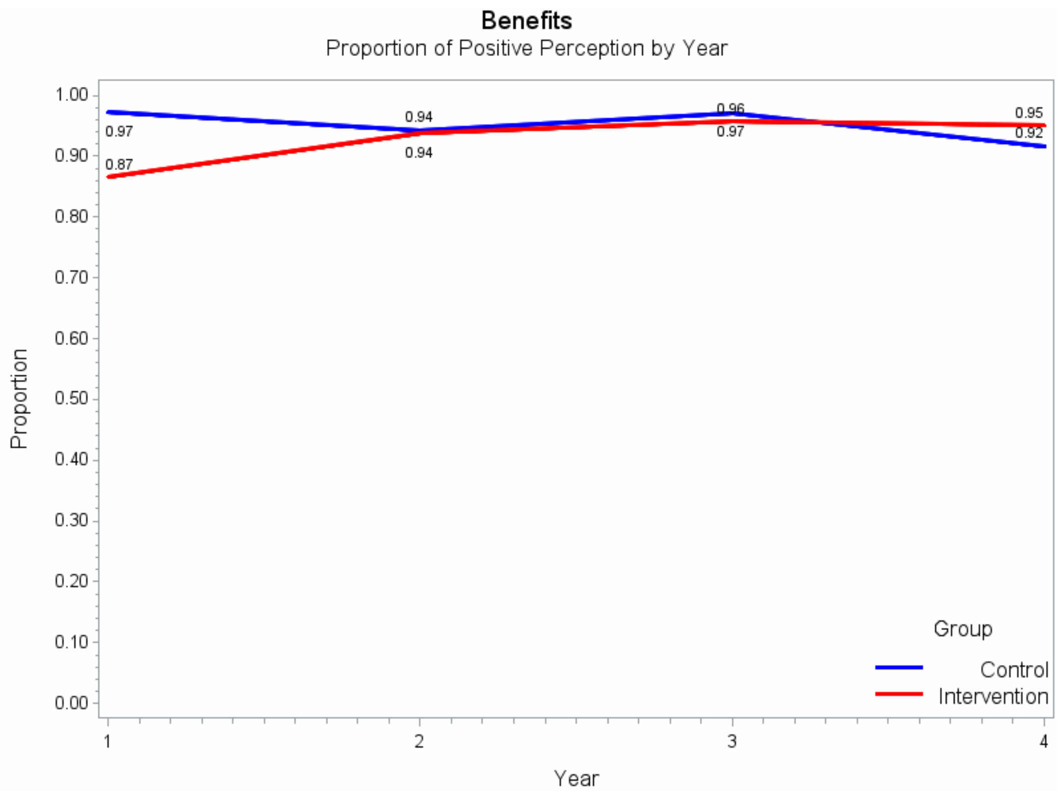
16.	I believe exposure to loud noise can hurt my hearing.	1	2	3	4	Perceived susceptibility to hearing loss.
17.	I am convinced I can prevent hearing loss by wearing hearing protectors whenever I work in loud noise.	1	2	3	4	Perceived benefits of preventive action
18.	I think my hearing is being hurt by exposure to loud noise at work.	1	2	3	4	Perceived susceptibility to hearing loss
19.	Hearing protectors limit my ability to hear problems on the job site.	1	2	3	4	Perceived barriers to preventive actions: muffle important sounds
20.	I don't think it would be such a big handicap to lose part of my hearing.	1	2	3	4	Perceived severity of consequences of hearing loss
21.	If I wear hearing protection, I can protect my hearing.	1	2	3	4	Perceived benefits of preventive action
22.	I know how to tell when an earmuff needs to be replaced.	1	2	3	4	Self-efficacy
23.	Wearing hearing protection is annoying.	1	2	3	4	Perceived barriers to preventive action: comfort
24.	Most of my co-workers think it is a good idea to wear hearing protectors in hazardous noise.	1	2	3	4	Social norms
25.	If co-workers asked me, I would be able to help them wear hearing protectors correctly.	1	2	3	4	Self-efficacy
26.	I don't think I have to wear hearing protectors every time I am working in noise.	1	2	3	4	Perceived susceptibility to hearing loss
27.	I can't hear problems with my tools and machinery if I wear hearing protectors.	1	2	3	4	Perceived barriers to preventive action: muffle important sounds
28.	I believe that daily exposure to loud machinery and tools will eventually damage my hearing.	1	2	3	4	Perceived susceptibility to hearing loss
29.	I think it would be a big problem if I lost my hearing.	1	2	3	4	Perceived severity of consequences of hearing loss
30.	I plan to wear hearing protection when I work near loud noises.	1	2	3	4	Behavioral intentions; future behaviors
31.	On my current job, I seldom wear hearing protectors when I work around loud noises.	1	2	3	4	Behavioral intentions; past behaviors

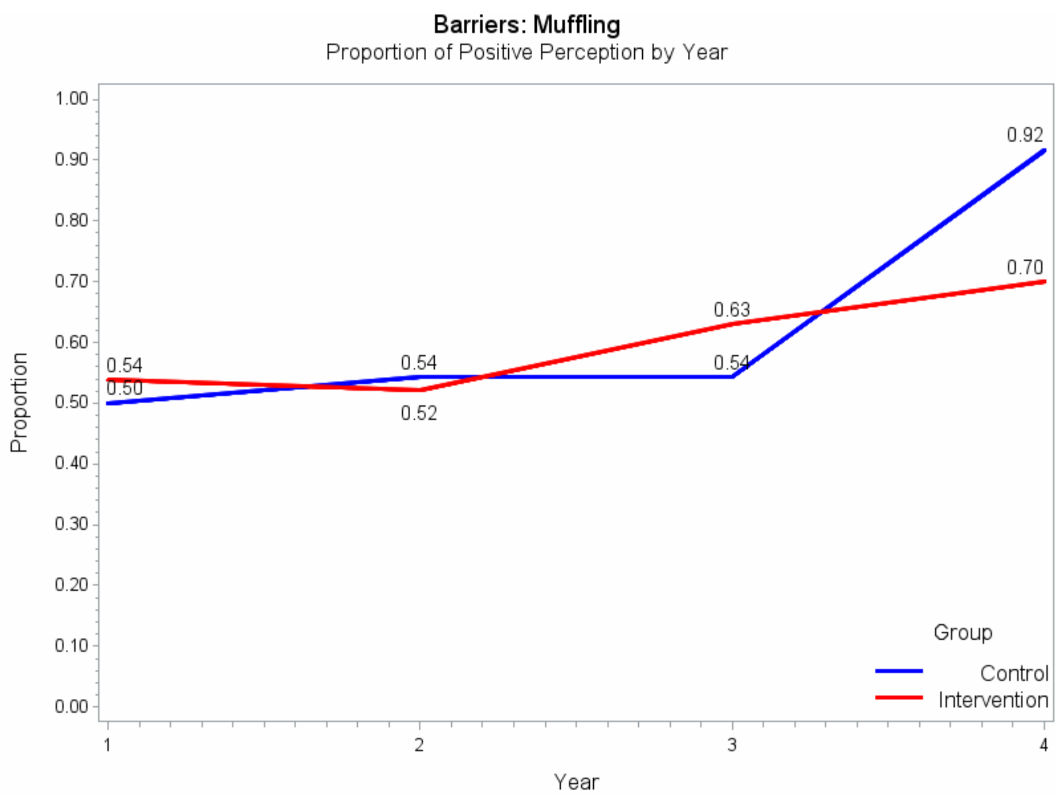
APPENDIX B – PROPORTIONAL CHANGES IN POSITIVE PERCEPTIONS TO BEHAVIORAL CONSTRUCTS




Self-Efficacy
Proportion of Positive Perception by Year
Proportion
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.66
0.58
0.83
0.84
0.91
0.83
0.95
0.89
Group
Control
Intervention
1
2
3
4
Year


Intent
Proportion of Positive Perception by Year
Proportion
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.55
0.47
0.83
0.66
0.85
0.66
0.83
0.75
Group
Control
Intervention
1
2
3
4
Year


Benefits
Proportion of Positive Perception by Year
Proportion
Year
0.97
0.87
0.94
0.94
0.96
0.97
0.95
0.92
Group
Control
Intervention


Barriers: Muffling
Proportion of Positive Perception by Year
Proportion
Year
0.54
0.50
0.54
0.52
0.63
0.54
0.92
0.70
Group
Control
Intervention

APPENDIX C – AUDIOGRAMS OF CONTROL FARMERS (n=35)

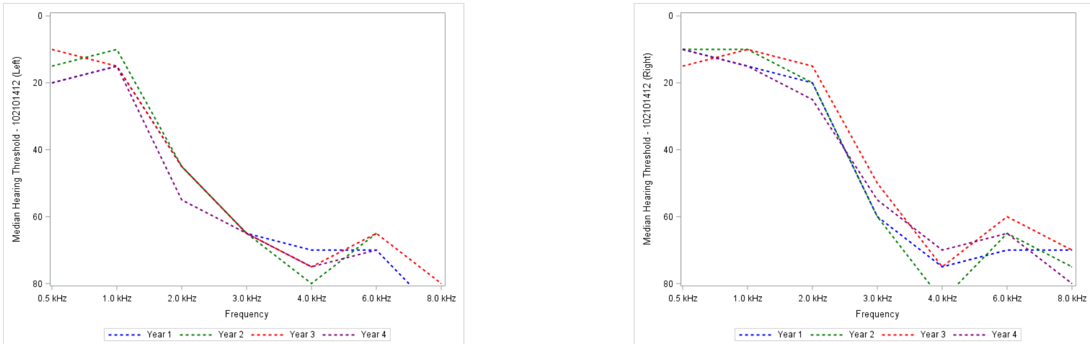


Figure 1 – Left and right audiograms for participant 102101412 across all study years

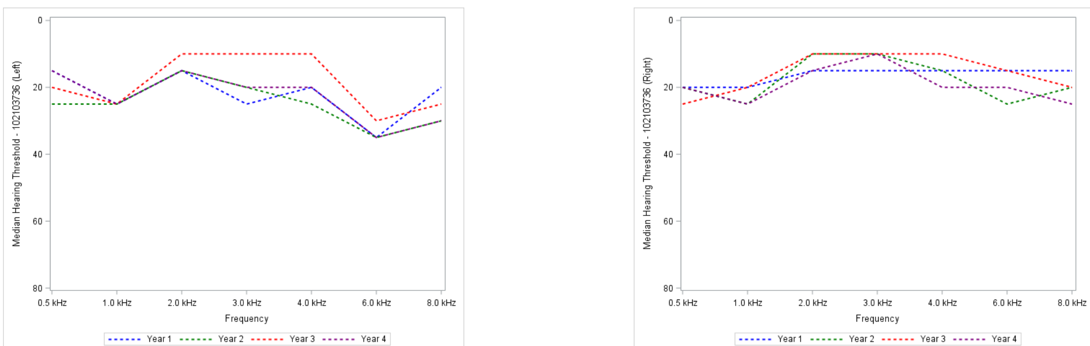


Figure 2 – Left and right audiograms for participant 102103736 across all study years

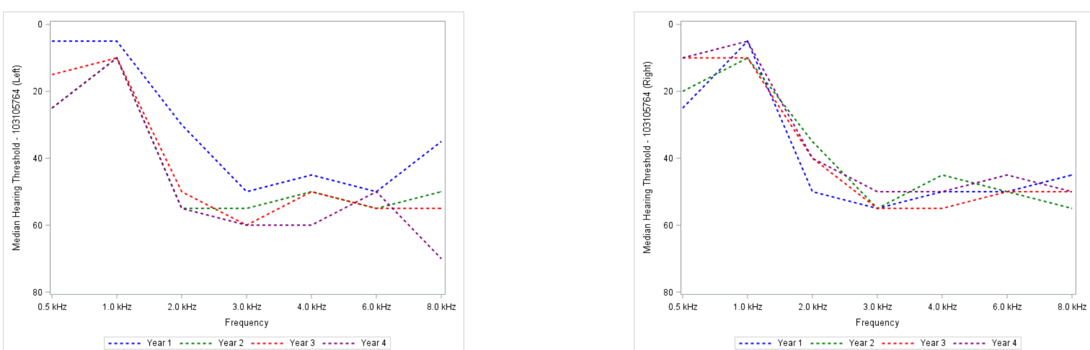


Figure 3 – Left and right audiograms for participant 103105764 across all study years

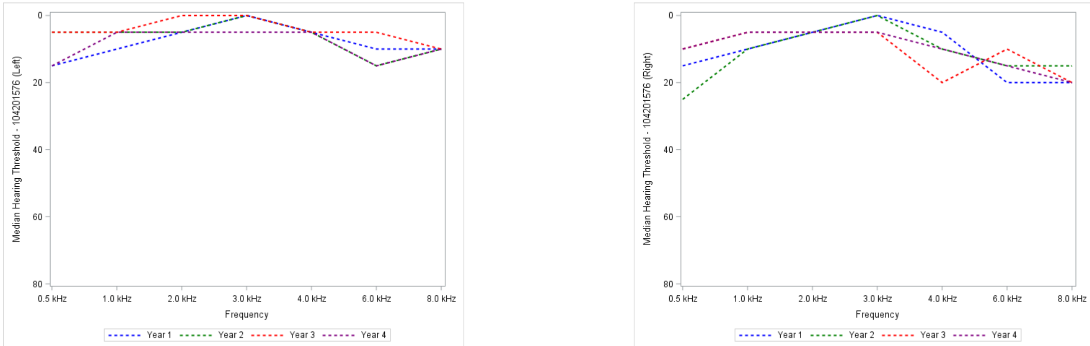


Figure 4 – Left and right audiograms for participant 104201576 across all study years

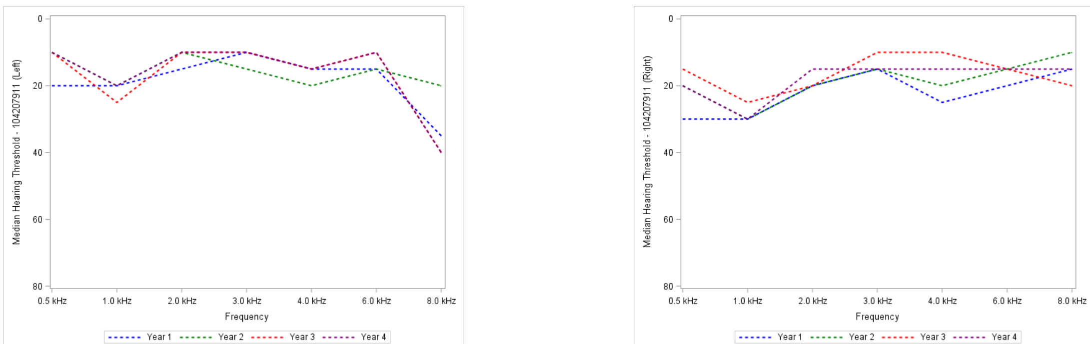


Figure 5 – Left and right audiograms for participant 104207911 across all study years

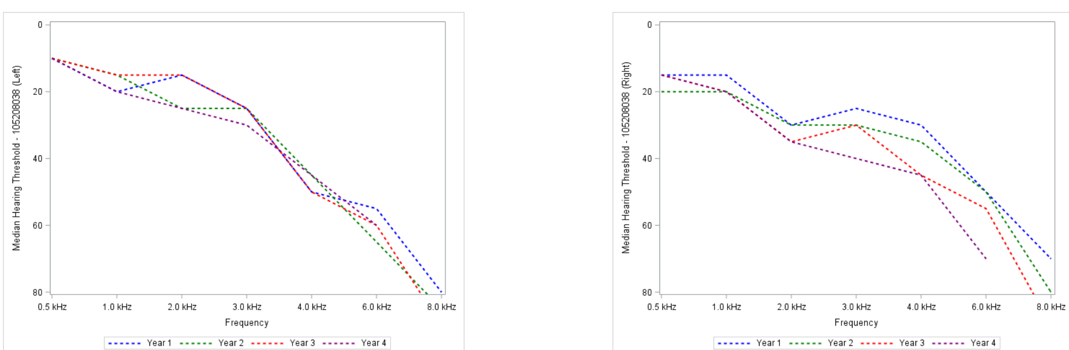


Figure 6 – Left and right audiograms for participant 105208038 across all study years

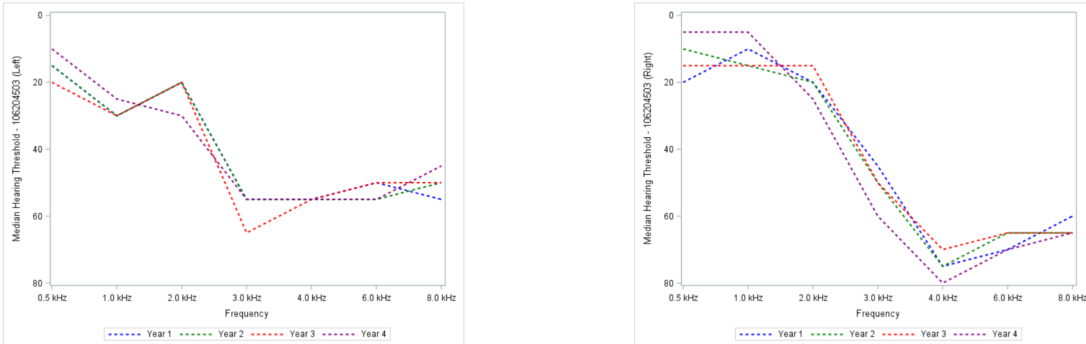


Figure 7 – Left and right audiograms for participant 106204503 across all study years

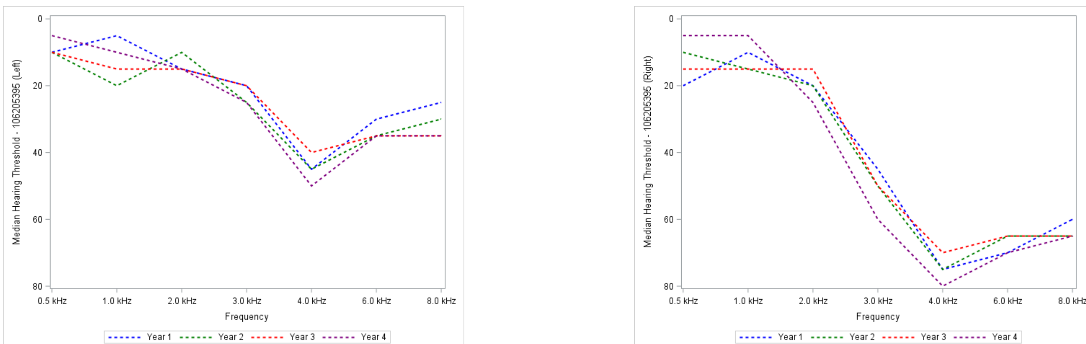


Figure 8 – Left and right audiograms for participant 106205395 across all study years

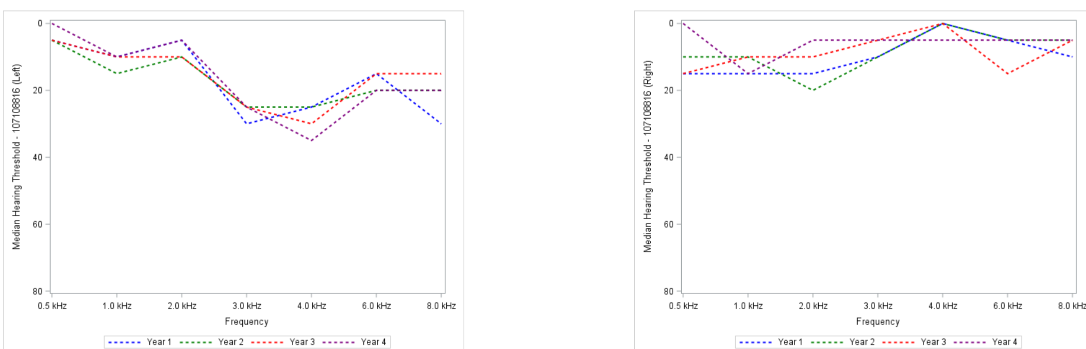


Figure 9 – Left and right audiograms for participant 107108816 across all study years

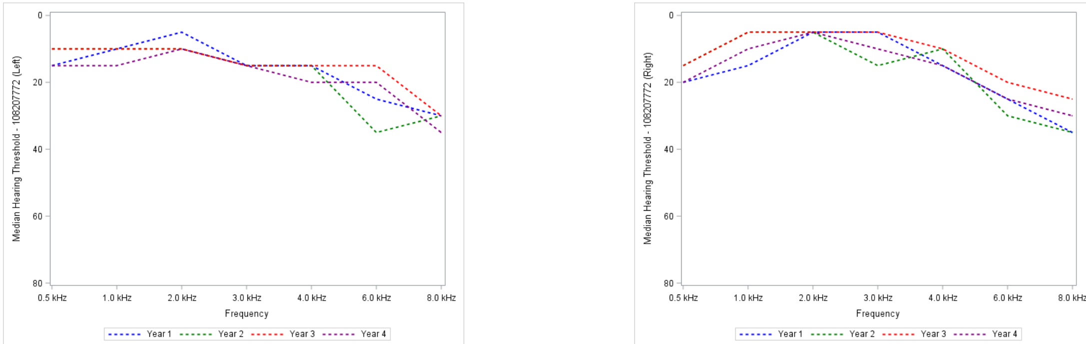


Figure 10 – Left and right audiograms for participant 108207772 across all study years

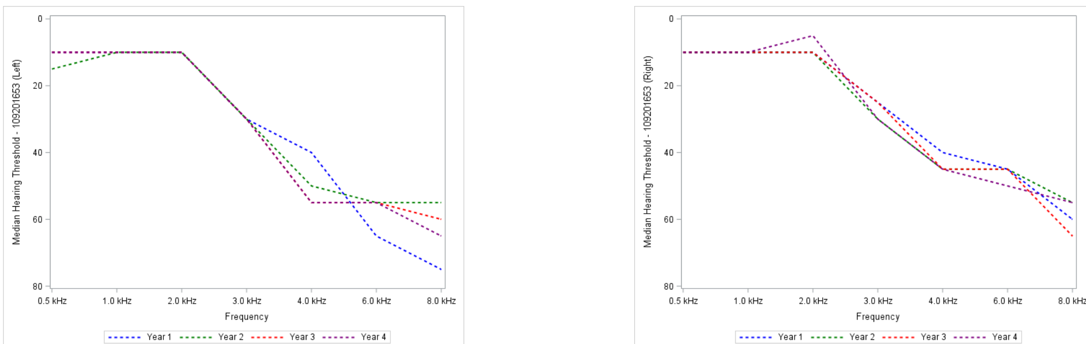


Figure 11 – Left and right audiograms for participant 109201653 across all study years

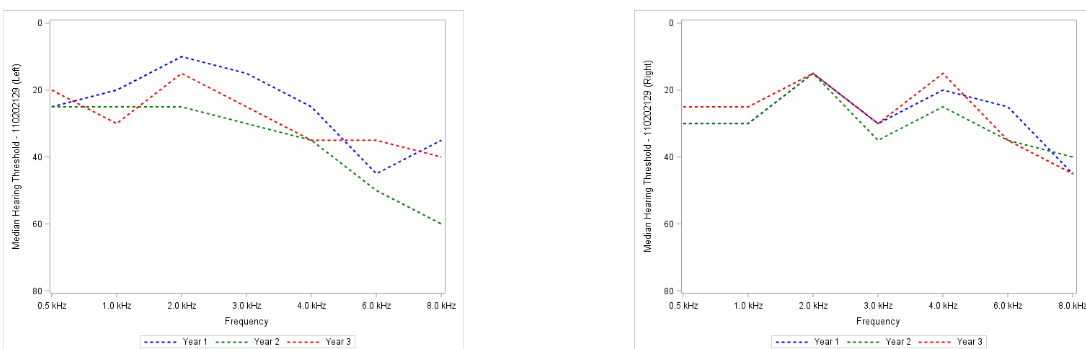


Figure 12 – Left and right audiograms for participant 110202129 across all study years

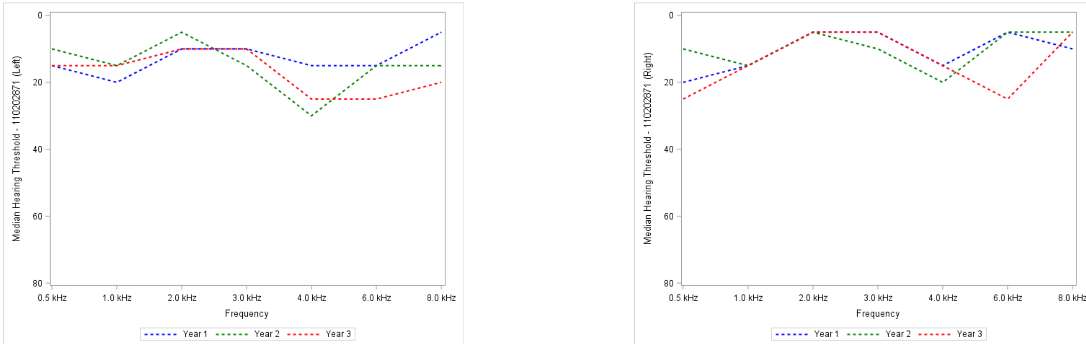


Figure 13 – Left and right audiograms for participant 110202871 across all study years

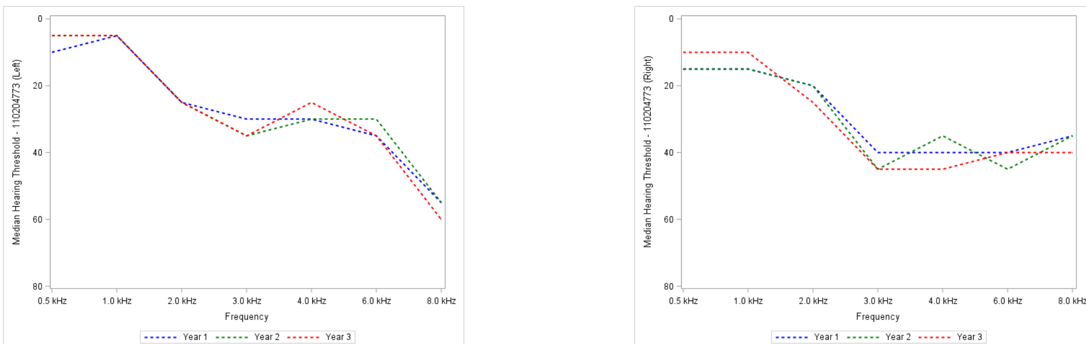


Figure 14 – Left and right audiograms for participant 110204773 across all study years

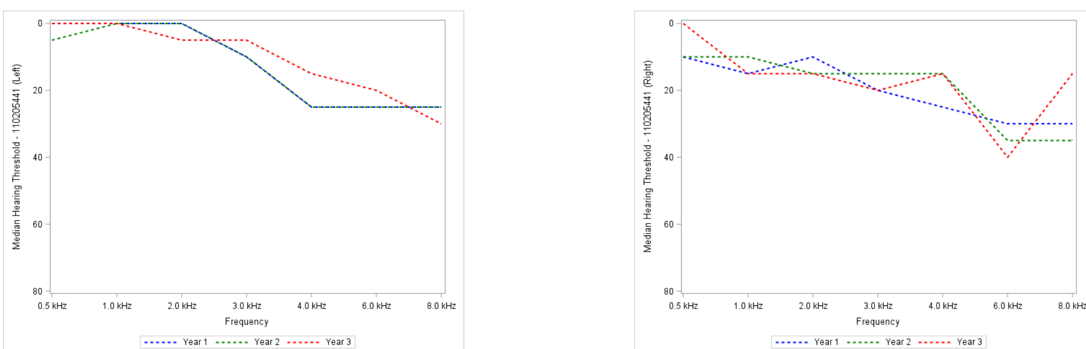


Figure 15 – Left and right audiograms for participant 110205441 across all study years

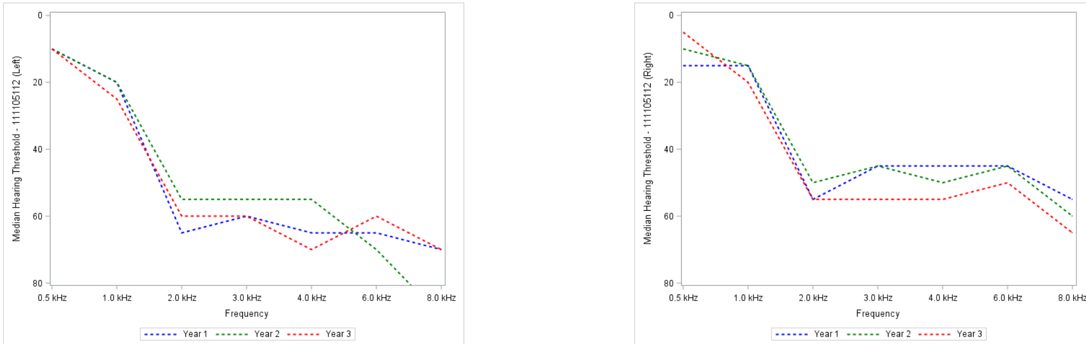


Figure 16 – Left and right audiograms for participant 111105112 across all study years

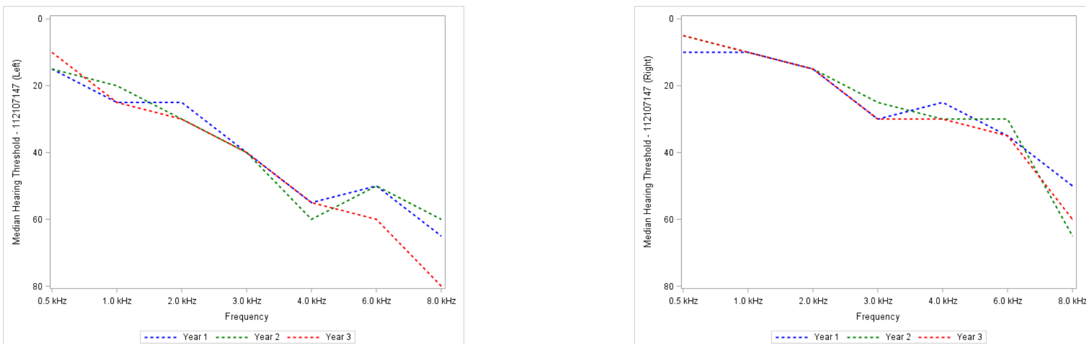


Figure 17 – Left and right audiograms for participant 112107147 across all study years

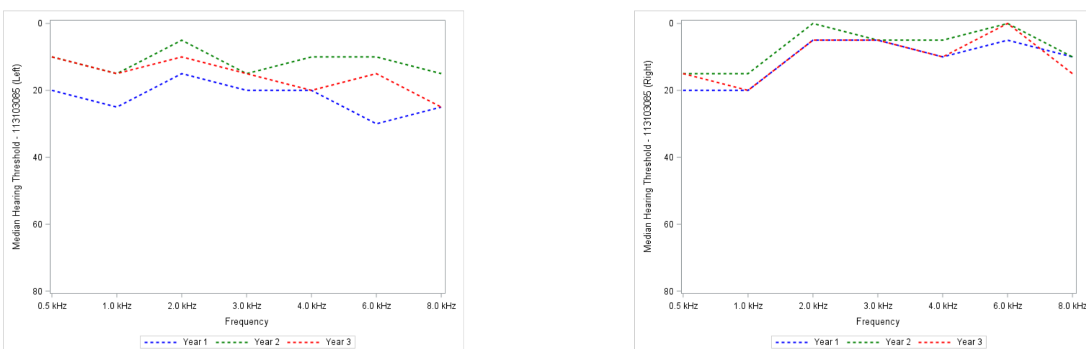


Figure 18 – Left and right audiograms for participant 113103085 across all study years

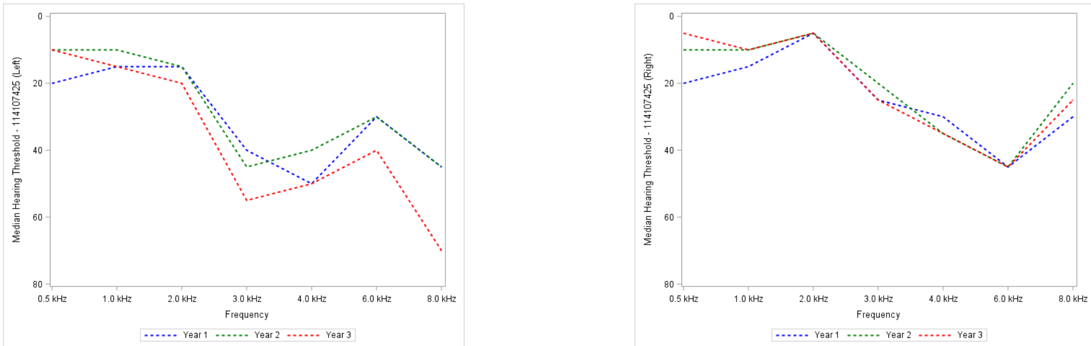


Figure 19 – Left and right audiograms for participant 114107425 across all study years

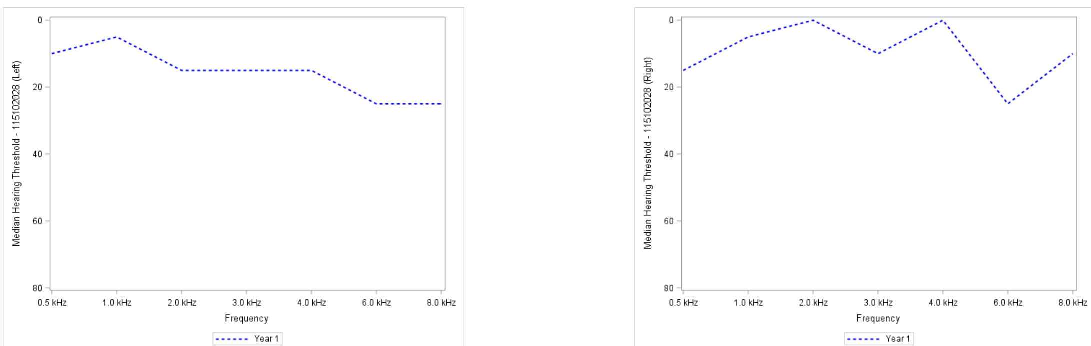


Figure 20 – Left and right audiograms for participant 115102028 across all study years

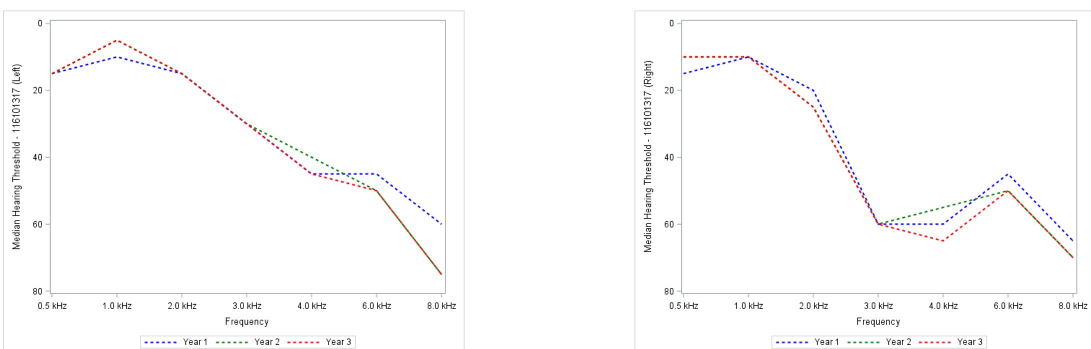


Figure 21 – Left and right audiograms for participant 116101317 across all study years

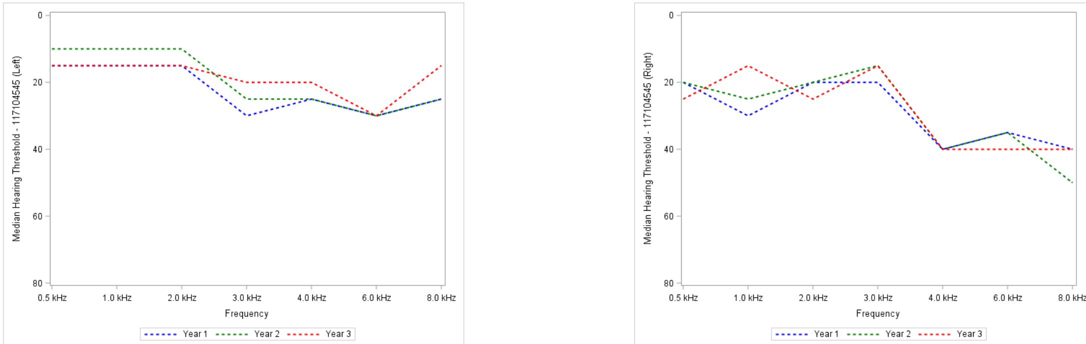


Figure 22 – Left and right audiograms for participant 117104545 across all study years

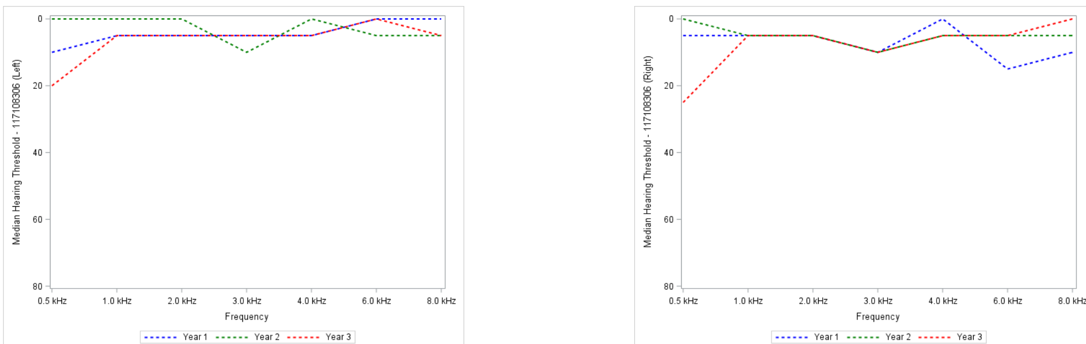


Figure 23 – Left and right audiograms for participant 117108306 across all study years

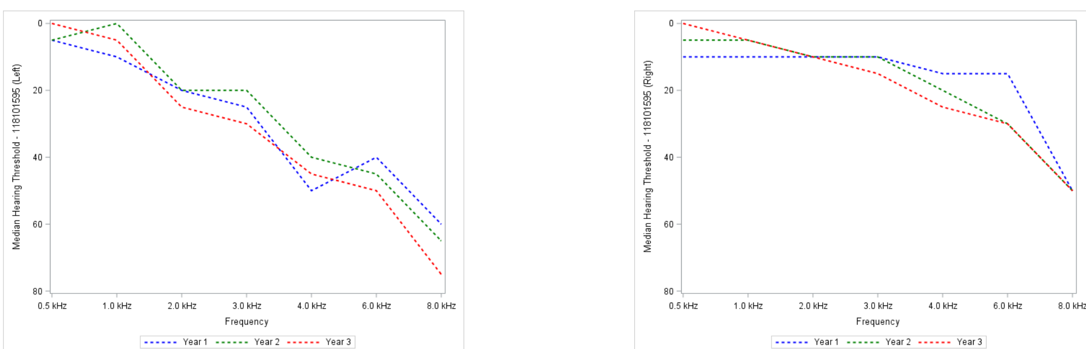
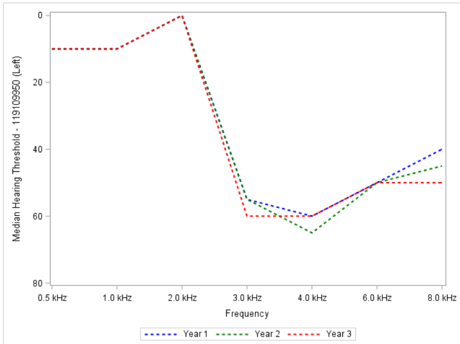


Figure 24 – Left and right audiograms for participant 118101595 across all study years



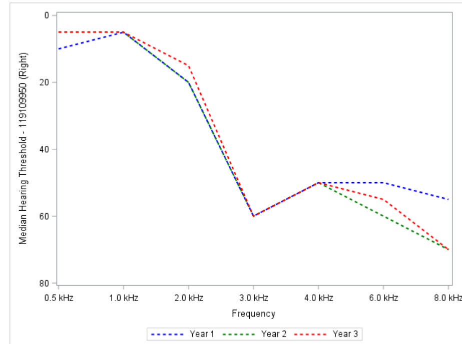
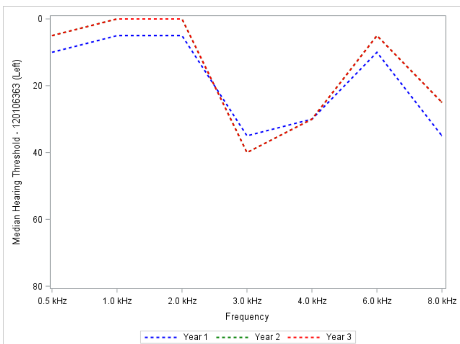


Figure 25 – Left and right audiograms for participant 119109950 across all study years



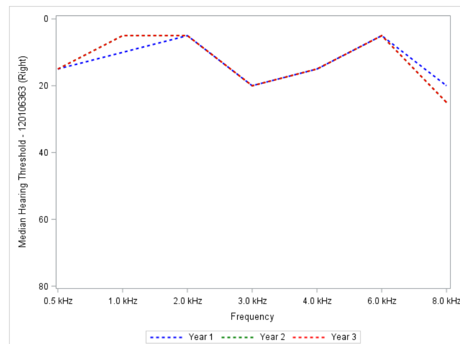
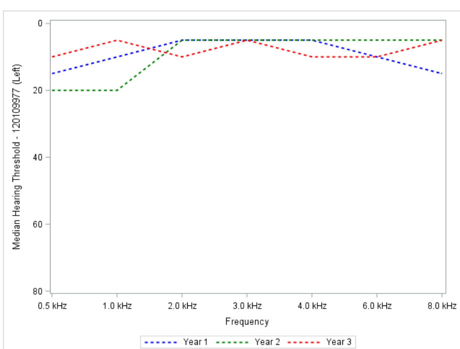


Figure 26 – Left and right audiograms for participant 120106363 across all study years



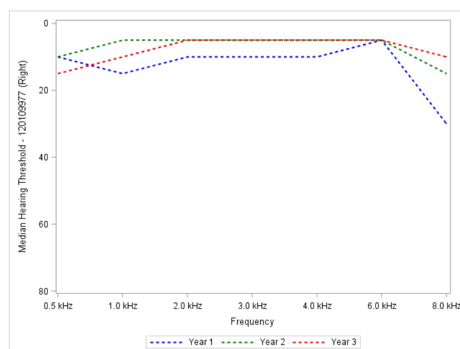


Figure 27 – Left and right audiograms for participant 120109977 across all study years

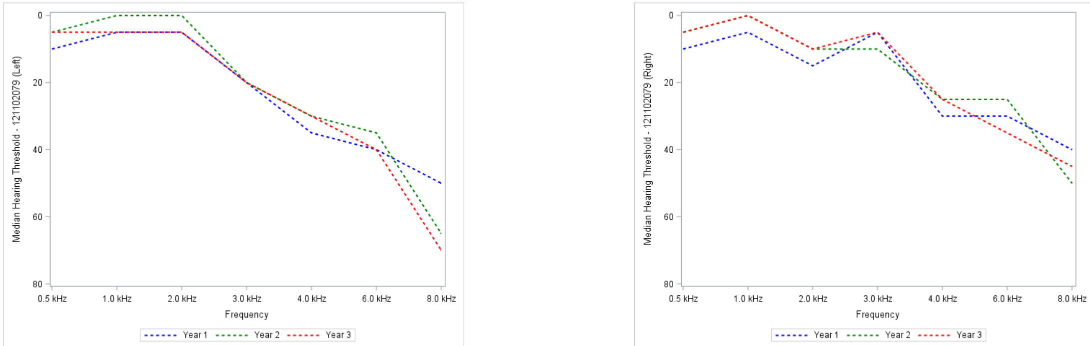


Figure 28 – Left and right audiograms for participant 121102079 across all study years

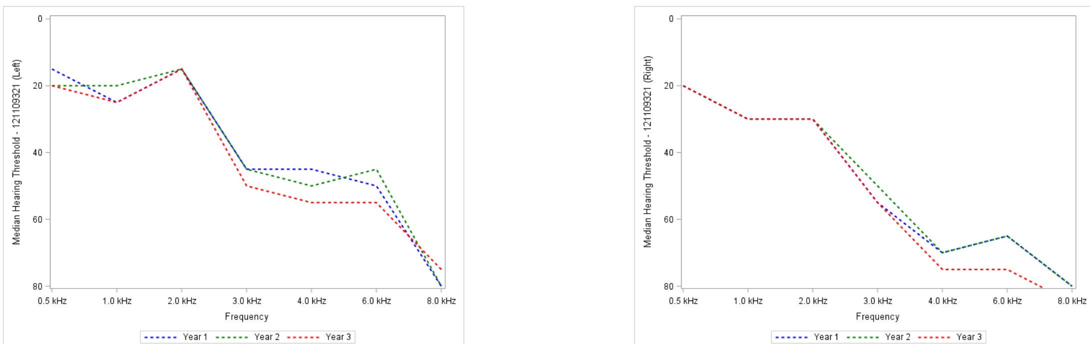


Figure 29 – Left and right audiograms for participant 121109321 across all study years

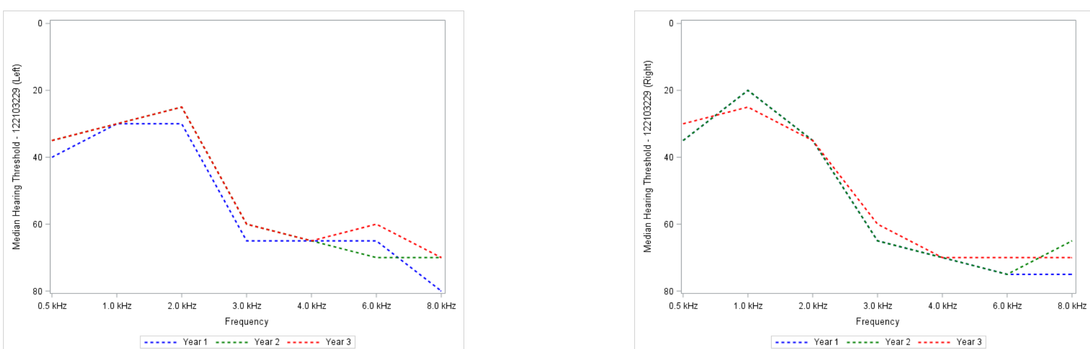


Figure 30 – Left and right audiograms for participant 122103229 across all study years

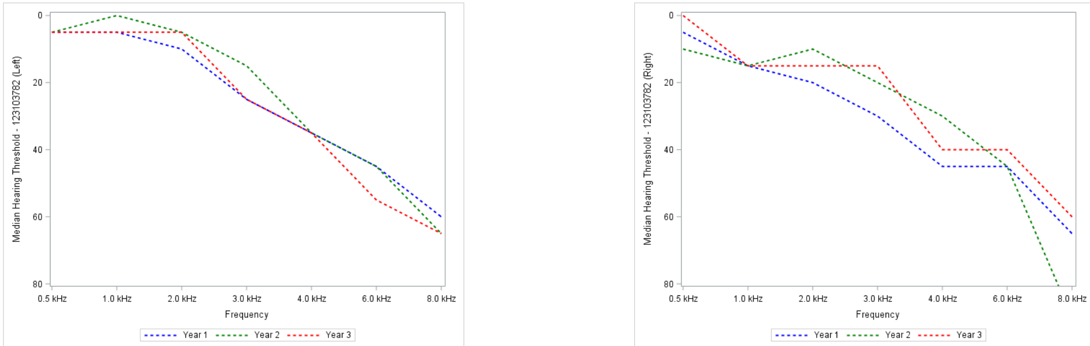


Figure 31 – Left and right audiograms for participant 123103782 across all study years

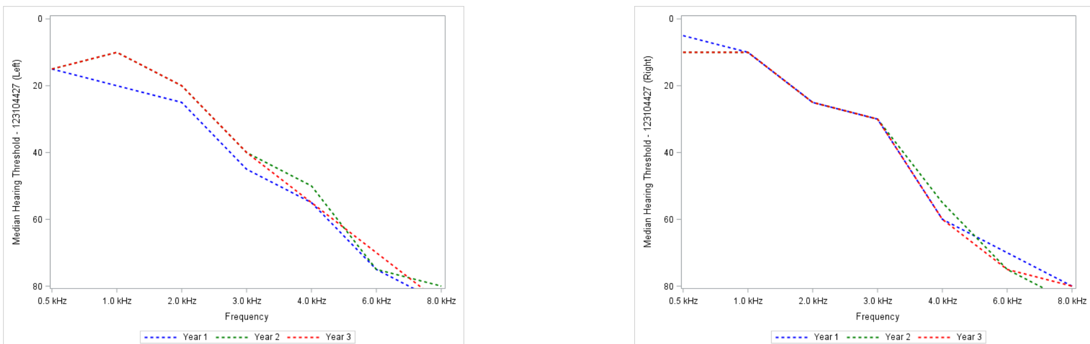


Figure 32 – Left and right audiograms for participant 123104427 across all study years

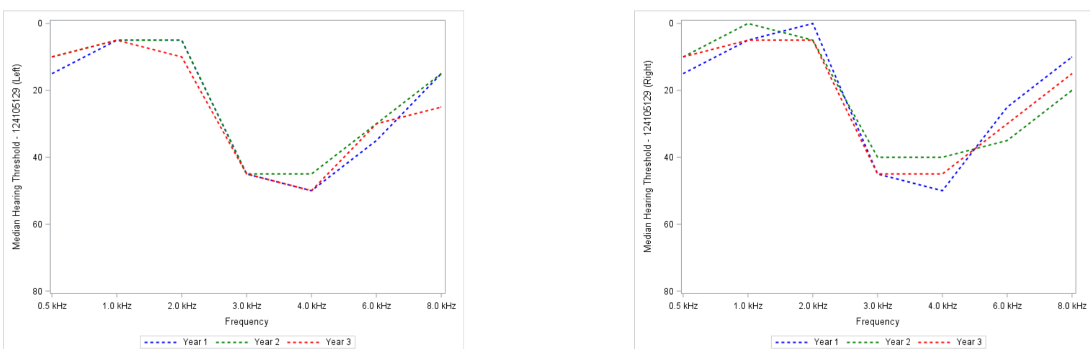


Figure 33 – Left and right audiograms for participant 124105129 across all study years

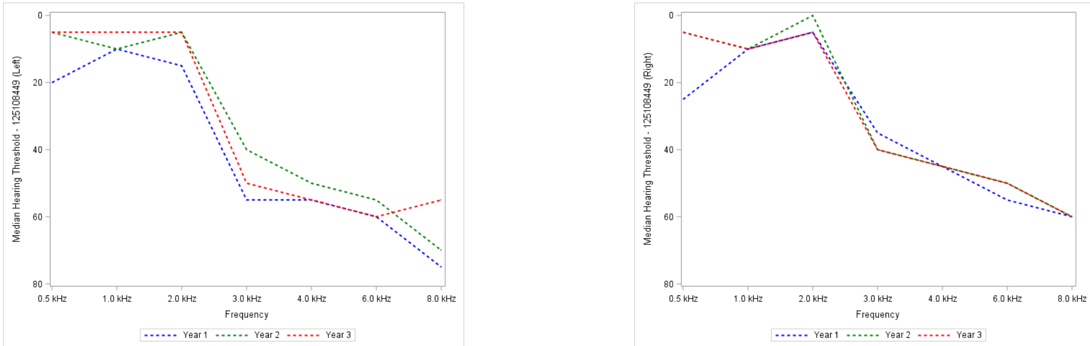


Figure 34 – Left and right audiograms for participant 125108449 across all study years

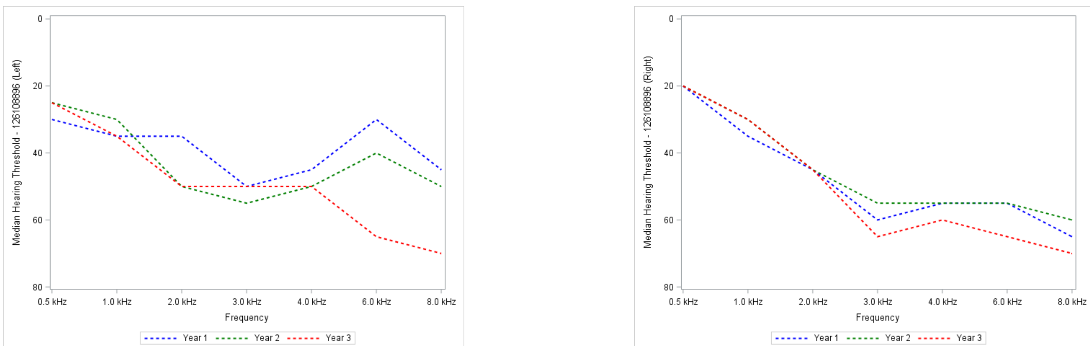


Figure 35 – Left and right audiograms for participant 126108896 across all study years

APPENDIX D – AUDIOGRAMS OF INTERVENTION FARMERS (n=52)

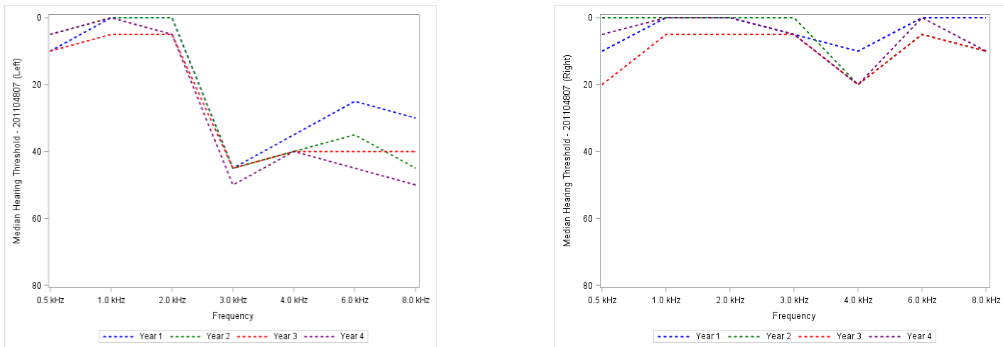


Figure 1 – Left and right audiograms for participant 201104807 across all study years

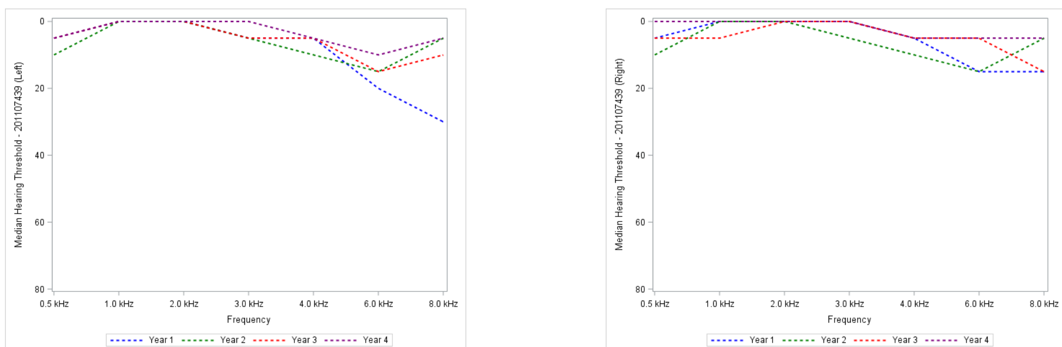


Figure 2 – Left and right audiograms for participant 201107439 across all study years

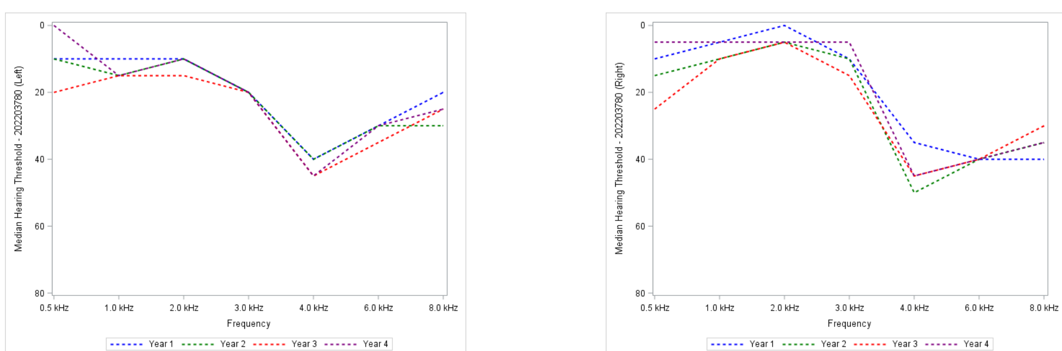


Figure 3 – Left and right audiograms for participant 202203780 across all study years

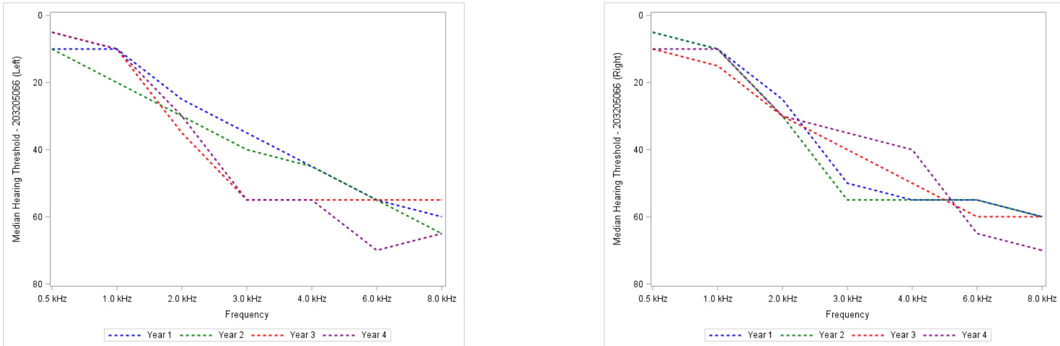


Figure 4 – Left and right audiograms for participant 203205066 across all study years

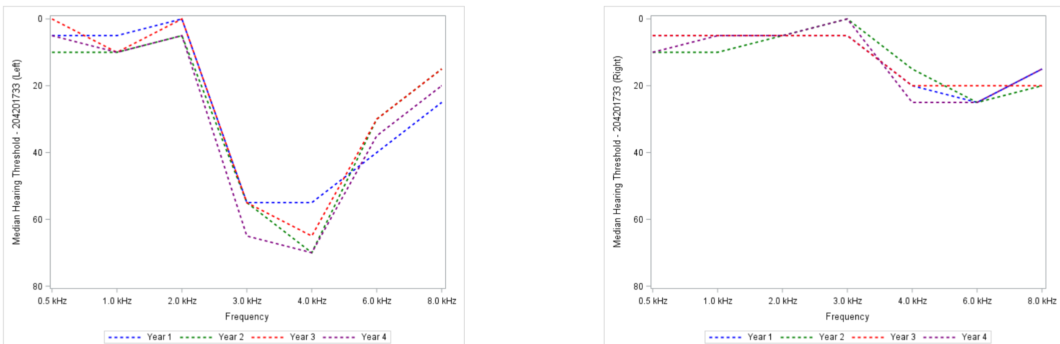


Figure 5 – Left and right audiograms for participant 204201733 across all study years

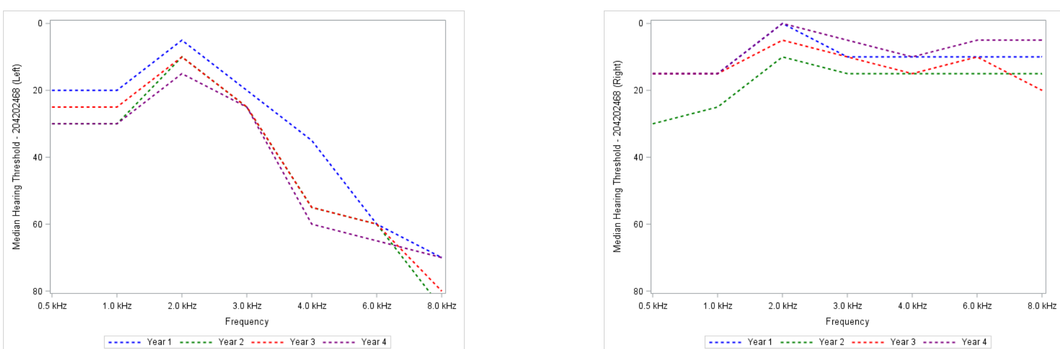


Figure 6 – Left and right audiograms for participant 204202468 across all study years

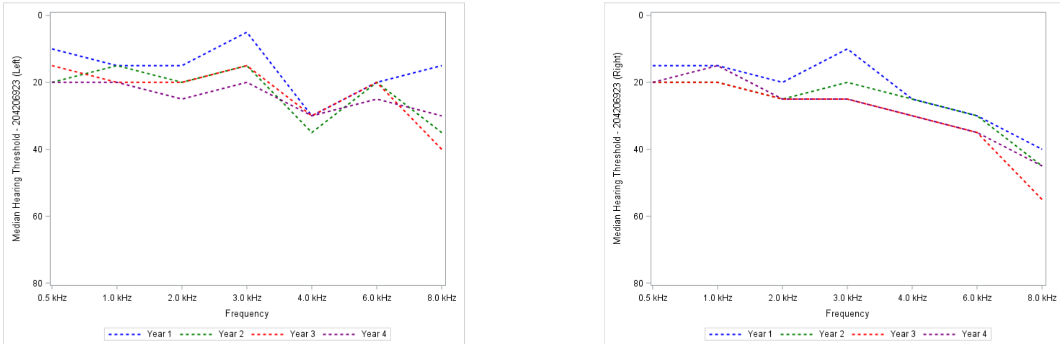


Figure 7 – Left and right audiograms for participant 204206923 across all study years

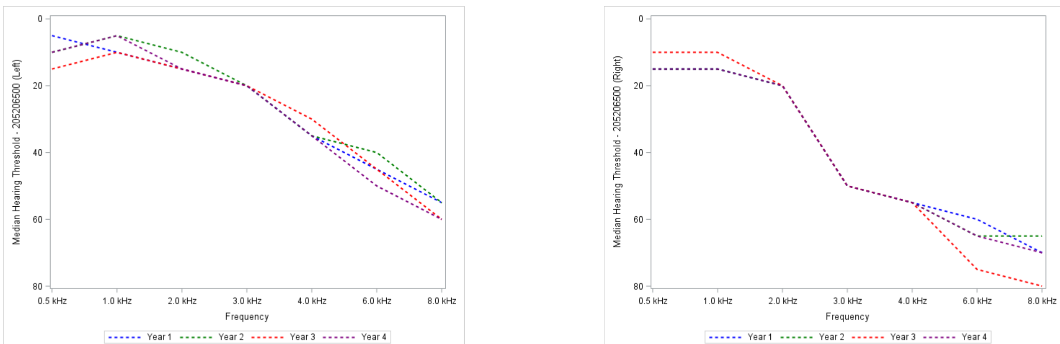


Figure 8 – Left and right audiograms for participant 205206500 across all study years

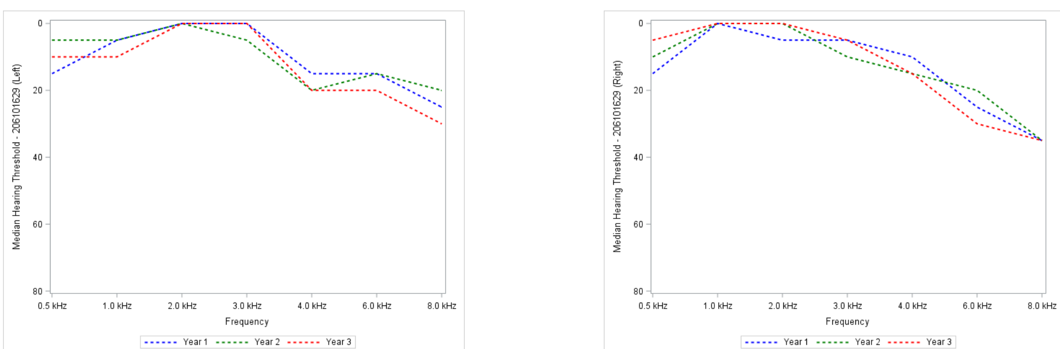


Figure 9 – Left and right audiograms for participant 206101629 across all study years

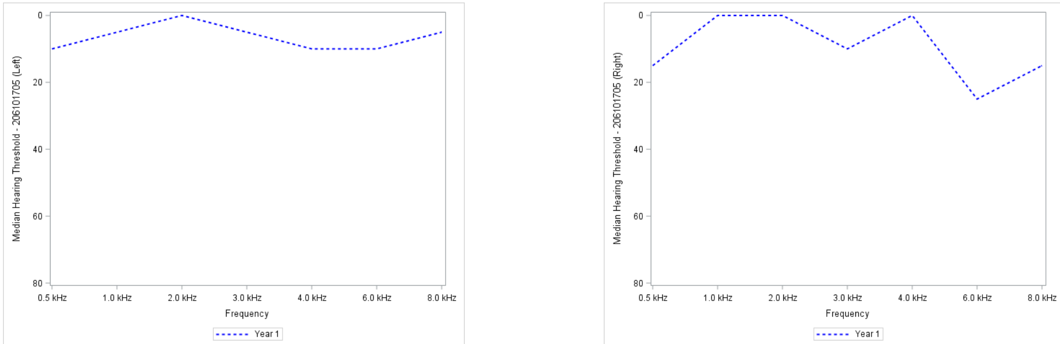


Figure 10 – Left and right audiograms for participant 206101705 across all study years

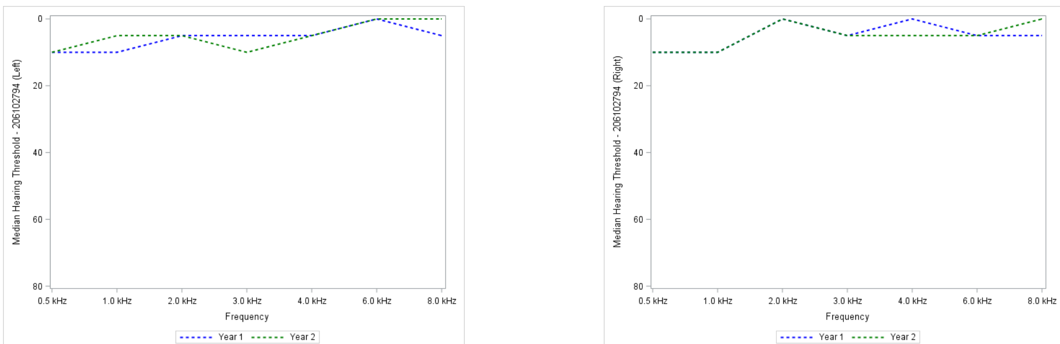


Figure 11 – Left and right audiograms for participant 206102764 across all study years

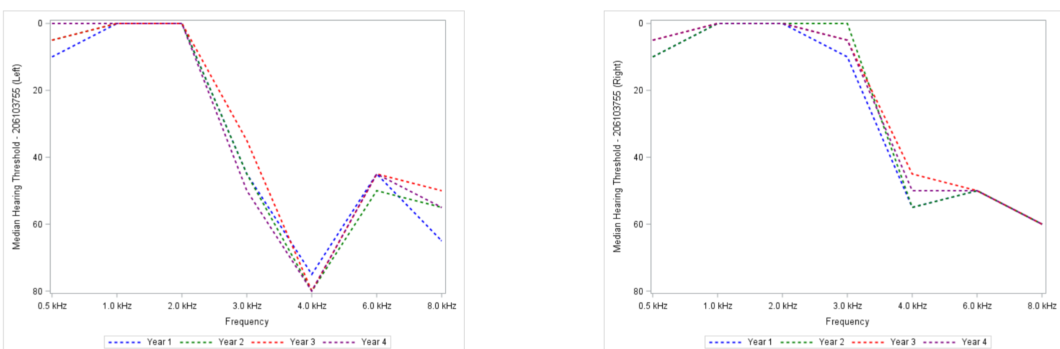


Figure 12 – Left and right audiograms for participant 206103755 across all study years

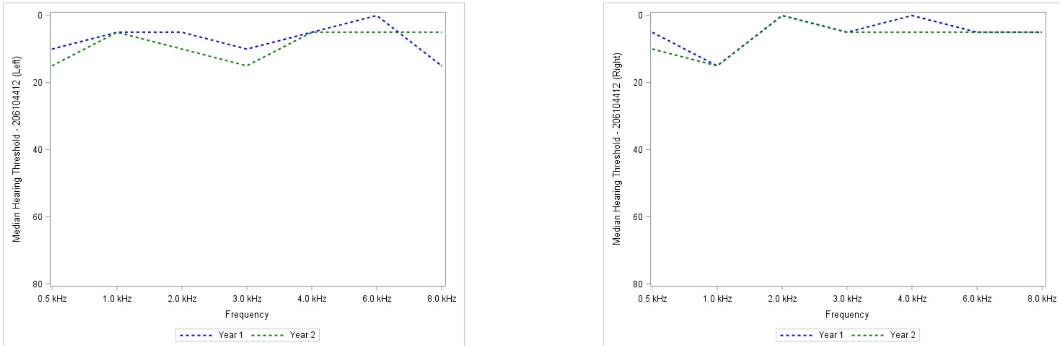


Figure 13 – Left and right audiograms for participant 206104412 across all study years

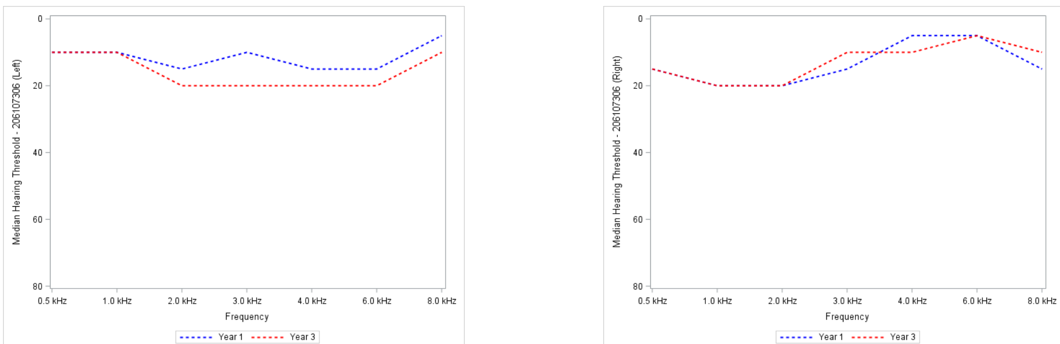


Figure 14 – Left and right audiograms for participant 206107306 across all study years

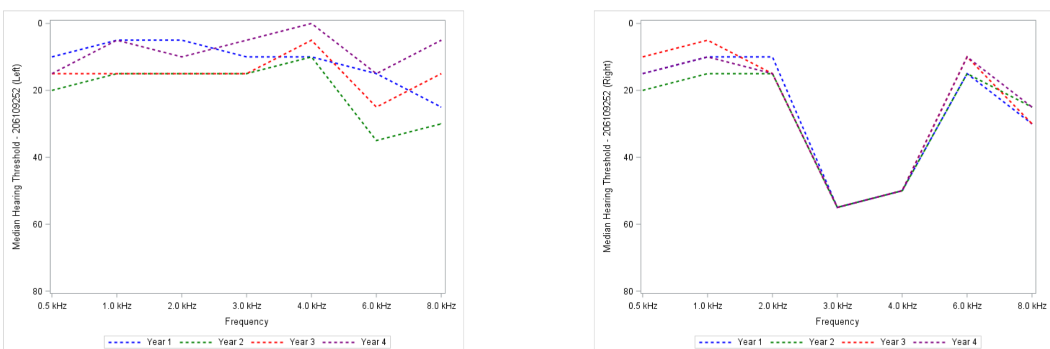


Figure 15 – Left and right audiograms for participant 206109252 across all study years

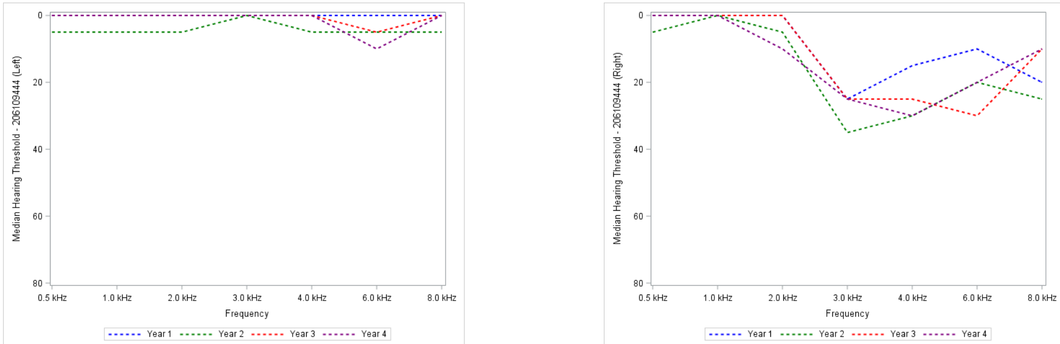


Figure 16 – Left and right audiograms for participant 206109444 across all study years

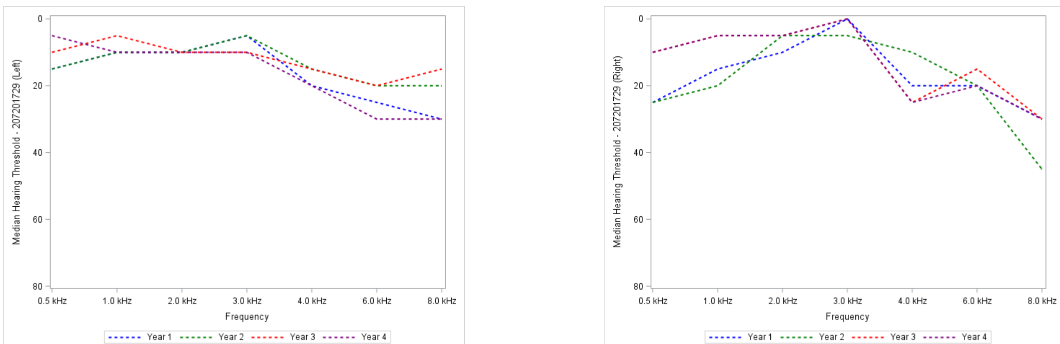


Figure 17 – Left and right audiograms for participant 207201729 across all study years

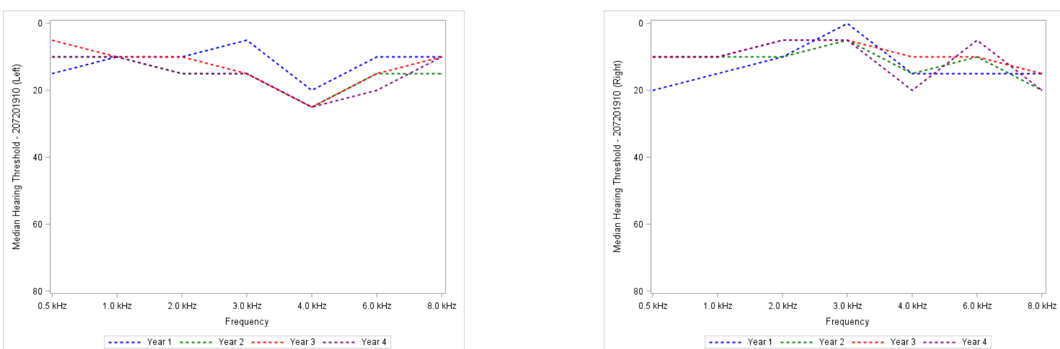


Figure 18 – Left and right audiograms for participant 207201910 across all study years

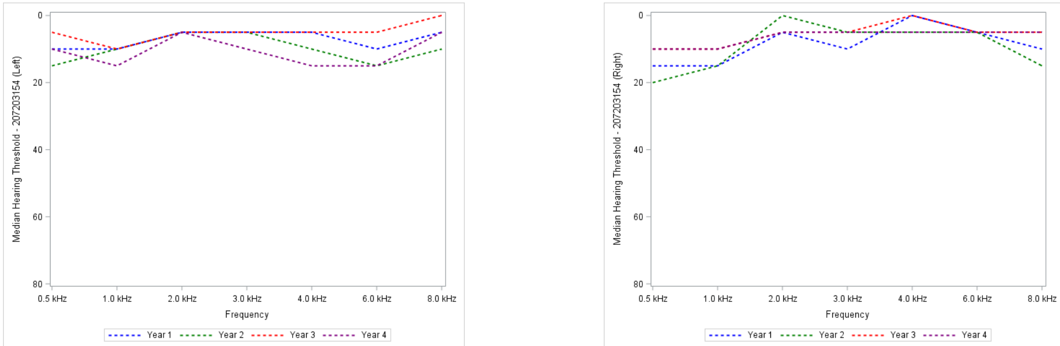


Figure 19 – Left and right audiograms for participant 207203154 across all study years

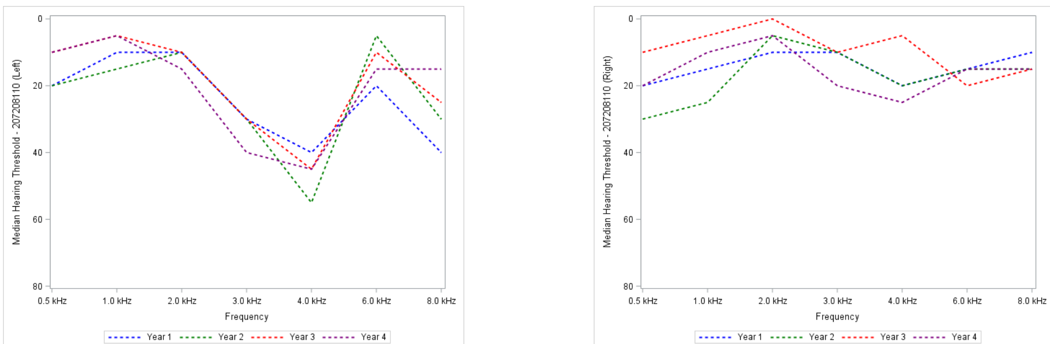


Figure 20 – Left and right audiograms for participant 207208110 across all study years

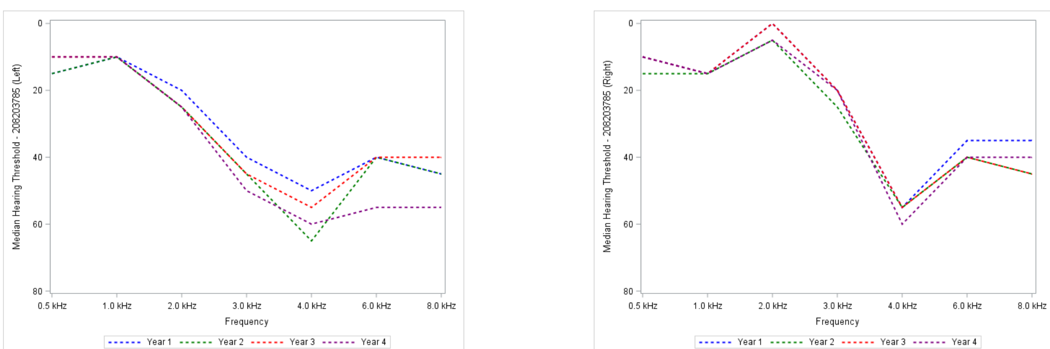


Figure 21 – Left and right audiograms for participant 208203785 across all study years

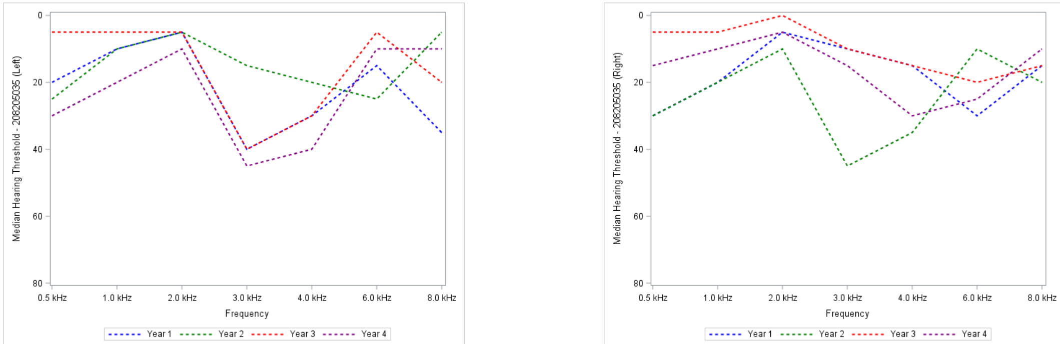


Figure 22 – Left and right audiograms for participant 208205035 across all study years

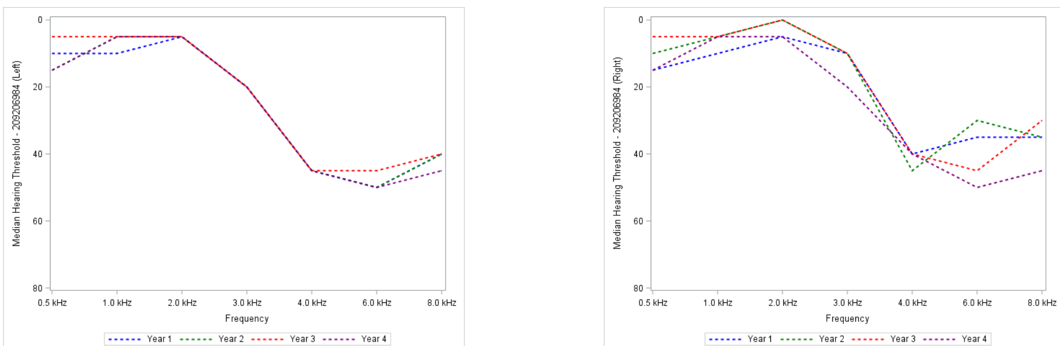


Figure 23 – Left and right audiograms for participant 209206984 across all study years

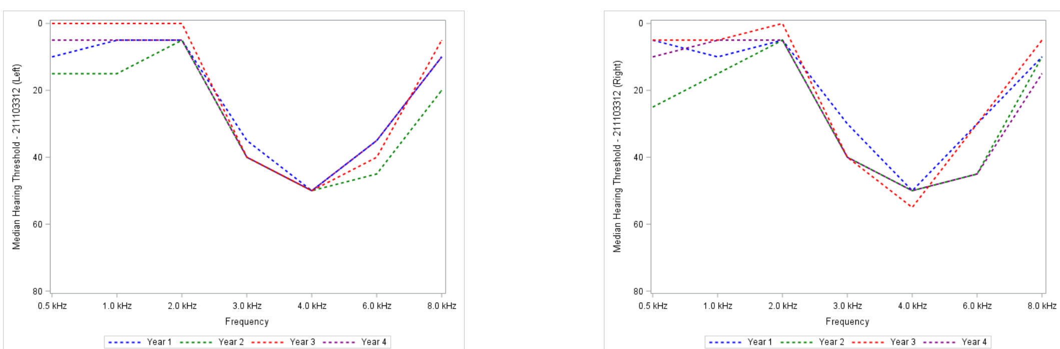


Figure 24 – Left and right audiograms for participant 211103312 across all study years

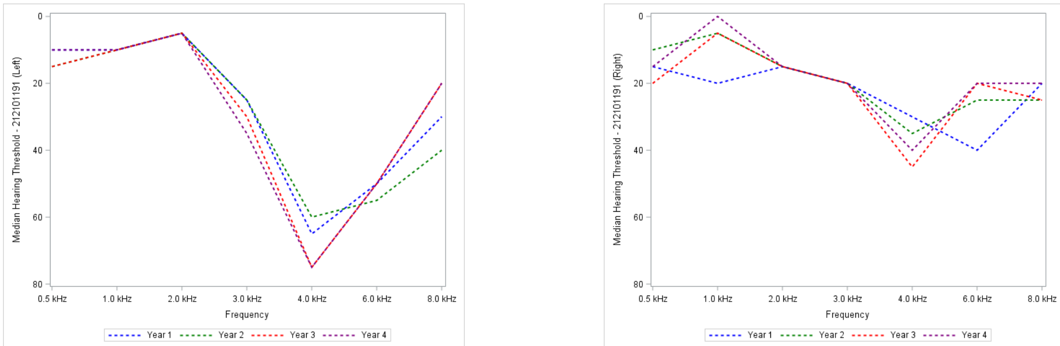


Figure 25 – Left and right audiograms for participant 212101191 across all study years

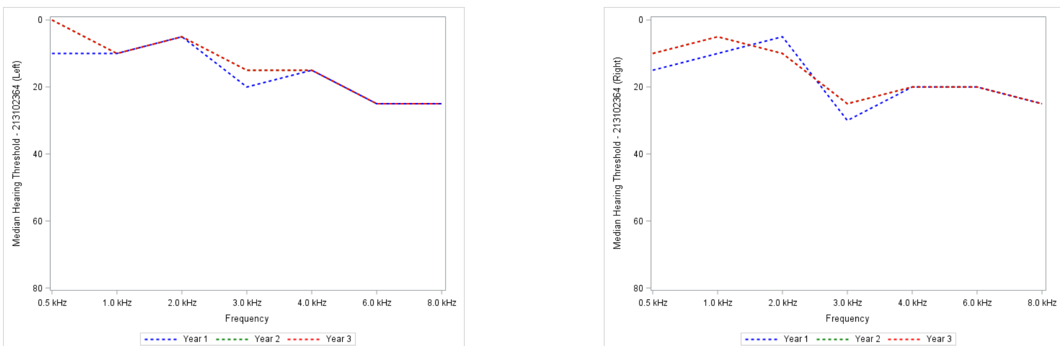


Figure 26 – Left and right audiograms for participant 213102364 across all study years

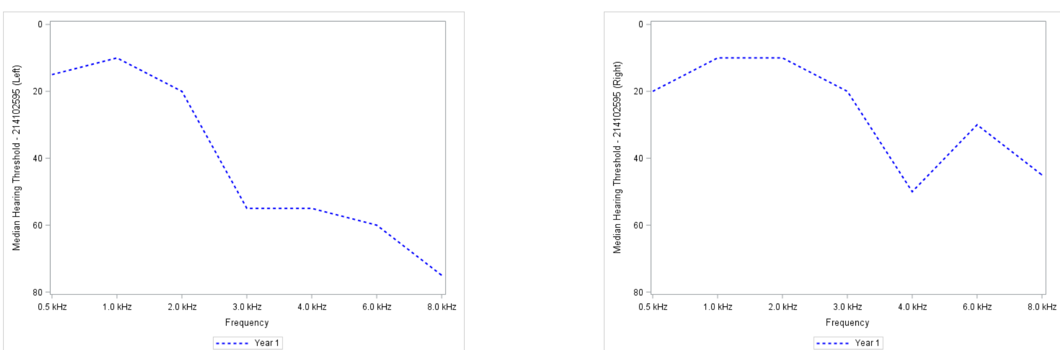


Figure 27 – Left and right audiograms for participant 214102595 across all study years

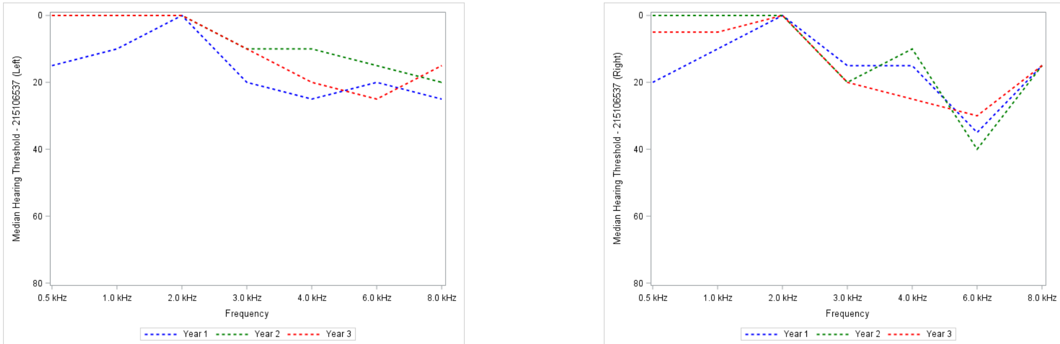


Figure 28 – Left and right audiograms for participant 215106537 across all study years

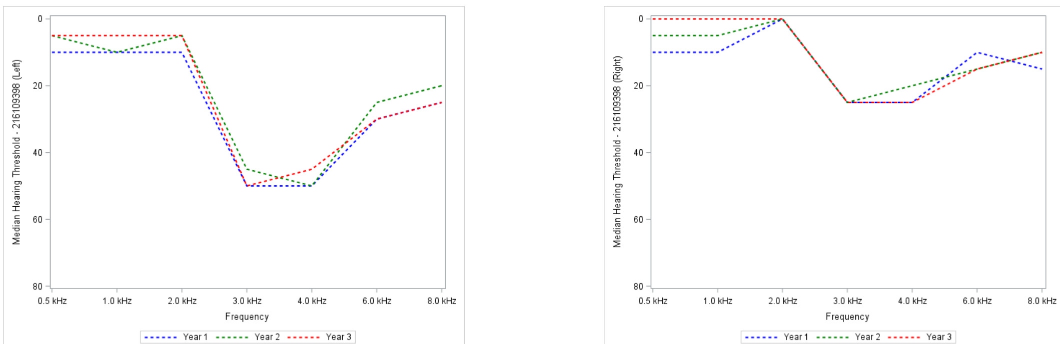


Figure 29 – Left and right audiograms for participant 216109398 across all study years

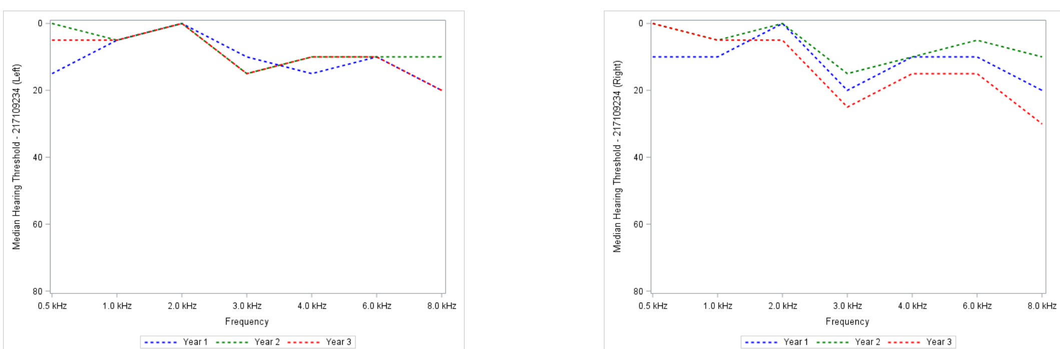


Figure 30 – Left and right audiograms for participant 217109234 across all study years

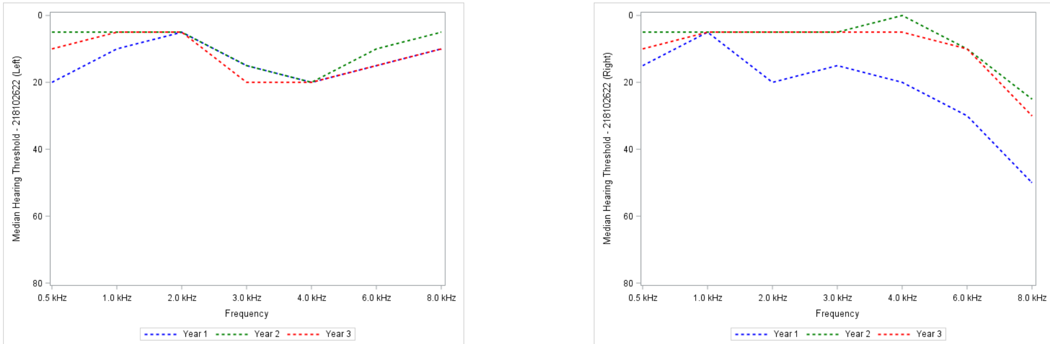


Figure 31 – Left and right audiograms for participant 218102622 across all study years

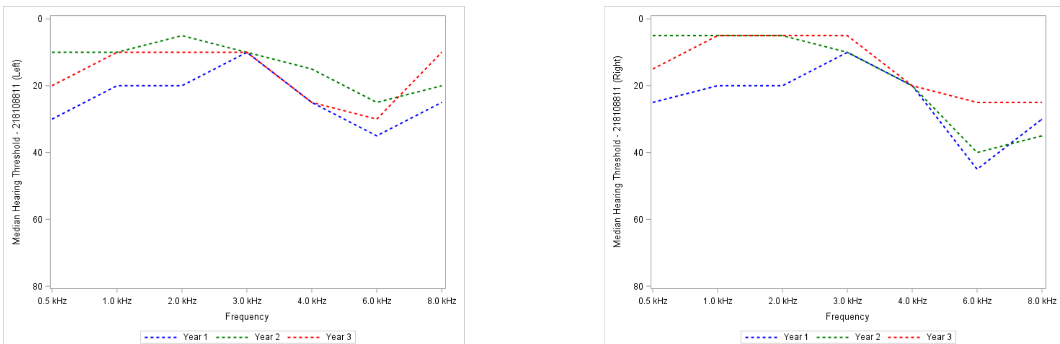


Figure 32 – Left and right audiograms for participant 218108811 across all study years

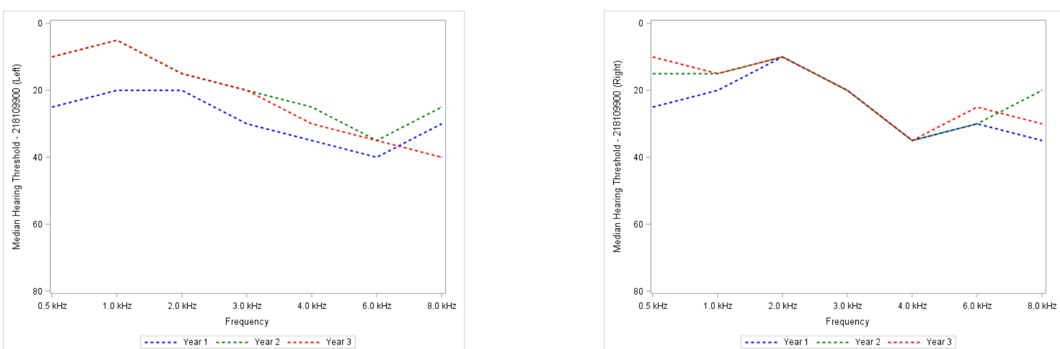


Figure 33 – Left and right audiograms for participant 218109900 across all study years

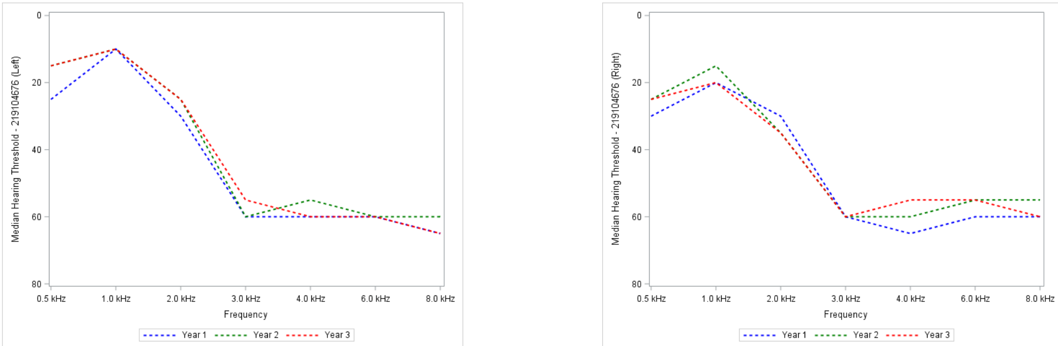


Figure 34 – Left and right audiograms for participant 219104676 across all study years

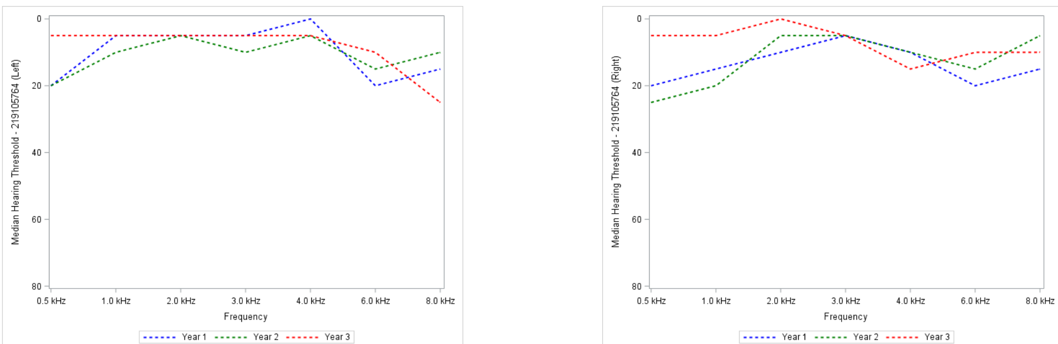


Figure 35 – Left and right audiograms for participant 219105764 across all study years

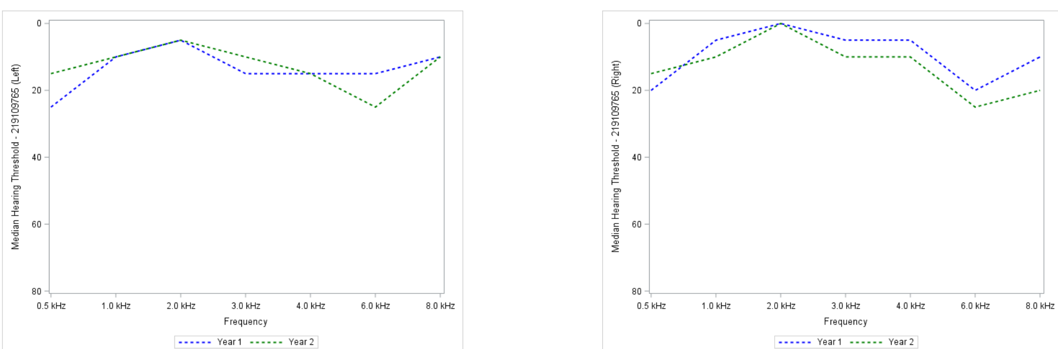


Figure 36 – Left and right audiograms for participant 219109765 across all study years

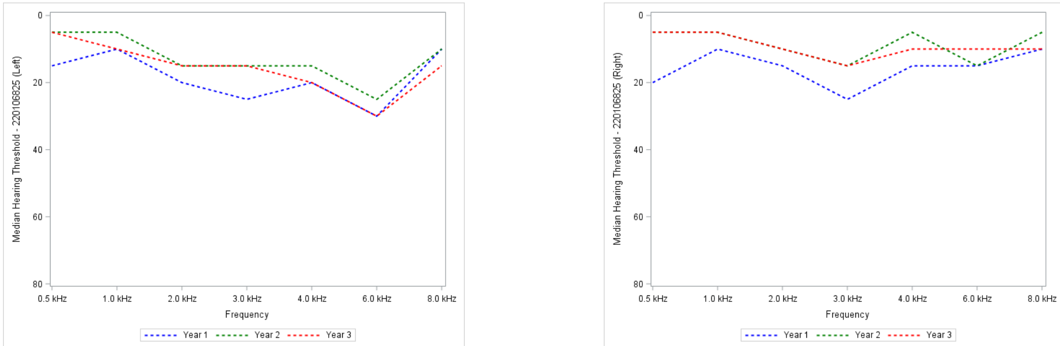


Figure 37 – Left and right audiograms for participant 220106825 across all study years

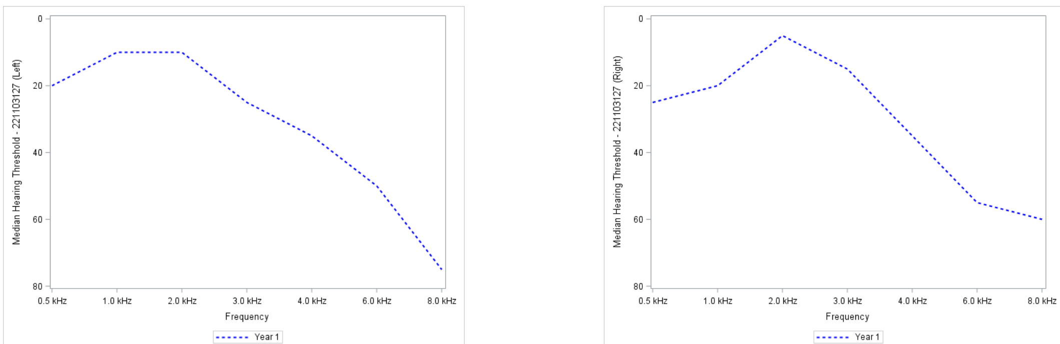


Figure 38 – Left and right audiograms for participant 221103127 across all study years

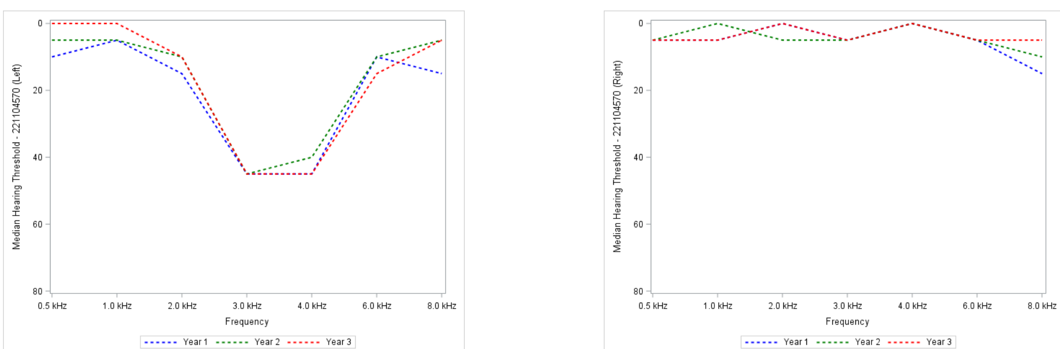


Figure 39 – Left and right audiograms for participant 221104570 across all study years

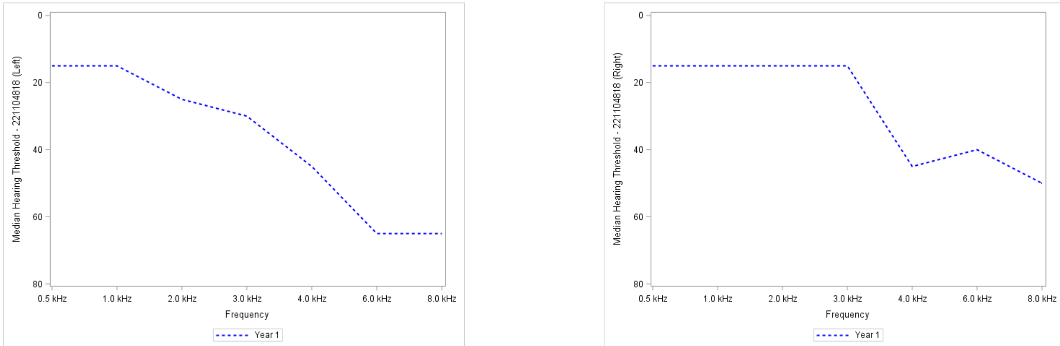


Figure 40 – Left and right audiograms for participant 221104818 across all study years

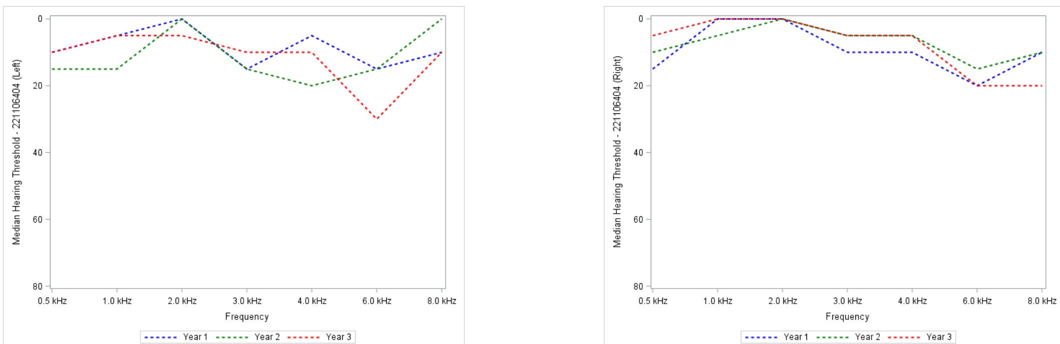


Figure 41 – Left and right audiograms for participant 221106404 across all study years

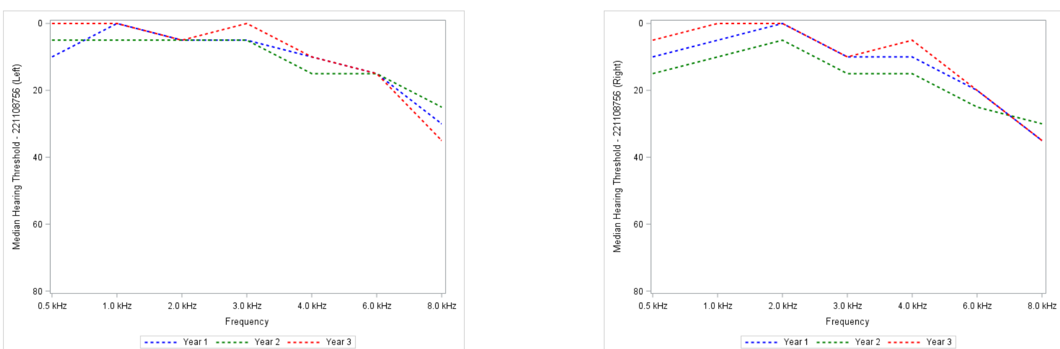


Figure 42 – Left and right audiograms for participant 221108756 across all study years

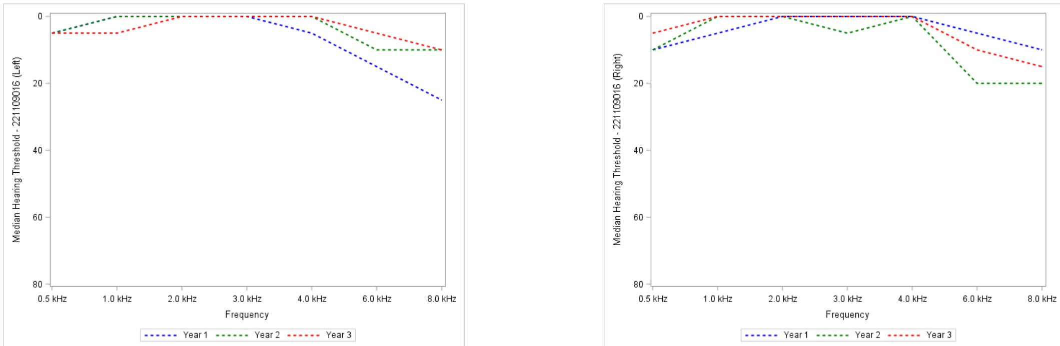


Figure 43 – Left and right audiograms for participant 221109016 across all study years

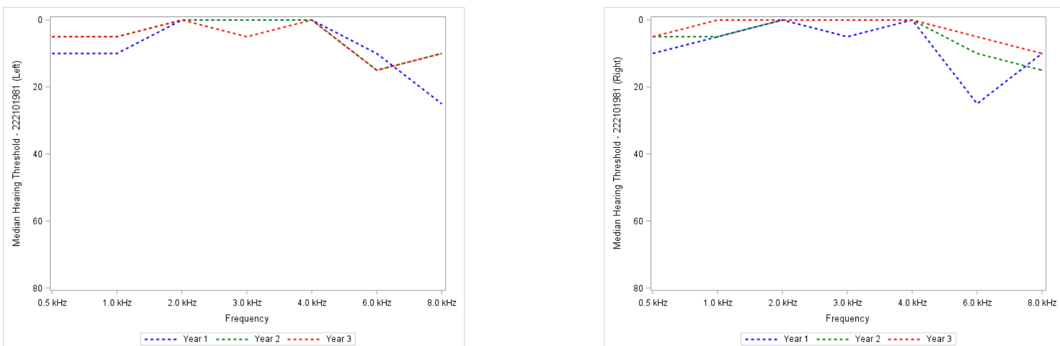


Figure 44 – Left and right audiograms for participant 222101981 across all study years

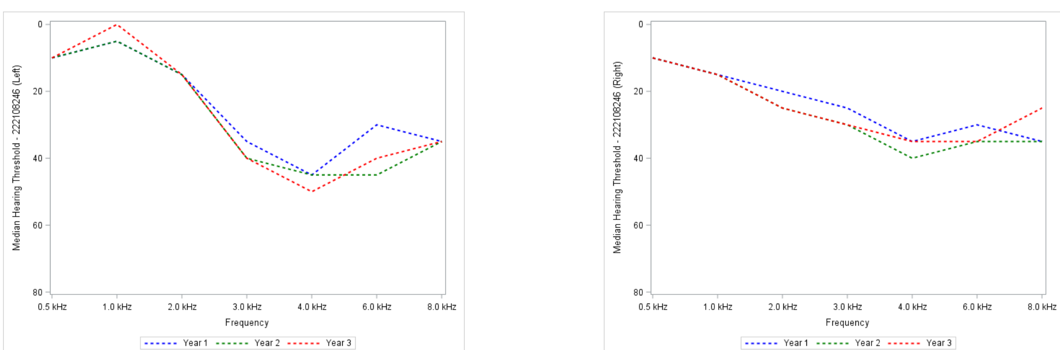


Figure 45 – Left and right audiograms for participant 222108246 across all study years

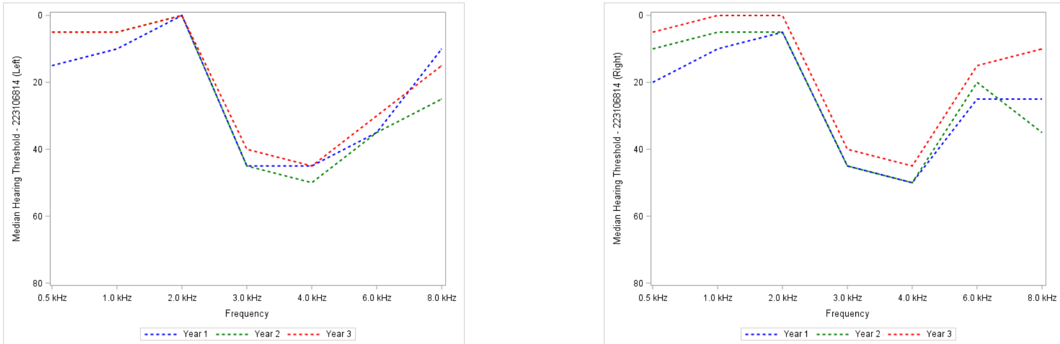


Figure 46 – Left and right audiograms for participant 223106814 across all study years

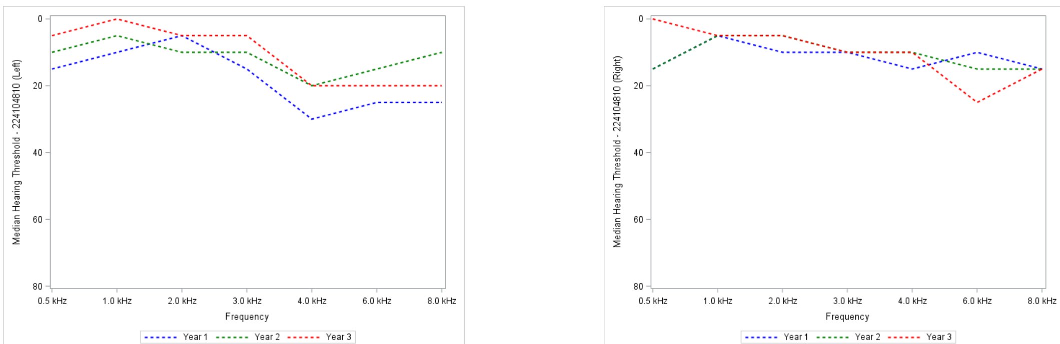


Figure 47 – Left and right audiograms for participant 224104810 across all study years

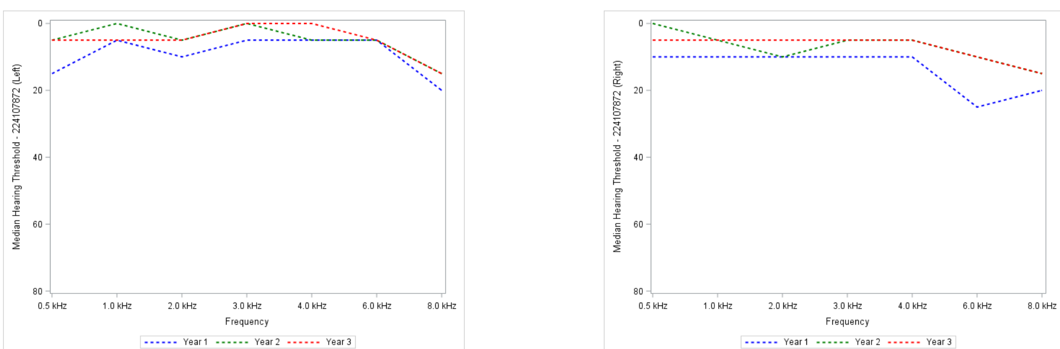


Figure 48 – Left and right audiograms for participant 224107872 across all study years

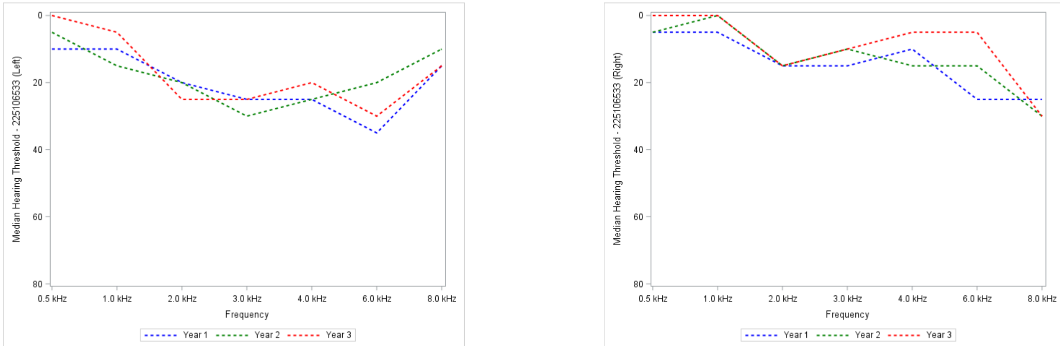


Figure 49 – Left and right audiograms for participant 225106533 across all study years

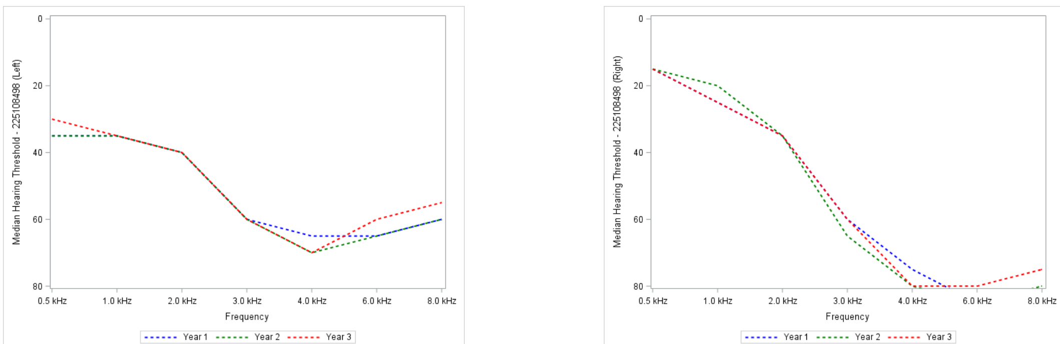


Figure 50 – Left and right audiograms for participant 225108498 across all study years

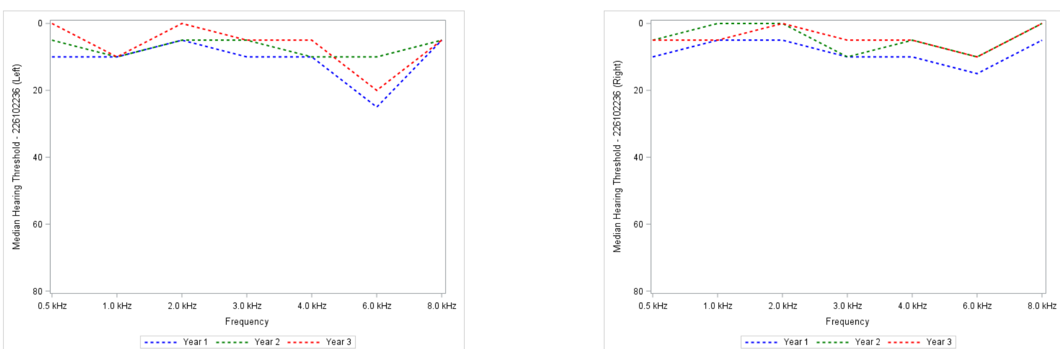


Figure 51 – Left and right audiograms for participant 226102236 across all study years

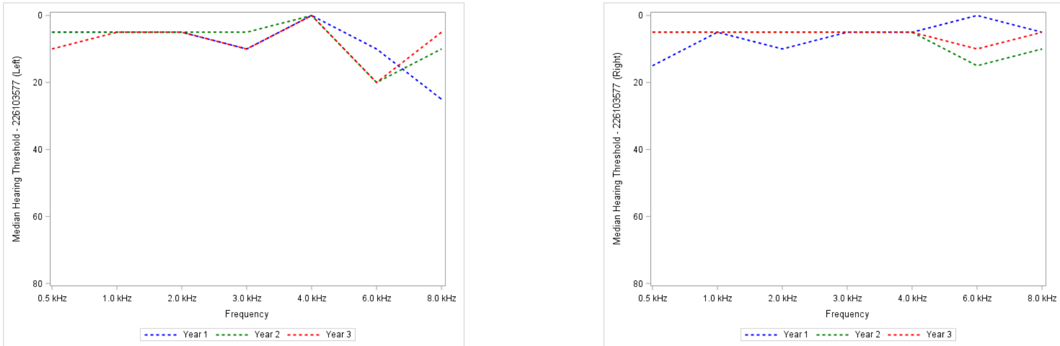


Figure 52 – Left and right audiograms for participant 226103577 across all study years

BIBLIOGRAPHY

1. National Institue for Occupational Safety and Health. Noise and hearing loss prevention. https://www.cdc.gov Web site. https://www.cdc.gov/niosh/topics/noise/stats.html. Published October 19, 2016. Updated 2016. Accessed September 30, 2017.

2. Masterson EA, Bushnell PT, Themann CL, Morata TC. Hearing impairment among noise-exposed workers - United States, 2003-2012. *MMWR Morb Mortal Wkly Rep*. 2016;65(15):389-394.

3. Achutan C. Chapter 2: The effects of noise and the conservation of hearing. In: *Hearing conservation manual.* Fifth Edition. Hutchison, T. & Schulz, T., eds. Milwaukee, WI: CAOHC; 2014:7-11.

4. Madison T., Riegel K. Chapter 6: Introduction to sound. In: *Hearing conservation manual.* Fifth Edition. Hutchison, T. & Schulz, T., eds. Milwaukee, WI: CAOHC; 2014:29-34.

5. Carroll YI, Eichwald J, Scinicariello F, et al. Vital signs: Noise-induced hearing loss among adults - United States 2011-2012. *MMWR Morb Mortal Wkly Rep*. 2017;66(5):139-144.

6. NDT Resource Center. The components of sound. www.nde-ed.org Web site. https://www.nde-ed.org/EducationResources/HighSchool/Sound/components.htm. Published n.d. Updated n.d. Accessed November 2, 2017.

7. Kujawa SG, Liberman MC. Synaptopathy in the noise-exposed and aging cochlea: Primary neural degeneration in acquired sensorineural hearing loss. *Hear Res*. 2015.

8. Danielson R. Chapter 10: Understanding audiograms. In: *Hearing conservation manual*. Fifth Edition. Hutchison, T. & Schulz, T., eds. Milwaukee, WI: CAOHC; 2014:69-78.

9. Kutz JW. Audioloy pure-tone testing. Medscape.com Web site. https://emedicine.medscape.com/article/1822962-overview. Published April 7, 2016. Updated 2016. Accessed November 15, 2017.

10. Danielson R. Chapter 9: Planning the audiometric monitoring program. In: *Hearing conservation manual.* Fifth Edition. Hutchison, T. & Schulz, T., eds. Milwaukee, WI: CAOHC; 2014:55-68.

11. Dobie R, Kopke R. Chapter 5: Causes and management of hearing disorders. In: *Hearing conservation manual.* Fifth Edition. Hutchison, T. & Schulz, T., eds. Milwaukee, WI: CAOHC; 2014:23-27.

12. Williams W, Purdy S, Murray N, LePage E, Challinor K. Hearing loss and perceptions of noise in the workplace among rural Australians. *Aust J Rural Health*. 2004;12(3):115-119.

13. Lindblad A, Rosenhall U, Olofsson Å, Hagerman B. Tinnitus and other auditory problems - occupational noise exposure below risk limits may cause inner ear dysfunction. *PLoS One*. 2014;9(5):e97377-e97377.

14. Irgens-Hansen K, Gundersen H, Sunde E, et al. Noise exposure and cognitive performance: A study on personnel on board royal Norwegian navy vessels. *Noise Health*. 2015;17(78):320-327.

15. Carruth A, Robert AE, Hurley A, Currie PS. The impact of hearing impairment, perceptions and attitudes about hearing loss, and noise exposure risk patterns on hearing handicap among farm family members. *AAOHN J*. 2007;55(6):227-234.

16. Hetu R, Getty L, Quoc HT. Impact of occupational hearing loss on the lives of workers. *OCCUP MED STATE ART REV*. 1995;10(3):495-512 18p.

17. Choi S, Peek-Asa C, Sprince NL, et al. Hearing loss as a risk factor for agricultural injuries. *Am J Ind Med*. 2005;48(4):293-301.

18. Cantley LF, Galusha D, Cullen MR, Dixon-Ernst C, Rabinowitz PM, Neitzel RL. Association between ambient noise exposure, hearing acuity, and risk of acute occupational injury. *Scand J Work Environ Health*. 2015;41(1):75-83.

19. Bruce R, Hart N, Arellano J. Chapter 7: Standards and regulations. In: *Hearing conservation manual.* Fifth Edition. Hutchison, T. & Schulz, T., eds. Milwaukee, WI: CAOHC; 2014:35-46.

20. Thunder TD. Hearing conservation in the US: A historical perspective. www.audiologyonline.com Web site. https://www.audiologyonline.com/articles/hearing-conservation-in-us-historical-1263. Published January 25, 2001. Updated 2017. Accessed November 2, 2017.

21. Occupational Safety and Health Administration. Occupational noise exposures. 2008:29 C.F.R. §1910.95.

22. Moritz C. Chapter 8: Noise measurement and control. In: *Hearing conservation manual.* Fifth Edition. Hutchison, T. & Schulz, T., eds. Milwaukee, WI: CAOHC; 2014:47-54.

23. United States Department of Agriculture Economic Research Service. Ag and food sectors and the economy. www.ers.usda.gov Web site. https://www.ers.usda.gov/data-products/ag-and-food-statistics-charting-the-essentials/ag-and-food-sectors-and-the-economy/. Published October 18, 2017. Updated 2017. Accessed October 20, 2017.

24. United States Department of Agriculture. 2012 census of agriculture, United States, summary and state data. 2014;AC-12-A-51.

25. United States Department of Agriculture Economic Research Service. Cash receipts by state. data.ers.usda.gov Web site. https://data.ers.usda.gov/reports.aspx?ID=17843. Published August 30, 2017. Updated 2017. Accessed October 15, 2017.

26. National Institue for Occupational Safety and Health. Agricultural safety. https://www.cdc.gov Web site. https://www.cdc.gov/niosh/topics/aginjury/default.html. Published June 6, 2017. Updated 2017. Accessed October 15, 2017.

27. Bureau of Labor Statistics. Incidence rates of nonfatal occupational injuries and illnesses by industry and case types, 2017. Injuries, Illnesses, and Fatalities Web site. https://www.bls.gov/iif/oshwc/osh/os/summ1_00_2017.htm. Published November 8, 2018. Updated 2018. Accessed November 24, 2018.

28. Runyan JL. A review of farm accident data sources and research: Review of recently published and current research. *Bibliographies and Literature of Agriculture*. 1993;125:1-7.

29. Tak S, Calvert GM. Hearing difficulty attributable to employment by industry and occupation: An analysis of the national health interview survey--United States, 1997 to 2003. *Journal of Occupational and Environmental Medicine*. 2008;50(1):46-56.

30. Depczynski J, Challinor K, Fragar L. Changes in the hearing status and noise injury prevention practices of Australian farmers from 1994 to 2008. *J Agromedicine*. 2011;16(2):127-142.

31. Broste SK, Hansen DA, Strand RL, Stueland DT. Hearing loss among high school farm students. *Am J Public Health*. 1989;79(5):619-622.

32. Thelin JW, Joseph DJ, Davis WE, Baker DE, Hosokawa MC. High-frequency hearing loss in male farmers of Missouri. *Public Health Rep*. 1983;98(3):268-273.

33. Plakke BL, Dare E. Occupational hearing loss in farmers. *Public Health Rep*. 1992;107(2):188.

34. Karlovich RS, Wiley TL, Tweed T, Jensen DV. Hearing sensitivity in farmers. *Public Health Rep*. 1988;103(1):61-71.

35. Berg RL, Pickett W, Fitz-Randolph M, et al. Hearing conservation program for agricultural students: Short-term outcomes from a cluster-randomized trial with planned long-term follow-up. *Prev Med*. 2009;49(6):546-552.

36. Knobloch MJ, Broste SK. A hearing conservation program for Wisconsin youth working in agriculture. *J Sch Health*. 1998;68(8):313-318.

37. Aybek A, Kamer HA, Arslan S. Personal noise exposures of operators of agricultural tractors. *Appl Ergon*. 2010;41(2):274-281.

38. Dewangan KN, Kumar GVP, Tewari VK. Noise characteristics of tractors and health effect on farmers. *Appl Acoust*. 2005;66(9):1049-1062.

39. Berger EH, Neitzel R, Kladden CA. Noise navigator sound level database. 2015;E-A-R 88-34/HP.

40. Axiom-Points L. Ambient noise readings technical memorandum, Little Canyon Mountain Prineville District Central Oregon resource area. 2010:1-8.

41. Achutan C, Tubbs RL. A task-based assessment of noise levels at a swine confinement. *J Agromedicine*. 2007;12(2):55-65 11p.

42. Khan KM, Evans SS, Bielko SL, Rohlman DS. Efficacy of technology-based interventions to increase the use of hearing protections among adolescent farmworkers. *Int J Audiol*. 2017:1-11.

43. Stewart M, Scherer J, Lehman ME. Perceived effects of high frequency hearing loss in a farming population. *J Am Acad Audiol*. 2003;14(2):100-108.

44. Donham KJ, Kline AK, Kelly KM, Lange JL, Rautiainen RH. Respirator and hearing protection use in the certified safe farm program. *J Agromedicine*. 2013;18(1):18-26.

45. McCullagh MC, Banerjee T, Cohen MA, Yang JJ. Effects of interventions on use of hearing protectors among farm operators: A randomized controlled trial. *Int J Audiol*. 2016;55:S3-S12.

46. Cramer ME, Wendl MJ, Sayles H, Duysen E, Achutan C. Knowledge, attitudes, and practices for respiratory and hearing health among midwestern farmers. *Public Health Nurs*. 2016.

47. Gates DM, Jones MS. A pilot study to prevent hearing loss in farmers. *Public Health Nursing*. 2007;24(6):547-553.

48. Kearney GD, Xu X, Balanay JAG, Allen DL, Rafferty AP. Assessment of personal protective equipment use among farmers in eastern North Carolina: A cross-sectional study. *J Agromedicine*. 2015;20(1):43-54.

49. Carpenter WS, Lee BC, Gunderson PD, Stueland DT. Assessment of personal protective equipment use among Midwestern farmers. *Am J Ind Med*. 2002;42(3):236-247.

50. McCullagh M, Lusk SL, Ronis DL. Factors influencing use of hearing protection among farmers: A test of the Pender health promotion model. *Nurs Res*. 2002;51(1):33-39.

51. McCullagh MC, Ronis DL, Lusk SL. Predictors of use of hearing protection among a representative sample of farmers. *Res Nurs Health*. 2010;33(6):528-538.

52. Gomez MI, Hwang S, Sobotova L, Stark AD, May JJ. A comparison of self-reported hearing loss and audiometry in a cohort of New York farmers. *J Speech Lang Hear Res*. 2001;44(6):1201-1208.

53. Kerr MJ, McCullagh M, Savik K, Dvorak LA. Perceived and measured hearing ability in construction laborers and farmers. *Am J Ind Med*. 2003;44(4):431-437.

54. Kirychuk S, Dwernychuk L, Akwasi O, et al. Hearing health in swine and grain workers. *J Agromed*. 2014;19(2):220.

55. Marlenga B, Linneman JG, Pickett W, et al. Randomized trial of a hearing conservation intervention for rural students: Long-term outcomes. *Pediatrics*. 2011;128(5):e1139-e1146.

56. Lusk SL, Ronis DL, Kerr MJ, Atwood JR. Test of the health promotion model as a causal model of workers' use of hearing protection. *Nurs Res*. 1994;43(3):151-157.

57. Lusk SL, Ronis DL, Hogan MM. Test of the health promotion model as a causal model of construction workers' use of hearing protection. *Res Nurs Health*. 1997;20(3):183-194.

58. Lusk SL, Kerr MJ, Ronis DL, Eakin BL. Applying the health promotion model to development of a worksite intervention. *Am J Health Promot*. 1999;13(4):219-227.

59. Lusk SL, Hong OS, Ronis DL, Eakin BL, Kerr MJ, Early MR. Effectiveness of an intervention to increase construction workers' use of hearing protection. *Hum Factors*. 1999;41(3):487-494.

60. Patel DS, Witte K, Zuckerman C, et al. Understanding barriers to preventive health actions for occupational noise-induced hearing loss. *J Health Commun*. 2001;6(2):155-168.

61. Kerr MJ, Lusk SL, Ronis DL. Explaining mexican american workers' hearing protection use with the health promotion model. *Nurs Res*. 2002;51(2):100-109.

62. Edelson J, Neitzel R, Meischke H, et al. Predictors of hearing protection use in construction workers. *Ann Occup Hyg*. 2009;53(6):605-615.

63. Hong O, Chin DL, Ronis DL. Predictors of hearing protection behavior among firefighters in the United States. *Int J Behav Med*. 2013;20(1):121-130.

64. Reed DB, Kidd PS, Westneat S, Rayens MK. Agricultural disability awareness and risk education (AgDARE) for high school students. *Inj Prev*. 2001;7 Suppl 1:i59-i63.

65. Reed DB, Westneat SC, Kidd P. Observation study of students who completed a high school agricultural safety education program. *J Agric Saf Health*. 2003;9(4):275-283.

66. McCullagh MC, Ronis DL. Protocol of a randomized controlled trial of hearing protection interventions for farm operators. *BMC Public Health*. 2015;15:399-399.

67. Sherman CR, Chertok IRA. Review of interventions to increase hearing protective device use in youth who live or work on farms. *J Clin Nurs*. 2014;23(1-2):3-12.

68. Roka F, Olexa M, Smallwood K, Polopolus L, Fountain C. *Handbook of employment regulations affecting Florida farm employers and workers: Occupational safety and health act (OSHA) (FE408).* Gainsville, FL: University of Florida IFAS Extension; 2009. http://edis.ifas.ufl.edu/fe408.

69. Cottrell RR, McKenzie JF. Chapter 4: Theory and research. In: *Health promotion and education research methods : Using the five-chapter thesis/dissertation model*. Second Edition ed. Sudbury, Mass: Jones and Bartlett Publishers.; 2011:63-78.

70. Hass-Slavin L, McColl MA, Pickett W. Challenges and strategies related to hearing loss among dairy farmers. *Journal of Rural Health*. 2005;21(4):329-336.

71. Ronis DL, Hong O, Lusk SL. Comparison of the original and revised structures of the health promotion model in predicting construction workers' use of hearing protection. *Res Nurs Health*. 2006;29(1):3-17.

72. Murray-Johnson L, Witte K, Patel D, et al. Using the extended parallel process model to prevent noise-induced hearing loss among coal miners in Appalachia. *Health Educ Behav*. 2004;31(6):741-755.

73. McCullagh M, Robertson C. Too late smart: Farmers' adoption of self-protective behaviors in response to exposure to hazardous noise. *AAOHN J*. 2009;57(3):99-105.

74. Smith SW, Rosenman KD, Kotowski MR, et al. Using the EPPM to create and evaluate the effectiveness of brochures to increase the use of hearing protection in farmers and landscape workers. *J Appl Commun Res*. 2008;36(2):200-218.

75. Farm Market ID. Know your market. identify your farm audience. serve your farmer. Farm Market iD Web site. http://www.farmmarketid.com/. Published 2016. Updated 2018. Accessed March 1, 2018.

76. Achutan C. Point source PPE: A strategy for controlling noise exposures in agriculture. *Synergist*. 2015 (December). http://synergist.aiha.org/201512-point-source-ppe/. Published 2015. Accessed October 20, 2017.

77. Svensson EB, Morata TC, Nylén P, Krieg EF, Johnson A. Beliefs and attitudes among Swedish workers regarding the risk of hearing loss. *INT J AUDIOL*. 2004;43(10):585-593 9p.

78. Stephenson MR, Merry CJ. A comparison and contrast of workers vs health and safety professionals attitudes and beliefs about preventing occupational hearing loss. 1999.

79. Jenkins PL, Stack SG, Earle-Richardson G, Scofield SM, May JJ. Screening events to reduce farmers' hazardous exposures. *J Agric Saf Health*. 2007;13(1):57-64.

80. Delgado-Rodriguez M, Llorca J. Bias. *J Epidemiol Community Health*. 2004;58(8):635-641.

81. Wickstrom G, Bendix T. The "Hawthorne effect"--what did the original Hawthorne studies actually show? *Scand J Work Environ Health*. 2000;26(4):363-367.

82. American National Standard. ANSI S3.1-1999 maximum permissible ambient noise levels for audiometric test rooms. www.whisperroom.com/pdf/ANSI-ASA-S3.1-1999-R2008.pdf. Updated 2008. Accessed October 1, 2017.

83. National Institute for Occupational Safety and Health. *Criteria for a recommended standard: Occupational noise exposure revised criteria 1998. publication no. 98-126.* Cincinnati, OH: DHHS (NIOSH); 1998. https://www.cdc.gov/niosh/docs/98-126/pdfs/98-126.pdf. Accessed October 20, 2017.

84. Buckey JC, Fellows AM, Jastrzembski BG, et al. Pure-tone audiometric threshold assessment with in-ear monitoring of noise levels. *Int J Audiol*. 2013;52(11):783-788.

85. Swanepoel DW, Maclennan-Smith F, Hall JW. Diagnostic pure-tone audiometry in schools: Mobile testing without a sound-treated environment. *J Am Acad Audiol*. 2013;24(10):992-1000.

86. Swanepoel DW, Matthysen C, Eikelboom RH, Clark JL, Hall JWI,II. Pure-tone audiometry outside a sound booth using earphone attentuation, integrated noise monitoring, and automation. *Int J Audiol*. 2015;54(11):777-785.

87. Maclennan-Smith F, Swanepoel DW, Hall JWI,II. Validity of diagnostic pure-tone audiometry without a sound-treated environment in older adults. *Int J Audiol*. 2013;52(2):66-73.

88. Brennan-Jones C, Eikelboom RH, Swanepoel DW, Friedland PL, Atlas MD. Clinical validation of automated audiometry with continuous noise-monitoring in a clinically heterogeneous population outside a sound-treated environment. *Int J Audiol*. 2016;55(9):507-513.

89. Margolis RH, Madsen B. The acoustic test environment for hearing testing. *J Am Acad Audiol*. 2015;26(9):784-791.

90. McPherson B, Law MMS, Wong MSM. Hearing screening for school children: Comparison of low-cost, computer-based and conventional audiometry. *Child Care Health Dev*. 2010;36(3):323-331.

91. Lankford JE, Perrone DC, Thunder TD. Ambient noise levels in mobile audiometric testing facilities: Compliance with industry standards. *AAOHN J*. 1999;47(4):163-167.

92. Taylor EJ, Emanuel DC. Assessment of the efficacy of a hearing screening program for college students. *J Am Acad Audiol*. 2013;24(7):607-615.

93. McBride DI, Firth HM, Herbison GP. Noise exposure and hearing loss in agriculture: A survey of farmers and farm workers in the southland region of New Zealand. *J Occup Environ Med*. 2003;45(12):1281-1288.

94. Humann MJ, Donham KJ, Jones ML, Achutan C, Smith BJ. Occupational noise exposure assessment in intensive swine farrowing systems: Dosimetry, octave band, and specific task analysis. *J Agromed*. 2005;10(1):23.

95. Wells L. The "problem audiogram," the occupational hearing conservationist and the professional supervisor. In: Hutchison TL, Schulz TY, eds. *Hearing conservation*

manual. 5th ed. Milwaukee, WI: Council for Accreditation in Occupational Hearing Conservation; 2014:91-105.

96. McCullagh MC. Validation of a questionnaire to identify hearing loss among farm operators. *Noise Health*. 2012;14(56):32-38.

97. Coles RR, Lutman ME, Buffin JT. Guidelines on the diagnosis of noise-induced hearing loss for medicolegal purposes. *Clin Otolaryngol Allied Sci*. 2000;25(4):264-273.

98. Renick KM, Crawford JM, Wilkins JR, 3. Hearing loss among Ohio farm youth: A comparison to a national sample. *Am J Ind Med*. 2009;52(3):233-239.

99. Wilson RH, McArdle R. Characteristics of the audiometric 4,000 Hz notch (744,553 veterans) and the 3,000, 4,000, and 6,000 Hz notches (539,932 veterans). *J Rehabil Res Dev*. 2013;50(1):111-132.

100. Osei-Lah V, Yeoh LH. High frequency audiometric notch: An outpatient clinic survey. *Int J Audiol*. 2010;49(2):95-98.

101. Lie A, Skogstad M, Johnsen TS, Engdahl B, Tambs K. The prevalence of notched audiograms in a cross-sectional study of 12,055 railway workers. *Ear Hear*. 2015;36(3):e86-92.

102. McBride DI, Williams S. Audiometric notch as a sign of noise induced hearing loss. *Occup Environ Med*. 2001;58(1):46-51.

103. Robinson DW. Threshold of hearing as a function of age and sex for the typical unscreened population. *Br J Audiol*. 1988;22(1):5-20.

104. Berg RL, Pickett W, Linneman JG, Wood DJ, Marlenga B. Asymmetry in noise-induced hearing loss: Evaluation of two competing theories. *Noise Health*. 2014;16(69):102-107.

105. Meyer JD. Noise-induced hearing loss. In: McCunney RJ, ed. *A practical approach to occupational and environmental medicine.* Philadelphia: PN: Lippincott Williams and Wilkins; 2003:381-394.

106. Rabinowitz PM, Galusha D, Slade MD, Dixon-Ernst C, Sircar KD, Dobie RA. Audiogram notches in noise-exposed workers. *Ear Hear*. 2006;27(6):742-750.

107. Achutan C. Noise exposures and hearing loss assessments among animal shelter workers. *Health Hazard Evaluation Report*. 2007;HETA 2007-0068-3042(May).