HEARING LOSS AND TASK-BASED NOISE EXPOSURES AMONG AGRICULTURAL POPULATIONS

by

Michael Jerome Humann

An Abstract

Of a thesis submitted in partial fulfillment
of the requirements for the Doctor of
Philosophy degree in Occupational and Environmental Health
in the Graduate College of
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Thesis Supervisors: Adjunct Professor Wayne T. Sanderson
Professor Kelley J. Donham

ABSTRACT

Hazardous noise exposures and hearing loss have been documented among farmers and farm workers for many years. However, little is known about the noise exposures during specific agricultural work tasks and their effect on hearing loss. The objective of this dissertation was to assess the effects of specific agricultural tasks on hearing loss and their contribution to total noise exposures.

Three studies were conducted to accomplish this objective. The first study examined associations between hearing sensitivity among rural residents ($n_{farmer} = 960$, $n_{non\text{-}farmers} = 608$) and self-reported years of participation in 12 agricultural tasks. Logistic regression analysis was used to examine associations between agricultural activities and hearing loss >25dB. Linear regression analysis was used to examine associations between agricultural tasks and mean decibels of hearing loss. The results indicated farmers have greater hearing loss than non-farmers. However years of participation in specific agricultural tasks was poorly associated with hearing loss. This result suggests that self-reported years engaging in specific agricultural activities may be a poor surrogate for true noise exposure

In the second study noise exposures (personal dosimetry) and corresponding task data (direct observation) were collected on 18 grain farms, and mean noise exposures (dBA) were calculated for specific agricultural tasks. Noise exposures ranged from 78.6 dBA to 99.0 dBA across all tasks. The noise exposures for each task varied greatly (large standard deviation and maximum exposure) with most of the variability within the farms. Although specific tasks with intense noise exposures were identified, most comparisons of mean noise exposures from one task to another were not statistically different and intense exposures were present for nearly all tasks. Therefore, controlling noise only for those tasks with the greatest mean noise exposures may not completely eliminate hazardous exposures or the hearing loss risk.

For the third study, estimates of 8-hr time-weighted-average (TWA) noise exposures were calculated using time-at-task observations from one population of farmers and prior dosimeter measured mean task-based noise exposures from an independent population of farmers. Additionally, dosimeter measured daily noise exposures from the independent population of farmers were also analyzed to identify significant determinants of noise exposure. Simple linear regression analysis was used to compare estimated and actual dosimeter-measured 8-hr TWA noise exposures. The noise exposure determinants were identified by conducting multivariable linear mixed-effects regression analysis on the one-minute noise measurements from the dosimeter measured daily noise exposures. The results indicated the estimated and measured 8-hr TWA noise exposures varied considerably. Therefore, the estimates were not considered reliable. Furthermore, task, number of noise sources and work area were found to have a statistically significant association with noise exposure.

In summary, hearing loss and noise exposures among agricultural populations are complex and cannot be completely explained by examining agricultural tasks only. More detailed evaluations of tasks are needed to increase the understanding of hearing loss and noise exposure in this dynamic work environment.

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CERTIFICATE OF APPROVAL

PH.D. THESIS

This is to certify that the Ph.D. thesis of

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To Mom and Dad

It is not the critic who counts; not the man who points out how the strong man stumbles, or where the doer of deeds could have done them better. The credit belongs to the man who is actually in the arena, whose face is marred by dust and sweat and blood; who strives valiantly, who errs, who comes short again and again, because there is no effort without error and shortcoming; but who does actually strive to do the deeds; who knows great enthusiasms, the great devotions; who spends himself in a worthy cause; who at the best knows in the end the triumph of high achievement, and who at the worst, if he fails, at least fails while daring greatly, so that his place shall never be with those cold and timid souls who neither know victory nor defeat.

Theodore Roosevelt, Citizenship in a Republic

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Three studies were conducted to accomplish this objective. The first study examined associations between hearing sensitivity among rural residents ($n_{farmer} = 960$, $n_{non\text{-}farmers} = 608$) and self-reported years of participation in 12 agricultural tasks. Logistic regression analysis was used to examine associations between agricultural activities and hearing loss >25dB. Linear regression analysis was used to examine associations between agricultural tasks and mean decibels of hearing loss. The results indicated farmers have greater hearing loss than non-farmers. However years of participation in specific agricultural tasks was poorly associated with hearing loss. This result suggests that self-reported years engaging in specific agricultural activities may be a poor surrogate for true noise exposure

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CHAPTER I
INTRODUCTION AND LITERATURE REVIEW

The advent of mechanized agriculture in the late 1800s had a profound impact on the agricultural industry.[1] The expansion of tractors and mechanized harvesting equipment across the agricultural industry allowed production to dramatically increase, while decreasing the labor force. From their inception to the time they saturated the agricultural industry in the 1940s, it is estimated that tractors saved approximately 940 million man-hours in production agriculture.[2,3] However, for farmers that remained working the land, the introduction of tractors and other mechanized equipment also introduced hazardous noise levels onto the once quite rural landscape.

In agricultural populations, hearing loss caused by excessive noise exposure is nothing new. The most obvious result of occupational noise-induced hearing loss (NIHL) is a decrease in hearing acuity, but beyond that there can be non-auditory effects such as high blood pressure, stress, sleep problems, social isolation and reduced work performance.[4] Because of the pervasiveness of hazardous noise exposures, NIHL, and the adverse effects they can have on health and quality of life, it is important to understand its pervasiveness on farms and prevalence in rural and agricultural populations. Furthermore it is crucial that a clear assessment of the noise exposures on farms and NIHL among rural and agricultural populations be completed.

Hearing Loss

Basics of Hearing Loss

Hearing loss is a decrease in the hearing sense of an individual and can be manifested as difficulty to hear sound, understand speech, and even deafness. Hearing loss can have several different causes and can occur instantaneously or over a period of time. There are two main types of hearing loss differentiated by the specific anatomical areas of the ear affected. Conductive hearing loss is caused by interruption of sound waves prior to entering the cochlea. This type of hearing loss does not involve the neurological components of hearing; instead sound is prevented from reaching the nerve cells of the ear. Conductive hearing loss can be caused by; a buildup of wax in the ear canal, fluid in the inner ear, ruptured eardrum, or trauma to the ossicles in the middle ear. Sensorineural hearing loss is the result of the disruption of the neural components of hearing, either the nerve pathways or the sensory receptors in the cochlea (hair cells).[5]

In addition to hazardous noise exposures, there are other causes of hearing loss including; genetic factors, infection, autoimmune disease, head injury, otosclerosis and exposure to ototoxic substances.[6] Along with exposure to hazardous noise levels, presbycusis, or age related hearing loss, is a common cause of hearing loss. It is the result of the steady degradation of the hair cells that transmit the mechanical energy of sound waves into neural signals. It is estimated that 30% of the hearing loss in persons over 70 years of age is the result of presbycusis.[7]

Determining Hearing Loss

Unlike other occupational illnesses, the prevalence and incidence rates for hearing loss is influenced by how hearing loss is calculated and defined. This has implications for studies of hearing loss. It is crucial that the definition of hearing loss and how it is calculated be clear, in order to accurately compare the results cross multiple studies.

An audiometric test is the most common and comprehensive way to identify hearing loss. Pure tone audiometry identifies a person's hearing level at specific frequencies between 250 and 8000 Hz, which corresponds to the frequency range of human speech. The results of an audiometric test are given in the form of an audiogram, either as a chart or table indicating the level of hearing loss in decibels at specific frequencies. The reference level on an audiogram is 0 dB which corresponds to average normal hearing.[5]

Calculation of Pure Tone Average

Hearing loss can be quantified by calculating the pure tone average (PTA), which is the average decibel loss across a specific frequency range for each ear. This method is inconsistent because there is not a universal standard for which frequencies make up the PTA. If the concern is hearing loss at low frequencies, then the PTA would be calculated using the lower frequencies from the audiogram (500, 1000 and 2000 Hz). While the PTA for high frequency hearing loss would be calculated using the higher frequencies from the audiogram (3000, 4000 and 6000 Hz).

Several agencies have developed recommendations to specify the frequency range that should be used for the PTA calculation. Covering the occupational sector are the Occupational Safety and Health Administration (OSHA) and the National Institute for Occupational Safety and Health (NIOSH). The PTA calculation according to OSHA is an average change in hearing threshold from a baseline at the frequencies of 2000, 3000 or 4000 Hz.[8] NIOSH calculates their PTA as an average change in hearing threshold from baseline at 1000, 2000, 3000 and 4000 Hz.[9]

Various organizations and associations have proposed their own recommendations for calculating hearing loss. The International Standards Organization (ISO) and the American National Standard Institute (ANSI) have each published several criteria for calculating a PTA (Table 1.1).[10,11] The American Academy of Otolaryngology (AAO) developed criteria adopted by the American Medical Association (AMA). According to the AAO/AMA criteria, hearing loss is calculated using the frequencies 500 Hz, 1000 Hz, 2000 Hz and 3000 Hz.[12] The AAO/AMA hearing threshold level is determined using a complex calculation, which multiplies the hearing threshold above 25 dB by 1.5 and then multiplies the hearing threshold in the better ear by five, adds it to the hearing threshold in the worse ear and divides the total by six.[12] Organizations such as the American Speech-Language-Hearing Association (ASHA) and the American Academy of Audiology calculate the PTA, by averaging the hearing thresholds at the frequencies of 500 Hz, 1000 Hz and 2000 Hz.[13]

Hearing Thresholds

The other important part of determining hearing loss is to establish the hearing threshold level that defines amount of hearing loss present. The hearing threshold level is the decibel decrease in hearing acuity, calculated from audiometric zero (0 dB) or some other baseline level determined by previous audiometric test. Similar to the calculation of the PTA, the hearing threshold levels vary between different organizations. OSHA uses a 10 dB decrease in hearing acuity as their hearing threshold level.[8,12,] NIOSH specifies that hearing loss begins at a hearing threshold level of 25 dB.[9]

Prevalence of Hearing Loss

NIHL is a significant public health threat throughout the world. According to the world health organization over 250 million people are affected by hearing loss, and it ranks as one of the most common health problems in the world.[14] Unlike other public health issues, its impact is felt in both developed and developing countries. In the United States, the 2006 National Health Interview Survey estimated that 37 million people were affected by hearing loss.[15] A study based on audiometric suggests that 29 million Americans suffer from hearing loss.[16] Two population based cohort studies involving several thousand participants found hearing loss prevalence rates to be 46% and 33%.[17,18] These studies also found that prevalence levels were higher for men and increased with age. A similar population based cohort study, which used several metrics for hearing loss, including the speech intelligibility index, found some degree of hearing loss to be present in 99% of participants.[19]

A great deal of exposure to noise can be found in occupational environments; as a result NIHL due to occupational exposure is a significant issue. NIHL resulting from occupational noise exposure is estimated to affect 16% of the world's population.[4] In the

United States alone 24% of the NIHL among workers is due to their job, with the highest prevalence among transportation workers, equipment operators, and farmers.[20,21]

Hearing Loss in Agricultural Populations

For the last several decades, many studies have been conducted to determine the prevalence of hearing loss among agricultural populations. Some have focused on specific subsets of the agricultural populations, while others have looked at the broader rural population. These studies used a variety of methods for calculating PTAs and defining hearing loss, thereby making comparison of results between studies difficult. Ultimately the goal of all of these studies was to document the hearing loss among agricultural populations and increase the understanding of this public health issue.

Several studies have documented the degree of hearing loss among farmers based on self-report. While not as accurate as pure tone audiometry, these studies still provide valuable insight into hearing loss in agriculture. Studies of self-reported hearing loss found the prevalence among farmers to be between 22% and 36%, depending on the specific hearing loss definition.[22-24] These studies also found farmers had greater prevalence of hearing loss than other rural residents or similar occupational groups.[22,24]

Studies assessing hearing loss among farmers using pure tone audiometry are more common. These studies indicate the prevalence of hearing loss is high among farmers and rural residents.[19,25-27] It is not uncommon to see hearing loss prevalence rates for farmers to be higher than 50%, and some studies have estimated that noticeable hearing loss among farmers to be as high as 98%.[28,29] Other studies have found that high frequency hearing loss, is the most prevalent among farmers.[25,29,30] Aside from consistently having prevalence rates above 50%, farmers have significantly more hearing loss than other non-farming populations or other occupational groups.[30-33]

In addition to higher prevalence rates, farmers are more likely to suffer from hearing loss at an earlier age.[26,31,34] One study among dairy farmers estimated that for every decade in age the hearing sensitivity of farmers decreased by four decibels. Therefore, years of farm work combined with presbycusis will likely results in substantial hearing loss later in life.

Predictors of Hearing Loss in Agricultural Populations

There is considerable evidence indicating increased prevalence of hearing loss among farmers. What is lacking is examination of the effects of specific agricultural tasks on the degree of hearing among farmers. Age, gender and socioeconomic status are all known risk factors for hearing loss among rural and farming population.[22,29,32,35]

Several studies have been conducted and identified specific agricultural tasks that are associated with hearing loss. Hwang et al. used data from the New York Farm Family Health and Hazard Survey to identify significant predictors of hearing loss among farmers.[22] Logistic regression was used to measure the associations between agricultural exposures and self-reported hearing loss. Six hundred and twenty-two farmers participated in the study. Lifetime exposure to farm equipment, noisy secondary non-farm jobs, lack of hearing protection use, and livestock farming were found to have a statistically significant association with hearing loss.

McBride et al. examined nine exposure variables related to rural and agricultural population for their association with hearing loss.[35] Two PTAs were used to calculate hearing loss, categorized as high (3000, 4000, and 6000 Hz) and low (500, 1000, and 2000 Hz). Hearing loss was defined as have a hearing threshold of at least 27 dB. Agricultural exposure variables were collected by questionnaires from 586 participants. Of the nine agricultural exposure variables analyzed by multivariable linear regression analysis, only driving tractors without cabs and metal working were associated with either low frequency or high frequency hearing loss.

Another study using agricultural exposure data from the New York Farm Family Health and Hazard Survey to identify predictors of hearing loss was conducted by

Beckett et al.[29] Unlike the study by Hwang et al. hearing loss for the 415 subjects was measured using pure tone audiometry. Hearing loss was defined and the PTA calculated using American Medical Association guidelines and NIOSH guidelines.[36,9] Logistic regression analysis was used to identify associations between agricultural exposures and hearing loss. Of the twelve agriculture exposures analyzed, only spraying chemicals, firearm use, and years of grain dryer exposure had a statistically significant association with hearing loss.

The previous studies that examined the associations between agricultural exposures and hearing loss used a variety of PTA calculations and hearing thresholds. They also all used a categorical hearing loss outcome variable (absence or presence of hearing loss). The agricultural exposures analyzed for associations with hearing loss also varied between the studies. For some studies the agricultural exposures were simply ever/never conducted the activity or ever/never used particular equipment. Other studies used more specific agricultural exposures variables, such as year engaged in particular agricultural tasks, but still used categorical variables for hearing loss. Overall the literature is lacking in studies that used linear regression analysis to measure the effect that years engaging in agricultural tasks have on decibels of hearing loss. Furthermore, while some agricultural tasks were found to be associated with hearing loss, the underlying noise exposures that those agricultural exposures represent are relatively unknown. Even though some agricultural tasks may not have a statistically significant association with hearing loss, they may be associated with intense noise exposures which have the potential to cause hearing loss.

Noise Exposure

In agriculture, as in other industries, noise is a major occupation health hazard.[37] While not fatal and generally not as debilitating as other occupational health and safety hazards, the impacts of exposure to intense noise levels on an individual are still significant. The primary consequence of exposure to hazardous noise levels is development of NIHL, and combined with the effect of age on hearing ability, serious hearing impairment is possible later in life.[38] In addition, intense noise levels in occupational setting can interfere with communication, increase accident rates, cause annoyance and tinnitus, and adversely affect sleep and blood pressure.[37,39-45] It is therefore important that hazardous noise exposures found in occupational settings be clearly understood in order for implementation of effective intervention and control strategies.

Measuring Noise Exposure

Noise is considered any unwanted sound. Sound itself is a wave of pressure differences that propagates from a source in all direction. Therefore, to measure the noise levels, instrumentation detects the differences in pressure emanating from the noise source. Sound level meters and noise dosimeters are two instruments used to measure sound pressure levels. These instruments measure the pressure in decibels, which is a measure of the sound pressure level generated, relative to a reference pressure level, and is given on a logarithmic scale. The difference between these two instruments is the situations where they are most useful. The sound level meter is used mainly to take short term measurements of noise levels produced by stationary machinery or in specific work areas. Noise dosimeters, having data logging capabilities, are used to measure personal noise exposures of workers. Dosimeters are worn by workers as they complete their work and measure sound continuously; these measurements are integrated into a single decibel level for specified time intervals. Most importantly noise dosimeters can calculate equivalent sound levels over an entire shift or work day as either a dose (%) or an 8-hr time weighted average (TWA).[46] Noise dosimeters would be the preferred equipment to measure noise exposures on agricultural operations because the noise sources are not continuous and farmers and farm workers are highly mobile.

For compliance purposes noise exposures are given as either an 8-hr TWA or dose (%). The 8-hr TWA is the decibels of noise exposure measured, normalized to eight hours. The dose is the maximum allowed noise exposure in relation to a specific criterion level and is reported as a percentage. OSHA and the NIOSH are the two most widely used criterions for compliance purposes.[8,9] Other criterions include, but are not limited to, the Mine Safety and Health Association (MSHA) and the American Conference of Governmental Industrial Hygienists (ACGIH).[47,48] For the OSHA criterion the permissible exposure limit (PEL) is 90 dB and for the NIOSH criterion the recommended exposure limit (REL) is 85 dB, both given as an 8-hr TWA.

Noise exposure measurements are dependent on the setting of the measurement instruments. Several government agencies have specified settings for noise monitoring equipment (Table 1.2).[8,9,47,48] The instrumentation settings for noise measurement equipment include the criterion level, criterion time, exchange rate, threshold, response rate, and frequency weighting. The criterion level and time are the maximum allowed noise exposure in decibels and the corresponding time period established by regulatory agency. The threshold is the minimum noise level that is integrated 8-hr TWA or dose. The exchange rate indicates the decibels that correspond to a doubling of the noise intensity, and also dictates how much the maximum allowed exposure can increase or decrease before the noise exposure duration is halved or doubled. The response rate specifies the speed the instrument responds to changes in noise level. The frequency weighting is a scale that weights noise depending on frequency. There are three noise weighting scales; A, C, and Z. The A scale is the most commonly used and weights the noise at frequencies similar to the human ear.[37,46]

Noise Exposures in Agriculture

According to the National Institute for Occupational Safety and Health approximately 4 million workers are exposure to hazardous noise levels greater than 85 dBA.[9] In the agriculture sector alone, of the total work force of approximately 90,000, about 20% are exposed to hazardous noise levels.[9] With estimates of 16 to 24% of all hearing loss being related to noise exposure at work, this indicates a substantial number of agricultural workers at risk of developing hearing loss.[4]

Mechanized equipment and animals are common sources of noise on farming operations. Several studies have looked at the noise levels on farms due to these noise sources and found that many produce noise levels great enough to damage hearing. Mechanical equipment such as tractors, combines, choppers, lawn movers, skid steers, various power tools, and work areas such as milking barns and swine buildings all have been shown to produce noise levels greater than 85 dBA. It was also common for some of these agricultural noise sources to produce noise levels in excess of 100 dBA.[30,49-52]

Due to the nature of work practices on farms, these intense noise exposures can result in varying degrees of average daily noise exposures. Measurements of 8-hr TWA noise exposures found that average daily noise exposures can range from 46.1 to 108.6 dBA.[49,51,53-55] These 8-hr TWA exposures were measured from numerous farms that produce varying agricultural commodities, from case crops to animal production. However, even within specific production types, the average daily noise exposures vary greatly. In addition to the day-to-day variability of 8-hr TWA noise exposures, there can also be substantial seasonal variation.[56,57]

The variability in 8-hr TWA noise exposures of farmers and farm workers is likely due to the changing work environment, variability in daily task, variability in the equipment used, and varying work hours. Thus it is unrealistic to measure an 8-hr TWA noise exposure for farmers and farm workers that is representative of a typical workday. Furthermore the 8-hr TWA does not provide any information regarding the sources of intense noise exposures. Determining noise exposures at the task-level for farmers and farm works may be a more useful metric. While compliance with noise exposure RELs and PELs still require 8-hr TWAs, task-based noise exposure measurements would allow identification of tasks that should be targeted for control strategies, to reduce exposure and limit the development of hearing loss.

Task-Based Noise Exposures in Agriculture

Task-based exposure assessments have been conducted for numerous hazards (chemicals, heavy metals and aerosols) and have been shown to be useful for identifying high exposure tasks that should be targeted for control strategies.[58-64] In addition, task-based exposure assessments allowed more detailed characterization of exposures and improve estimates of full-shift exposure measurements.[58,59,65] Task-based exposures have also been shown to improve estimates of past exposures that were reconstructed using employment records or work histories, providing valuable data for occupational epidemiology studies.[66]

The literature indicates few studies have measured task-based exposures for agricultural hazards.[62,67] Assessments of task-based noise exposures for agricultural operations are limited as well. Depczynski et al. and Franklin et al. both report task-based noise measurements of farmers in Austrailia.[68,69] Noise exposures for twenty-two agricultural tasks were measured using short-term samples on 48 farms. Noise exposures for the 22 tasks ranged from 73 dBA to106 dBA. The 95% confidence intervals for the task-based exposures were as low as 3 dBA and as great as 25 dBA, indicating that there is considerable variability in the task-based noise exposures for these farmers.

Milz et al. assessed noise exposure for twelve tasks completed by members of three Ohio farm families.[70] Task-based noise exposures were measured with personal noise dosimeters using the NIOSH and OSHA monitoring criteria. The task-based noise exposures were standardized to an 8-hr TWA. Harvesting, operating a front-end loader, and plowing all exceeded the 85 dBA when measured using the OSHA criteria. For the NIOSH criteria, tasks exceeding 85 dBA included harvesting, operating a front-end loader, plowing and repair/maintenance. The task-based noise exposures were also highly variable, with as much as a 57 dBA range between the lowest and highest noise exposure for a particular task.

Humann et al. measured the task-based noise exposures for 10 tasks completed by workers involved in swine production.[49] Between one and 12 task observations were made for the swine production tasks. Task-based noise exposures were monitored using personal noise dosimeters set to the NIOSH measurement criteria. Mean noise exposures for the 12 task ranged from 76.1 to 92.1 dBA, with variability in the task-based noise exposures as much as 36 dBA.

Other task-based noise exposures assessments focused on tasks completed by adolescents. Humann et al. and Lander et al. used personal dosimetry to measure task-based noise exposures using the NOISH and OSHA criteria respectively.[51,71] The study by Humann found the mean noise exposures for 15 agricultural tasks to be between 81.6 and 89.6 dBA, with standard deviations as high as 8.9 dBA. Tasks with the highest noise exposures were those associated with agricultural equipment.[71] The study by Lander measured the noise exposures of nine agricultural tasks. The mean task-based noise exposures ranged from 97 to 82 dBA, with variability in the task-based noise exposures as much as 25 dBA.[51]

Although studies assessing agricultural task-based noise exposures are limited, they have identified tasks that are associated with intense noise exposures. Furthermore, these studies provide valuable information about tasks that should be targeted for control strategies. Unfortunately many of these studies only measured the noise exposures for a few select tasks. Also, the mean task-based noise exposures in these studies were calculated using a limited number of measurements. Thus, studies assessing the noise exposures of additional agricultural tasks and with larger sample sizes are needed.

Estimates of 8-hr TWA Using Task-Based Noise Exposures

Task-based noise exposures have been shown to be more useful than the 8-hr TWA for identifying tasks with intense noise exposures. Regrettably, for compliance purposes, task-based noise exposures do not provide information about whether or not daily noise exposures of farmers and farm workers exceed the NIOSH REL or OSHA PEL. As of now, it is unclear if task-based noise exposures can be used to accurately estimate the dosimeter-measured 8-hr TWAs for farmers and farm workers. Evaluating the capability of predetermined task-based noise exposures to accurately estimate an 8-hr TWA could have considerable implications on the agricultural industry. If predetermined task-based noise exposures can be used to estimate the 8-hr TWA it would eliminate the need to conduct expensive and time consuming full-day noise monitoring. This is particularly important for a relatively unregulated industry such as agriculture, where resources for extensive monitoring of health and safety hazards are limited.

Using the dose equation is a standard method for calculating the daily noise dose or 8-hr TWA when the noise levels of specific time intervals are known.[37] This concept could be expanded by using the noise dose equation, along with predetermined task-based noise exposure levels and time-at-task information, to estimate the 8-hr TWA. However, little research has been conducted to evaluate the accuracy of this method. Hagar et al. called this concept sound exposure profiling and gave a description of the methodology required to estimate the daily noise exposures.[72]

No studies have been conducted evaluating the agreement between task-based estimated daily noise exposures and measured daily noise exposures for workers in the agricultural industry. In the construction and manufacturing industry there have been several studies that have assessed the agreement between full-day noise exposures measurements and estimated daily noise exposures.[73-75] These studies all used models more sophisticated than the dose equation to estimate daily noise exposures using task-based measurements. The task-based noise exposures these studies used to estimated daily noise exposures were of varying complexity. In addition, different methods for collecting time-at-task data were used throughout these studies, with some using direct observation and other using worker self-reports.

Using task-based noise exposures from 189 subjects on 502 work shifts, Seixas et al. evaluated the agreement between task-based estimated and full-shift noise exposures.[74] Six linear regression models were used to obtain estimates of full-shift noise exposures. These models varied in complexity, from estimates using task-based noise exposures alone to estimates using task-based noise exposures grouped by equipment, work location and trade. Agreement (R^2) between task-based estimates and measured full-shift noise exposures ranged from an $R^2 = 0.11$ to an $R^2 = 0.90$. This study found that the R^2 increases when the specificity of the task definitions increases. This study also found that task-based estimates of full-shift exposure include a high degree of error when the task-based noise exposures are highly variable.

Reeb-Whitaker et al. looked at agreement between task-based estimates of daily noise exposure and measurements of daily noise exposure as part of a larger study examining the accuracy of time-at-task recall.[73] Twenty-five construction workers had noise exposures measured by dosimeters, and time-at-task information recorded on activity cards or questionnaires. Simple linear regression was used to determine the agreement between the task-based estimated and dosimetry measured daily noise exposures. The relationship between dosimeter measured daily noise exposures and task-base estimated daily noise exposures calculated from activity cards and questionnaires had an $R^2 = 0.62$, and $R^2 = 0.59$ respectively.

The studies by Seixas et al. and Reeb-Whitaker et al. used the same dosimeter data for the task-base estimated and measures noise exposures.[73,74] Virji et al. compared estimated and measured daily noise exposures that were independent of each other, where the daily noise exposures were measured using personal noise dosimetry and the task-based noise exposures were measured using short-term sound level meter measurements.[75] Eight estimates of daily noise exposures were calculated for each of the 198 dosimeter measured daily noise exposures. Estimates were calculated using time-at-task data collected by; direct observation, worker diary, and supervisor summary. In addition, the estimated daily noise exposures were calculated using either the arithmetic or geometric mean task-based noise exposures. Agreements (R^2) between estimated daily noise exposure and measured daily noise exposures ranged from 0.70 – 0.77 for direct observation, 0.63 – 0.71 for worker reports, and 0.49 -0.62 for supervisor assessments.

The previously mentioned studies indicated that the accuracy of the exposure assessments depended on how well tasks were defined and the ability of statistical models to account for the variability in noise exposures. They also indicated that clearly defined beginning and ending times for each task increase the agreement between estimated and measured daily noise exposures. These studies also indicate there is generally agreement between time-at-task information collected from direct observation and worker self-reports.[73,76,77] Overall, these studies found moderate to good agreement between measured and task-based estimated daily noise exposures. However, none of the studies examined the accuracy of measured and task-based estimated daily noise exposures, where the task-based noise exposures were measured from a truly independent sample of workers. Unfortunately for industrial hygienists and other health and safety professionals, these modeling techniques are complex and require considerable effort, and therefore may not be more convenient that monitoring daily noise exposures directly.

Estimating 8-hr TWA noise exposures using the dose equation is a much more simplistic method that should be evaluated for accuracy. Unlike estimating daily noise exposures using complex modeling techniques, the dose equation does not take into account additional determinants of exposure. Therefore, determinants of noise exposures for farmers and farm workers should be examined to identify those that should be taken into account when categorizing task-based noise exposures and collecting time-at-task information.

Determinants of Noise Exposures in Agriculture

Unlike predictors of hearing loss that have been studied extensively, few studies have been conducted to identify determinants of noise exposure. Studies examining determinants of exposure for hazards, such as aerosols and solvents, have found that tasks, time-at-task, equipment, and work area had statistically significant associations with exposure.[63,78-81] A couple of studies have investigated determinants of noise exposure specifically.

Neitzel et al. collected 338 full-shift noise exposure measurements from 133 construction workers.[77] Linear regression analysis was performed on the one-minute noise exposure means from the dosimeter data to identify work characteristics of construction that had a statistically significant association with noise exposure. The results of this study identified a statistically significant association between tasks and noise exposures, as well as tool use and noise exposures. The specific trade of the construction workers did not have a statistically significant associate with noise exposure.

Nieuwenhuijsen et al. examined the association between characteristics of agricultural work and noise exposure.[82] A telephone questionnaire was administered to 1947 farm operations collecting information about farm characteristics, percent time participating in specific agricultural task, percent time working in noisy environment and use of hearing protection. Logistic regression analysis was used to identify agricultural exposure variables that were associated with self-reported percent time working in a noisy environment, and were categorized as either low ($\leq$ 10% of the time), medium (11 to 39% of the time), or high ($\geq$ 40% of the time). Of the agricultural exposure variables analyzed, working outdoors, operating a tractor, field work, field supervision and repair work were associated with greater percent time working in a noisy environment, while working with livestock, fertilizing crops and working at a larger farm were associated with less time working in a noisy environment.

The literature indicates that important determinants of noise exposure are related the tasks being conducted, the equipment used and the areas work is carried out. The previous studies primarily focused on work characteristics when examining factors that are associated with noise exposure. In the agricultural industry no studies have evaluated the association between noise exposure and personal demographic or farm characteristics. A comprehensive assessment of determinants of noise exposure for agricultural operations is important to identify factors that should be included in the categorization of task-based noise exposures, in order to increase the accuracy of estimated 8-hr TWA noise exposures.

Specific Aims

A fair amount of research has already been conducted examining hearing loss and noise exposures among farmers. It is know that farmers suffer more hearing loss than the general population, and that hazardous noise levels are commonly found on agricultural operations. However, little work has been done to identify the extent specific agricultural tasks have on exposure to hazardous noise levels and ultimately the development of hearing loss. Furthermore, it is unknown if task-based noise exposures usefulness for industrial hygienist and other health and safety professionals, either by directing control strategies or allowing estimates of the 8-hr TWA. The primary purpose for this dissertation was to identify agricultural tasks that have a significant association with hearing loss and/or noise exposure. In addition, the ability of task-based noise exposures to accurately estimate 8-hr TWA noise exposures was also evaluated. Three studies, with their own specific goals, were conducted for this dissertation:

Study 1 Goal: Examine the association between years spent performing common agricultural tasks and measures of hearing loss among farmers and rural residents.

Study 2 Goal: Calculate and characterize the task-based noise exposures of farmers and farm workers.

Study 3 Goal: Evaluate the effectiveness of the noise dose equation at estimating the 8-hr TWA noise exposure of farmers and farm workers using predetermined task-based noise exposures and identify determinants of noise exposures that would likely improve 8-hr TWA noise exposure estimates.

Significance of Research

The results of this dissertation will provide important information for industrial hygienists and other health and safety professionals working to decrease the prevalence of hearing loss among farmers and farm workers. Identification of agricultural tasks that are associated with hearing loss and/or exposures to hazardous noise levels will allow control strategies to be targeted to the tasks that represent the most risk. Furthermore, if accurate estimates of 8-hr TWA noise exposures can be made using task-based noise exposures, then expensive noise dosimeter measurement would not be needed. This is especially vital in the agricultural industry, due to relatively unregulated family farms not having the means for comprehensive noise exposure evaluation or control, and the limited use of hearing protection among farmers and farm workers.

Table 1.1 Equations for calculating average hearing threshold levels to assess hearing disability as indicated by the International Standards Organization and the American National Standards Institute

International Standards Organization				
Calculation	Frequencies (Hz)			
	Freq #1	Freq #2	Freq #3	Freq #4
Mean of hearing threshold levels at	500	1000	2000	
Mean of hearing threshold levels at	500	1000	2000	3000
Mean of hearing threshold levels at	500	1000	2000	4000
Mean of hearing threshold levels at	1000	2000	3000	
Mean of hearing threshold levels at	1000	2000	3000	4000
Mean of hearing threshold levels at	2000	4000		
One-tenth of hearing threshold levels at	500[a]	1000[b]	2000[c]	4000[d]
Sum of hearing threshold levels at	2000	3000		
Mean of hearing threshold levels at	2000	3000	4000	

American National Standards Institute				
Calculation	Frequencies (Hz)			
	Freq #1	Freq #2	Freq #3	Freq #4
Mean of hearing threshold levels at	500	1000	2000	4000
Mean of hearing threshold levels at	500	1000	2000	3000
Mean of hearing threshold levels at	3000	4000	6000	

[a] 2 X hearing threshold level at frequency

[b] 4 X hearing threshold level at frequency

[c] 3 X hearing threshold level at frequency

[d] 1 X hearing threshold level at frequency

Table 1.2. Noise dosimeter and sound level meter settings for noise monitoring equipment

	Organization (PEL, REL, TLV)			
Settings	OSHA	NIOSH	ACGIH	MSHA
Criterion Level (dB)	90	85	85	90
Criterion Time (hrs)	8	8	8	8
Exchange Rate (dB)	5	3	3	5
Threshold (dB)	90	80	80	90
Response Rate	Slow	Slow	Slow	Slow
Weighting	A	A	A	A

CHAPTER II
EFFECTS OF COMMON AGRICULTURAL TASKS ON MEASURES OF HEARING LOSS

Abstract

The purpose of this study was to examine the effect of lifetime duration engaging in common agricultural tasks on hearing loss among farmers and rural residents. Specifically, associations between audiometric data and self-reported years of engaging in 12 agricultural tasks were collected among 1568 study participants. Three hearing loss summary variables, low frequency pure tone average (PTA) threshold, high frequency PTA threshold, and the National Institute for Occupational Safety and Health (NIOSH) hearing loss PTA criterion were calculated from audiometric data. Logistic regression methods were used to examine associations between agricultural tasks and hearing loss >25dB. Linear regression methods were used to examine associations between agricultural tasks and mean decibels of hearing loss for each of the three hearing loss metrics. A backward multivariable selection procedure was used to identify agricultural tasks associated with hearing loss while controlling for potential confounding variables. Statistically significant differences in the mean decibels of hearing loss and the prevalence of hearing loss >25dB were found between male farmers and male non-farmers only for the lower frequency PTAs (NIOSH and low frequency). Except for years worked with livestock ($p<0.01$) no agricultural-specific activity was statistically significantly associated with any of the dichotomized hearing loss outcomes. In covariate-adjusted linear regression analyses, the interaction of years worked on a farm and age was statistically significantly associated with all three PTA hearing loss outcomes ($p<0.01$), and the interaction of years worked on a farm and male gender was statistically significantly associated with the NIOSH PTA outcome ($p=0.03$). Years of electric or pneumatic tools use, years ridden an ATV or motorcycle, years hunting or target shooting and the interaction of years noisy job other than farming and male gender

was statistically significantly associated with either one or more of the three PTA hearing loss outcomes. Although farmers had greater mean hearing loss and a higher prevalence of hearing loss than non-farmers, self-reported years of specific agricultural tasks were poorly associated with hearing loss outcomes. Self-reported years engaging in specific agricultural tasks may be a poor surrogate of true noise exposure. Future studies with objective assessment of noise exposure may better estimate effects of agricultural tasks.

Introduction

Farmers are more likely to experience hearing loss than other occupational groups.[30-32] It has been shown that farmers can have a 25 dB decrease in their hearing threshold by the age of 35, and as much as 40 decibels of hearing loss by age 60.[32] One study of high school-aged farm youth found a 14% increase in the prevalence of hearing loss compared to their non-farming classmates.[31] Among adult farmers, the prevalence of hearing loss has been shown to be almost double that for non-farmers.[24,30] A detailed assessment of the hearing thresholds of 1727 farmers and farm residents reported hearing loss prevalence rates between 9% and 47%, with the highest prevalence rate for high frequency hearing loss.[23]

In addition to having a higher prevalence of hearing loss, hearing acuity among the farming population starts to decrease at an earlier age than non-farming populations, with significant differences seen by age 40.[26,34] Even at younger ages there can be as much as a 6 dB decrease in the hearing threshold among farm residents.[34] One study among dairy farmers found that hearing thresholds decrease by 4 dB for each decade of age.[83] Some studies have also shown that hearing loss commonly occurs at frequencies between 4000 and 6000 Hz, indicating the loss is likely noise-induced.[26,34]

Members of farming populations frequently engage in noisy tasks.[22,30,32,84] Age, male gender, years farming, and specific agricultural practices, such as, driving tractors and working around grain bins, have been associated with hearing loss.[22,29,30,35]

Hazardous levels of noise have been documented around grain dryers, tractors, and livestock, indicating that those tasks have the potential to cause NIHL.[22,25,29-31]

Certain behaviors increase the risk of hearing loss among farmers. Farmers are known for their independent lifestyles and resistance to use of hearing protection. Several studies have found that between 55% and 60% of farmers rarely or never use hearing protection.[85,86] In addition to limited use of hearing protection, farmers and rural residents are more likely to engage in recreational activities that are associated with intense noise exposure, such as hunting and riding all-terrain vehicles.[87,88]

While studies have shown an association between common farm practices and hearing loss, they have not provided task-specific hearing loss information to guide intervention strategies. The goals of this research study is to examine the association between years spent performing common agricultural tasks and measures of hearing loss among farmers and rural residents. Specifically this study was conducted: 1) to determine the prevalence of hearing loss among rural populations; and 2) to examine associations between years participating in common agricultural tasks and hearing loss. A set of hearing loss summary measures were used, including categorical and continuous variables. This study was designed to provide information on agricultural tasks that are associated with hearing loss that should be targeted for exposure control.

Materials and Methods

Study Population

Audiometric and agricultural exposure information was collected from subjects enrolled in the Keokuk County Rural Health Study (KCRHS). The KCRHS is a long-term prospective cohort study of rural health that began in 1994. The methodology used to compile the KCRHS cohort has been published previously.[89] The KCRHS cohort is a stratified random sample of households located in Keokuk County in southeast Iowa. Of the original 1004 households in Round One of the KCRHS, 707 continued into round two. An additional 2471 households were recruited for Round Two. Of these households, 295 chose to participate, 1,151 refused participation, and 1,320 were unable to be contacted. At inception of the cohort, each study subject eight years or older completed a detailed clinical screening which included blood testing, vision and hearing tests, spirometry, methacholine challenge, allergy testing, measurements of blood pressure, and basic anthropometry. In addition adult subjects completed interviews about health status, injuries, demographics, occupational history, recreational activities and behavior.

Keokuk County is considered a rural county by definition of the US Census Bureau, with no town having a population > 2,500 residents.[89] The 2000 United States Census Bureau reported the population at 11,400, with a gender distribution of 50.9% female and 49.1% male.[90] The Census Bureau also calculated the median age of Keokuk County residents to be 40 years and the average family size to be 2.45 persons. There were 1163 farms in Keokuk County, with an average size of 274 acres; of those farms, 583 were operated by an owner who considered his/her primary occupation to be farming.[91] Primary agricultural products included hogs, corn and soybeans.

Data Collection

For this study, audiometric, agricultural exposure and covariate data were taken from Round Two of the KCRHS between 1999 and 2004. Individuals from 1,002 households participated with ages at enrollment from less than one year to 92 years. Participants were equally divided between males and females and the cohort was stratified by farm, rural non-farm and town households. Only subjects who completed the audiometric testing were included in the analysis for this study.

Of the 2164 participants in Round Two, 1920 completed audiometric testing. Among participants who completed the audiometric testing, those under the age of 18 (N=352) were not included in the current study because they did not complete the adult interview which included the covariate and agricultural exposure data. Therefore, data from 1568 subjects were analyzed. A few subjects were missing thresholds at key frequencies in the audiogram. Because of this, the numbers of participants available for specific analyses varied depending on which PTA audiometric summary variables were used.

Audiometric Data

Audiometric data was collected during the health screening completed at the KCRHS clinic in Sigourney, IA by a trained staff member. The audiometric data was collected by pure tone audiometry using a Maico 800 audiometer in a sound proof chamber. The audiometer was calibrated and audiometry conducted following guidelines developed by the American National Standards Institute.[92]

To identify factors that may have affected the results of the pure tone audiometry, subjects completed a pre-screening questionnaire and underwent an otoscopic examination by a KCRHS staff member. Pure tone audiometric testing was conducting at 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz, with a repeat of the 1000 Hz. The repeatability of the subject's responses was deemed valid if the threshold of the 1000 Hz retest was within 5 dB of the initial 1000 Hz test. Upon conclusion of the test, the audiometer produced an audiogram of the results which were then entered in the KCRHS database.

For purposes of data analysis, pure tone audiograms were reduced to three continuous summary metrics of hearing loss as a function of decrements in dB units measured at each frequency of the audiogram. The first summary metric was based on methods developed by NIOSH and was calculated as the arithmetic mean of decrements measured at 1000, 2000, 3000 and 4000 Hz (the *NIOSH PTA*).[9] The second and third summary metrics were designed to separately capture low and high frequency losses. Specifically, low frequency hearing loss was calculated as the arithmetic mean of decrements measured at 500, 1000, 2000 and 3000 Hz (the *Low Frequency PTA*) and high frequency hearing loss was calculated as the arithmetic mean of decrements measured at 3000, 4000 and 6000 Hz (the *High Frequency PTA*). The three calculations for PTA thresholds used in this study are among those recommended by either ANSI or the ISO.[10,11] Hearing loss was characterized separately for the left and right ears. For each participant, the greater loss of the two ears was used in the analysis.

Finally, three separate categorical outcome variables were created from the three continuous hearing loss variables by dichotomizing each at a value >25 dB. Consequently, three continuous and three categorical hearing loss metrics were included in this study.

<u>Agricultural Exposure Data</u>

Agricultural exposure information was collected through in-person interviews administered at the KCRHS clinic on the same day of as the audiometric test. During the interviews, questionnaires were used to collect occupational histories as well as home and farm information. The questionnaires were created from existing national and previously published surveys.[93] Subject's answers during the interview were entered into the KCRHS database.

Thirteen agricultural exposure variables from the KCRHS database were examined for their association with hearing loss. One agricultural exposure variable classified the participants as either a farmer or non-farmer. To be classified as a farmer, the participant must have either worked on a farm for at least one hour per week for one year, or worked for at least one month out of a year during their lifetime. Participants who indicated that they worked for one year or more on a farm were also classified as farmers. The remaining twelve agricultural exposure variables were characterized by self-reported years of participation in common agricultural tasks.

Data Analysis

Associations between agricultural exposures and the three continuous hearing loss summary metrics were examined with multiple linear regression methods and associations between agricultural exposures and the three categorical hearing loss summary metrics were examined with multiple logistic regression methods. A reduced set of base model covariates was identified for each of the regression methods, separately. The initial procedures for base model variable selection were similar, however, and are described, below.

Selection of Potential Confounders

For both the linear and logistic regression analyses, nine covariates (age, sex, alcohol consumption, smoking, military service, marital status, education, income, and financial assets) were identified *a priori* as possible confounders of the association between agricultural exposures and hearing loss. Age was selected because of its known association with hearing acuity. Gender, drinks per day, years smoked and past military job involving use of firearms were included because they have been shown to be associated with hearing loss. The remaining covariates, marital status, education, income and household financial assets were included as indicators of socioeconomic status.

Base Models

The nine covariates described above were entered simultaneously into separate logistic and linear regression models for each of the three PTA hearing loss summary variables. A backward elimination procedure was used to sequentially remove covariates starting with the largest p-value. This process was continued until all covariates remaining in the model had a Wald Chi-square p-value <0.10. Once backward selection was completed, Spearman correlation coefficients were calculated for all pairs of remaining covariates. Pairs with correlations > 0.30 were considered correlated and the variable with the lower p-value was retained in the base model and the correlated variable was removed. For consistency across the analyses, a standard base model of all covariates that were associated with any of the three continuous PTA audiometric summary variables (p-value < 0.10) was created, as was a standard base model of all covariates that were associated with any of the three categorical PTA audiometric summary variables. The continuous standard base model covariates were subsequently included in all multivariable analyses of the three PTA continuous hearing loss outcomes and the categorical base model covariates were included in all multivariable analyses of the three PTA categorical hearing loss outcomes.

Statistical Analysis

Multiple logistic regression methods were used to examine associations between agricultural exposures and the three categorical PTA summary variables and multiple linear regression methods were used to examine associations between agricultural exposures and the three continuous PTA summary variables while controlling for the respective standard base model covariates. All analyses were conducted with SAS, version 9.2 (SAS Institute, Inc., Cary, NC).

The initial step of the multivariable regression analysis was to estimate the standard base model adjusted relationship between each of the 13 agricultural exposure variables and the six hearing loss outcomes, separately. Odds ratios (ORs), 95% confidence ratios (CIs) and probabilities for the standard base model adjusted association between individual agricultural exposures and hearing loss >25dB were calculated using logistic regression analysis. Parameter estimates (β) and probabilities for the base model adjusted association between the individual agricultural exposures and mean dB of hearing loss were calculated using linear regression analysis. In addition to investigating the individual associations between the agricultural exposures and hearing loss outcomes, *a priori* interactions between farmer and age, farmer and gender, years worked noisy job other than farming and age, years worked noisy job other than farming and gender, years worked on a farm and age, and years worked on a farm and gender were investigated by inclusion of with cross product terms in the appropriate regression model.

After examination of standard base model adjusted associations between each of the 13 individual exposure variables and the six hearing loss outcomes, full multiple regression models were created.

Specifically, for each of the six outcomes separately, agricultural exposure variables and any interaction terms with a (Wald Chi-square or F-statistic) associated with that outcome (p-value <0.20) were included simultaneously in multivariable logistic and linear regression models, along with their respective standard base model covariates.

A backwards selection procedure was then used to eliminate agricultural exposure variables with p>0.10 from the multivariable regression models. The process was repeated until all agricultural exposures with a p>0.10 were eliminated from the model. In the final multivariable models, agricultural exposures associated with hearing loss were determined at a significance level of $\alpha=0.05$. For final multivariable logistic and linear regression models, Spearman correlation coefficients were calculated for all pairs of remaining agricultural exposure variables. Pairs with correlations > 0.60 were considered correlated and the variable with the lower p-value was retained in the base model and the correlated variable was removed.

Regression diagnostics were performed to verify the assumptions of the logistic and linear regression analysis. For the logistic regression analysis, the Logit Step Test was used to examine the linear relationship between the agriculture exposures and the logit of the hearing loss outcome variables. For the linear regression analyses, analysis of residuals was conducted to check the normality assumption. The residuals were observed to be approximately normally distributed and additional data transformations were not necessary. The analysis of residuals was also used to identify possible outliers and influential values. Data from any participant that exceeded the cutoffs for the studentized residuals (studentized residual >2 or <-2), leverage (>0.02) and Cook's D (>0.003) were investigated. All data identified as outliers by the regression diagnostics were investigated and verified as valid.

Results

Demographic Characteristics

The demographic and agricultural exposure characteristics of the study population are presented in Table 2.1. Of the 1568 participants, 960 were classified as farmers. The average age of participants was 55.1 years with farmers having a statistically significant higher mean age (56.5, SD=15.8) than non-farmers (52.8, SD=16.4) A statistically significantly greater proportions of farmers were male when compared to non-famers (59.3% vs. 19.2%, p<0.01).

Farmers spent more years than non-farmers engaged in the tasks associated with the 12 agricultural exposures. Across all subjects or stratified by farming status, there was a high degree of variability in the years that the participants engaged in agricultural tasks. Except for marriage status and years smoked, the means and proportions of all covariates and agricultural exposure variables were significantly different between the farmer and non-farmer groups. The farmers were less educated than the non-farmers and had higher incomes and higher values of household assets. The farmers were also more likely to have past military experience and consume more alcohol than the non-farmers.

Unadjusted Analysis

Mean hearing loss and the proportion of participants with >25 dB loss for the three PTA audiometric summary variables for the sample stratified by age and for the entire study sample are presented in Table 2.2. For the entire study sample, the mean NIOSH, low frequency, and high frequency PTA summary hearing loss variables were 24.6 dB, 19.8 dB and 35.4 dB. The proportion of participants with NIOSH, low frequency and high frequency summary hearing loss variable values >25dB were 39.6%, 27.8% and 55.2%. The mean hearing loss and the prevalence of hearing loss >25 dB increased significantly with age category for the three PTA audiometric summary variables.

The prevalence of hearing loss >25dB among farmers and non-farmers stratified by age group and gender is provided for the three PTA calculations in Table 2.3. For the full study sample, across the three PTA summary variables, a larger proportion of male and female farmers met the criteria for hearing loss than did male and female non-farmers. The difference was statistically significant for male farmers in comparison to male non-farmers for the NIOSH and Low Frequency PTA summary variables and for female farmers in comparison to female non-farmers for the Low Frequency PTA summary variable. When stratified by age, the prevalence of hearing loss greater than 25 dB increased with increasing age for males and females, and farmers and non-farmers. In the stratified analysis, a statistically significant difference in the proportion of participants with hearing loss was observed only for the Low Frequency PTA summary variable when male farmers >= 70 years (77.4%) of age were compared to male non-farmers >= 70 years of age (55.0%, $p<0.05$).

The mean hearing loss in dB among farmers and non-farmers stratified by age group and gender is provided for the three PTA summary methods in Table 2.4. For the full study sample, mean hearing loss was greater among male and female farmers than among male and female non-farmers for all three PTA summary methods. The difference was statistically significant for male farmers vs. male non-farmers for the NIOSH PTA summary method (mean NIOSH $PTA_{\text{all male farmer}}$ = 32.6 dB, SD=19.3 dB; mean NIOSH $PTA_{\text{all male non-farmer}}$ = 28.3 dB, SD=18.8 dB) and for female farmers vs. female non-farmers for the High Frequency summary method (mean High Frequency $PTA_{\text{all female farmer}}$ = 24.8 dB, SD=11.4 dB; mean High Frequency $PTA_{\text{all female non-farmer}}$ = 20.7 dB, SD=10.7 dB). When stratified by age, mean hearing loss increased monotonically across the four age groups for both genders and farmers and non-farmers. In the stratified analysis, mean hearing loss was statistically significantly greater among women farmers than among women non-farmers for the High Frequency summary method, only (mean High Frequency PTA $_{\text{female farmer 50-59 yo}}$ = 24.8 dB, SD=11.4 dB; mean High Frequency PTA $_{\text{female non-farmer 50-59 yo}}$ = 20.7 dB, SD=10.7 dB)

Base Model Analysis

Unadjusted associations between each base model covariates and the dichotomized hearing loss outcomes are presented in Table 2.5. Each of the covariates was statistically significantly associated with one or more of the outcome measures. Unadjusted associations between the base model covariates and the continuous hearing loss outcomes are presented in Table 2.6. Except for the association between marital status and the High Frequency PTA (p=0.34), each of the covariates was statistically significantly associated with all three continuous outcomes.

After the backwards selection procedure, age, gender, education, and total household assets were statistically significantly associated with one or more of the dichotomized outcome measures and were subsequently retained as the final standard base model covariates for multiple logistic regression models of the three dichotomized hearing loss outcomes (Table 2.7). A larger number of covariates were retained in the models of continuous outcome measures. After the backwards elimination procedure, age, gender, education, marital status, drinks per day, and total household assets were significantly associated with one or more of the three continuous outcome measures (Table 2.8).

Multivariable Regression Analysis

The results of the multivariable regression analyses were different depending on which PTA audiometric summary variables were used for the outcome measure, and if the outcome measure was treated as a categorical or continuous variable. The multivariable linear regression analysis identified more agricultural exposures with a statistically significant association with hearing loss compared to the multivariable logistic regression analysis.

Multivariable Logistic Regression

The unadjusted association between each agricultural exposure variable and the hearing loss outcomes (hearing loss > 25dB) using the three PTA summary variables, and controlled using the respective standard base model covariates are presented in Table 2.9. The interaction between years at noisy job other than farming and gender (p <0.01), years ridden ATV or motorcycle (p=0.03) and years used electric or pneumatic tools (p=0.04) had a statistically significant association with the NIOSH PTA hearing loss outcome. The agricultural exposure variables that had a statistically significant association with the Low Frequency PTA hearing loss outcome were, years used electric or pneumatic tools (p=0.04), years worked on a farm (p=0.05), years operated tractor without a cab (p=0.02), years worked around livestock (p<0.01) and years worked in a confinement building (p=0.04). Only years hunting or target shooting (p=0.02) and years ridden ATV or motorcycle (p=0.04) had a statistically significant association with the High Frequency PTA hearing loss outcome.

The results of the final multivariable logistic regression models, selected using a backwards elimination procedure and controlled using the respective standard base model covariates, are shown in table 2.10. Only one agricultural exposure had a statistically significant association for each of the three PTA hearing loss outcomes, when adjusted for the other agricultural exposures and the standard base model covariates.

The interaction of years worked at a noisy job other than farming and gender had a statistically significant association (p<0.01) with the NIOSH PTA hearing loss outcome. Two additional agricultural exposures, years hunting or target shooting and years ridden ATV or motorcycle, meet the criteria (p-value ≤10) to remain in the final multivariable logistic regression model, but did not reach the significant level (α=0.05).

Years worked with livestock ($p<0.01$) was the only agricultural exposure variable with a statistically significant association with the Low Frequency PTA hearing loss outcome. Years operated pneumatic/electric tools was kept in the final model because a nearly-significant association with the Low Frequency hearing loss outcome was observed ($p=0.08$).For the High Frequency PTA hearing loss outcome, years hunting or target shooting had a statistically significant association with hearing loss ($p=0.03$). Similar to the NIOSH PTA hearing loss outcome, a nearly-significant relationship between years ridden an ATV or motorcycle and the High Frequency hearing loss outcome was observed ($p=0.06$).

Multivariable Linear Regression

The associations between the unadjusted agricultural exposures controlled using the respective standard base model covariates and hearing loss outcomes (mean dB) are presented in Table 2.11. Unlike the multivariable logistic regression analysis, many of the agricultural exposures variables and the interaction terms had a statistically significant association with the three PTA hearing loss outcomes. The NIOSH PTA hearing loss outcome had the most statistically significant agricultural exposures and the Low Frequency PTA hearing loss outcome had the fewest. For all three PTA hearing loss outcomes only eight agricultural exposure variables did not meet the cutoff ($p<0.20$) for inclusion in the initial full multivariable linear regression models.

Table 2.12 presents the results of the final multivariable linear regression models, selected using a backwards elimination procedure and controlled using the respective standard base model covariates. For the NIOSH PTA hearing loss outcome, a statistically significant association was found for years ridden ATV or motorcycle ($p=0.04$) and years operated pneumatic or electric tools ($p=0.01$). The interactions of years at noisy job other than farming and gender ($p=0.01$), years worked on a farm and age ($p<0.01$), as well as years worked on a farm and gender ($p=0.03$) also had a statistically significant association with the NIOSH PTA hearing loss outcome. Years worked in a hog confinement building had a nearly statistically significant association with the NIOSH PTA hearing loss outcome (p=0.07). Years operated pneumatic or electric tools (p=0.03), the interaction of years at noisy job other than farming and gender (p=0.03), and the interaction of years worked on a farm and age (p<0.01) had a statistically significant association with the Low Frequency hearing loss outcome. The agricultural exposures with nearly-significant associations with the Low Frequency hearing loss outcome included years ridden ATV or motorcycle (p=0.07), years worked in a hog confinement (p=0.06) and the years worked on a farm and gender interaction term (p=0.09). The agricultural exposure variables with a statistically significant association with the High Frequency hearing loss outcome included, years hunting or target shooting (p<0.01), years ridden ATV or motorcycle (p=0.01) and the interaction of years worked on a farm and age (p<0.01). The high frequency PTA hearing loss outcome did not have any nearly-significant agricultural exposures.

Table 2.13 presents the parameter estimates (β) for the interaction terms in the final multivariable linear regression models with a statistically significant association with the three PTA hearing loss outcomes. For the males there is a statistically significant association for the interaction term, years noisy job other than farming and male gender, and the NIOSH (p=0.01) and Low Frequency (p=0.03) PTA hearing loss outcomes. Also for the NIOSH PTA hearing loss outcome, both age (p<0.01) and gender (p=0.03) had a statistically significant interaction with the agricultural exposure variable years worked on a farm. This imparts a complex relationship on the parameter estimate for this variable, because it is modified by both age and gender. Furthermore the interaction between two continuous variables means that at each age and for every year worked on a farm, there is a specific parameter estimate. Years worked on a farm is a protective factor for hearing loss among the younger participants, but becomes a risk factor for older ages. The results for the males are similar to the females, except that the protective effect for the younger ages is less than that of the females. For the Low Frequency and High Frequency PTA hearing loss outcomes, both had a statistically significant interaction between years worked on a farm and age. The interaction for the Low Frequency PTA hearing loss outcome ($p<0.01$) showed a protective effect at younger ages. The results were similar for the High Frequency PTA hearing loss outcome ($p<0.01$).

Discussion

In the current study, few of the agricultural exposure variables examined were significantly associated with hearing loss. The strongest associations with hearing loss were observed for years at noisy job other than farming, years hunting or target shooting, years operated pneumatic or electric tool, years worked with livestock, and years worked on a farm. Inconsistencies in association between specific agricultural exposures and hearing loss was often observed between the categorical and continuous hearing loss analyses For example, for all three PTA calculations years worked on a farm and the age interaction was significantly associated the categorical hearing loss outcome but not with continuous hearing loss outcome. Most of the agricultural exposure variables that were significantly associated with hearing loss were common to both farmers and rural residents (e.g., years hunting or target shooting, years ridden ATV or motorcycle, and years operated pneumatic tools).

This study was one of the larger studies to examine the effects of agricultural tasks on measures of hearing loss. It is the only study thought to examine these associations using a categorical hearing loss outcome as well as a more precise continuous hearing loss outcome measure. Comparing the results of the current study with the published literature is difficult due to the use of inconsistent PTA calculations and thresholds for the hearing loss outcome measures across studies. While results presented in the literature confirm some of the finding in the current study, they also contradict other results.

Hwang et al. found lifetime exposure to farm equipment, noisy secondary non-farm jobs, and livestock farming were statistically significantly associated with self-reported hearing loss.[22] This is contrary to the current study where none of the exposure variables specific to agricultural equipment (i.e. tractors, combines, grain dryers) were associated with hearing loss. Also unlike the current study, Hwang et al. did not find a significant association between firearm use and hearing loss. Comparison between Hwang et al. and the current study is complicated because of different hearing loss outcome variables (self-reported vs. audiometry-verified hearing loss) used in the analysis. However, self-reported hearing loss has been reported to be a good representation of audiometric-verified hearing loss, thereby increasing the validity of the study by Hwang et al.[23]

A 2003 study of hearing loss among New Zealand farmers found few significant associations between agricultural exposures and hearing loss.[35] Those agricultural exposures that were associated with hearing loss in that study were inconsistent with findings in the current study, however. Using high and low frequency PTA calculations and a categorical hearing loss outcome ($\geq$ 27dB), the investigators reported that operating tractor without a cab and metal working were associated with hearing loss whereas firearm use was not.

Results from analyses of data from the New York Farm Family Health and Hazard Survey to examine associations between agricultural tasks and hearing loss were inconsistent with those of the current study. [29] Methods of calculating high and low frequency PTA hearing loss and 25dB thresholds were identical to those of the current study. Exposure to “other noisy non-farm jobs” was significantly associated with high frequency hearing loss. However in the current study, years working at a noisy job other than farming was associated only with the low frequency hearing loss outcome. The authors of the New York Farm Family study reported significant associations between hearing loss and years driving a tractor, as well as years of grain dryer exposure, whereas no associations with these exposures were observed in the current study.

Another study among dairy farmers examined associations between agricultural exposures and hearing loss using PTA calculations similar to the current study, but with a hearing loss threshold of ≥ 20dB.[30] The authors reported that chain saws, firearms, years farming, and other noisy jobs were significantly associations with either low frequency or high frequency hearing loss. These results are consistent with the results of the current study, except that other noisy jobs were associated with high frequency hearing loss specifically.

Overall, the results of the current study are consistent with the results of other studies in which few agricultural exposure variables were statistically significantly associated with hearing loss outcomes. When included in previous studies, exposure to noisy non-farm jobs was consistently associated with hearing loss. The current study also found an association between noisy jobs other than farming and hearing loss, but only for hearing loss in the lower frequencies, where other studies have observed associations with high frequency hearing loss. Furthermore, none of the published studies examined modification of the effect of agricultural exposure on hearing loss by either age or gender, which were important effect modifiers in the current study.

In the current study, significant interactions were observed between "years at noisy job other than farming" and gender, years worked on a farm and gender, as well as years worked on a farm and age. The strength of the interaction was greater in analyses of continuous outcomes than analyses of categorical outcomes. When present, the interaction between gender and years at noisy job other than farming and years worked on a farm were only significant for male participants.

It is unclear what explains these interactions. The interaction between gender and the agricultural exposures may be the result of greater hearing loss susceptibility among men. However, a more plausible explanation is that systematic differences in actual noise exposure were experienced by men and women reporting similar years of exposure. An example would be the case of a husband and wife, where the husband was a fulltime farmer and the wife periodically helped out on the farm. If the husband worked on the farm every day and the wife only helped out for a few weeks each year, both might report the same number of years they have been farming, but their actually noise exposures over that time would have been quite different. For the interaction of age and years worked on a farm, years working on a farm is protective among those less than 50 whereas years working on a farm is hazardous to hearing for those over 50. One possibility is that the interaction between age and agricultural exposures is the result of the initial years of exposure to noise having less effect on hearing loss than later years of exposure to noise. This interaction could also be due to differences in the self-reporting of agricultural exposures between younger and older participants.

The prevalence of hearing loss among participants in the current study was greater than what has been estimated in the general population. The hearing loss prevalence in the 1999 to 2004 National Health and Nutrition Examination Survey (NHANES) was 16% for low frequency hearing loss and 32% for high frequency hearing loss.[16] In the current study the prevalence of the Low Frequency PTA hearing loss outcome was 28% and the prevalence of High Frequency PTA hearing loss was 55. The mean High Frequency hearing loss among participants in the current study was 15 dB greater than that of participants in the NHANES sample. The higher prevalence and greater decibels of hearing loss is likely due to the participants in the current study being older and having more presbycusis.

Consistent across both the current study and the published literature is the observation that the prevalence of hearing loss and the magnitude of hearing loss is greater for farmers than non-farmers.[22-26,29-31,34,94] However, differences in high frequency hearing loss between farmers and non-farmers are more commonly reported in the literature than are differences in other hearing loss frequencies. In addition, in comparison to non-farmers, farmers are commonly reported to experience hearing loss at an earlier age. In the current study, no significant differences in high frequency hearing loss were observed between male farmers and male non-farmers nor were significant difference in mean high frequency hearing loss observed between younger farmers and younger non-farmers. The greater age of the participants in the current study may explain why statistically significant differences in high frequency hearing loss were not observed between male farmers and male non-farmers. Specifically, older male farmers and older male non-farmers have reached the same amount of high frequency hearing loss, and therefore differences could not be discerned. A possible explanation for the failure to observe significant differences between younger farmers and younger non-farmers is because the non-farmer comparison group consists of rural residents and they may have similar exposure histories to hazardous noise levels and have similar levels of hearing loss at early ages.

Several limitations may have affected the results of the current study. One limitation is the relatively broad classification of farmers likely included many participants with little exposure to noise from agricultural tasks. Such heterogeneity of exposure among farmers would attenuate observed differences in hearing loss between farmers and non-farmers in comparison to a less inclusive definition that was limited to those with longer duration of actual farming experience. For the multivariable logistic and linear regression analyses, this may explain why no association was found between farmer status and hearing loss outcomes in any of the models.

Another limitation is the advanced age of many participants resulting in greater overall hearing loss. Since noise-induced hearing loss first affects the higher frequencies, it is possible not finding a statistically significant difference between the male farmers and non-farmers is because participants in both groups had reached similar levels of hearing loss. Also because the study participants were older, the stratified analysis of hearing loss by age resulted in the younger age groups to have a limited number of participants.

Another important limitation is that the current study lacked information on two important potential confounders. Past use of hearing protection and loss of consciousness due to head trauma were not available for analysis. Use of hearing protection by some participants would decrease their noise exposure and increase the heterogeneity of the agricultural exposures. However, farmers are known to use hearing protection infrequently and the contribution of hearing protection to exposure variability is likely small.[31,32] Also past instances of loss of consciousness due to head trauma has been shown to be associated with hearing loss, but was not available for analysis in the current study.[30]

In comparison to other published studies, the large sample size and use of established audiometric methods to formally ascertain hearing loss are strengths of this study. Studies involving audiometric measurements usually have sample sizes far smaller than 1000 participants[23,26,30-32,95]. The large sample size in the current study also allows greater power for hypothesis testing and weak relationships between hearing loss and the agricultural exposures are likely to be found. This would explain why the odds ratios and parameter estimates for some of the statistically significant associations are small. Furthermore, the large sample size is from a stratified random sample of rural residents and participants are likely generalizable to other rural or agricultural populations.

Use of a continuous metric of hearing loss also contributed to the statistical power of the study. Collapsing hearing loss measures into categories results in loss of information and ultimately loss of statistical power. Furthermore, in comparison to imprecise self-report of hearing loss, use of audiometric measurements of hearing loss reduces non-differential misclassification and improves the power to detect associations. Measurement error when performing audiograms is expected to be non-differential, affecting all study participants equally, and unlikely to create the appearance of associations between agricultural exposures and hearing loss when none existed. In summary, using audiometric measures of hearing loss resulted in greater power to identify associations between the agricultural exposures and hearing loss than studies in which less precise or more biased metrics are used.

Conclusions

Hearing loss among agricultural populations has been recognized as an important public health problem for years, yet few studies have attempted to examine associations between agricultural tasks and hearing loss. The results of this study confirm a high prevalence of hearing loss, but also indicate that hearing loss in this context is far more complex than just being a farmer.

In the current study, hearing loss among farmers was confounded by age and gender. Once stratified by age and gender, no statistically significant differences in high frequency hearing loss (the outcome most clearly associated with noise exposure) was observed between male farmers and male non-farmers. However, a statistically significant difference in high frequency hearing loss was observed between women famers and women non-farmers. It would be logical to hypothesize that, because the study population was made up of farmers and rural residents, male rural residents have similar noise exposures as farmers, hearing loss in agricultural communities is part of a larger problem, i.e., hearing loss among men in rural communities.

Few of the agricultural exposure variables in the current study were statistically significantly associated with any of the three PTA hearing loss outcomes, and those that were varied by PTA hearing loss outcome (i.e., frequency) and type of metric used (i.e., continuous vs. categorical). The one agricultural exposure variable exclusive to farmers with a consistent significant association with hearing loss was years worked on a farm, and this was only observed for the more precise multivariable linear regression analysis. Other agricultural exposures specific to farmers, such as operating tractors and farm equipment were not associated with hearing loss whereas those less specific to agriculture operations were associated with hearing loss (e.g., rural residents, such as hunting/target shooting, pneumatic/electric tool use, ATV/motorcycle use and noisy non-farm jobs).

Overall, years engaging in common agricultural tasks may not be the best metric for determining the extent of hearing loss in agricultural populations. The actual noise exposures that these variables represent are likely to vary greatly from person to person and year to year. Consequently, exposure expressed in use of years engaging in common agricultural tasks is probably a poor representation of actual lifetime noise exposures. Future studies to determine the actual noise exposures associated with agricultural tasks may contribute substantially to the understanding and prevention of hearing loss among agricultural workers.

Table 2.1. Characteristics of study population for all participants and stratified by farming status

Characteristics	All Subjects Mean (SD) or % (N=1568)	Farming Status		
		Non-Farmer Mean (SD) or % (N=608)	Farmer Mean (SD) or % (N=960)	P-Value
Average Age of Subjects	55.1 (16.2)	52.8 (16.4)	56.5 (15.8)	<0.01
Years at noisy job other than farming	4.8 (9.9)	4.1 (8.8)	5.3 (10.4)	0.02
Years hunting or target shooting	8.9 (15.9)	2.9 (8.7)	12.7 (18.1)	<0.01
Years ridden ATV or motorcycle	5.3 (9.4)	2.4 (6.4)	7.1 (10.4)	<0.01
Years operated a chain saw	6.5 (11.5)	1.4 (5.3)	9.6 (13.2)	<0.01
Years operated pneumatic or electric tools	10.7 (15.5)	3.5 (9.0)	15.2 (16.9)	<0.01
Years lived on a farm	27.2 (24.1)	14.7 (20.2)	35.1 (22.9)	<0.01
Years worked on a farm	14.3 (18.5)	---	23.4 (18.6)	<0.01
Years operated tractor without a cab	12.5 (16.1)	1.8 (5.2)	19.3 (16.9)	<0.01
Years operated tractor/combine with a cab	5.8 (9.9)	0.8 (3.2)	9.0 (11.2)	<0.01
Years used grain dryer, feed mill, hay chopper	7.1 (11.7)	0.7 (3.7)	11.1 (13.1)	<0.01
Years worked with livestock	7.8 (13.0)	1.7 (5.8)	11.7 (14.7)	<0.01
Years worked in hog confinement building	4.1 (9.0)	0.6 (2.9)	6.3 (10.7)	<0.01
Gender				
Female	56.2	80.8	40.7	<0.01
Male	43.8	19.2	59.3	
Marital Status				
Not Married	22.5	22.7	22.4	0.89
Married	77.5	77.3	77.6	
Education				
Some High School	8.4	6.1	9.8	<0.01
High School Graduate	44.6	40.9	47.0	
Some College	29.0	30.6	28.0	
College Graduate	18.0	22.4	15.2	
Income				
< $40,000	38.6	41.1	37.0	<0.01
$40K to $79K	36.9	37.2	36.8	
≥ $80K	15.6	11.0	18.4	
Don't Know/Refused	8.9	10.7	7.8	
Total Household Assets				
< $80K	22.4	26.0	20.1	<0.01
$80K to $299K	36.9	39.0	35.5	
≥ $400K	25.4	15.4	31.8	
Don't Know/Refused	15.3	19.6	12.6	
Military Experience				
No	87.6	94.2	83.3	<0.01
Yes	12.4	5.8	16.7	
Drinks Per Day				
Do Not Drink	37.1	38.3	36.3	<0.01
< One Drink	54.3	56.3	53.1	
One Drink or More	8.6	5.4	10.6	
Years Smoked				
Never Smoked	62.4	65.1	60.6	0.20
<14 years	12.7	11.7	13.3	
≥ 14 years	24.9	23.2	26.1	

Table 2.2. Measures of hearing loss (mean and prevalence) using NIOSH PTA, low frequency PTA, and high frequency PTA calculations

Age Group	**NIOSH PTA** (N=1567)		**Low Frequency PTA** (N=1568)		**High Frequency PTA** (N=1566)	
	Mean (SD)	**Prevalence**	**Mean (SD)**	**Prevalence**	**Mean (SD)**	**Prevalence**
< 50	14.0 (12.9)	15.1 (N=94)	11.2 (10.5)	7.9 (N=49)	21.5 (16.9)	26.3 (N=164)
50 to 59	20.3 (13.4)	26.2 (N=75)	15.7 (10.8)	15.0 (N=43)	31.4 (18.5)	51.4 (N=147)
60 to 69	31.1 (18.3)	51.0 (N=149)	24.8 (15.5)	37.9 (N=111)	43.3 (22.2)	74.7 (N=218)
≥ 70	41.1 (17.6)	78.6 (N=287)	33.6 (16.1)	63.8 (N=233)	55.9 (19.0)	91.8 (N=335)
All ages	24.6 (18.8)	38.6 (N=605)	19.8 (15.9)	27.8 (N=436)	35.4 (23.3)	55.2 (N=864)

* Prevalence for hearing loss > 25dB

Table 2.3. Hearing loss prevalence stratified by age group, farming status and gender using NIOSH, low frequency and high frequency PTA calculations

Age Group	NIOSH PTA				Low Frequency PTA				High Frequency PTA			
	Farmers (N=959)		Non-Farmers (N=608)		Farmers (N=960)		Non-Farmers (N=608)		Farmers (N=958)		Non-Farmers (N=608)	
	Male (N=568)	Female (N=391)	Male (N=117)	Female (N=491)	Male (N=569)	Female (N=391)	Male (N=117)	Female (N=491)	Male (N=567)	Female N=391)	Male (N=117)	Female (N=491)
< 50	28.2 (N=209)	5.2 (N=136)	28.6 (N=63)	4.6 (N=216)	12.4 (N=209)	3.7 (N=136)	14.3 (N=63)	4.2 (N=216)	47.1 (N=208)	12.5 (N=136)	46.0 (N=63)	9.3 (N=216)
50 to 59	51.9 (N=104)	12.0 (N=75)	33.3 (N=15)	7.6 (N=92)	24.0 (N=104)	10.7 (N=75)	26.7 (N=15)	6.5 (N=92)	76.9 (N=104)	38.7 (N=75)	86.7 (N=15)	27.2 (N=92)
60 to 69	76.2 (N=109)	30.8 (N=78)	73.7 (N=19)	32.6 (N=86)	60.0 (N=110)	20.5 (N=78)	42.1 (N=19)	24.4 (N=86)	92.7 (N=109)	59.0 (N=78)	94.7 (N=19)	61.6 (N=86)
≥ 70	92.5 (N=146)	64.7 (N=102)	85.0 (N=20)	71.1 (N=97)	**77.4 (N=146)**	54.9 (N=102)	**55.0 (N=20)**	54.6 (N=97)	100.0 (N=146)	83.3 (N=102)	100.0 (N=20)	86.6 (N=97)
All ages	**58.3 (N=568)**	27.1 (N=391)	**46.2 (N=117)**	23.2 (N=491)	**40.4 (N=569)**	21.7 (N=391)	**27.4 (N=117)**	18.1 (N=491)	75.0 (N=567)	**45.3 (N=391)**	68.4 (N=117)	**37.1 (N=491)**

* Prevalence for hearing loss > 25dB

* Chi Square Test to examine if the prevalence of hearing loss between the farmer and non-famer groups are equal, values in bold have a statistically significant p-value <0.05.

Table 2.4. Mean (S.D.) decibels of hearing loss stratified by age group, farming status and gender using NIOSH, low frequency and high frequency PTA calculations

Age Group	NIOSH PTA				Low Frequency PTA				High Frequency PTA			
	Farmer (N=959)		Non-Farmer (N=608)		Farmer (N=960)		Non-Farmer (608)		Farmer (N=958)		Non-Farmer (N=608)	
	Male (N=568)	**Female** (N=391)	**Male** (N=117)	**Female** (N=491)	**Male** (N=569)	**Female** (N=391)	**Male** (N=117)	**Female** (N=491)	**Male** (N=567)	**Female** (N=391)	**Male** (N=117)	**Female** (N=491)
< 50	19.4 (13.9)	10.1 (10.0)	19.9 (14.0)	9.6 (10.3)	14.1 (11.5)	8.7 (8.3)	14.5 (11.5)	8.9 (9.6)	29.4 (19.1)	16.1 (11.9)	30.7 (18.9)	14.5 (11.5)
50 to 59	28.0 (15.1)	16.1 (9.3)	26.5 (12.7)	13.9 (9.2)	19.7 (12.8)	13.6 (8.1)	19.2 (11.0)	12.3 (8.5)	44.3 (19.9)	**24.8 (11.4)**	41.4 (16.0)	**20.7 (10.7)**
60 to 69	41.1 (17.0)	21.6 (13.0	39.3 (18.3)	25.1 (17.0)	30.8 (14.8)	18.9 (12.3)	28.8 (16.2)	21.6 (16.0)	57.2 (20.2)	30.1 (14.4)	58.8 (20.1)	34.3 (18.7)
≥ 70	48.4 (15.1)	35.4 (18.4)	45.7 (20.1)	35.1 (15.3)	37.3 (14.7)	30.7 (17.5)	36.5 (19.2)	30.5 (14.8)	65.9 (14.9)	47.4 (19.6)	63.2 (18.8)	48.3 (16.1)
All ages	**32.6 (19.3)**	20.1 (16.5)	**28.3 (18.8)**	18.2 (16.1)	24.3 (16.4)	17.4 (14.9)	21.2 (16.2)	16.0 (14.6)	46.9 (23.8)	**28.7 (19.1)**	42.2 (23.1)	**25.8 (19.1)**

*Students T-Test to examine if the mean decibels of hearing loss between the farmer and non-famer groups are equal, values in bold have a statistically significant p-value <0.05.

Table 2.5. Unadjusted associations between potential confounders and hearing loss > 25dB (logistic regression analysis)

	NIOSH PTA		Low Frequency PTA		High Frequency PTA	
Variable	**OR (95% CI)**	**P-Value**	**OR (95% CI)**	**P-Value**	**OR (95% CI)**	**P-Value**
Age	1.09 (1.08-1.10)	<0.01	1.10 (1.09-1.11)	<0.01	1.10 (1.09-1.11)	<0.01
Gender						
Female	1.00	<0.01	1.00	<0.01	1.00	<0.01
Male	3.86 (3.12-4.79)		2.51 (2.01-3.15)		4.11 (3.31-5.11)	
Marital Status						
Not Married	1.00	0.11	1.00	0.02	1.00	0.06
Married	0.82 (0.65-1.05)		0.74 (0.58-0.96)		0.80 (0.63-1.01)	
Education						
Some High School	1.00	<0.01	1.00	<0.01	1.00	<0.01
High School Graduate	0.48 (0.33-0.71)		0.47 (0.32-0.68)		0.51 (0.33-0.78)	
Some College	0.26 (0.17-0.39)		0.26 (0.17-0.39)		0.30 (0.19-0.47)	
College Graduate	0.17 (0.11-0.27)		0.17 (0.11-0.28)		0.24 (0.15-0.38)	
Income						
< $40,000	1.00	<0.01	1.00	<0.01	1.00	<0.01
$40K to $79K	0.46 (0.36-0.58)		0.39 (0.30-0.50)		0.44 (0.34-0.55)	
≥ $80K	0.64 (0.47-0.87)		0.46 (0.32-0.64)		0.59 (0.43-0.79)	
Don't Know/Refused	0.71 (0.49-1.03)		0.75 (0.51-1.12)		0.51 (0.35-0.75)	
Total Household Assets						
< $80K	1.00	<0.01	1.00	<0.01	1.00	<0.01
$80K to $299K	0.83 (0.63-1.10)		0.66 (0.49-0.89)		0.81 (0.62-1.05)	
≥ $400K	1.38 (1.03-1.85)		1.12 (0.82-1.52)		1.35 (1.01-1.81)	
Don't Know/Refused	0.85 (0.61-1.20)		0.90 (0.63-1.29)		0.81 (0.58-1.12)	
Military Experience						
No	1.00	<0.01	1.00	<0.01	1.00	<0.01
Yes	4.52 (3.26-6.27)		2.87 (2.12-3.91)		5.99 (3.93-9.11)	
Drinks Per Day						
Do Not Drink	1.00	<0.01	1.00	<0.01	1.00	<0.01
< One Drink	0.51 (0.41-0.63)		0.44 (0.35-0.56)		0.48 (0.39-0.60)	
One Drink or More	0.88 (0.60-1.28)		0.57 (0.38-0.87)		0.95 (0.64-1.40)	
Years Smoked						
Never Smoked	1.00	<0.01	1.00	<0.01	1.00	<0.01
< 14 years	1.09 (0.79-1.49)		1.24 (0.88-1.74)		1.38 (1.01-1.87)	
≥ 14 years	1.97 (1.55-2.50)		1.73 (1.34-2.22)		2.04 (1.60-2.61)	

Table 2.6. Unadjusted associations between potential confounders and decibels of hearing loss (linear regression analysis)

	NIOSH PTA		Low Frequency PTA		High Frequency PTA	
Variable	**β**	**P-Value**	**β**	**P-Value**	**β**	**P-Value**
Age	0.69	<0.01	0.57	<0.01	0.88	<0.01
Gender						
Female	0.0	<0.01	0.0	<0.01	0.0	<0.01
Male	12.82		7.15		18.98	
Marital Status						
Not Married	0.0	0.11	0.0	<0.01	0.0	0.34
Married	-1.84		-2.50		-1.34	
Education						
Some High School	0.0	<0.01	0.0	<0.01	0.0	<0.01
High School Graduate	-9.09		-7.63		-10.77	
Some College	-15.38		-12.36		-18.61	
College Graduate	-18.19		-14.64		-21.97	
Income						
< $40,000	0.0	<0.01	0.0	<0.01	0.0	<0.01
$40K to $79K	-8.01		-7.25		-9.29	
≥ $80K	-4.77		-5.02		-5.28	
Don't Know or Refused	-2.84		-1.48		-4.93	
Total Household Assets						
< $80K	0.0	<0.01	0.0	<0.01	0.0	<0.01
$80K to $299K	-2.63		-3.00		-2.01	
≥ $400K	2.76		1.28		4.61	
Don't Know or Refused	-0.92		-0.03		-1.00	
Military Experience						
No	0.0	<0.01	0.0	<0.01	0.0	<0.01
Yes	14.94		9.57		21.92	
Drinks Per Day						
Do Not Drink	0.0	<0.01	0.0	<0.01	0.0	<0.01
< One Drink	-7.97		-7.52		-8.71	
One Drink or More	-2.74		5.17		0.09	
Years Smoked						
Never Smoked	0.0	<0.01	0.0	<0.01	0.0	<0.01
< 14 years	2.04		1.76		2.61	
≥ 14 years	6.38		3.80		9.58	

Table 2.7. Covariates included in the standard base model for multivariable logistic regression analysis

Variable	NIOSH PTA		Low Frequency PTA		High Frequency PTA	
	OR (95% CI)	P-Value	OR (95% CI)	P-Value	OR (95% CI)	P-Value
Age	1.11 (1.10-1.12)	<0.01	1.10 (1.09-1.12)	<0.01	1.11 (1.11-1.14)	<0.01
Gender						
Female	1.00	<0.01	1.00	<0.01	1.00	<0.01
Male	7.66 (5.66-10.41)		3.629 (2.70-4.86)		10.4 (7.55-14.42)	
Education						
Some High School	1.00	<0.01	1.00	0.04	1.00	0.30
High School Graduate	0.72 (0.42-1.24)		0.89 (0.54-1.47)		0.65 (0.34-1.24)	
Some College	0.62 (0.35-1.11)		0.81 (0.47-1.40)		0.67 (0.35-1.28)	
College Graduate	0.36 (0.19-0.67)		0.50 (0.27-0.90)		0.53 (0.26-1.05)	
Total Household Assets						
< $80K	1.00	0.30	1.00	0.02	1.00	0.01
$80K and $299K	0.70 (0.48-1.02)		0.55 (0.37-0.80)		0.55 (0.38-0.81)	
> $400K	0.81 (0.55-1.20)		0.69 (0.47-1.02)		0.55 (0.37-0.84)	
Don’t Know/Refused	0.74 (0.46-1.17)		0.70 (0.44-1.12)		0.57 (0.36-0.93)	

Table 2.8. Covariates included in the standard base model for multivariable linear regression analysis

Variable	NIOSH PTA		Low Frequency PTA		High Frequency PTA	
	β	P-Value	β	P-Value	β	P-Value
Age	0.65	<0.01	0.53	<0.01	0.85	<0.01
Gender						
Female	0.0	<0.01	0.0	<0.01	0.0	<0.01
Male	12.71		7.38		18.58	
Education						
Some High School	0.0	<0.01	0.0	<0.01	0.0	<0.01
High School Graduate	-3.21		-2.74		-3.38	
Some College	-4.46		-3.59		-4.64	
College Graduate	-6.58		-5.34		-7.10	
Marital Status						
Not Married	0.0	0.27	0.0	0.10	0.0	0.48
Married	-0.92		-1.27		-0.60	
Drinks Per Day						
Do Not Drink	0.0	0.19	0.0	0.01	0.0	0.57
< One Drink	-1.29		-1.90		-0.50	
One Drink or More	-1.40		-2.68		0.97	
Total Household Assets						
< $80K	0.0	0.08	0.0	0.03	0.0	0.12
$80K and $299K	-2.32		-2.30		-2.29	
> $400K	-1.56		-1.43		-1.94	
Don’t Know/Refused	-0.49		-0.18		-0.12	

Table 2.9. Individual associations (logistic regression analysis) of each agricultural exposure variable and hearing loss > 25dB adjusted for base model covariates (age, gender, education level and household assets)

Exposure Variable	NIOSH PTA		Low Frequency PTA		High Frequency PTA	
	Odds Ratio (95% CI)	P-Value	Odds Ratio (95% CI)	P-Value	Odds Ratio (95% CI)	P-Value
Farmer	0.97 (0.72-1.31)	0.84	1.06 (0.77-1.46)	0.71	1.06 (0.78-1.42)	0.72
Farmer by age	1.00 (0.73-1.38)	0.53	0.99 (0.69-1.43)	0.48	1.05 (0.78-1.42)	0.63
Farmer by male gender	1.11(0.66-1.86)	0.52	1.35 (0.78-2.34)	0.30	0.94 (0.55-1.63)	0.58
Years at noisy job other than farming	1.01 (0.99-1.02)	0.48	1.01 (0.99-1.02)	0.47	1.01 (0.99-1.02)	0.34
Years noisy job by age	1.01 (0.99-1.02)	0.24	1.01 (0.99-1.03)	0.49	1.01 (0.99-1.02)	0.80
Years noisy job by male gender	1.02 (1.00-1.04)	<0.01	1.01 (0.99-1.02)	0.70	1.02 (0.99-1.04)	0.25
Mean years hunting or target shooting	1.01 (1.00-1.02)	0.28	1.00 (0.99-1.01)	0.50	1.02 (1.00-1.03)	0.02
Years ridden ATV or motorcycle	1.02 (1.00-1.03)	0.03	1.01 (1.00-1.03)	0.10	1.02 (1.00-1.03)	0.04
Years operated a chain saw	1.01 (0.99-1.02)	0.23	1.01 (1.00-1.03)	0.07	1.02 (1.00-1.03)	0.10
Years operated pneumatic or electric tools	1.01 (1.00-1.03)	0.04	1.01 (1.00-1.02)	0.04	1.01 (0.99-1.02)	0.29
Years lived on a farm	1.00 (1.00-1.01)	0.37	1.01 (1.00-1.01)	0.13	1.00 (0.99-1.01)	0.69
Years worked on a farm	1.00 (1.00-1.01)	0.42	1.01 (1.00-1.02)	0.05	1.01 (1.00-1.02)	0.21
Years worked on farm by age	1.00 (0.99-1.01)	0.69	1.01 (1.00-1.02)	0.64	1.01 (1.00-1.02)	0.53
Years worked on farm by male gender	1.01 (0.99-1.01)	0.60	1.01 (1.00-1.02)	0.10	1.00 (0.99-1.02)	0.16
Years operated tractor without a cab	1.01 (1.00-1.02)	0.12	1.01 (1.00-1.02)	0.02	1.00 (0.99-1.01)	0.73
Years operated tractor/combine with a cab	1.00 (0.99-1.02)	0.86	1.01 (1.00-1.03)	0.21	1.01 (0.99-1.02)	0.38
Years around grain dryer, feed mill, hay chopper	1.01 (0.99-1.02)	0.26	1.01 (1.00-1.02)	0.14	1.01 (0.99-1.02)	0.28
Years worked with livestock	1.00 (0.99-1.02)	0.44	1.02 (1.01-1.03)	<0.01	1.01 (0.99-1.02)	0.35
Years worked in hog confinement building	1.01 (0.99-1.02)	0.42	1.02 (1.00-1.03)	0.04	1.01 (0.99-1.02)	0.54

Table 2.10. Final multivariable logistic regression model of agricultural exposure variables and hearing loss adjusted for base model covariates (age, sex, education level and household assets)

Exposure Variable	NIOSH PTA		Low Frequency PTA		High Frequency PTA	
	Odds Ratio (95% CI)	P-Value	Odds Ratio (95% CI)	P-Value	Odds Ratio (95% CI)	P-Value
Years at noisy job other than farming						
Females[1]	0.97 (0.95-1.00)	0.06	---	---	---	---
Males[1]	1.02 (1.00-1.04	<0.01	---	---	---	---
Mean years hunting or target shooting	---	---	---	---	1.02 (1.00-1.03)	0.03
Years ridden ATV or motorcycle	1.02 (1.00-1.02)	0.06	---	---	1.02 (1.00-1.03)	0.06
Years operated pneumatic or electric tools	1.01 (1.00-1.02)	0.08	1.01 (1.00-1.02)	0.08	---	---
Years worked with livestock	---	---	1.02 (1.00-1.03)	<0.01	---	---

[1] Years at noisy job other than farming and gender interaction term for NIOSH (p-value <.01) PTA calculation

Table 2.11. Individual associations (linear regression analysis) of each agricultural exposure variable and decibels of hearing loss adjusted for base model covariates (age, sex, education level, marital status, drinks per day and household assets)

	NIOSH PTA		Low Frequency PTA		High Frequency PTA	
Exposure Variable	**β**	**P-Value**	**β**	**P-Value**	**β**	**P-Value**
Farmer	-0.41	0.60	-0.63	0.37	-0.38	0.67
Farmer by age	---	0.02	---	0.10	---	0.04
Farmer by male gender	---	0.35	---	0.38	---	0.76
Years at noisy job other than farming	0.05	0.20	0.03	0.31	0.06	0.17
Years noisy job by age	0.004	<0.01	0.004	0.12	0.004	0.17
Years noisy job by male gender	0.18	0.02	0.14	0.05	0.18	0.05
Mean years hunting or target shooting	0.06	<0.01	0.02	<0.01	0.11	<0.01
Years ridden ATV or motorcycle	0.08	<0.01	0.07	<0.01	-0.15	<0.01
Years operated a chain saw	0.10	<0.01	0.06	<0.01	0.14	<0.01
Years operated pneumatic or electric tools	0.10	<0.01	0.08	<0.01	0.10	<0.01
Years lived on a farm	0.03	0.08	0.02	0.25	0.02	0.22
Years worked on a farm	0.06	0.01	0.02	0.13	0.06	0.03
Years worked on farm by age	0.004	<0.01	0.003	0.03	0.004	<0.01
Years worked on farm by male gender	0.10	0.02	0.08	0.06	0.09	0.06
Years operated tractor without a cab	0.06	0.01	0.04	0.07	0.23	<0.01
Years operated tractor/combine with a cab	0.06	0.14	0.03	0.38	0.06	0.18
Years around grain dryer, feed mill, hay chopper	0.07	0.05	0.04	0.20	0.06	0.15
Years worked with livestock	0.08	<0.01	0.06	0.02	0.07	0.03
Years worked in hog confinement building	0.09	0.03	0.07	0.05	0.07	0.13

Table 2.12. Final multivariable linear regression model of agricultural exposure variables and hearing loss adjusted for base model covariates (age, sex, education level, marital status, drinks per day and household assets)

Exposure Variable	NIOSH PTA		Low Frequency PTA		High Frequency PTA	
	β	P-Value	β	P-Value	β	P-Value
Years Noisy Job by female gender	-0.08	0.24	-0.07	0.27	---	---
Years Noisy Job by male gender	0.20	0.01	0.16	0.03	---	---
Year hunting or target shooting	---	---	---	---	0.10	<0.01
Years ridden ATV or motorcycle	0.08	0.04	0.07	0.07	0.10	0.04
Years operated pneumatic or electric tools	0.08	0.01	0.06	0.03	---	---
Years worked on a farm	-0.34	<0.01	-0.28	<0.01	-0.30	0.01
Years worked on a farm by age	0.005	<0.01	0.004	<0.01	0.005	<0.01
Years worked on a farm by male gender	0.09	0.03	0.07	0.09	---	---
Years worked in hog confinement building	0.08	0.07	0.08	0.06	---	---

Table 2.13. Example effect size for significant agricultural exposures that interact by age and/or gender (linear regression analysis)

	NIOSH PTA	Low Frequency PTA	High Frequency PTA
Exposure Variable	**Effect Size**	**Effect Size**	**Effect Size**
Years worked on a farm			
Females 25 years of age	-0.22	---	---
Females 50 years of age	-0.11	---	---
Females 75 years of age	0.01	---	---
Males 25 years of age	-0.13	---	---
Males 50 years of age	-0.01	---	---
Males 75 years of age	0.11	---	---
Years worked on a farm			
25 years of age	---	-0.15	-0.17
50 years of age	---	-0.06	-0.04
75 years of age	---	0.03	0.09

CHAPTER III
TASK-BASED NOISE EXPOSURES FOR FARMERS AND FARM WORKERS INVOLVED IN GRAIN PRODUCTION

Abstract

Few studies have been done to determine the noise exposures associated with tasks routinely conducted by farmers and farm workers on agricultural operations. This study was conducted to address that research gap by measuring the noise exposures for tasks associated with grain production and assessing the variability in those measurements. A specific goal was to identify specific tasks which could be targeted for intervention strategies as a means toward reducing the total noise exposures of farmers and farm workers. Through the use of personal noise dosimetry and direct observation, over 30,000 one-minute noise exposure measurements and corresponding task information was collected on 18 farms involved in grain production and compiled into a task-based noise exposure database.. Initially noise exposure measurements for 41 tasks were calculated, which were then collapsed into 23 broad task categories and recalculated. Noise exposures were then calculated for these 23 categories under specific exposure scenarios. Finally the noise exposures of specific agricultural equipment use were calculated. The mean noise exposures for the final 23 task categories ranged from 78.6 dBA to 99.0 dBA, with each having a large standard deviation and maximum noise exposure level. Most of the variability in the task-based noise exposures was attributable to within-farm variations in the noise measurements. This indicated that the manner in which each farmer or farm worker performed tasks accounted for most of the variability. Multiple comparisons of the mean task-based noise exposures revealed that most were not statistically different. While task-based noise exposures can be calculated for grain production tasks, the substantial variability in exposures attributable to worker practice, the lack of a significant difference between mean noise exposures for the tasks, and the presence of intense noise exposures for nearly every task, indicated that identifying

specific tasks to target for intervention strategies will reduce lifetime noise exposures, but may not completely eliminate exposure to hazardous noise levels on farms.

Introduction

Task-based noise exposure analysis has the potential to be widely used in the agricultural industry. While all-day monitoring to determine time-weighted average (TWA) exposures is useful, the changing work environment, variability in tasks and equipment, and varying workday hours, limit the ability of the 8-hr TWA to accurately characterize the exposures and associated health risks for agricultural workers. For most family farms, access to industrial hygiene services is also limited and it is unlikely family farms would pay to have a complete noise survey conducted to determine personal exposures. An alternative noise exposure analysis methodology, developed from a comprehensive task-based exposure database, is thus an attractive option for estimating the personal noise exposures of workers with irregular tasks, such as those in agriculture.

Task-based exposure assessments have been conducted for numerous hazards, in addition to noise exposure.[59-62] These assessments allow for the characterization of full-day exposure, while also permitting assessment of short-term hazards which might not be identified through a standard full-day exposure sampling protocol.[58] Taking measurements at the task level has been shown to be a useful method for determining hazardous exposures in complex dynamic environments.[63] Furthermore, epidemiologic studies benefit from task-based exposure assessments because they support the validity of cumulative exposure histories by limiting misclassifications which can occur when reconstructing past exposures through employment records or work histories.[66]

Assessment data on task-based noise exposures for agricultural operations are limited.[35,51,68-71] The few studies which calculated task-based noise exposures all used a variety of measurement techniques. Each study also presented noise exposures for a varying number of tasks, with some reporting a range of exposures while others calculated an average exposure. In all cases, the exposure levels for several tasks exceeded 85dBA, indicating a risk for developing noise-induced hearing loss. Most important the noise exposures measured for the agricultural tasks in these studies were all highly variable.

In recent years task-based assessments have been used in noise exposure studies of workers in industries other than agriculture. A number of these studies focused on the effectiveness of task-based noise assessments for estimating daily noise exposures.[64,72,74,96-99] These studies found that the accuracy of the exposure assessments depended on how well tasks were defined and the ability of statistical models to account for the variability in noise exposures as they applied to each worker. They also indicated that the beginning and ending times, and activities involved in each task needed to be clearly defined. Task-based assessments may still improve overall noise exposure estimates for epidemiologic studies even if they fail to accurately predict individual noise exposures, because they may account for some of the variability in full day noise exposure measurements.

Before task-based analyses can be conducted, a comprehensive database of task-based noise exposures must be created. Several studies have shown that task-based exposure databases show great promise for exposure surveillance, identification of hazards, and implementation of control strategies.[65,100,101] Furthermore, the National Institute for Occupational Safety and Health (NIOSH), the American Council of Governmental Industrial Hygienists (ACGIH), the American Industrial Hygiene Association (AIHA), the Environmental Protection Agency, and the Departments of Defense and Energy have all recognized the importance of and support the development of task-based exposure databases.[102-104]

The objectives of the current study was to calculate the noise exposures for farmers and farm workers at the task level by developing a large database of noise exposures and corresponding task information for farmers involved in grain production.

A field study was conducted to: 1) measure and calculate the noise exposures for specific tasks conducted on grain production operations and; 2) characterize the variability in the task-based noise exposure measurements. The results of this study will provide useful information on the noise exposures of agricultural tasks by identifying tasks with potentially hazardous noise levels that should be targeted for control.

Material and Methods

Study Population

Data for this study were collected from farmers and farm workers located in two adjacent counties in the southern Red River Valley region of Minnesota and North Dakota. According to the 2007 Census of Agriculture, the characteristics of farms in the two counties are very similar.[105,106] Cash crops accounted for 98% and 88% of all farm products sold, with most acres in production of soybeans, wheat, corn and sugar beets. For the county in North Dakota, there are 943 farms with a mean size of 961 acres. The county in Minnesota has 428 farms with a mean size of 993 acres. The majority of principal operators in both counties are male (97% & 93%) with an average age of 54 years.

Farms where production was primarily grain crops were eligible for participation. The recruitment target for this study was 20 farms from either county. Eligible farms in the North Dakota county were identified from a list of grain producers provided by the North Dakota State University County Extension Office, and a list of eligible farms for the county in Minnesota was supplied by the County Farm Services Agency office. Thirty farms from each county were randomly selected for recruitment. A recruitment letter was sent to all farms with information about the study, notification about an upcoming recruitment phone call and a “Do Not Contact” return postcard which allowed the recipient to opt out prior to follow-up phone call.

Because of poor response rates, a secondary non-random recruitment process was conducted. The principal investigator visited three farms where a prior personal relationship existed to discuss the project and inquire about participation. From there a networking “snowball” sampling method was carried out. The principal investigator talked to friends and neighbors of farmers at these previously identified farms, utilized county-based contacts to identify additional farms, and attended local events to speak to farmers about participation. Eligible farms where the principal operator indicated a willingness to participate were then sent the standard recruitment letter and recruitment was completed with a follow-up phone call.

Data Collection

Task and Covariate Data

An observational form (Appendix A) in conjunction with direct observation of participants was used to collect task and covariate data corresponding to noise measurements. The observational form allowed the field researcher to identify within an accuracy of five minutes, noise sources, when participants initiated or completed a particular task, moved from one work area to another, and used hearing protection. Additional covariate information was collected using a pre-monitoring questionnaire consisting of four sections: 1) demographic information; 2) activity survey; 3) importance scale survey; and 4) farm information (Appendix B).

Noise Exposure Data

Noise exposure measurements were collected using Quest NoisePro DL® noise dosimeters with the National Institute for Occupational Safety and Health (NIOSH) criteria (slow response, an A-weighting and three decibel exchange rate).[9] The dosimeters were programmed to calculate the average noise exposure every minute.

Dosimeter thresholds were disabled allowing measurement of noise exposures for tasks where noise levels were consistently less than 80 dB.

Noise exposure measurements were collected at each farm three times during the growing season: 1) spring, 2) summer and 3) fall. This ensured data collection occurred during a time of the year when a variety of grain production tasks were taking place. One to two individuals were monitored at a farm during sampling. Farms were randomly scheduled for noise monitoring during each round of data collection. Due to complex work schedules and weather delays, little advanced notice was given prior to noise monitoring. The evening before a suitable sampling day, farmers were randomly contacted until a farm was available for sampling. Two criteria were used to determine if a farm was available: 1) whether they would be putting in a full work day; and 2) whether the primary work tasks that day would be related to grain production. These criteria were used to increase the number of grain production tasks monitored.

On the day of noise exposure monitoring, the investigator met with the principal operator and employees or family members working on the farm and chose one or two participants for monitoring. Two participants were chosen if they would be working in close proximity to each other. One was designated the primary and observed continuously and the other the secondary and observed periodically during sampling. The participants were also given the pre-monitoring survey to complete.

To conduct the noise exposure monitoring, participants were fitted with a calibrated noise dosimeter with the microphone situated in their hearing zone. Once the dosimeters were activated and sampling began, the participants resumed their normal work routine. The investigator then recorded task and additional covariate data on the observational form during direct observation of participants. The noise dosimeters were post-calibrated and the data from the dosimeters downloaded to a computer using the Questsuite® software at the conclusion of the sampling day.

Data Analysis

Data from the dosimeters, task and covariate observational form, and pre-monitoring questionnaire were assembled into a master database. The one-minute noise exposure measurements and corresponding timestamps were exported into an Excel® spreadsheet and labeled with the farm identifier (FID), subject identifier (SID) and sample date. Demographic data from the pre-monitoring questionnaire was manually entered into an Epi Info™ database. Task and covariate data from the observational form was manually entered into an Access® dataset with corresponding timestamps, FIDs, SID and sample dates.

Task data from the observational form information needed to be standardized into specific task categories because it was recorded as a written description. This process was completed during the manual entry of the task and covariate data, by assigning task descriptions to a specific task category. Subsequent activity descriptions were then assigned to an existing category or a new category. The final database contained all one-minute noise exposure measurements linked with the corresponding task, covariate and demographic data. To ensure that the stop time for one task was not the same as the succeeding start time for the next task, the stop times for all tasks were pushed back one minute. All data analyses were performed with SAS statistical software package [version 9.2].

Task-based noise exposures (L_{task}) were determined by taking the one-minute mean noise exposures, corresponding to a specific task with the same FID, SID and date, and calculating the mean noise exposures using Equation 3.1.[37] This procedure pooled all the one-minute noise exposure values and calculated a single task-based noise exposure for a specific individual, at a specific farm, on a specific day.

$$L_{task} = q \log 10 \left[\left(\frac{1}{T} \right) * \sum_{i=1}^{N} \left(t_i * 10^{\left(\frac{L_i}{q} \right)} \right) \right] \qquad \text{(Equation 3.1)}$$

Where: L_i = one-minute noise exposure values

t_i = duration of the L_i exposure

T = duration of the total sample time for a specific task

q = exchange rate / log 2

Demographic characteristics of the farms and farm workers were summarized using the Proc Means and Proc Freq procedures. Using the Proc Mixed procedure, an unconditional random effects model was used to calculate the within- and between-farm variance components for the mean task-based noise exposures. This type of linear regression model does not contain additional covariates, and is used to determine the variability in the tasks within an individual farm and between all the farms. The Proc Means procedure was used to calculate the mean, standard deviation, and minimum and maximum decibel values of the task-based noise exposures.

To reduce the numbers of categories, tasks involving similar activities were combined (if the mean noise exposures for those tasks were found to be similar) using a Tukey-Kramer multiple comparison of the means with a p-value of <0.05. A multiple comparison of the means was also conducted for these broad task categories and the Tukey-Kramer p-value was evaluated to determine if the mean noise exposures for the tasks were statistically different. Task-based noise exposures under specific exposure conditions such as primary work area, number of noise sources, use of specific equipment, and use of hearing protection were also evaluated using the Proc Mixed and Proc Means procedures to calculate the mean noise exposure and summary statistics for the tasks. Within and between variance components were calculated only for task scenarios that took place on more than one farm.

Results

Demographic Characteristics

Overall, workers from 18 farms participated in the study. Only three farms were recruited as a result of the random recruitment process, the remaining 15 were recruited using the non-random recruitment method. In total, 35 farmers and farm workers enrolled in the study, and these individuals provided 79 daily noise samples. Over the entire course of the study 30,580 minutes of noise exposure data were collected, corresponding to noise exposures for 588 individual task events. Initially, 41 specific task categories were created. Appendix C contains a list of the task descriptions assigned to each task category. These 41 tasks were further collapsed into 23 broad task categories based on similarity of activities and equipment used, and insignificant differences between their means. Tasks involving similar activities with a Tukey-Kramer p-value <0.05 were pooled into single categories. Appendix D contains a list of tasks not pooled and pooled into combined task categories.

Demographic characteristics of the study participants are presented in table 3.1. All but one of the participants was male. On average participants were 42.7 years of age and had been farming for 24.1 years. All participants but one considered farming their primary occupation and during the growing season worked on average 58.1 hours per week. All participants reported working around loud noises. However, nearly 60% of participants reported never using hearing protection when they worked, yet only six participants (19%) reported ever being diagnosed with hearing loss. The average size of participating farms were 2357 acres with 2.8 family members and 2.2 hired employees per farm. Nearly all (15/17) farms grossed over $100,000 per year and over half had farm assets valued over $1,000,000. Remaining farm characteristics are given in table 3.2.

Task-Based Noise Exposures

The mean decibel level and summary statistics for the initial 41 task categories are presented in table 3.3. The mean decibel levels ranged from 74.0 dBA to 99.9 dBA for all tasks. Tasks with noise levels ≥85 dBA were: operating a grain vacuum, driving skid steers (95.0 dBA), operating other equipment (93.8 dBA), unloading and loading grain into grain bins (90.3 dBA), changing tires on implements and vehicles (89.6 dBA), working around grain bins (86.3 dBA), prepping for crop spraying (86.3 dBA), driving grain trucks (86.2 dBA), unloading grain at elevator (86.0 dBA), operating an ATV (85.7 dBA) and prepping equipment (85.0 dBA). The lowest noise levels were associated with tasks that took place indoors or involved limited use of powered equipment such as: picking up parts and supplies at the store (79.4 dBA), in house or office (75.6 dBA), in shop not working (74.0 dBA) and talking to neighbors or employees (79.2 dBA). Miscellaneous work around the farm also had little noise exposure (79.6 dBA), even though this task included a wide variety of activities.

The standard deviation of the task-based mean noise exposures were large, in the context that a three decibel increase or decrease in the noise level is a doubling or halving of the exposure's intensity. Among the 41 tasks, only driving grain trucks (STD=2.4dB), plowing, digging or ditching fields (STD=2.5dB), operating a tractor during other field work (STD=2.3dB) and in shop not working (STD=2.3dB) had standard deviations less than 3dB. Within-farm variability accounted for most of the variability in the task-based noise exposures. The within-farm variance is attributed to the variability in the measurements of noise exposures at a specific farm, whereas the between-farm variance is attributed to the variability in the measurements from one farm to another. For tasks with few or no repeated measurements on a farm, there was little within-farm variability.

The mean decibel levels for the 23 broad task categories and accompanying summary statistics are found in table 3.4. Operating other equipment and driving grain trucks had noise levels ≥85 dBA. Of the eight remaining categories that were created by combining similar tasks, noise exposures ranged between 83.6 and 78.6 dBA. There was a great deal of variability in the mean noise levels of the combined tasks categories, similar to the initial 41 task categories. Only driving grain trucks, plowing/digging/ditching fields, and operating tractor-other field work had standard deviations <3.0 dBA. There was greater variability in the mean noise levels between farms for operating a grain vacuum, operating an ATV, operating a grain cart, plowing/digging/ditching fields and operating a tractor-other field work. Operating other equipment did not have a variance component because this took place only once at one farm. The variability in mean noise levels within a farm was greater for the remaining tasks.

The majority of the mean noise exposures were not statistically different between most of the 23 tasks (Table 3.5). The mean noise exposure for operating a grain vacuum was significantly greater than all other tasks, except for changing tires on vehicles and implements (p-value=0.16). Similarly, the mean noise exposure for miscellaneous work around farm was significantly lower than all other tasks except, driving pickup/personal vehicles (p-value=0.13), in shop working (p-value=0.08), operating grain cart (p-value=0.82), operating tractor other field work (p-value=1.00), plowing/digging/ditching field (p-value=0.23), spraying fields (p-value=0.62) and unaccounted for work time (p-value=0.97). Unloading grain at elevator was significantly higher than all tasks except, changing tires on vehicles and implements (p-value=1.00), driving grain trucks (p-value=0.36), planting grain crops (p-value=0.05), spraying fields (p-value=0.05) and working around grain bins (p-value=0.06). The mean noise exposure for unaccounted for work time was significantly lower than changing tires on vehicles and implements (p-value=0.01), driving grain trucks (p-value<0.01), operating grain vacuum (p-value<0.01), unloading grain at elevator (p-value<0.01) and unloading/loading grain at elevator (p-value=0.02).

Table 3.6 presents the mean noise exposures and accompanying summary statistics for 20 grain production tasks, calculated for specific exposure scenarios. There was no clear trend for the noise exposures by the specific exposure scenarios. For some tasks, noise exposures indoors were louder than outdoors and for others, vice versa. This was also the case for tasks performed with windows and cab doors open or closed. Of the tasks where hearing protection was used, noise exposures were greater, except for operating grain cart and spraying fields. However, among all the one-minute noise exposure measurements, hearing protection was only used 3.8% of the time. Noise exposures generally increased when there were more noise sources, but that was not always the case.

Table 3.7 contains the mean noise exposure for participants only during use of specific agricultural equipment. Just like the task-based noise exposures, the noise exposure from the grain vacuum was the highest (96.2 dBA). Other equipment resulting in mean noise exposures greater than 85 dBA included: grain bin spreaders (93.6 dBA), grain dryers (91.4 dBA), bulldozers (90.7 dBA), grain augers (89.8 dBA), skid steers (89.2 dBA), air compressors (89.1 dBA), fans on grain bins (88.8 dBA), continuous use of power tools (87.5 dBA), grain elevators (86.5 dBA) and grain trucks (85.3 dBA). The mean noise exposures associated with specific equipment were more variable than the task-based noise exposures. Only the exposure from the grain dryer had a standard deviation of less than 3 dBA. For grain vacuums, grain dryers, bulldozers, air compressors, intermittent use of power tools, and continuous use of non-power tools, the variability between the farms was greatest, with the remaining equipment exposures demonstrating higher within-farm variability.

The mean noise exposures for equipment use were even more similar than the task-based exposures (Table 3.8). The noise exposures from the grain auger was significantly higher than the combine (p-value=0.04), pickup/personal vehicles (p-value<0.01), tractor (p-value=0.01) and continuous use of non-powered tools (p-value=0.02). The grain vacuum had a noise exposure significantly greater than the ATV (p-value<0.01), combine (p-value<0.01), grain truck (p-value<0.01), continuous and intermittent use of non-power tools (p-value<0.01 and p-value=0.01), pickup/personal vehicles (p-value<0.01), semis (p-value<0.01) and tractors (p-value<0.01). The mean noise exposure for pickups/personal vehicles was significantly less than the mean exposure for the air compressors (p-value<0.01).

Discussion

The results of this study indicate that even though mean noise exposures can be calculated for agricultural tasks, there are two important characteristics of the data. First there is a high degree of variability in the mean task-based noise exposures. Secondly the means for most tasks contained some high noise exposures (> 85 dB) loud enough to contribute to hearing loss if exposed for sufficient duration[9]. This has important implications health and safety practices. Identifying tasks associated with the highest noise exposures allows for the development of targeted intervention strategies. However, using the results of this study to target interventions for specific tasks will reduce lifetime exposures, but my not completely eliminate exposure to all hazardous noise levels. Therefore, the risk of noise-induced hearing loss may still be present.

This study is one of the few to evaluate task-based noise exposures in agriculture and the only one to focus on grain production. Because of a lack of research in this area, direct comparison of the results of this study with similar published work is limited. In addition, prior studies used a variety of methodologies and equipment, further limiting the ability to compare results directly.

A comprehensive assessment of task and equipment noise exposures was conducted on farms in Australia by Depczynski and Franklin.[68,69] Five of those exposure measurements were directly comparable to tasks and equipment in the current study. Mean noise levels of ATVs, augers, farm trucks, harvesters and tractors with cabs were

86, 93, 85, 83 and 76 dBA respectively. With the exception of tractors, these measurements were similar to the equipment in the current study, as well as for the tasks for which that particular piece of equipment was the primary noise source. The average noise level of tractors measured in the Australia study were similar to the current study only when comparing the average noise levels of older tractors (81.0 dBA) with the added effect of having the radio on in the cab (3 to 5 dBA increase). A key difference between the studies was that Depczynski and Franklin did not measure personal noise exposures, but rather short-term noise levels measured near the farmers' ear. The fact that similar results were achieved in both studies when conducting short-term measurements of equipment and tasks may indicate that an accurate estimate of task-based noise exposure can be made without having to measure the entire task duration.

Another task-based assessment of agricultural noise exposures was conducted by Milz et al. as part of a study on the occupational noise exposures of three farm families in Ohio.[70] The noise exposures for power tools and tractors ranged from 75.2 to 82.3 decibels and 75.8 to 78.3 decibels, respectively, much lower than those measured in the current study. There were six tasks in that study also measured in the current study: harvesting (78.4 - 88.0 dBA); planting (79.5 - 84.2 dBA); plowing (77.4 – 91.3 dBA); spraying fields (64.5 – 74.0 dBA); and maintenance (50.8 – 86.1 dBA).[53] Except for spraying fields, the mean noise exposures measured in the current study were within the range of the exposures measured by Milz. However, the results were standardized to 8-hour time-weighted averages and the range of noise exposures were reported for both studies instead of the mean, making direct comparison of the results difficult.

Two other studies have also measured task-based noise exposures of agricultural operations, but unlike the current study, these focused on exposures specific to children and adolescents.[51,71] Human et al. measured the task-based noise exposures for adolescents in agriculture, for which five tasks or equipment can be directly compared to the current study.[71] Operating a tractor with a cab (86.7 dBA) and working in a shop

(83.2 dBA) had mean noise exposures greater than the exposures measured in the current study, while working around grain bins (85.5 dBA), riding ATV (84.1 dBA) and using power tools (81.9 dBA) had mean noise exposures less than the current study. A study by Lander et al. found comparable results; operating power tools (89.0 dBA), skid steers (88.0 dBA) and tractors with a cab (84.0 dBA) were all within two decibels of the noise exposures measured in the current study.[51]

It is possible the results of this study cannot be generalized to other farms. Farmers living in both counties are primarily male (97% and 93%), as were the farmers that participated in the study (97%). However, the average age of farmers who personally participated in noise monitoring was younger (43 yrs) than the remaining farms in the study area, as well as the nation (55 yrs).[105,106,107] The average sizes of the participating farms were also much larger (2357 acres) than the farm in the study area, as well as nationwide (418 acres) [105,106,107] This is likely the result of the networking sampling method, which recruited mostly full-time farmers from larger operations with a visible presence in the community. It is unknown what effect this may have had on the outcomes of the task-based noise exposure assessment. Larger, full-time farming operations could use more equipment and therefore generate more noise. However the equipment on these farms may also be newer and designed to produce less noise.

The range between the minimum and maximum task-based noise exposures indicate the individual measurements that constitute the mean noise exposure for each task are highly variable. The consequence of the small sample sizes can be seen when comparing the standard deviations for the initial 41 tasks with those of the tasks that have been collapsed into 23 broad categories. There appears to be more variability in the initial 41 task categories than the final 23 categories. By collapsing the tasks from 41 to 23, the sample sizes of many of the tasks increased, thereby decreasing the standard error of the means.

Accurate characterization of the within- and between-farms variance components was limited due to lack of repeated measurements at some farms. For the tasks without repeated measures or small sample sizes, the variability between farms was the highest. This is expected since there would not be a within-farm variability component or the within-farm variability component would be small, due to a lack of sufficient repeated measures. For other tasks that had sufficient repeated measurements at a farm, most of the exposure variability was attributable to factors within each farm.

The multiple comparisons of the means indicated no significant differences in the mean noise exposures between most tasks and equipment. The results of this study indicated a highly variable and complex noise environment with large standard deviations. It is unclear what effect the small sample sizes for some of the tasks and equipment had on the standard error of the noise exposures, and ultimately on the results of the comparisons of the means. Even though most task-based noise exposures are not significantly different and nearly all are between 90 and 80 dBA, the intensity of the noise from one task to another in this range can be two, four our even eight times as powerful by comparison.

While this study provides valuable information on the noise exposure of specific agricultural tasks, there were still some limitations. This was a small study of only 35 farmers on 18 farms; therefore there were few measurements available for calculating the task-based noise exposures under specific exposure scenarios. While this component of the study provided more detailed characterization of noise in the agricultural environment, more accurate assessment of task-based noise exposures under specific scenarios requires more samples than were available. The process of categorizing the tasks into specific exposure scenarios reduced the available number of samples to such a small size that many of the noise exposures were calculated with only a couple of measurements. However, what was gained by calculating the noise exposures under these specific exposure scenarios was the knowledge that more specific task-based characterization of noise exposures could be achieved if the sample size is increased.

The identification, recruitment and enrollment of participating farms was one of the most challenging issues with this study. The networking recruitment method, while not random, was the most effective process for recruiting farms. Obtaining sufficient sample sizes to get an accurate estimate of task-based noise exposures would not have been feasible if only a random recruitment process was used. It is unclear what potential biases, if any, were introduced by not recruiting via random selection, and how this affects the generalizability of the results. Although there were demographic differences between the participating and non-participating farms and farmers in the study area (i.e. younger farmers and larger farms), these differences may not have diminished the generalizability of our results since the process of grain production is similar on both large and small farms. However, the equipment used on larger vs. smaller farms may be different and produce noise of differing intensities. There could also be differences between the work practices of younger and older farmers in terms of how they complete the tasks. Whether these differences increase or decrease the noise exposures is unknown. What is known is that considerably more time and funding than available would have been necessary to implement an entirely random recruitment.

In addition to the small sample size and non-random recruitment method, there are additional limitations that affected the data collection and analysis. Tasks were not selected for sampling in advance of noise monitoring. Applying the criteria for selecting a suitable sampling day was intended to increase the collection of noise exposures of relevant tasks. Aside from that, there was no additional control over the tasks monitored. As a result the final number of tasks monitored was not known until after the study was completed, resulting in a disproportionate number of samples across the tasks.

Another limitation that is likely to account for the large variability seen in the task-based noise exposures is the inability to account for distances from noise sources during monitoring. As sound energy radiates from a source, the intensity of noise decreases by six decibels when the distance from the noise source is doubled.[37] Therefore, not accounting for distance from the noise sources when calculating the task-based noise exposures will introduce substantial variability. While the task observational form allowed a great deal of information on the tasks to be collected, collecting information on the distances from noise sources during sampling was not feasible. Furthermore, collecting data to account for the distance from noise sources were attempted, it is likely that distances would have been imprecise.

A major strength of the current study was the use of direct observation of subjects to collect task and covariate information, as opposed to interviewing the farmers at the end of the workday or by having the farmers record their own tasks in a task diary. Misclassification of tasks with their corresponding one-minute noise levels was likely reduced because a clear start and stop time for the tasks is established. Several studies have shown that there can be differences in task information when self-reported using task diaries or by worker recall at the end of the day. One study found that users of task diaries underreport the changes in tasks, resulting in tasks of short duration not being recorded at all, as well as the recorded start and stop times for tasks not corresponding to the actual time these tasks were conducted [108]. Another study comparing the agreement of task diaries to direct observation of tasks in a musculoskeletal study found that self-reported task diaries can cause misclassification of tasks and result in inaccurate task-based exposure assessments.[109] A third study specific to task-based noise exposures found only moderate agreement between tasks reported using worker diaries and observations made by researchers, with kappa statistics between 0.51 and 0.67.[73]

In addition to being more accurate, collecting task data by direct observation eliminates the need to determine the tasks of interest a priori. This eliminates the possibility of the study participants conducting tasks that the researchers did not anticipate, or misclassifying the tasks completed. More importantly, additional information such as work area and detailed equipment descriptions can be collected, allowing determination of noise exposures for tasks that are categorized either broadly or more specifically, as well as under a variety of scenarios.

Another important strength of this study is the capacity to include future noise exposure and task data into the task-based noise exposure database. The task and covariate observational form can be used to collect additional data on task-based noise exposures in agriculture in a manner similar to the data currently in the database. This will increase the number of task-based noise exposure measurements and allow them to be calculated using larger sample sizes, increasing the accuracy of future task-based noise exposure calculations. Furthermore, because the database was designed to permit tasks to be determined posteriori the database can be shared with other researchers and allow tasks to be categorized to their desired level of specificity.

Finally, the results of this study have significant implications for intervention strategies to reduce noise exposure. Administrative controls involve modifying the work schedule to limit exposure to hazardous noise, but the nature of agricultural work renders this strategy impractical. The use of hearing protection is one possible option. If the task-based noise exposures had identified tasks with consistently high or low exposures then efforts to promote the use of hearing protection could be targeted specifically to those tasks. However, the results of this study indicate that none of the tasks should be excluded from hearing protection use. Engineering controls to reduce the sound levels produced by agricultural equipment are the best option for limiting the noise exposures of farmers and farm workers. Controlling the noise at the source, such as decreasing the noise output of power tools, building tractors and combine cabs to reduce even more noise, and isolating loud equipment such as grain dryers and air compressors, is the only way to ensure a reduction of the noise exposures in this highly variable work environment.

Conclusions

Several tasks with particularly high noise exposures, such as operating grain vacuums and loading/unloading grain bins were identified, but most tasks had noise exposures between 90 and 80 dBA and all were highly variable. With small sample sizes and high variability there was not a statistically significant difference in the mean noise exposures between most of the tasks. Most of the variability in the noise exposures can be attributable to variation in the noise measurements within each farm, indicating that variability in work practices and work scenarios within the farms contributed most to the exposure levels. In addition, for nearly every task there were instances of noise exposures loud enough to cause hearing loss (> 85dBA).

Consequences of the high variability in noise exposure at the task level indicate that using task-based noise exposures to target specific agricultural tasks for intervention strategies will still have limitations. Focusing on just a few tasks for intervention will likely diminish farmers' overall noise exposure, but potential exposure to hazardous noises would still exist along with the risk of hearing loss. Therefore, controlling noise at the source is the best overall approach to reduce the overall noise exposure for farmers and farm workers in such a dynamic work environment.

Although the variability in the task-based noise exposure signifies no agricultural task should be overlooked as a potential source of hazardous noise exposure, the database developed from this study still has important implications for future work. The data from the current study can potentially be used to develop models that can estimate noise exposures for farmers and agricultural workers. A model that can accurately estimate noise exposures will allow health and safety professionals to determine noise exposures for workers in an industry that is largely unregulated and unlikely to pay for comprehensive noise monitoring.

Table 3.1. Demographic characteristics of study participants (N=32)[1]

Characteristics	Mean[2] (SD) or Frequency[3]	Median	Min	Max
Age	42.7 (14.3)	44.0	16	71
Years Farming	24.1 (13.6)	23.5	3	55
Hours per week growing season	58.1 (17.7)	60.0	8	100
Hours per week off season	26.7 (13.6)	30	0	50
Diagnosed Hearing Loss	6 (18.7%)			
Primary Occupation Farming	31 (96.9%)			
Participants with Second Job	8 (25%)			
Gender				
Male	31 (96.9%)			
Female	1 (3.1%)			
Education				
Some High School	3 (9.4%)			
High School Graduate	8 (25.0%)			
Some College	7 (21.9%)			
College Graduate	14 (43.7%)			
Marital Status				
Single	7 (21.9%)			
Married	22 (68.7%)			
Divorced	2 (6.3%)			
Widowed	1 (3.1%)			
Income				
Less than $40,000	9 (28.1%)			
$40,000 to $80,000	10 (31.3%)			
More than $80,000	8 (25.0%)			
Refused to Answer	5 (15.6%)			
Often work around loud noises				
Never	0 (0%)			
Some of the Time	21 (65.6%)			
Most of the Time	10 (31.3%)			
All of the Time	1 (3.1%)			
Hearing Protection				
Never	19 (59.4%)			
Some of the Time	9 (28.1%)			
Most of the Time	3 (9.4%)			
All of the Time	1 (3.1%)			

[1] Three study participants involved in noise monitoring did not complete surveys

[2] Continuous variables given as mean (standard deviation)

[3] Categorical variables are expressed by frequency (percent)

Table 3.2. Characteristics of participating farms where noise exposure monitoring of farmers, family members and farm workers took place (N=18)

Characteristics	Mean[1] (SD) or Frequency[2]	Median	Min	Max
Number of Workers (Family)	2.8 (1.6)	3	0	6
Number of Workers (Hired)	2.2 (3.9)	1	0	12
Number of Tractors	5.6 (1.4)	6	3	8
Number of Combines	1.6 (0.5)	2	1	2
Number of Portable Augers	3.2 (1.0)	3	2	6
Number of Skid Steers	0.8 (0.4)	1	0	2
Number of Grain Bins	10.7 (6.1)	10	0	24
Number of Grain Dryers	0.5 (0.5)	1	0	1
Number of Grain Trucks	3.3 (1.8)	3	0	8
Number of Semis	1.8 (1.4)	2	0	5
Size of farm (acres)	2357 (1286)	2250	800	5400
< 1200	4 (22.2%)			
1200 to 2199	4 (22.2%)			
2200 to 3199	5 (27.8%)			
> 3200	5 (27.8%)			
Grain Farms with Livestock				
Grain + Livestock	2 (11.1%)			
Grain Only	16 (88.9%)			
Gross Income from Farm				
Refused	2 (16.7%)			
Over $100,000	15 (83.3%)			
Value of Farm Assets				
Refused	3 (16.7 %)			
Under $1,000,000	3 (16.7 %)			
$1,000,000 to $5,000,000	8 (44.4 %)			
Over $5,000,000	4 (22.2 %)			

[1] Continuous variables given as mean (standard deviation)

[2] Categorical variables are expressed by frequency (percent)

Table 3.3. Noise exposure characteristics of common grain production tasks

					Variability in Measurement				
Grain Production Activity	**Sample Days (N)**	**Subject Farms (N)**	**Mean Sample Time (Minutes)**	**Mean (dBA)**	**STD (dBA)**	**Within Farm Variability**	**Between Farm Variability**	**Min (dBA)**	**Max (dBA)**
Operating Grain Vacuum	4	4	140	99.9	3.0	0.9	7.9	96.8	102.8
Operating Skid Steer/Bobcat	1	1	28	95.0	--	---	---	---	---
Operating Other Equipment	1	1	97	93.8	--	---	---	---	---
Unloading Grain/Loading Grain Bin at Farm	11	7	40	90.3	3.2	10.2	0	85.1	94.1
Changing Tires on Vehicles and Implements	4	2	44	89.6	5.4	29.6	0	81.9	93.7
Working Around Grain Bins	11	7	21	86.3	3.7	13.9	0	79.0	91.3
Prepping For Spraying	8	7	45	86.3	4.5	3.7	14.8	78.9	93.2
Driving Grain Trucks	21	13	53	86.2	2.4	4.7	0.9	82.2	90.3
Unloading Grain at Elevator	12	9	25	86.0	3.6	10.5	2.8	82.1	95.4
Operating ATV	2	2	21	85.7	3.6	0.9	12.2	83.2	88.3
Prepping Equipment	12	9	17	85.0	5.1	4.5	26.6	79.1	93.9
Driving Semi	15	8	68	84.9	4.2	11.0	5.6	72.6	89.4
Checking Equipment/Field/Crops During Field Work	30	17	17	84.0	4.7	15.7	7.2	72.7	94.3
Combining Grain Crops	22	14	205	83.8	3.7	1.9	14.2	77.3	92.4
Planting Grain Crops	13	12	202	83.7	3.6	13.2	<0.1	76.5	89.4
Operating Grain Cart	8	6	93	83.3	5.8	2.5	30.7	75.4	93.7
Cleaning Equipment	9	7	64	83.1	4.4	19.4	0	75.7	88.9
Unaccounted for start and stop time	31	15	7	83.0	6.1	37.2	0	68.0	92.9
Prepping For Combining	9	8	24	83.0	4.2	13.5	4.1	73.7	87.8
Attaching/Moving Implements and Vehicles	38	17	16	82.8	3.4	11.6	0	75.4	89.0
Prepping For Planting	14	12	22	82.8	4.6	20.9	0	73.7	87.7

Table 3.3 Continued.

Grain Production Activity	Sample Days (N)	Subject Farms (N)	Mean Sample Time (Minutes)	Mean (dBA)	Variability in Measurement: STD (dBA)	Within Farm Variability	Between Farm Variability	Min (dBA)	Max (dBA)
Spraying Fields	8	5	161	82.8	3.4	11.3	0	77.9	88.1
Maintenance on Equipment	26	13	71	82.7	5.4	13.5	15.2	73.4	94.9
Plowing/Digging/Ditching Fields	14	9	142	82.6	2.5	2.6	4.5	77.8	87.9
Operating Tractor Other Field Work	4	2	178	82.6	2.3	0.1	10.4	80.0	84.9
Misc. Work In Field	14	10	29	82.4	5.5	25.5	4.4	72.8	91.9
Waiting in Grain Truck/Semi	9	8	31	82.3	3.2	0.4	11.1	80.1	90.3
Driving Tractor Non-Field Work	33	17	27	82.1	3.8	11.5	3.3	74.4	89.1
Driving Combine	19	13	29	81.6	4.0	14.1	1.9	73.4	88.3
In Shop Working	29	13	36	81.6	5.7	32.0	0.3	72.6	97.3
Driving Pickup/Personal Vehicles	29	15	36	81.4	4.1	12.4	5.0	72.7	89.7
Loading and Unloading Pickups/Trailers	3	3	20	81.4	5.2	1.0	25.7	78.4	87.4
Fueling Equipment	14	10	7	80.7	4.6	0.7	23.6	73.8	90.8
Maintenance on Structures	2	2	78	80.4	14.8	1.0	218.3	69.9	90.8
Mowing Ditches	2	2	177	80.4	3.6	0.9	12.1	77.8	82.9
Unaccounted for work time	28	12	55	80.2	4.8	23.3	0	70.0	91.2
Misc. Work Around Farm	22	13	13	79.6	4.6	4.9	18.6	71.8	86.7
Picking Up Parts, Fertilizer, Misc. at Store	7	6	8	79.4	6.1	37.5	0	67.6	85.7
Talking to Employees, Family, Neighbors	17	10	25	79.2	5.1	26.0	0	68.8	88.0
In House or Office	27	12	42	75.6	4.9	18.2	6.3	67.4	83.8
In Shop Not Working	5	4	36	74.0	2.3	5.2	0	70.8	76.4

Table 3.4 Noise exposure characteristics of common grain production tasks combined into broad categories.

					Variability in Measurement				
Grain Production Activity	Sample Days (N)	Subject Farms (N)	Mean Sample Time (Minutes)	Mean (dBA)	STD (dBA)	Within Farm Variability	Between Farm Variability	Min (dBA)	Max (dBA)
Operating Grain Vacuum	4	4	140	99.9	3.0	0.9	7.9	96.8	102.8
Operating Other Equipment	1	1	125	94.1	---	---	---	---	---
Unloading Grain/Loading Grain Bin at Farm	11	7	40	90.3	3.2	10.2	0	85.1	94.1
Changing Tires on Vehicles and Implements	4	2	44	89.8	5.4	29.6	0	81.9	93.7
Working Around Grain Bins	11	7	21	86.3	3.7	13.9	0	79.0	91.3
Unloading Grain at Elevator	12	9	25	86.0	3.6	10.5	2.8	82.1	95.4
Driving Grain Trucks	29	15	73	85.9	2.7	4.4	2.5	78.9	90.3
Operating ATV	2	2	21	85.7	3.6	0.9	12.2	83.2	88.3
Checking Equipment/Field/Crops During Field Work	30	17	17	84.0	4.7	15.7	7.2	72.7	94.3
Planting Grain Crops	13	12	202	83.7	3.6	13.2	<0.1	76.5	89.4
Prepping Equipment	56	18	32	83.6	3.7	13.9	0	73.7	90.6
Operating Grain Cart	8	6	93	83.3	5.8	2.5	30.7	75.3	93.7
Combining Grain Crops	25	14	202	83.2	3.6	6.8	6.4	77.3	92.2
Maintenance on Equipment	30	15	81	83.0	5.0	17.0	7.7	77.1	94.9
Spraying Fields	8	5	161	82.8	3.4	11.3	0	77.9	88.1
Plowing/Digging/Ditching Fields	14	9	142	82.6	2.5	2.5	4.5	77.8	87.9
Misc. Work In Field	19	12	36	82.6	4.9	20.1	4.3	72.8	91.9
Driving Tractor Non-Field Work	33	17	27	82.1	3.8	11.5	3.3	74.4	89.1
In Shop Working	29	13	42	81.9	6.0	35.7	0	72.6	97.3
Driving Pickup/Personal Vehicles	29	15	38	81.7	3.9	12.8	2.2	73.9	89.7
Operating Tractor Other Field Work	6	4	178	81.5	2.5	0.1	9.3	77.8	84.9
Unaccounted for work time	28	12	55	80.2	4.8	23.3	0	70.0	91.2
Misc. Work Around Farm	49	18	42	78.6	4.9	19.6	4.9	68.7	86.7

Table 3.5. Adjusted p-values for Tukey-Kramer multiple comparisons of mean noise exposures for grain production tasks

Tasks	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
A		0.66	0.38	0.99	0.11	0.16	0.13	0.57	**<0.01**	0.38	0.43	0.16	0.28	0.72	0.35	0.53	0.56	**0.01**	1.00	1.00	1.00
B			1.00	1.00	0.98	1.00	0.99	1.00	**<0.01**	1.00	1.00	**<0.01**	1.00	1.00	1.00	1.00	1.00	0.25	**0.01**	1.00	1.00
C				0.83	1.00	1.00	1.00	1.00	**<0.01**	1.00	1.00	**<0.01**	1.00	1.00	1.00	1.00	1.00	0.88	**<0.01**	0.91	0.97
D					0.11	0.21	0.17	0.98	**<0.01**	0.86	0.95	**<0.01**	0.84	1.00	0.86	0.94	0.99	**<0.01**	0.36	1.00	1.00
E						1.00	1.00	1.00	0.13	1.00	1.00	**<0.01**	1.00	1.00	1.00	0.97	1.00	1.00	**<0.01**	0.34	0.51
F							1.00	1.00	**0.03**	1.00	1.00	**<0.01**	1.00	1.00	1.00	1.00	1.00	1.00	**<0.01**	0.49	0.67
G								1.00	0.08	1.00	1.00	**<0.01**	1.00	1.00	1.00	0.99	1.00	1.00	**<0.01**	0.42	0.59
H									**<0.01**	1.00	1.00	**<0.01**	1.00	1.00	1.00	1.00	1.00	0.41	**<0.01**	0.99	1.00
I										**0.03**	0.82	**<0.01**	1.00	**0.02**	0.23	**<0.01**	0.62	0.97	**<0.01**	**<0.01**	**<0.01**
J											1.00	**<0.01**	1.00	1.00	1.00	1.00	1.00	0.97	**<0.01**	0.91	0.97
K												**<0.01**	1.00	1.00	1.00	1.00	1.00	1.00	**0.02**	0.94	0.98
L													**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**0.03**	**<0.01**	**<0.01**
M														1.00	1.00	1.00	1.00	1.00	**0.01**	0.84	0.90
N															1.00	1.00	1.00	0.84	0.05	1.00	1.00
O																1.00	1.00	1.00	**<0.01**	0.90	0.95
P																	1.00	0.15	**<0.01**	0.98	1.00
Q																		1.00	0.05	0.99	1.00
R																			**<0.01**	**0.02**	0.06
S																				0.88	0.84
T																					1.00
U																					

*Values in bold indicated statistically significant (p-value <0.05) differences between the mean noise exposure levels

** Mean noise exposure levels for operating ATV and operating other equipment not significantly different from mean noise exposures for all the other tasks (p-values > 0.05)

[A] Changing Tires on Vehicles and Implements [B] Checking Equipment/Field/Crops During Field Work [C] Combining Grain Crops [D] Driving Grain Trucks [E] Driving Pickup/Personal Vehicles [F] Driving Tractor Non-Field Work [G] In Shop Working [H] Maintenance on Equipment [I] Misc. Work Around Farm [J] Misc. Work In Field [K] Operating Grain Cart [L] Operating Grain Vacuum [M] Operating Tractor Other Field Work [N] Planting Grain Crops [O] Plowing/Digging/Ditching Fields [P] Prepping Equipment [Q] Spraying Fields [R] Unaccounted for work time [S] Unloading Grain at Elevator [T] Unloading Grain/Loading Grain Bin at Farm [U] Working Around Grain Bins

Table 3.6. Noise exposure characteristics of common grain production tasks under specific exposure scenarios

Grain Production Activity	Sample Days (N)	Subject Farms (N)	Mean Sample Time (Minutes)	Mean (dB)	STD (dB)	Min (dB)	Max (dB)
Changing Tires on Vehicles and Implements							
Indoors	2	1	42	86.5	6.6	81.9	91.2
Outdoors	3	2	30	91.7	2.9	88.4	93.7
Zero Primary Noise Sources	2	1	4	86.2	3.2	84.0	89.0
One Primary Noise Sources	4	2	22	89.4	5.3	81.9	93.5
Two Primary Noise Sources	3	2	23	92.3	2.8	89.1	94.0
Three Primary Noise Sources	1	1	7	95.6	---	---	---
Checking Equipment/Field/Crops During Field Work							
Cab Windows and Doors Closed	5	4	4	84.1	4.2	77.7	89.1
Cab Windows and Doors Open	1	1	19	87.5	---	---	---
Outdoors	28	17	15	84.0	4.8	72.7	94.3
Zero Primary Noise Sources	5	5	6	84.8	1.5	82.3	85.8
One Primary Noise Sources	27	16	13	83.3	4.7	72.7	91.7
Two Primary Noise Sources	8	7	12	84.3	4.2	76.1	89.4
Three Primary Noise Sources	2	1	17	91.4	7.6	86.0	96.7
Combining Grain Crops							
Cab Windows and Doors Closed	25	14	195	82.6	3.2	77.3	92.5
Cab Windows and Doors Open	3	3	18	82.2	4.3	77.8	86.4
Outdoors	6	6	8	87.8	9.5	76.7	104.4
When using hearing protection	1	1	188	92.3	---	---	---
When not using hearing protection	23	13	184	83.1	3.0	77.6	91.1
Zero Primary Noise Sources	2	2	3	80.6	2.3	79.0	82.2
One Primary Noise Sources	25	14	202	83.2	3.6	77.3	92.2

Table 3.6. Continued.

Grain Production Activity	Sample Days (N)	Subject Farms (N)	Mean Sample Time (Minutes)	Mean (dB)	STD (dB)	Min (dB)	Max (dB)
Driving Grain Trucks							
Cab Windows and Doors Closed	18	11	44	84.9	2.7	79.5	89.5
Cab Windows and Doors Open	13	11	88	86.9	2.1	83.1	90.3
Outdoors	1	1	14	79.5	---	---	---
When using hearing protection	2	1	66	89.3	0.5	89.0	89.6
When not using hearing protection	27	14	65	85.7	2.7	79.5	90.3
Zero Primary Noise Sources	9	7	15	85.1	3.7	78.9	90.2
One Primary Noise Sources	28	15	69	86.0	2.4	80.0	90.3
Two Primary Noise Sources	2	2	27	84.2	1.9	82.9	85.6
Three Primary Noise Sources	1	1	4	88.8	---	---	---
Driving Pickup/Personal Vehicles							
Cab Windows and Doors Closed	21	13	31	80.7	4.3	72.7	88.1
Cab Windows and Doors Open	11	7	26	82.7	4.1	76.4	89.7
Indoors	1	1	29	82.3	---	---	---
Outdoors	4	4	16	83.1	5.3	78.4	88.7
Zero Primary Noise Sources	12	9	9	79.8	5.5	71.3	89.7
One Primary Noise Sources	28	15	34	81.3	3.7	72.7	88.0
Two Primary Noise Sources	3	3	8	78.7	2.3	76.4	81.0
Driving Tractor Non-field Work							
Cab Windows and Doors Closed	29	16	27	81.9	3.9	74.4	89.1
Cab Windows and Doors Open	5	5	11	83.2	4.5	76.7	87.9
Outdoors	3	2	8	81.8	5.7	77.1	88.3
When using hearing protection	2	1	17	78.5	2.1	77.0	80.0
When not using hearing protection	31	16	27	82.0	3.8	74.4	89.1
Zero Primary Noise Sources	7	6	25	82.6	4.7	76.8	88.9
One Primary Noise Sources	30	17	23	81.7	3.7	74.4	89.1
Two Primary Noise Sources	1	1	7	84.3	---	---	---

Table 3.6. Continued.

Grain Production Activity	Sample Days (N)	Subject Farms (N)	Mean Sample Time (Minutes)	Mean (dB)	STD (dB)	Min (dB)	Max (dB)
In Shop Working							
Indoors	27	13	37	81.6	6.0	69.5	97.3
Outdoors	7	5	27	79.5	6.8	72.6	90.8
Zero Primary Noise Sources	28	12	30	80.7	4.9	72.6	97.3
One Primary Noise Sources	11	10	18	83.3	8.9	69.9	98.2
Two Primary Noise Sources	3	2	53	88.6	6.4	81.2	93.0
Maintenance on Equipment							
Cab Windows and Doors Closed	3	3	8	81.2	7.7	76.3	90.1
Indoors	11	9	60	81.9	5.2	73.5	91.9
Outdoors	25	14	67	83.6	5.0	76.5	95.1
Zero Primary Noise Sources	24	15	29	81.7	5.9	70.0	94.2
One Primary Noise Sources	24	14	58	83.0	5.0	77.6	98.0
Two Primary Noise Sources	9	8	36	88.7	4.1	83.3	95.2
Three Primary Noise Sources	1	1	1	95.2	---	---	---
Misc. Work Around Farm							
Cab Windows and Doors Closed	2	2	10	79.4	6.2	75.0	83.8
Indoors	32	14	42	75.6	4.5	68.4	83.7
Outdoors	33	17	17	80.3	4.6	68.8	88.0
Zero Primary Noise Sources	47	18	41	78.2	4.9	68.8	87.9
One Primary Noise Sources	12	9	9	82.3	5.8	69.3	92.7
Two Primary Noise Sources	3	2	7	84.3	7.2	79.4	92.5
Misc. Work in Field							
Cab Windows and Doors Closed	7	5	35	82.8	4.3	77.8	89.3
Cab Windows and Doors Open	7	7	18	82.7	4.4	76.2	90.3
Outdoors	10	8	31	81.7	5.8	72.8	91.9
Zero Primary Noise Sources	7	6	39	81.0	5.9	72.7	89.2
One Primary Noise Sources	16	11	25	83.4	4.6	75.1	91.9
Two Primary Noise Sources	1	1	11	80.3	---	---	---
Three Primary Noise Sources	1	1	4	77.3	---	---	---

Table 3.6. Continued.

Grain Production Activity	Sample Days (N)	Subject Farms (N)	Mean Sample Time (Minutes)	Mean (dB)	STD (dB)	Min (dB)	Max (dB)
Operating Grain Cart							
Cab Windows and Doors Closed	8	6	92	82.6	5.7	75.4	93.7
Outdoors	1	1	4	89.0	---	---	---
When using hearing protection	1	1	8	79.9	---	---	---
When not using hearing protection	7	5	102	83.4	6.1	75.4	93.7
One Primary Noise Sources	8	6	93	83.3	5.8	75.4	93.7
Operating Tractor Other Field Work							
Cab Windows and Doors Closed	5	3	209	80.4	1.8	77.8	82.9
Outdoors	1	1	19	84.9	---	---	---
Zero Primary Noise Sources	1	1	101	81.3	---	---	---
One Primary Noise Sources	3	3	36	79.4	2.1	77.0	80.7
Two Primary Noise Sources	6	4	143	81.6	2.6	78.0	84.9
Operating Grain Vacuum							
Indoors	3	3	71	87.3	17.0	67.6	97.6
Outdoors	4	4	86	100.0	2.9	97.0	103.0
When using hearing protection	5	4	108	100.0	2.9	96.8	103.3
When not using hearing protection	3	3	5	84.9	0.9	84.0	95.0
Zero Primary Noise Sources	2	2	5	87.3	5.4	83.5	91.1
One Primary Noise Sources	4	4	7	93.7	2.3	91.4	97.0
Two Primary Noise Sources	4	4	37	99.3	4.1	95.4	103.7
Three Primary Noise Sources	4	4	94	100.0	2.8	97.0	102.4
Planting Grain Crops							
Cab Windows and Doors Closed	12	11	203	83.8	3.8	76.3	89.5
Cab Windows and Doors Open	1	1	14	86.4	---	---	---
Outdoors	4	4	6	82.1	6.7	75.4	90.6
Zero Primary Noise Sources	6	6	33	79.6	2.1	77.2	82.2
One Primary Noise Sources	13	12	179	83.9	4.0	76.5	90.8
Two Primary Noise Sources	1	1	103	83.7	---	---	---

Table 3.6. Continued.

Grain Production Activity	Sample Days (N)	Subject Farms (N)	Mean Sample Time (Minutes)	Mean (dB)	STD (dB)	Min (dB)	Max (dB)
Plowing/Digging/Ditching Fields							
Cab Windows and Doors Closed	13	9	139	82.7	2.8	77.8	87.9
Cab Windows and Doors Open	1	1	77	83.6	---	---	---
Zero Primary Noise Sources	1	1	5	77.2	---	---	---
One Primary Noise Sources	14	9	142	82.6	2.5	77.8	87.9
Prepping Equipment							
Cab Windows and Doors Closed	23	13	7	81.0	3.8	73.8	88.9
Cab Windows and Doors Open	21	15	7	82.9	4.1	73.6	90.0
Indoors	9	6	10	80.9	4.9	74.1	85.3
Outdoors	46	18	27	84.2	4.2	73.7	92.2
Partial Enclosure	4	3	17	83.6	6.8	73.7	89.5
Zero Primary Noise Sources	30	13	15	80.6	4.4	71.5	91.3
One Primary Noise Sources	53	18	19	83.8	3.5	73.7	90.2
Two Primary Noise Sources	13	12	19	86.2	2.9	81.3	89.7
Three Primary Noise Sources	3	3	12	88.6	1.7	87.0	90.4
Spraying Fields							
Cab Windows and Doors Closed	7	4	147	82.2	3.9	77.8	88.1
Cab Windows and Doors Open	3	3	65	80.5	3.0	78.1	83.9
Outdoors	5	4	8	83.5	6.5	76.4	90.2
When using hearing protection	2	1	162	80.0	3.0	77.9	82.1
When not using hearing protection	7	5	138	82.7	3.9	76.8	88.1
Zero Primary Noise Sources	2	2	31	87.7	2.4	86.0	89.4
One Primary Noise Sources	7	4	151	82.5	3.4	77.9	87.2
Two Primary Noise Sources	2	2	62	84.5	0.7	84.0	85.0
Three Primary Noise Sources	1	1	49	83.5	---	---	---

Table 3.6. Continued.

Grain Production Activity	Sample Days (N)	Subject Farms (N)	Mean Sample Time (Minutes)	Mean (dB)	STD (dB)	Min (dB)	Max (dB)
Unloading Grain/Loading Grain Bin at Farm							
Cab Windows and Doors Closed	2	2	10	94.7	2.0	93.3	96.1
Cab Windows and Doors Open	1	1	7	82.1	---	---	---
Outdoors	10	6	40	90.0	3.1	85.1	93.5
When using hearing protection	1	1	66	93.0	---	---	---
When not using hearing protection	11	7	34	90.2	3.1	85.1	94.1
Zero Primary Noise Sources	2	2	7	83.6	2.5	81.8	85.3
One Primary Noise Sources	4	4	7	90.4	3.3	85.7	93.3
Two Primary Noise Sources	2	2	4	89.9	2.4	88.2	91.6
Three Primary Noise Sources	6	5	35	88.0	2.7	85.1	91.7
Four Primary Noise Sources	2	1	10	94.5	2.3	92.9	96.1
Five Primary Noise Sources	2	2	60	93.5	<0.1	93.5	93.5
Six Primary Noise Sources	1	1	40	91.9	---	---	---
Unloading Grain at Elevator							
Cab Windows and Doors Closed	1	1	10	86.3	---	---	---
Cab Windows and Doors Open	2	2	7	90.4	9.1	83.9	96.8
Indoors	11	9	21	86.2	3.3	82.1	93.2
Outdoors	2	2	19	83.6	0.4	83.3	83.8
When using hearing protection	1	1	14	86.7	---	---	---
When not using hearing protection	11	9	24	85.7	3.9	82.1	95.4
Zero Primary Noise Sources	2	2	13	84.7	1.0	83.9	85.4
One Primary Noise Sources	5	5	7	83.8	3.8	78.3	87.7
Two Primary Noise Sources	11	9	22	85.9	4.1	81.2	95.4
Working Around Grain Bins							
Indoors	1	1	46	89.3	---	---	---
Outdoors	11	7	17	86.2	3.7	79.0	91.3
Zero Primary Noise Sources	4	3	11	87.7	1.7	86.0	90.0
One Primary Noise Sources	8	6	9	85.5	3.8	79.0	90.8
Two Primary Noise Sources	5	4	13	88.2	3.0	83.3	91.3
Three Primary Noise Sources	2	1	6	86.2	7.6	80.8	91.6
Four Primary Noise Sources	1	1	40	92.2	---	---	---

Table 3.7. Noise exposure characteristics of common grain production equipment

Grain Production Equipment	Sample Days (N)	Subject Farms (N)	Mean Sample Time (Minutes)	Mean (dBA)	Variability in Measurement			Min (dBA)	Max (dBA)
					STD (dBA)	Within Farm Variability	Between Farm Variability		
Grain Vacuum	5	5	82	96.2	8.9	1.0	78.4	80.8	102.4
Grain Bin Spreader	1	1	24	93.6	---	---	---	---	---
Grain Dryer	5	4	24	91.4	2.7	0.5	6.8	88.0	94.9
Bulldozer	2	2	54	90.7	4.3	0.9	17.8	87.7	93.8
Grain Auger	14	10	23	89.8	3.8	14.2	0	84.8	96.8
Skid Steer	5	4	17	89.2	3.9	15.2	0	85.7	93.8
Air Compressor	11	10	19	89.1	6.1	1.5	39.8	79.8	102.2
Grain Bin Fans	3	2	40	88.8	4.2	13.9	5.3	85.4	93.7
Power Tools (Continuous)	10	8	6	87.5	8.7	75.9	0	70.5	96.4
Grain Elevator	10	9	20	86.5	4.1	16.2	0.8	81.2	95.4
Grain Truck	27	13	57	85.3	4.8	23.0	0	69.6	96.9
Power Tools (Intermittent)	8	6	36	84.5	8.6	1.6	87.2	68.9	94.6
Semi	20	9	71	84.4	3.8	8.0	5.3	72.6	89.4
Power Washer	2	2	63	84.1	4.8	23.0	0	80.7	87.5
Non-Powered Tools (Intermittent)	8	7	85	83.8	7.8	60.3	0	73.5	97.1
Combine	32	16	171	83.7	3.8	12.2	2.6	77.4	92.0
Tractor	59	18	147	83.6	4.7	21.9	0	73.2	98.8
ATV	6	5	10	81.6	7.5	34.5	23.8	67.6	88.3
Pickup/Personal Vehicles	32	15	36	81.1	4.0	11.3	5.3	72.7	88.4
Non-powered Tools (Continuous)	11	9	33	80.8	5.3	6.9	21.1	70.2	91.0
Forklift	1	1	13	80.8	---	---	---	---	---

Table 3.8. Adjusted p-values of Tukey-Kramer multiple comparisons of the mean noise exposures from grain production equipment

Tasks	A	B	C	D	E	F	G	H	I	J	K	L	M	N
A		0.49	1.00	0.23	0.92	0.19	1.00	**<0.01**	1.00	1.00	1.00	1.00	0.81	1.00
B			0.26	1.00	1.00	1.00	0.93	0.67	0.09	0.83	**<0.01**	0.58	1.00	0.17
C				**0.04**	0.97	0.12	1.00	**<0.01**	1.00	1.00	0.96	1.00	0.85	1.00
D					1.00	1.00	0.56	0.79	**0.02**	0.51	**<0.01**	0.18	1.00	**0.01**
E						1.00	1.00	1.00	0.85	0.99	0.77	0.98	1.00	0.97
F							0.57	1.00	**0.04**	0.44	**<0.01**	0.26	1.00	0.09
G								**<0.01**	0.93	1.00	0.22	1.00	1.00	1.00
H									**<0.01**	**0.01**	**<0.01**	**<0.01**	0.91	**<0.01**
I										1.00	1.00	1.00	0.47	1.00
J											1.00	1.00	0.98	1.00
K												0.95	0.16	0.84
L													0.95	1.00
M														0.81
N														

*Values in bold indicated statistically significant (p-value <0.05) differences between the mean noise exposure levels

** Mean noise exposure levels for bulldozer, forklift, grain bin fans, grain elevator, power tools (continuous), power tools (intermittent), power washer and skid steer not significantly different from mean noise exposures for all the other equipment (p-values > 0.05)

[A] ATV [B] Air Compressor [C] Combine [D] Grain Auger [E] Grain Bin Spreader [F] Grain Dryer [G] Grain Truck [H] Grain Vacuum [I] Non-powered Tools (Continuous) [J] Non-Powered Tools (Intermittent) [K] Pickup/Personal Vehicles [L] Semi [M] Skid Steer [N] Tractor

CHAPTER IV
ESTIMATION OF DAILY NOISE EXPOSURES FOR FARMERS AND FARM WORKERS INVOLVED IN GRAIN PRODUCTION USING TASK-BASED NOISE MEASUREMENTS

Abstract

Due to the complex work environment on agricultural operations, task-based noise exposures have been shown to be useful for identifying tasks associated with exposure to hazardous noise levels, and for targeting intervention strategies designed to reduce lifetime noise exposure. However, limited work has been done evaluating the effectiveness of using task-based noise exposures to estimate 8-hr TWA noise exposures. Additionally, few studies have been conducted to identify significant determinants of noise exposure. Estimates of 8-hr TWA noise exposures for a group of farmers were calculated using time-at-task observations for these farmers and prior dosimeter measured mean task-based noise exposures from an independent population of farmers. Estimated 8-hr TWA noise exposures were compared to corresponding full-day dosimeter-measured 8-hr TWA noise exposures using simple linear regression analysis. In addition, graphical representations of the variability in the 8-hr TWA estimates and the dosimeter-measured 8-hr TWAs were made. Associations between noise exposures and task, demographic and farm characteristics were examined using multivariable linear mixed-effect regression analysis and a database of one-minute noise exposure levels with corresponding task, farm and demographic information. Task, number of noise sources, and work area were found to have a statistically significant association with noise exposure. However, the results of the study indicate the noise dose equation does not accurately estimate 8-hr TWA noise exposures of farmers and farm workers, when calculated using predetermined task-based noise exposures from an independent group of farmers.

Introduction

Task-based noise exposure assessments have been useful for characterizing noise exposure in dynamic work environments where tasks, equipment, work areas and work hours vary day-to-day. Specifically, task-based noise exposures have been used to identify tasks with intense noise levels, which can be targeted for intervention strategies intended to reduce daily noise exposure.[65,72] For exposures other than noise, task-based exposures have been shown to increase the validity of exposure characterization for epidemiological studies.[66] While greater understanding of the noise exposures in the workplace is one benefit of task-based noise exposure measurements, the prospect of using task-based noise exposures to estimate daily exposures is most intriguing. The ability to estimate daily noise exposures without the need for all day noise dosimeter measurements has tremendous implications for the agricultural industry. Family farms have few health and safety regulations, and are not likely to pay for costly and time consuming noise dosimeter measurements. Farmers and farm workers would benefit from a methodology that estimates daily noise exposures and eliminates the need for full-day noise dosimeter measurements. More importantly health and safety researchers would have a simple method for calculating daily noise exposure data for epidemiological and intervention studies for an occupational group that is difficult to access.

Few studies have examined the accuracy of estimated 8-hr TWA noise exposures calculated using predetermined task-based noise exposures. Studies that have been conducted found agreements (R^2) between dosimeter measured and estimated 8-hr TWA noise exposures to be between 0.08 and 0.90, indicating poor to excellent agreement between measured and estimated exposures.[73-75] The broad range of agreements between estimated and measured noise exposures found in the literature is the consequence of varying complexity in the statistical models and the task-based noise exposures. Specifically, these studies found that increasing variability in the task-based noise exposures decreases the agreement between the estimated and measured daily noise exposures.

In the agriculture industry, few studies have investigated task-based noise exposures, and no published studies have attempted to estimate daily noise exposures using task-based noise measurements.[35,51,68-71] Due to limited research of task-based noise exposure in agriculture and complexity of noise exposure assessment models published in the literature, an evaluation of the effectiveness of a simpler noise exposure assessment model for agricultural operations may be advantageous.[73-75] Using sophisticated exposure models may also be beyond the skill set of most industrial hygienists or health and safety professionals. A more simplistic approach using the noise dose equation, in combination with task-based noise exposures could be a more practical method for estimating 8-hr TWA noise exposures.[9] Estimating 8-hr TWA noise exposures using the dose equation and short term noise exposure measurements is a firmly established method, however little work has been done to evaluate its effectiveness at estimating an 8-hr TWA exposure when substituting predetermined task-based noise levels for short term measurements.[37]

Even though task-based noise exposures can effectively identify hazardous noise exposure on agricultural operations, it is unclear if this will translate into accurate estimates of 8-hr TWA noise exposure.[65,72] The substantial variability identified in task-based noise exposures measured on agricultural operations indicate determinants of noise exposure besides task may need to be taken into account to accurately estimate 8-hr TWA noise exposure.[35,51,68-71]

Limited research has been conducted to identify determinants of noise exposure besides task. Published studies have found that factors specific to work practices are the main determinants of noise exposure, but few investigated the effects demographic factors of farmers and farm workers, or characteristics of the farms have on exposure to noise.[63,78-81] One study has examined determinants of noise exposure specific to agricultural operations and found task, work area, and size of the farm operation had a statistically significant associations.[82] Furthermore, because demographic characteristics have been identified as significant predictors of hearing loss, it is important to determine if demographic factors or farm characteristics are associated with noise exposures that can lead to development of noise-induced hearing loss.[22,29,30,35] Identification of noise exposure determinants is vital information that may increase the accuracy of 8-hr TWA noise exposure estimates calculated using task-based noise exposures.

This study was conducted to meet the following specific aims: 1) estimate the 8-hr TWA noise exposures for farmers using predetermined task-based noise exposure levels of an independent group of farmers; 2) compare the estimated 8-hr TWA noise exposures to dosimetry measured 8-hr TWA noise exposures; and 3) conduct multivariable linear mixed-effect modeling using information from a task-based noise exposure database to identify significant determinants of noise exposure. The results of this study will determine if the noise dose equation can accurately estimate 8-hr TWA noise exposures when calculated using prior dosimeter measured task-based noise levels. Furthermore, this study will examine the determinants of noise exposure specific to agricultural operations, and provide information about work characteristics in addition to task, that could increase the accuracy of estimated 8-hr TWA noise exposures.

Materials and Methods

Study Population

Data analysis was conducted using noise exposure and task data from two populations of farmers in two geographically distinct locations. The first population of farmers (database group) is described in Chapter 3. These were the farmers and farm workers from which data for the task-based noise exposure database were collected and the mean task-based noise exposures were calculated. The database group also provided the one-minute noise exposure measurements, task, and covariate data for the multivariable linear mixed-effect model used to identify significant predictors of noise exposure. The second population of farmers (test group) came from North Central, North Dakota. The 8-hr TWA noise exposures were estimated for the farmers in the test group. This group provided the time-at-task data for the estimates of the 8-hr TWA, and the dosimeter measured 8-hr TWAs used to evaluate the accuracy of the 8-hr TWA noise exposure estimates.

Cash crops made up the majority of agricultural products sold and the numbers of farms in the counties were similar for both groups.[110] Overall the farms in the county where the test group was recruited were larger (1136 acres) than the farms in the counties where the database group were recruited. The farmers in the test group recruitment area were also slightly older (59 yrs) than the farmers in the database group recruitment area.[110]

Recruitment of participants for the database group is detailed in Chapter 3. Participants that provided time-at-task data used for estimating 8-hr TWAs, and daily noise dosimeter measurements used for evaluating the accuracy of the estimated 8-hr TWAs, were recruited from farms in north central North Dakota. Recruitment of these participants was not done randomly; only farms that had previously worked with the Dakota Center for Technology Optimized Agriculture (DCTOA) or had a personal relationship with DCTOA staff were contacted and asked to participate.

Data Collection

Collection of noise exposure and task data for the task-based noise exposure database was described previously in Chapter 3 (Data Collection). Data for farmers and farm workers in the test group were collected using a similar methodology by staff at the DCTOA. Characteristics of farmers and farm workers in the test group were collected using the pre-monitoring questionnaire. Observations for the test group collected data about tasks completed; however unlike the database group the task data for the test group did not include equipment use, work area or secondary noise sources. Furthermore, accuracy of task start and stop times for the test group were within 15 minutes as opposed to five minutes for the database group. Because one of the aims of the study was to determine if noise dose equation can accurately estimate the daily 8-hr TWA using prior dosimeter measured task-based noise exposures from an independent group of farmers, the written description of the farmer's daily tasks was considered to be representative of the quality of task data that would be available through self-reporting by farmers.

Prior to the beginning of data collection for the test group, personnel from the DCTOA were given instruction on suitable days to conduct data collection, the operation of the noise dosimeters, and the collection of observational task data. This was done to ensure consistency in the sampling methodology for the two groups of farmers. The same criteria was used to determine if farms in the test group were available for sampling and included: 1) whether farmers and farm workers would be putting in a full work day; and 2) whether the primary work that day would be related to grain production.

Noise exposure measurements were collected using Quest Edge® noise dosimeters programmed to monitor noise using the NIOSH criteria: with a slow response, A-weighting, 80 decibel threshold, and a three decibel exchange rate.[9] On a suitable sampling day, a staff member from the DCTOA went to the participating farm and explained the study procedures, had the participants complete the pre-monitoring questionnaire, and fit the participant with a pre-calibrated personal noise dosimeter. The participant then went about their work day while the DCTOA staff member observed and recorded the tasks that they completed and the corresponding start and stop times (time-at-task). At the conclusion of the 8-hr sampling period, the noise dosimeters were post-calibrated and the data from the dosimeters downloaded to a computer using the Questsuite® software. Dosimeter data, time-at-task descriptions and the pre-monitoring survey were then sent to the principal investigator. Data from the pre-monitoring questionnaire was entered into an Epi Info™ database and then imported into SAS. The written task descriptions from the daily observations were categorized *a posteriori* into one of the 23 task established in Chapter 3 (Table 3.4). Time-at-task data for these tasks along with the corresponding dosimeter measured dose (%) and 8-hr TWA (dBA) were entered into Excel®.

Data Analysis

For the database group, one-minute noise exposure measurements and corresponding task data for twenty daily samples were randomly selected and removed from the task-based noise exposure database. The one-minute noise measurements and corresponding task data for the remaining 59 daily samples were used to calculate (Equation 3.1) the mean task-based noise exposures (L_{task}) using SAS, version 9.2 (SAS Institute, Inc., Cary, NC). The mean task-based noise exposures (L_{task}) were used to calculate the allowed duration to accumulate 100% noise dose (T_i) based on the NIOSH criteria of an 8-hr workday using Equation 4.1.[9]

$$T_i = 480/\left[2^{\frac{(L_{task}-85)}{3}}\right], \text{minutes} \qquad \text{(Equation 4.1)}$$

The allowed duration (T_i) was used with the time-at-task (C_i) data (in minutes) for the 20 daily samples removed from the task-based noise exposure database to calculate the estimated daily noise dose using equation 4.2, where N is the total number of tasks observed during the daily sample.

$$Dose = \left[\sum_{i=1}^{N} \frac{C_i}{T_i}\right] * 100, \text{percent} \qquad \text{(Equation 4.2)}$$

The estimated dose (%) was converted to an estimated 8-hr TWA using equation 4.3.

$$8hr\ TWA = 10 \log\left(\frac{Dose\%}{100}\right), \text{dBA} \qquad \text{(Equation 4.3)}$$

All calculations for estimating daily noise exposures (T_i, Dose%, and 8-hr TWA) were made using Excel®. Simple linear regression was performed to measure the agreement (R^2) between the a) estimated and dosimeter measured dose (%) and b) the estimated and dosimeter measured 8-hr TWA (dBA) for these 20 daily samples.

For the test group (N=20) descriptive statistics for farmer demographic information and farm characteristics were calculated. Daily dose (%) and 8-hr TWA were estimated using time-at-task observations for these 20 daily samples from the test group and task-based noise exposures (L_{task}) calculated (Equation 3.1) from an independent population of farmers (Table 3.4). This again required the allowed duration to accumulate 100% noise dose (T_i) based on the NIOSH criteria to be calculated using equation 4.1.[9] Allowed exposure durations (T_i) and the time-at-task (C_i) data for famers in the test group were used to calculate the estimated dose (%) using equation 4.2. Estimated dose (%) was then converted to an 8-hr TWA using equation 4.3. Simple linear regression was performed to measure the agreement (R^2) between the 1) estimated and dosimeter measured dose (%) and 2) the estimated and dosimeter measured 8-hr TWA (dBA) for these 20 daily samples from the test group.

Additional information about the variability in the estimated 8-hr TWAs and relationship to the measured 8-hr TWAs for the farmers in the test group were determined by plotting the measured 8-hr TWA for each of the observations with an upper and lower estimate of each 8-hr TWA. Two sources of variability are possible with the dose equation: 1) variability in the reported time-at-task; and 2) the variability in the mean task-based noise exposures. The first upper and lower estimates were calculated using the task-based noise exposure means ± one standard deviation for L_{task} in the calculation of allowed duration to accumulate 100% noise dose (T_i). The second upper and lower estimates were determined using the reported time-at-task (C_i) ± 15 minutes. To examine how the variability in C_i and L_{task} affected the estimated 8-hr TWAs simultaneously, a

Monte Carlo simulation was conducted to establish a mean 8-hr TWA estimate and standard deviation for each of the observations.[111] The estimated 8-hr TWAs ± one standard deviation were then plotted with the corresponding dosimeter measured 8-hr TWAs.

Multivariable linear mixed-effect regression analysis was performed to identify work, farm, and demographic covariates that had a statistically significant association with noise exposure. Specifically, the linear regression analysis was conducted using the one-minute dBA levels from the task-based noise exposure database developed in Chapter 3 as the dependent variable. The independent variables included covariates related to work, personal demographic, and farm characteristics for the participants and farms in the database group that were matched to their corresponding one-minute noise exposures. Twenty-six covariates were analyzed for their association with noise exposure. The regression analysis was conducted using the Proc Mixed procedure in SAS, version 9.2. Farm and subject were treated as random effects in the multivariable linear mixed-effect model, and the remaining covariates were treated as fixed effects.

For the initial step of the regression analysis each of the 26 covariates were entered individually into a multivariable linear mixed-effects model. Parameter estimates (β) and probabilities (p-values) for the association between individual exposure covariates and noise exposures (dBA) were calculated. Any covariate with a p-value<0.20 was included simultaneously in an initial multivariable linear mixed-effects model. A backwards selection procedure was used to eliminate non-significant variables from the regression model. For the backwards selection process a p-value ≤0.10 was considered statistically significant. The process was repeated until all variables with a p-value >0.10 were eliminated from the model. In the final multivariable model, covariates associated with noise exposure were determined at a significance level of α=0.05.

Regression diagnostics were performed to verify the assumptions of the multivariable linear mixed effects model. Analysis of residuals was conducted to check the normality assumption of the regression models. The residuals were determined to be approximately normally distributed, therefore additional data transformation were not necessary. The analysis of residuals was also used to identify possible outliers and influential values. Data from any participant that exceeded the cutoffs for the studentized residuals (studentized residual >2 or <-2), leverage (>0.0004) and Cook's D (>0.00014) were investigated and verified as valid.

Results

Demographic Characteristics

Tables 4.1 and 4.2 compare the demographic and farm characteristics for the test group and database group. Staff at the DCTOA collected a total of 20 daily dosimeter measurements and task observations from farmers in the test group. This is equivalent to approximately 25% of the daily noise exposure measurements used to build the task-based noise exposure database. There were 12 farmers and farm workers from five farms in the test group. The farmers had a mean age of 41 years, and on average had been farming for 24 years. The remaining characteristics of the farmers in the test group were similar to the characteristics of the famers in the database group. However, the farmers in the test group were less educated and were represented by more women. The farm characteristics between the test group and the database group were also similar, except the farms in the test group were on average larger (2750 acres) and had less overall financial value.

Estimates of Dose and 8-hr TWA

Figures 4.1 through 4.4 display the results of the comparisons between the estimated and measured 8-hr TWA noise exposures for farmers in both the database and test groups. Simple linear regression analysis calculated a coefficient of determination (R^2) of 0.41 and 0.15 for the agreement between the estimated and measured 8-hr TWA and dose percent for the farmers in the database group. For the farmers in the test group the simple linear regression analysis calculated a coefficient of determination (R^2) of <0.01 and 0.04 for the agreement of the estimated and measured 8-hr TWA and dose percent.

Because there was less agreement between the estimated 8-hr TWAs and the measured 8-hr TWAs for the farmers in the test group, a graphical representation was made showing the two sources of variability in the 8-hr TWA estimates, and its relationship to the measured 8-hr TWAs. For the upper and lower estimates calculated taking into account the variability in the allowed duration to accumulate 100% noise dose (T_i), only nine of the 20 dosimeter-measured 8-hr TWAs were within the estimated range using the mean task-based noise exposures plus ± one standard deviation (Figure 4.5). For the remaining 12 dosimeter-measured 8-hr TWAs, seven were greater than the estimated range and four were less than. For the upper and lower estimates calculated taking into account the variability in the exposure duration for the tasks (C_i), five of the dosimeter measured 8-hr TWAs fell within the range using the time-at-task ±15 minutes, with six overestimating the actual exposure and seven underestimating (Figure 4.6).

Figure 4.7 presents the results of the Monte Carlo simulation, taking into account the variability in the task-based noise exposures (T_i) and the time-at-task observations (C_i) simultaneously. Between 1000 and 20,000 iterations were required to identify a stable mean and standard deviation for the 20 test group observations. Most of the estimated means were between 80 and 85 dBA. Only six of the dosimetry measured 8-hr TWA noise exposures fell within the estimated ranges calculated by the Monte Carlo simulations. Six of the measured 8-hr TWAs were greater than the estimated ranges and eight were less than.

Determinants of Noise Exposure

Seven covariates with the potential to be associated (p-value <0.20) with noise exposure (dBA) were identified with the mixed-effect linear regression model (Table 4.3). Three of those covariates were related directly to the task being completed and include: task (p<0.01), work area (p<0.01), and the number of noise sources (p<0.01). As expected, use of hearing protection had a significant association with noise exposure (p<0.01). Although statistically significant, use of hearing protection was not included in the initial multivariable linear mixed effect model because it does not affect the amount of noise measured by the dosimeter, but rather is a reaction to being in a loud environment. The three remaining covariates with p-values below the cutoff for inclusion in the initial multivariable linear mixed-effects model were education level (p=0.12), diagnosed hearing loss (p=0.06) and whether or not the participant was the principal operator or an employee/family member (p=0.06). The remaining demographic characteristics and all the farm characteristics, such as the specific equipment on the farm and the farm size, all had p-values greater than the cutoff (p≥0.20).

When controlling for the other covariates in the multivariable linear mixed-effects model, only task (p<0.01), work area (p<0.01), and number of noise sources (p<0.01) had a statistically significant association with noise exposures (Table 4.2). The remaining demographic covariates included in the initial multivariable linear mixed-effects model, did not have a statistically significant association with noise exposure. The statistically significant associations with noise exposure were for covariates directly related to the tasks and work environment.

For the discrete independent variable, numbers of noise sources, the results of the multivariable linear mixed regression analysis calculated a parameter estimate (β) of 1.7 dBA. For work area, only performing work indoors had a significant association with hearing loss (p<0.01), with a parameter estimate (β) of -4.0 dBA. The remaining work areas did not have much of an effect on noise exposures and were not statistically significant. For the 23 task categories, operating an ATV ($p=0.12$) did not have a statistically significant association with noise exposure, and unaccounted work time ($p=0.05$), had a near statistically significant association with noise exposure. The effects of the individual tasks controlled for work area and number of noise sources as indicated by the intercept and parameter estimates indicate tasks such as operating other equipment ($\beta=17.5$ dBA), operating a grain vacuum ($\beta=18.6$ dBA), and unloading grain ($\beta=8.9$ dBA) resulted in more intense exposures. However, for the estimated task-based exposures from the regression model only two tasks had noise exposures greater than 85 dBA as indicated by the parameter estimates (β). Furthermore, the 95% confidence intervals for the task estimated exposures were constrained with all except operation an ATV less than 3 dBA.

Discussion

The results of this study indicate that the noise dose equation dose not accurately estimate either the noise dose percent or 8-hr TWA noise exposure, when calculated using predetermined task-based noise exposures from and independent population of farmers. The coefficient of determination indicates there is almost zero agreement between the estimated and measured daily noise exposures. Even taking into account the variability in the underlying task-based noise exposures and the reported time-at-task information, the measured 8-hr TWA noise exposures are not likely to fall within the expected range. However, when calculated using more accurate time-at-task (C_i) data for farmers not independent of the task-based mean noise exposures ($L_{task)}$ the noise dose equations provides better estimates of daily noise exposures.

Studies conducted to determine the agreement between full-day noise exposure measurements and estimated full-day exposures using task-based noise measurements are limited, and none have specifically estimated exposures for the agricultural industry. Two studies in the construction industry examined the agreement between full-day dosimeter-measured noise exposures and daily noise exposure estimates calculated using task-based noise exposures. Unlike the current study, these studies only assessed the agreement between dosimeter-measured daily noise exposures and estimated daily noise exposures, using the same noise exposure data.[74,73]

Seixas et al. reported agreement (R^2) between dosimeter-measured full-shift noise exposure and six estimates of full-shift noise exposure to be between 0.08 and 0.90.[74] The agreements between most of the measured and estimated full-shift noise exposure are greater than those in the current study. However the agreements between measured and estimated noise exposures improved when the specificity of the task-based noise exposures increased by incorporating additional information about tool, work area, and trade into the task categories. The current study did not have the level of detail for the task descriptions to create highly specific task categories, and was restricted to categorizing the task descriptions into one of 23 categories.

Reeb-Whitaker et al. reported agreement (R^2) between full-shift dosimeter-measured and estimated daily noise exposures to be 0.62 for estimates made using activity cards filled out during the work shift, and 0.59 for estimates made using questionnaires six months later.[73] Unlike the current study, this study found moderate correlations between the measured and estimated daily noise exposures. The number of observations made for comparison between full-shift dosimeter-measured noise exposures and the estimates based on activity cards (N=17) and questionnaires (N=23) were similar to the number of comparisons made in the current study, indicating that it is possible to get moderate agreement even with small sample sizes.

Only one study evaluated the agreement between full-shift dosimeter-measured and estimated daily noise exposures, using independent time-at-task observations and task-based mean noise exposures. For this particular study the samples were independent, but the population from which they were collected was not. Virji et al. measured the agreement (R^2) between dosimeter-measured full-shift noise exposures and three estimated full-shift noise exposures based on the collection methods for time-at-task data.[75] Agreements (R^2) were between; (0.70 – 0.77) for direct observation, (0.63 – 0.71) for worker reports, and (0.49 -0.62) for supervisor assessments. The current study also used direct observation of participants to collect task-based noise exposures, but found little agreement between measured and estimated noise exposures. Furthermore, the study by Virji et al. found that when the mean task-based exposures are highly variable the measures of agreement between the measured and estimated full-shift noise exposures are small, confirming the results of the current study.[75]

The graphs representing the different sources of variability in the estimated noise exposures demonstrate why almost no agreement was found between the measured and estimated noise exposures. Less than half of the 20 observations from the test group were within the ranges calculated taking into account different sources of variability in the noise dose equation. It appears that the variability in the underlying task-based noise exposures (L_{task}) account for most of the variation in the estimated 8-hr TWAs. Overestimation or underestimation of the time-at-task appears to have little influence on the estimated 8-hr TWAs. This may explain why past studies have shown noise exposure estimates using both worker self-reports and direct observations are similar.[73,75-77]

The Monte Carlo simulation allowed the variability in the time-at-task (C_i) and task-based noise exposure (L_{task}) components of the dose equation to be taken into account simultaneously, allowing standard deviations for each of the 20 observations to be calculated. This information would not be possible from the single point estimate calculated using the dose equation. Less than half of the measured 8-hr TWAs were in the range of ± one standard deviation of the estimated 8-hr TWA calculated using the Monte Carlo simulations. This results is similar to the ranges of the estimated 8-hr TWA noise exposures calculated using the variability in C_i and L_{task} individually.

It is unclear why the 8-hr TWA do not agree with measured values. Previous studies have found using highly variable task-based noise exposures result in less agreement between measured and estimated daily noise exposures.[74,75] For the current study it is likely the variability in the task-based noise exposures is too large to get an accurate estimate of an 8-hr TWA. The mean task-based noise exposures had standard deviations between 2.5 dBA and 6.0 dBA, and only one of the tasks had a standard deviation less than 3 dBA. It may be possible noise exposures for tasks conducted on agricultural operations are simply more variable than in other industries, and accurate estimates of noise exposure for farmers and farm workers is unachievable. Furthermore, because the noise dose equation provided better estimates of daily noise exposures when the time-at-task (C_i) data and the mean task-based noise exposures (L_{task}) came from the same population of farmers, it is possible that mean noise levels of agricultural tasks from one population of farmers cannot be generalized to another.

It is also possible that misclassification of the time-at-task data lead to the inability to accurately estimate 8-hr TWAs. Due to direct observations, accurate time-at-task data would have been expected. However, other studies have shown moderate to good correlation between self-reported and observed time-at-task information.[73,74,77] Also the range of estimated 8-hr TWA noise exposures calculated taking into account variability in the time-at-task (C_i) are noticeably smaller than the ranges calculated using the variability in the task-based noise exposures (L_{task}). It is unclear to what extent the accuracy in the time-at-task data was improved due to direct observation of time-at-task.

Another possibility for inaccurate estimated 8-hr TWAs is short duration tasks with high noise exposures went unreported by the observers, negating the benefit of the more accurate time-at-task observations of longer duration tasks. This may explain why more than half of the measured 8-hr TWAs did not fall within the estimated ranges accounting for the variability in time-at-task (C_i) and the task-based noise exposures (L_{task}).

In addition to evaluating the accuracy of the estimated 8-hr TWA noise exposures, the associations between noise exposure and work, demographic, and farm characteristics were also examined. The results indicate that task, work area, and number of noise sources are significant determinants of noise exposure. No associations between noise exposure and any demographic or farm characteristics were identified by the multivariable linear mixed regression analysis, indicating factors related directly to work practices determine noise exposure.

The current study is one of the few to look at determinants of noise exposure in an occupational setting. Other studies examining determinants of exposure for hazards, such as aerosols and solvents, have found that the task, time-at-task, equipment, and work area have statistically significant associations with exposure.[63,78-81] Two studies have examined determinants of noise exposure specifically. One study of noise exposures in the construction industry found that task and equipment were statistically significantly association with noise exposure.[77] Another study, specific to the agricultural industry, found tasks and work area had a significant association with noise exposure.[82] The results of the current study coincide with the results of other studies in the literature indicating factors specific to how jobs are performed determine noise exposure.

Contrary to other studies, the current study did not examine the association between specific pieces of equipment and noise exposure, or time-at-task and noise exposure. For the current study equipment was closely related to task; therefore that particular determinant of exposure was not examined. Although equipment was not included in the analysis, the number of noise sources was examined, and found to have a statistically significant association with noise exposure. The parameter estimate for number of noise sources indicates that each additional noise source increases the noise exposure by only 1.7 dBA. This may seem insignificant, but not unexpected because adding multiple noise sources is not arithmetic due to the logarithmic decibel scale.[37] Time-at-task was also not analyzed in the current study. However, if included in the analysis time-at-task would have calculated the effect varying task times had on the decibels of noise exposure.

The current study also went beyond the scope of previous studies by analyzing the associations between a number of personal demographic and farm characteristics, and noise exposure. The unadjusted regression analysis indicated that education level, diagnosed hearing loss, and being the principal farm operator could potentially be associated with noise exposure. However, when controlled for task, work area and number of noise sources, those demographic or farm characteristic did not have a significant association with noise exposure. The study by Nieuwenhuijsen et al. did find an association between farm size and noise exposure. This runs contrary to the current study, where size of farm (acres) was investigated, but not associated with noise exposure.[82]

Not only did this study identify statistically significant determinants of noise exposure, it also provides valuable insight into why the task-based noise exposures were unable to accurately estimate the 8-hr TWAs. The task-based noise exposures used to estimate the 8-hr TWAs were simply the mean noise exposures for particular agricultural tasks. However, the results of the multivariable linear mixed regression analysis indicate task, number of noise sources, and work area are significant determinants of noise exposure, and should be taken into account when estimating 8-hr TWAs. It is unclear how much the accuracy would improve by including number of noise sources and work area in the 8-hr TWA estimates. In order to incorporate these determinants of noise exposure into 8-hr TWA estimates calculated using the noise dose equation; tasks would need to be placed into additional categories representing number of noise sources and work area. While this may increase the accuracy of the estimated 8-hr TWA noise exposures, the complexity required to collect this additional data make this approach impractical.

This study had several limitations, in addition to the limitations discussed in Chapter 3 that could have affected the agreement between the measured and estimated 8-hr TWA noise exposures. The test group also consisted of a small sample size with a lack of repeated measures per farmer. The sample size diminished the power of the simple linear regression analysis to measure the agreement between the measured and estimated 8-hr TWAs. The population of farmers in both the database group and the test group were selected non-randomly and restricted to precise geographical areas with highly specific agricultural operations. It is possible that the noise exposures used to build the task-based noise exposures database cannot be generalized to the farming population from which the test group was selected.

Another limitation of the current study is the possibility that the time-at-task observations are inaccurate. The direct observations of time-at-task should have reduced misclassification. The observers for the test group were give instruction on the study protocol and equipped with the same observational form, but an evaluation between the observers for the two groups of farmers was not done, therefore concordance between them could not be determined.

The current study also had limitations specific to identifying determinants of noise exposure. The task-based noise exposure database used in the multivariable linear mixed regression analysis was from a relatively small sample size. Noise exposure and task data corresponding to approximately 30,000 one-minute noise measurements were collected. However, the data only came from 32 farmers on 18 farms, with one to three repeated measures per farmer. Additionally, the number of tasks monitored was left to chance, and in a few instances there were very few noise measurements for some tasks. This would limit the power of the linear regression analysis to identify statistically significant associations between the independent variables and noise exposure. This may explain why a statistically significant association between operating an ATV and noise exposure was not found. Also, with only 32 farmers and 18 farms in the study, there were few demographic and farm characteristics relative to the 30,000 one-minute noise measurements. This may explain why none of the demographic or farm characteristic had a statistically significant association with noise exposure.

Even though the noise dose equation was ineffective at estimating accurate 8-hr TWA noise exposures, there were strengths for this study in addition to those in Chapter 3. One of the strengths was that the time-at-task data for the 20 farmers in the test group were collected by direct observation, in a manner similar to the collection of the task data for the task-based noise exposure database. However, the observational data for the test group was less detailed than the observational data for the database group. Given that the variations in the time-at-task data do not lead to much variability in the final estimates of 8-hr TWAs, accuracy within 15 minute appears to be acceptable.

An additional strength of this study is the 8-hr TWA estimates were made for farmers independent of the farmers used to calculate the task-based noise exposures. Using an independent population allows validation of not only the agreement between measured and estimated 8-hr TWAs, but also assesses the generalizability of the task-based noise exposures. The agreement between the measured and estimated 8-hr TWAs were greater when the time-at-task data used in the estimates were from the same population as the task-based noise exposures.

For the identification of significant determinates of noise exposure a major strength was that task and covariate data used in the multivariable linear mixed regression analysis was collected by direct observation. Direct observation allowed precise start and stop times for tasks to be recorded. Furthermore, direct observation established accurate counts of noise sources and correct identification of work areas. Therefore, it is unlikely that there were any misclassification of these independent variables.

An additional strength is the continuous outcome measure used in the multivariable linear mixed regression analysis. The only other study to identify determinants of noise exposure for agricultural operations was the study by Nieuwenhuijsen et al., which used dichotomous outcome variables of low versus medium noise exposure and low versus high noise exposure in their analysis.[82] Use of a continuous outcome measure for the current study reduced non-differential misclassification and improved the power to detect associations between the independent variables and noise exposure.

Conclusions

In summary, the results indicate the noise dose equation, when calculated using predetermined task-based noise exposures, does not accurately estimate 8-hr TWA noise exposures. There was almost no agreement between the estimated and dosimeter-measured 8-hr TWA noise exposures. Furthermore, individual observations of the measured 8-hr TWA did not consistently fall within the expected ranges of the estimated 8-hr TWA noise exposures calculated taking into account the expected variability in the time-at-task observations and the task-based noise exposure means. Ultimately, there is too much variability in the task-based noise exposures to use them to accurately estimate 8-hr TWA noise exposures of farmers and farm workers. Furthermore, task-based noise exposures measured for one population of farmers may not be generalizable to another population.

The current study did identify several determinants of noise exposure. The results of the multivariable linear mixed-effects model found that factors directly related to how the job of grain production is performed had a statistically significant association with noise exposure. Furthermore, the results of the regression analysis indicate that estimates of 8-hr TWA noise exposures could be improved if task-based noise exposure were further categorized to account for work area and number of noise sources. However the detailed task, noise source and work area information needed would be difficult to collect by farmer self-reporting. Accurate collection of this data could be achieved by direct observation, but would be no more practical than measuring actual noise exposures.

Table 4.1. Comparisons of demographic characteristics between farmers and farm workers in the database group and the test group

Characteristics	Mean[1] (SD) or Frequency[2] Database Group[3] (N=32)	Test Group[4] (N=12)
Age	42.7 (14.3)	41.0 (17.3)
Years Farming	24.1 (13.6)	24.2 (13.2)
Hours per week growing season	58.1 (17.7)	66.5 (32.8)
Hours per week off season	26.7 (13.6)	20.7 (19.9)
Diagnosed Hearing Loss	6 (18.7%)	8 (66.7%)
Primary Occupation Farming	31 (96.9%)	8 (66.7%)
Participants with Second Job	8 (25%)	5 (41.7%)
Gender		
Male	31 (96.9%)	8 (66.7%)
Female	1 (3.1%)	4 (33.3%)
Education		
Some High School	3 (9.4%)	2 (16.7%)
High School Graduate	8 (25.0%)	3 (25.0%)
Some College	7 (21.9%)	6 (50.0%)
College Graduate	14 (43.7%)	1 (8.3%)
Marital Status		
Single	7 (21.9%)	4 (33.3%)
Married	22 (68.7%)	6 (66.8)
Divorced	2 (6.3%)	2 (16.8%)
Widowed	1 (3.1%)	0 (0%)
Income		
Less than $40,000	9 (28.1%)	4 (33.3%)
$40,000 to $80,000	10 (31.3%)	4 (33.3%)
More than $80,000	8 (25.0%)	2 (16.7%)
Refused to Answer	5 (15.6%)	2 (16.7%)
Often work around loud noises		
Never	0 (0%)	0 (0%)
Some of the Time	21 (65.6%)	6 (50.0%)
Most of the Time	10 (31.3%)	4 (33.3%)
All of the Time	1 (3.1%)	2 (16.7%)
Hearing Protection		
Never	19 (59.4%)	5 (41.7%)
Some of the Time	9 (28.1%)	2 (16.7%)
Most of the Time	3 (9.4%)	4 (33.3%)
All of the Time	1 (3.1%)	1 (8.3%)

[1] Continuous variables given as mean (standard deviation)

[2] Categorical variables are expressed by frequency (percent)

[3] Consists of farmers who provided noise exposure data for calculation of mean task-based noise exposures (three study participants did not complete surveys)

[4] Consists of farmers who provided observational task data for estimation of 8-hr TWAs (two study participants did not complete surveys)

Table 4.2. Comparisons of farm characteristics between farms in the database group and the test group

Characteristics	Mean[1] (SD) or Frequency[2]	
	Database Group[3]	Test Group[4]
Number of Workers (Family)	2.8 (1.6)	3.4 (0.9)
Number of Workers (Hired)	2.2 (3.9)	2.8 (1.8)
Number of Tractors	5.6 (1.4)	4.6 (0.9)
Number of Combines	1.6 (0.5)	2 (0)
Number of Portable Augers	3.2 (1.0)	2.8 (1.3)
Number of Skid Steers	0.8 (0.4)	0.2 (0.4)
Number of Grain Bins	10.7 (6.1)	24 (2.2)
Number of Grain Dryers	0.5 (0.5)	0.8 (1.3)
Number of Grain Trucks	3.3 (1.8)	2.6 (1.1)
Number of Semis	1.8 (1.4)	0.6 (1.3)
Size of farm (acres)	2357 (1286)	2750 (500)
< 1200	4 (22.2%)	
1200 to 2199	4 (22.2%)	1 (20%)
2200 to 3199	5 (27.8%)	3 (60%)
> 3200	5 (27.8%)	--
Unknown	--	1 (20%)
Gross Income from Farm		
Refused	2 (16.7%)	1 (20%)
$60,000 to $79,999	--	1 (20%)
$80,000 to $99,999	--	1 (20%)
Over $100,000	15 (83.3%)	2 (40%)
Value of Farm Assets		
Refused	3 (16.7 %)	1 (20%)
Under $1,000,000	3 (16.7 %)	4 (80%)
$1,000,000 to $5,000,000	8 (44.4 %)	--
Over $5,000,000	4 (22.2 %)	--

[1] Continuous variables given as mean (standard deviation)

[2] Categorical variables are expressed by frequency (percent)

[3] Consists of farms where noise exposure data for calculation of mean task-based noise exposures were collected

[4] Consists of farms where observational task data for estimation of 8-hr TWAs were collected (data from one farm not available)

Figure 4.1. Comparisons of predicted and measured 8-hr TWA noise exposures for farmers and farm workers in the database group

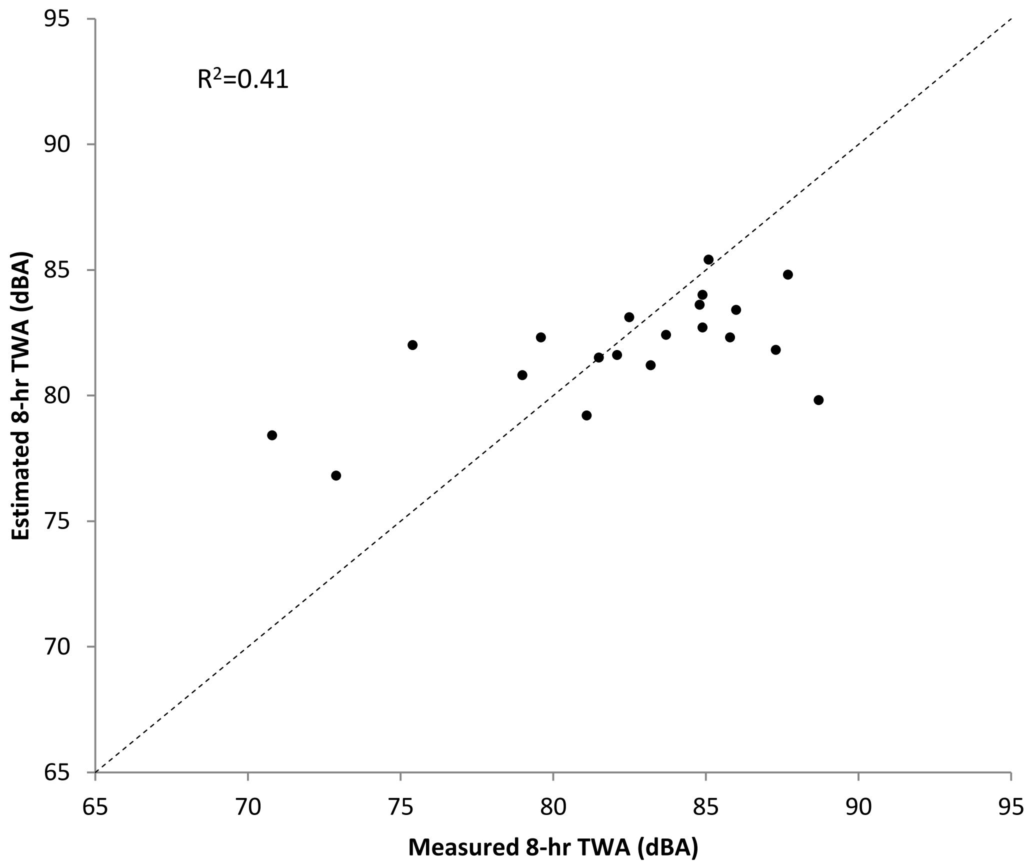

Figure 4.2. Comparisons of predicted and measured noise dose for farmers and farm workers in the database group

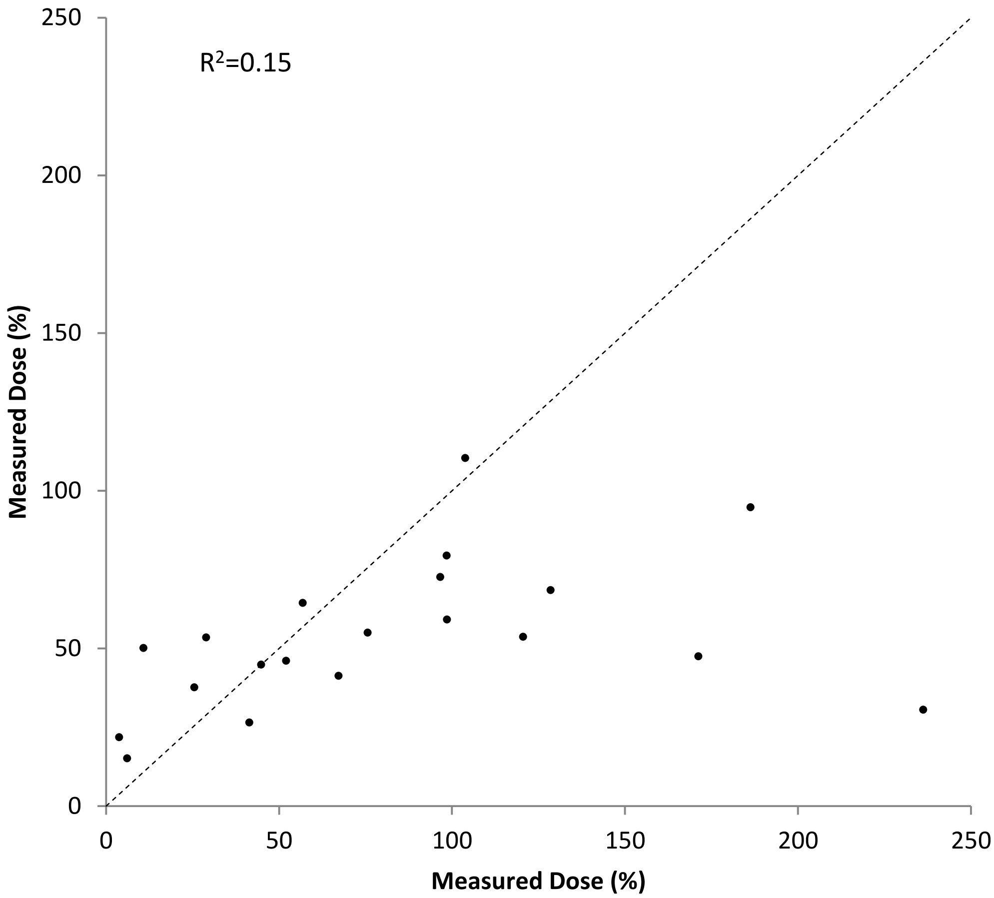

Figure 4.3. Comparisons of predicted and measured 8-hr TWA noise exposures for farmers and farm workers test group

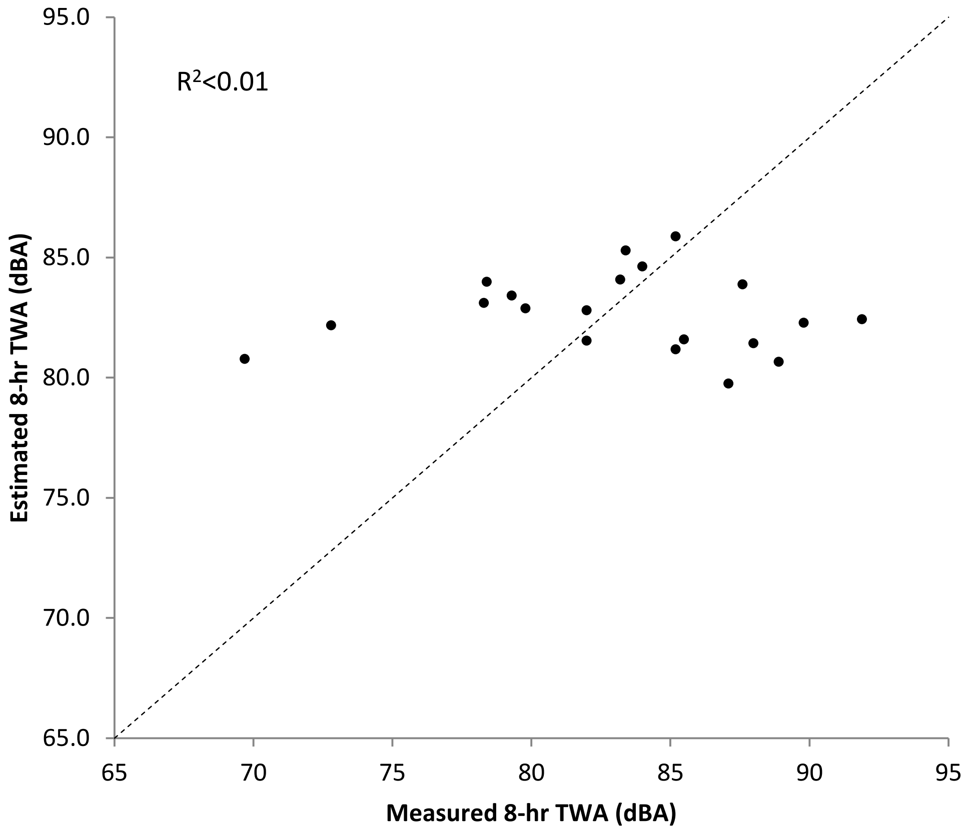

Figure 4.4. Comparisons of predicted and measured noise dose for farmers and farm workers in the test group

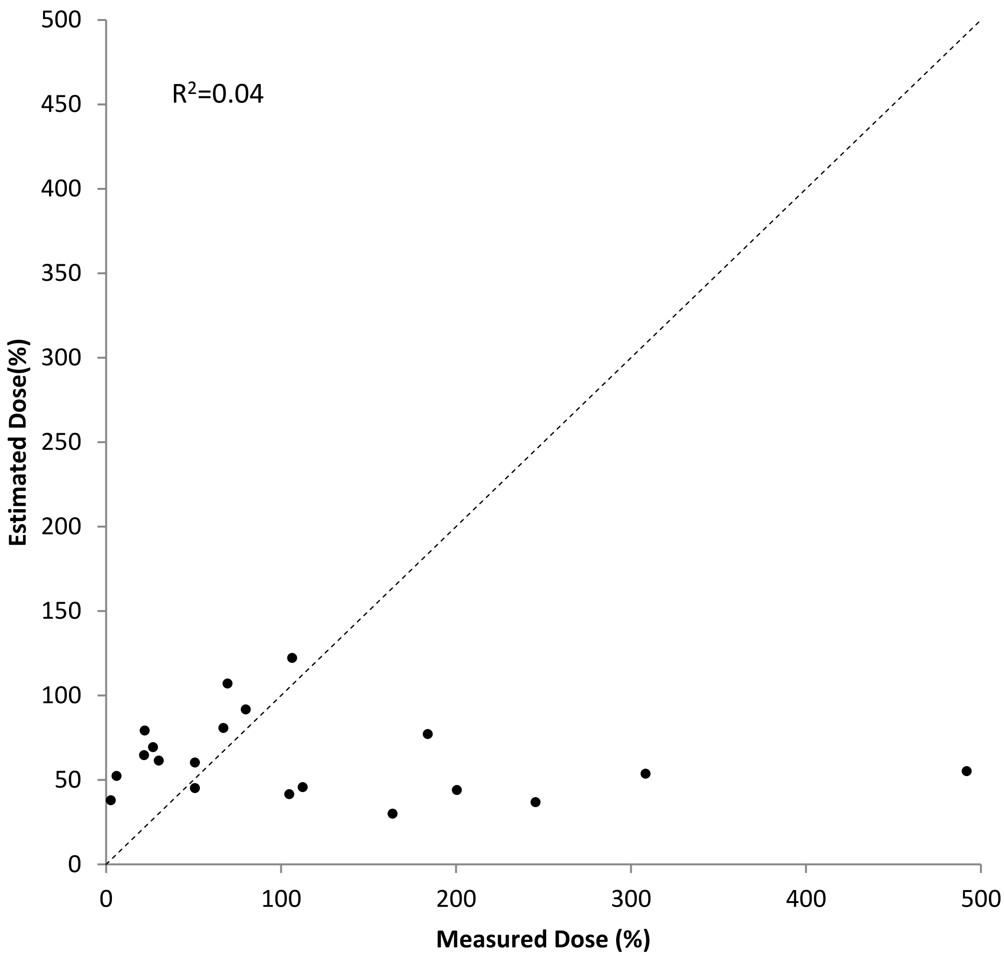

Figure 4.5. Comparisons of measured 8-hr TWA noise exposures to an upper and lower 8-hr TWA estimate based on the standard deviation in the predetermined task-based noise exposures (L_{Task})

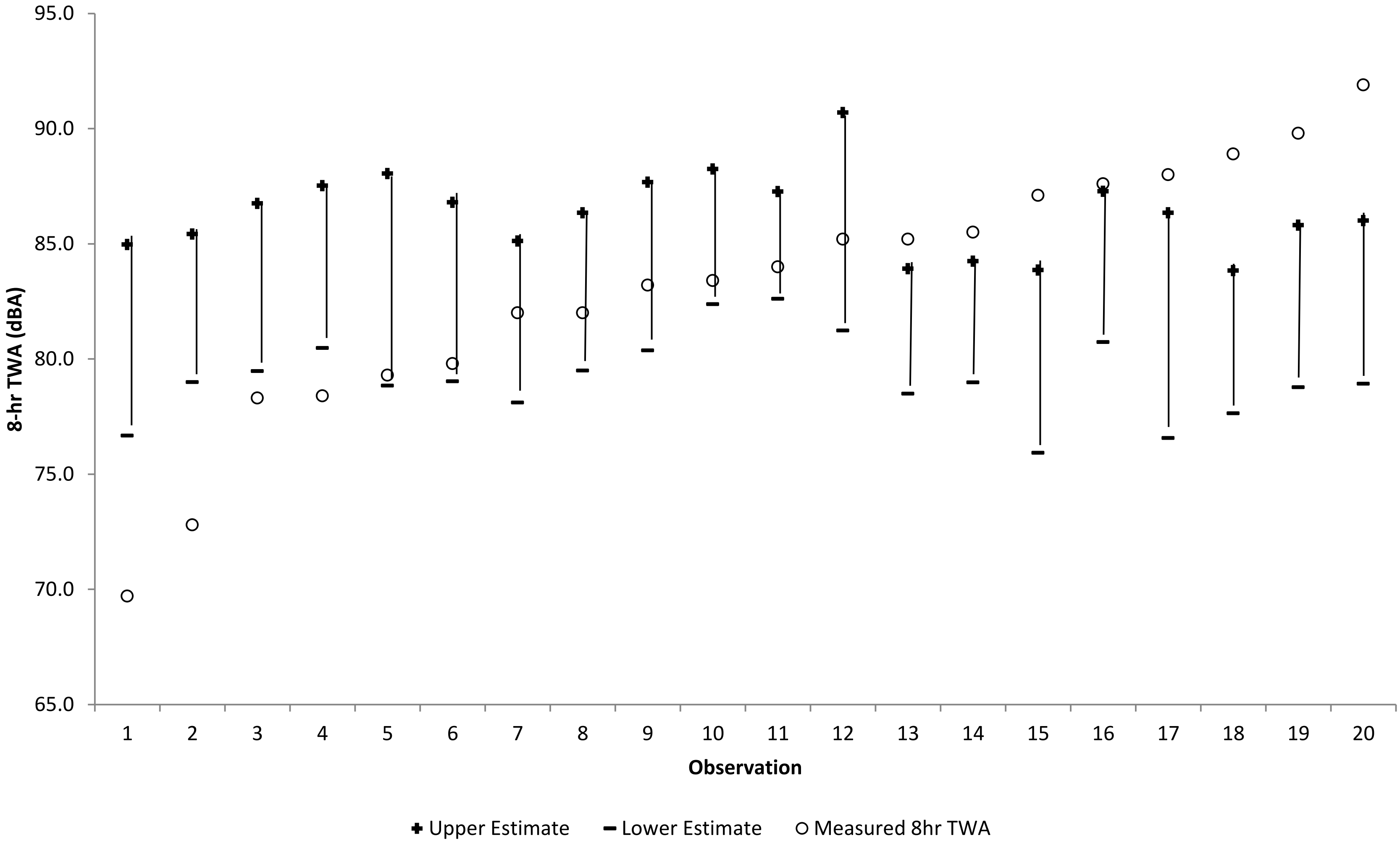

Figure 4.6. Comparisons of measured 8-hr TWA noise exposures to an upper and lower 8-hr TWA estimate based on ±15 minute variations in the time-at-task observations (C_i)

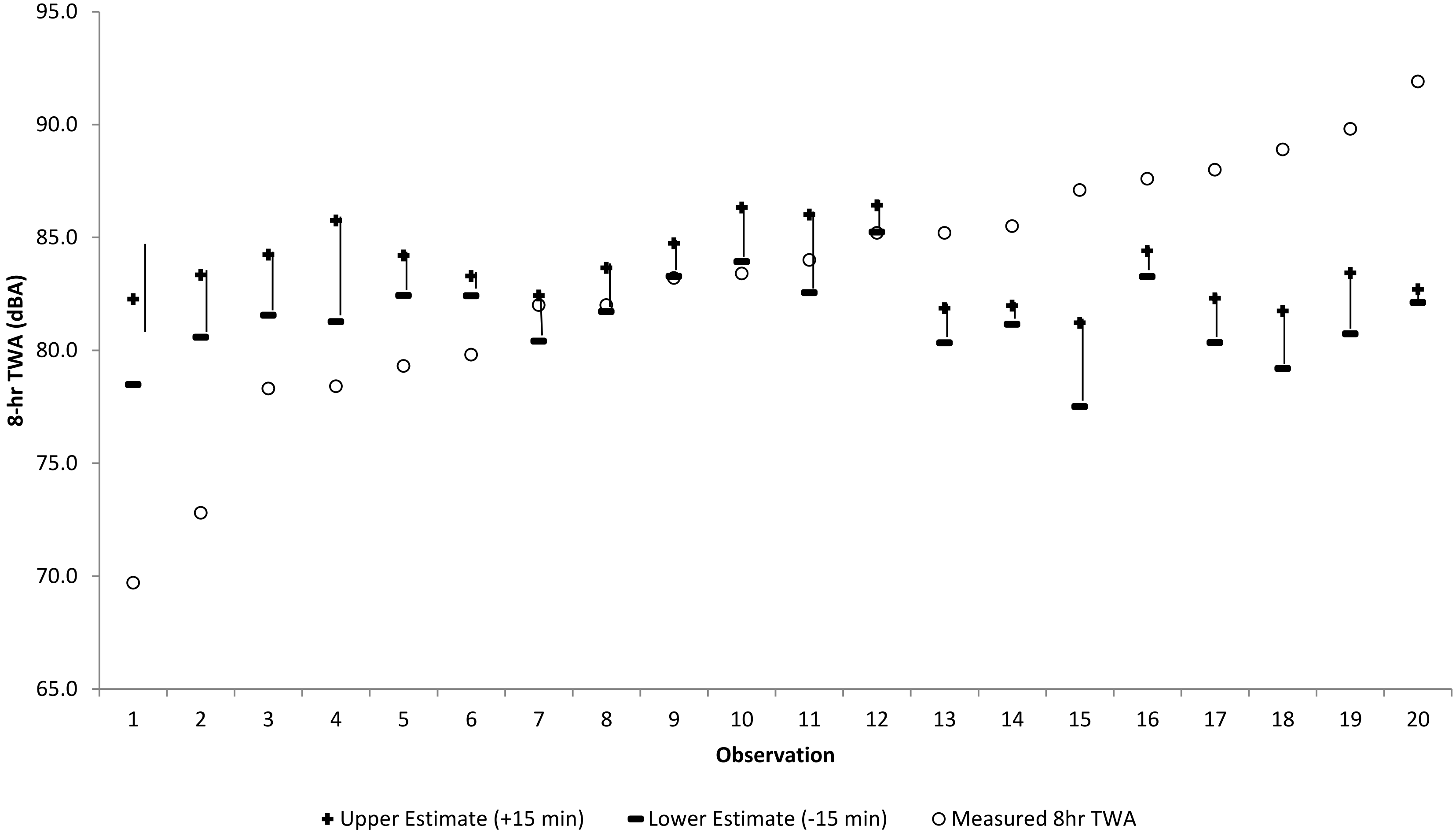

Figure 4.7. Comparisons of measured 8-hr TWA noise exposures to an upper and lower 8-hr TWA estimate using a Monte Carlo simulation to account for variations in the time-at-task observations (C_i) and task-based noise exposures (L_{Task}) simultaneously

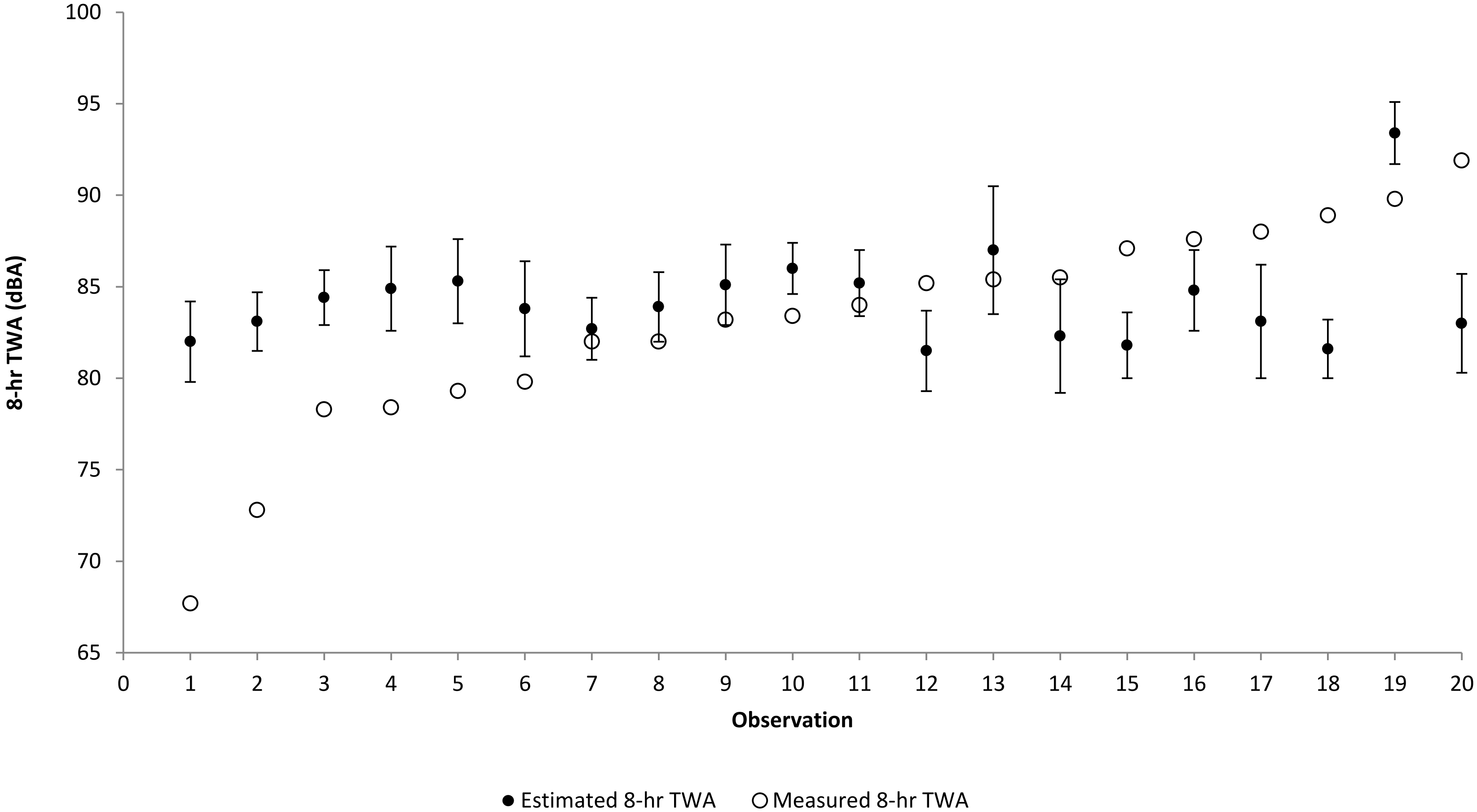

Table 4.3. Unadjusted associations (multivariable linear mixed regression analysis) between agricultural exposure variables and noise exposure in dBA.

Exposure Variable	**P-Value**
Task	<0.01
Work Area	<0.01
Hearing Protection Use	<0.01
Number of noise sources	<0.01
Age	0.62
Size of farm (acres)	0.89
Income	0.80
Marital Status	0.60
Education	0.12
Diagnosed Hearing Loss	0.06
Years Farmed	0.81
Often work around loud noises	0.65
Number of employees working	0.30
Number of family members working	0.38
Total number of workers	0.23
Farm Assets	0.43
Total number of tractors	0.99
Total number of combines	0.58
Total number of grain augers	0.79
Total number of grain bins	0.73
Total number of grain dryers	0.53
Total number of grain trucks	0.32
Total number of semis	0.35
Farm Upkeep	0.74
Machinery Upkeep	0.28
Principal Operator or Employee/Family	0.06

Table 4.4. Final multivariable linear mixed effects model of agricultural noise exposure variables and noise exposure in dBA

Exposure Variable	β	95% CI Lower	95% CI Upper	P-Value	Type III Tests of Fixed Effects
Intercept	73.9	72.8	74.9		
Number of noise sources	1.7	1.6	1.9	<0.01	<0.01
Task					
Operating Grain Vacuum	18.6	17.7	19.5	<0.01	
Operating Other Equipment	17.5	16.4	18.5	<0.01	
Unloading Grain at Elevator	8.9	8.2	9.7	<0.01	
Driving Grain Trucks	8.2	7.6	8.7	<0.01	
Working Around Grain Bins	8.0	7.2	8.8	<0.01	
Unloading Grain/Loading Grain Bin at Farm	7.6	6.6	8.7	<0.01	
Changing Tires on Vehicles and Implements	6.8	5.9	7.7	<0.01	
Planting Grain Crops	5.1	4.5	5.6	<0.01	
Combining Grain Crops	5.1	4.6	5.6	<0.01	
In Shop Working	4.9	4.5	5.4	<0.01	
Plowing/Digging/Ditching Fields	4.8	4.2	5.4	<0.01	
Prepping Equipment	4.7	4.3	5.2	<0.01	<0.01
Checking Equipment/Field/Crops During Field Work	4.7	4.2	5.5	<0.01	
Driving Tractor Non-Field Work	4.6	4.0	5.2	<0.01	
Spraying Fields	3.4	2.9	4.0	<0.01	
Maintenance on Equipment	2.8	2.5	3.2	<0.01	
Operating Tractor Other Field Work	2.5	1.9	3.2	<0.01	
Driving Pickup/Personal Vehicles	2.2	1.6	2.8	<0.01	
Misc. Work In Field	1.8	1.2	2.3	<0.01	
Operating Grain Cart	1.7	0.9	2.5	<0.01	
Operating ATV	1.4	-0.4	3.2	0.12	
Unaccounted for work time	0.7	0.0	1.3	0.05	
Misc. Work Around Farm	0.0	--	--	--	
Work Area					
Cab (Windows or Doors Open)	0.3	-0.1	0.8	0.12	
Partial Enclosure	0.3	-0.8	1.4	0.58	
Cab (Windows or Doors Closed)	0.1	-0.3	0.5	0.50	
Outdoors	0.0	--	--	--	<0.01
Unaccounted For Work Area	-0.3	-0.9	0.3	0.30	
Indoors	-4.0	-4.3	-3.7	<0.01	

* Hearing protection had a statistically significant association (p-value <0.01) with noise exposures, but was removed from the final model because hearing protection does not affect the amount of noise measured by dosimetry

CHAPTER V
CONCLUSIONS

Summary

The primary objective of this dissertation was to provide a detailed assessment of the effects of agricultural tasks on hearing loss and noise exposures and determine if task-based noise exposure measurements can be used to accurately estimate the 8-hr TWA noise exposures of farmers and farm workers. To accomplish this objective, three studies were conducted to: 1) examine the effect of lifetime duration engaging in common agricultural tasks on hearing loss among farmers and rural residents; 2) calculate and characterize the task-based noise exposures of farmers and farm workers; and 3) evaluate the effectiveness of estimating the 8-hr TWA for farmers and farm workers using predetermined task-based noise exposures and identify determinants of noise exposure that may improve estimates.

This dissertation study found that hearing loss and noise exposures among farmers are complex. The work environment of agricultural operations is dynamic, where the jobs change with the seasons, activities and tasks change day-to-day, equipment use is unpredictable, and the workforce is highly mobile. The hypothesis was that investigating hearing loss associations and noise exposures at the task level would explain some of this complexity, and allow tasks associated with hearing loss and tasks that have intense noise exposures to be identified. Control strategies designed to limit exposure to hazardous noise and ultimately decreased the prevalence of hearing loss among agricultural populations could then be targeted to these specific tasks. Furthermore, it was thought that task-based noise exposures, in addition to identifying tasks with hazardous noise exposures, could be used to estimate the daily noise exposures of farmers and farm workers.

Overall, tasks provide important information about hearing loss prevalence and exposure to hazardous noise, and can be used to guide intervention strategies. However, there are still unknown factors that influence exposure to hazardous noise levels and ultimately the development of noise-induced hearing loss. Most likely, there are aspects about how farmers and farm workers complete their jobs, specific to each individual, that determine exposure to noise and hearing loss development. More detailed evaluation of tasks is needed to increase the understanding of hearing loss and noise exposure in this dynamic work environment.

Study Findings

Effects of Common Agricultural Tasks on Measures of Hearing Loss

Self-reported years engaged in common agricultural tasks may not be the most suitable metric for determining the amount of hearing loss in agricultural populations. The multivariable linear regression analysis identified only a few agricultural exposure variables had a statistically significant association with hearing loss. The significant agricultural exposures varied depending on how the PTA hearing loss outcome was calculated and if hearing loss was analyzed as a categorical or continuous variable. The agricultural exposures analyzed for their association with hearing loss are likely a poor representation of the actual lifetime noise exposures of farmers and farm workers. More specific exposure variables for agricultural tasks, such as days per year or hours per week, may better represent the underlying noise exposures.

In addition, male farmers and male non-farm residents may have similar noise exposure histories. Agricultural exposure variables specific to agricultural operations such as operating tractors and farm equipment were less likely to be associated with hearing loss, while agriculture exposures related to both farmers and rural residents, such as hunting/target shooting, pneumatic/electric tool use, ATV/motorcycle use and noisy non-farm jobs, were more likely to have an association with hearing loss. Furthermore, hearing loss caused by exposure to hazardous noise levels primarily affects hearing at the higher frequencies, and there was not a statistically significant difference in the prevalence or decibels of high frequency hearing loss between male farmers and male non-farm residents, indicating that both groups have achieved a similar amount of high frequency hearing loss.

Description of Task-Based Noise Exposures for Farmers and Farm Workers Involved in Grain Production

Several tasks were identified as having hazardous noise exposures. Agricultural tasks such as operating a grain vacuum, loading and unloading of grain bins, working around grain bins, unloading grain at elevators, and changing tires on vehicles and implements have noticeably intense noise exposures. Similar to 8-hr TWA noise exposure measurements, there is still considerable variability in these mean task-based noise exposures. Due to this variability, most of the mean task-base noise exposures in this study were not statistically different from one another. In addition to tasks, specific pieces of equipment were identified as having intense noise exposures, but there is also considerable variability in the measurements. Another important finding from this study was that for most tasks the variability in the noise exposure measurements was within each farm. The majority of the variability being within each farm indicates that the manner in which each individual farmer or farm worker completes these tasks is what ultimately determines noise exposure.

The results of this study can be used to identify agricultural tasks that should be targeted for noise control strategies. Focusing on limiting the noise exposures for high noise exposure tasks would reduce lifetime noise exposure and likely decrease the risk of noise-induced hearing loss. However, the variability in the mean task-based noise exposure and the presence of intense noise exposure levels for nearly every task signifies no agricultural task should be overlooked as a potential source of hazards noise.

Estimations of 8-hr TWA Noise Exposures for Farmers and Farm Workers Involved in Grain Production Using Task-Based Noise Measurements

The noise dose equation does not accurately estimate the 8-hr TWA noise exposures for farmers and farm workers when calculated using predetermined task-based noise exposures measured from an independent population of farmers. Even when calculating an expected range for the estimated 8-hr TWA noise exposures, taking into account the variability in the task-based noise exposures and the time-at-task information, the measured 8-hr TWAs do not fall within the expected range. Furthermore, the estimated TWAs were sometimes greater than and other times less than the actual 8-hr TWA noise exposure measurements. Ultimately, the variability in the mean task-based noise exposures is too great to obtain an accurate 8-hr TWA estimate.

To potentially improve the accuracy of 8-hr TWA estimates, information in addition to task, such as the number of noise sources and the work area need to be incorporated into the task-based noise exposure categories. This may account for some of the variability in the task-based noise exposure measurements. This could also be accomplished by using statistical models more sophisticated than the dose equation that can take into account additional determinants of noise exposure. However, additional information about determinants of noise exposure would be difficult accurately collected by worker self-reports, and the detailed observations required would be no less labor intensive than measuring actual noise exposures.

Implications for Industrial Hygienists and Public Health

The results of this dissertation give new insight into the public health approach that should be considered to reduce noise exposure and prevent hearing loss among farmers and farm workers. Several tasks were identified that should be the focus of interventions to reduce hearing loss. A common tendency is to focus on the tasks that constitute a farmer’s workday as the source of hazardous noise exposures leading to noise-induced hearing loss. Because male gender and agricultural exposures common to both farmers and rural residents (i.e. noisy non-farm jobs, hunting/target shooting, and pneumatic/electric tool use) were associated with hearing loss, it is likely that male farmers and rural residents have similar noise exposure histories. Therefore, interventions should focus on those tasks in which males in the rural environment participate and not just on farming tasks alone.

The results of this study revealed that years performing common agricultural tasks are a poor representation of actual noise exposure. Therefore, caution should be used if substituting years engaging in agricultural tasks for noise exposure when researching hearing loss in agricultural populations. Studies using duration of performing agricultural tasks in their analysis should use a more specific estimate of duration rather than years, such as weeks per year or days per week. Ultimately quantitative measurements of noise exposure would be best when investigating the associations between hearing loss and agricultural tasks. However, this is often not feasible, especially when collecting research data from surveys and questionnaires.

The current study identified several tasks that consistently had intense noise exposures. Targeting noise control strategies such as: hearing protection use, changes in work practices, and engineering controls for equipment, will most likely decrease lifetime noise exposures for farmers and farm workers. However, due to the variability in the task-based noise exposures caution needs to be used when relying on them to guide interventions.

Instances of intense noise levels were measured for nearly every task; therefore no task should be disregarded as a potential source of hazardous noise. This finding has implications when choosing the control strategy to reduce noise exposures. If health and safety professionals proposed work changes or hearing protection use only for tasks with mean noise exposure >85 dBA, it could lead to a feeling among farmers and farm workers that other agricultural tasks pose no risk, when in fact, noise exposures intense enough to damage hearing may still be present. The best approach to reduce noise exposures would be to implement engineering controls to limit the production of noise at the source, thereby taking some of the responsibility of hearing protection away from farmers and farm workers.

The oval intent of this dissertation was to determine if task-based noise exposures have usefulness beyond simply identifying tasks with hazardous noise exposures, and give industrial hygienists and other health and safety professional the ability to accurately estimate 8-hr TWA noise exposure without the need to conduct noise monitoring. The results of the current study indicate that models more complex than the noise dose equation would be needed to obtain accurate estimates of 8-hr TWA noise exposures. Also, information such as the equipment being used, and the work area would need to be collected and included in the categorization of tasks. Due to the complexity of the prediction models needed and the considerable effort required to observe and record task, equipment, and work area information; estimating the 8-hr TWA using task-based noise exposure may be no more practical than directly measuring noise exposure using personal noise dosimeters or sound level meters. Ultimately, at the present time, quantitative measurement of noise exposures is the only dependable way to get accurate representations of noise exposures for farmers and farm workers.

Future Research

Occasionally, the length of time farmers and farm workers perform agricultural tasks will be the only exposure information available when studying hearing loss in agriculture. Because years performing agricultural tasks are a poor representation of lifetime noise exposure, studies examining the associations between more specific durations of agricultural tasks and hearing loss are merited. Furthermore, because the results of the current study indicated that tasks common to both farmers and rural residents were associated with hearing loss, studies exploring the risk of hearing loss from non-farm rural tasks, as well as studies examining hearing loss of rural non-farm residents are warranted.

The task-based noise exposure database used to calculate the task-based noise exposures was designed for the inclusion of additional task and noise exposure data. While the current 30,000, one-minute noise exposures may seem substantial, the analyses in Chapters 3 and 4 of this dissertation were conducted using a relatively small sample size. Continued effort should be made to provide additional task and noise data for the task-based noise exposure database. This will allow the noise exposures of additional tasks to be calculated and increase the overall number of measurements for each task, which would likely decrease the uncertainty in the mean task-based noise exposures.

Finally, one area of research that would fill a gap of knowledge in the literature would be an examination of noise-induced hearing loss risk as a function of task-based noise exposures. The current risk assessment of noise-induced hearing loss is based on lifetime exposure to average daily noise levels. Even if task-based noise exposures cannot accurately estimate daily noise levels, and may only be useful for identifying tasks with intense noise exposures, there may still be valuable information about the risk of noise-induced hearing loss for farmers and farm workers that can be learned from task-based noise measurements. Unfortunately the hearing loss and task-based noise exposure data in this dissertation are from two separate agricultural populations, and an evaluation of risk could not be made. The task-based noise exposure database developed for this project could be used for this research if audiometric data was included with future additions of noise exposure and task data.

APPENDIX A: TASK AND COVARIATE OBSERVATIONAL FORM

Description of Task:												
						AM/PM						AM/PM
Start Time AM/PM	:00	:10	:20	:30	:40	:50	:00	:10	:20	:30	:40	:50
Stop Time AM/PM												
Included Activities												
1:												
2:												
3:												
4:												
5:												
6:												
Primary Noise Sources From Task												
1:												
(Tractors, Combines, Etc.) Make:_______________ Model:____________ Year:________ Maintenance: ☐Good ☐Poor												
2:												
Tractors, Combines, Etc.) Make:_______________ Model:____________ Year:________ Maintenance: ☐Good ☐Poor												
3:												
Tractors, Combines, Etc.) Make:_______________ Model:____________ Year:________ Maintenance: ☐Good ☐Poor												
4:												
Tractors, Combines, Etc.) Make:_______________ Model:____________ Year:________ Maintenance: ☐Good ☐Poor												
Loud Noise Sources Not From Task												
1:												
2:												
3:												
Simultaneous/Secondary Tasks												
1:												
2:												
Primary Work Area												
Indoors:												
Outdoors:												
Partial Enclosure:												
Cab: Windows/Doors Open:												
Cab: Windows/Doors Closed:												
Hearing Protection Use												
Ear Plugs:												
Ear Muffs:												
Miscellaneous												
Unaccounted for time:												
Overall Condition of Work Site: ☐Good Maintenance ☐Average Maintenance ☐Poorly Maintenance												
Comments:												

SID#_______________ Page_______ Date__________________

APPENDIX B: TASK-BASED NOISE EXPOSURE STUDY QUESTIONNAIRE

SID NUMBER: ____ ____ - ____

Task-Based Agricultural Noise Exposure Study
Farm Owner-Operator Questionnaire

Please take a few minutes to fill out this questionnaire. This is important information that we need for the study of agricultural noise exposures that you are participating in. We need to know some information about the type of production that occurs on your farm as well as some demographic information about yourself. This will enable us to accurately analyze the noise data that we have been, and will be collecting from you over this growing season. Completing all aspects of this study will allow us to reach our goal making farming as safe and healthy as possible for you, your family, employees and other producers.

Please answer each question as it relates to the current growing season (2009). Your answers will be kept confidential and you may skip any question you do not wish to answer. If you are not sure about the answer for questions that ask specific information such as acres of crops, income and assets please provide your best estimate.

The questionnaire should only take about 10 to 15 minutes to fill out. When you are done please mail it back to me at the University of Iowa by using the self-address postage paid envelope provided.

Thank you for your participation.

Michael Humann
The University of Iowa
100 Oakdale Campus, 124 IREH
Iowa City, IA 52242
319-335-4431

SID NUMBER: ____ ____ - ____

General Demographic Information

1. Please write in today's date?

____________	__________	___________
Month	Day	Year

2. What is your date of birth?

____________	__________	___________
Month	Day	Year

3. What is your gender?

O	O
Male	Female

4. What is your current marital status?

O	O	O	O
Single	Married	Divorced	Widowed

5. Which hand do you write with? This is important so that we can determine which ear may be most exposed to noise.

O	O	O
Right	Left	Both

6. What is the highest grade or year of school you have FINISHED?

O	O	O	O	O
Some High School	High School Graduate or GED Certificate	Some College	College Graduate (2yr or 4yr Degree)	Masters Degree or Higher

7. How much was your total income last year?

O	O	O	O	O	O
Less than $19,999	$20,000 to $39,999	$40,000 to $59,999	$60,000 to $79,999	$80,000 to $99,999	Over $100,000

SID NUMBER: ____ ____ - ____

8. During the past 12 months, have you ever had an injury while working on the farm?

O Yes O No

If yes, what type of injury was it? (Mark all that apply)

O Scrape/Abrasion	O Bruise/Contusion	O Sprain/Strain/Torn Ligament	O Broken Bone/Fracture	O Dislocation
O Cut/Laceration	O Puncture Wound	O Loss of Body Part	O Nerve Injury	O Burn
O Concussion/Loss of Consciousness	O Other (Please Specify) ______________________________			

9. Has a doctor or other health professional ever told you that you suffer from hearing loss?

O Yes O No

10. Do you consider farming to be your primary occupation?

O Yes O No

11. Approximately how many years have you been farming? ______________years

12. On average, how many hour per week do you work on the farm during the growing season? ______________________hr/week

13. On average, how many hours per week do you work on the farm during the off (winter) season? _________________hr/week

14. Do you have a second job?

O Yes O No

If yes, please specify what your second job is: ____________________________

If yes, how many hours per week do you work? ______________hr/week

SID NUMBER: ____ ____ - ____

Activity Survey

15. How often are you around loud noises while working on the farm? Noise on the farm that can be considered loud is noise from grain dryers, tractors or chain saws.

○ Never ○ Some of the time ○ Most of the time ○ All of the time

16. How often do you wear hearing protection while working around loud equipment?

○ Never ○ Some of the time ○ Most of the time ○ All of the time

17. In the table below indicate how often you do each of the following activities.

Activity	Less than 1 time each year or never	More than 1 time each year, and not more than 1 time each month	More than 1 time each month, and not more than 1 time each week	1 – 2 times each week	3 – 4 times each week	Nearly every day
Work around hogs	○	○	○	○	○	○
Work in a hog confinement building	○	○	○	○	○	○
Work around cattle	○	○	○	○	○	○
Work around other livestock	○	○	○	○	○	○
Operate four-wheelers or snowmobiles	○	○	○	○	○	○
Operate a riding lawnmower	○	○	○	○	○	○
Operate a push lawnmower	○	○	○	○	○	○
Operate a tractor	○	○	○	○	○	○
Use power tools	○	○	○	○	○	○
Go to car or truck races	○	○	○	○	○	○
Listen to loud music	○	○	○	○	○	○
Around gunshots (hunting or target shooting)	○	○	○	○	○	○
Drive a car or pickup with windows down	○	○	○	○	○	○

SID NUMBER: ____ ____ - ____

Importance Scale Survey

18. For each question below, circle the number to the right that best fits your opinion on the importance of the issue.

Question	Scale of Importance				
	Strongly Agree	Agree	No Opinion	Disagree	Strongly Disagree
If I am standing next to a person, and I need to shout for them to hear me, it is too noisy.	1	2	3	4	5
My hearing will get worse no matter what I do.	1	2	3	4	5
I know what I need to do to protect my hearing.	1	2	3	4	5
Hearing protection (earplugs, earmuffs, etc.) are uncomfortable.	1	2	3	4	5
It is hard to stay away from noise, even when I know it is too loud.	1	2	3	4	5
If hearing protection (earplugs, earmuffs, etc.) was around when I needed them, I would use them.	1	2	3	4	5
I can easily get hearing protection (earplugs, earmuffs, etc.) when I need them.	1	2	3	4	5
The sound of a four-wheeler is too loud and could damage my hearing.	1	2	3	4	5
I can still understand people talking when I wear hearing protection (earplugs, earmuffs, etc.).	1	2	3	4	5
I need to wear hearing protection (earplugs, earmuffs, etc.) at all times in order to protect my hearing.	1	2	3	4	5
My hearing could be damaged by chemicals.	1	2	3	4	5
I will hear ringing in my ears if I have been around noise that is to loud.	1	2	3	4	5

SID NUMBER: ____ ____ - ____

Farm Information

Please answer these questions for the current growing season.

19. How many total acres are included in the farm operation? ________________

20. How many acres are owned by the farm operator? ________________

21. How many acres are leased or rented? ________________

22. How many acres do you have in active production? (Row crops, hay,) ________________

23. How many acres do you have in pasture? ______________

24. In the tables below please indicate how many acres of each crop are/were under production during the most recent growing season.

Crop	Acres
Corn	________
Soybeans	________
Wheat	________
Barley	________
Hay	________
Sunflowers	________

Crop	Acres
Sugar Beats	________
Canola	________
Eatable Beans	________
Sorghum	________
Other _____________	________
Other _____________	________

25. How many employees and/or family members assisted with the farm operation during the current growing season?

Number of Family Members: ___________

Number of Paid Employees: ___________

Number of Other Workers: ____________

SID NUMBER: ___ ___ - ___

26. In the table below indicate how many livestock or animals are/were in production during the most recent growing season. Check yes, no or not applicable (NA) to indicate if the livestock are/were kept in a confinement building or high density feedlot.

Livestock/Animal Type	Number of Animals	Were animals ever kept in confinement building or high density feedlot		
Hogs	______	Yes O	No O	Don't Know O
Cows (non-dairy)	______	Yes O	No O	Don't Know O
Cows (dairy)	______			
Horses	______			
Chickens	______	Yes O	No O	Don't Know O
Turkeys	______	Yes O	No O	Don't Know O
Sheep	______			
Goats	______			
Other ______________	______			
Other ______________	______			

27. How much was your GROSS farm income last year?

O	O	O	O	O	O
Less than $19,999	$20,000 to $39,999	$40,000 to $59,999	$60,000 to $79,999	$80,000 to $99,999	Over $100,000

28. What would you estimate the current assets of the farm? This would include farm assets alone such as land, buildings, machinery and livestock, as well as money in the bank or investments specifically related to the farm.

O	O	O	O	O	O
No Assets	$0 to $49,999	$50,000 to $99,000	$100,000 to $199,999	$200,000 to $299,999	$300,000 to $399,999
O	O	O	O		
$400,000 to $499,999	$500,000 to $999,999	Over $1,000,000	Over $5,000,000		

SID NUMBER: ____ ____ - ____

29. In the table below please indicate how many pieces of farm equipment are/were/will be used during the current growing season.

Equipment Type	Number
Tractors	________
Combines	________
Skid Steers	________
Front End Loader	________
Grain/Beet Trucks	________
Semis	________

Equipment Type	Number
Gravity Flow Wagons	________
Portable Augers	________
Grain Bins	________
Grain Dryers	________
	________
	________

30. Overall how would you rate the upkeep and maintenance on your farm property?

O	O	O	O	O	O	O	O	O	O
10	9	8	7	6	5	4	3	2	1
Excellent		Very Good		Good		Fair		Poor	

31. Overall how would you rate the upkeep and maintenance on your farm machinery?

O	O	O	O	O	O	O	O	O	O
10	9	8	7	6	5	4	3	2	1
Excellent		Very Good		Good		Fair		Poor	

Additional Feedback

Please share any additional comments.

____

____

____

____

Thank you for taking the time to fill out our survey. We rely on this information to help us analyze our noise exposure data. Your input is greatly appreciated.

APPENDIX C: TASK DESCRIPTIONS ASSIGNED TO EACH TASK CATEGORY

Attaching/moving implement and vehicles

attaching header	moving implements
attaching drag	moving lawn mower
attaching drag	moving trailer
attaching header	moving vehicles into shed
attaching planter	parking tractor
changing combine header	putting away harvest equipment
detaching header and putting it on trailer	starting trucks/tractors
detaching seed bedder	swapping out anhydrous tanks
detaching sprayer	swapping out plows/diggers/seed bedder
loading up and moving mower	unhitching implement
lubing mower and attaching to tractor	unhitching plow/hitching new plow
moving around empty pesticide tanks/vehicles	unhooking header
moving auger and other equipment	unhooking implement (digger)
moving boat to make way for combine	unhooking implements
moving chemical	walking around farm (starting/moving truck)
moving combine (moving headers)	working/hooking up bailer
moving combine, going to pick up headers	moving tractor
moving equipment	moving tractor/digger
moving equipment around	moving combine and tractors
moving grain vacuum/prepping vacuum	

Changing tires on vehicles and implements

changing tire (in shop)	putting tires on rims
changing tire (outside)	removing tire
changing tire on digger	removing tractor tires
putting duels	replacing tires on combine

Checking equipment/field/crops during field work

checking anhydrous tank	checking plow
checking chisel plow	checking plow
checking combine	checking rows
checking combine header	checking rows outside
checking digger	checking seed bedder
checking digger in field	checking tank connection
checking digger/seed bedder	checking tractor and implement connection
checking laser	counting rows (outdoors)
checking on equipment	loading planter, checking planter
checking planter	removing debris from ditch
checking planter and rows	swapping anhydrous tanks checking connections
checking planter, metering out seed	working around combine in field
checking planter/loading planter	

Cleaning equipment

cleaning off combine	power washing
cleaning off header	power washing tractor
cleaning out combine	scraping mud off planter
cleaning out combine, prep so can combine diff variety	scraping mud off tractor
shoveling grain into truck/ cleaning off combine	cleaning out tractor
cleaning planter, for season end maintenance	washing tractor

Combining grain crops

Combining	driving combine harvesting wheat
combining soybeans	driving combine, combining wheat
combining sunflowers	operating combine
combining wheat	

Driving combine

Driving combine	riding in combine
driving combine on road	riding in combine (passenger)
driving combine to field/farm	riding in combine to field
driving combine to next field	

Driving grain trucks

driving back to field in grain truck	driving truck to elevator
driving empty grain truck to field	Driving truck to elevator/farm
driving empty truck back to farm	driving truck to farm
driving empty truck back to field	driving truck to field
driving grain truck	hauling grain back to farm
driving grain truck to elevator	hauling soybeans to elevator
driving grain truck to farm	moving grain truck
driving loaded grain truck to farm	moving grain truck holding chemical
driving loaded truck to elevator	moving grain truck/driving grain truck
driving pickup back to field	moving trucks
driving truck (to town)	parking grain truck

Driving pickup/personal vehicles

delivering anhydrous to field	driving service truck to field/farm
riding in car back to farm	driving to check fields
driving car out to field and back	driving to field my car
driving pickup truck	driving truck checking fields
driving out to field	driving truck/sprayer to field
driving part to neighbors in pickup	driving water truck to field
driving pickup to farm	getting pickup truck
driving pickup to farm to get anhydrous	moving pickup truck
driving pickup to field	picking up worker at other farm site
driving pickup truck to elevator/farm	raking soybean stalks

Driving semi

driving empty semi to farm with grain bins	driving semi back to farm
driving empty semi to field	driving semi from town to field
driving leaded semi to farm	driving semi to elevator
driving loaded semi to farm	driving semi to farm/field
driving loaded semi to farm	driving semi to field
driving loaded semi to farm	driving semi to town
driving semi	driving/moving semi
driving semi #1	moving semi
driving semi #2 to field	

Driving tractor non-field work

driving auger back to farm (with tractor)	driving tractor move implements
driving to next field in tractor	driving tractor to ditch
driving tractor	driving tractor to field
driving tractor back to farm/field	riding in tractor to combine
driving tractor back to the farm	swapping out tractors

Fueling equipment

fueling combine	fueling tractor
fueling semi with diesel	fueling truck with diesel (outside)

In house or office

break in house	in office talking with salesman
in house	lunch
in house checking market/DTN	running to house to get paperwork
in office	

In shop not working

coffee break in shop	in shop, not working, going over paperwork
in shop waiting for parts	washing up in shop

In shop working

checking moisture in shop	organizing and getting chemicals in shop
checking soybean moisture in shop	testing moisture in shop
cleaning up shop	working in shop
fixing combine header at shop	working in shop, fixing moisture probe
in shop	working in shop, gathering up tools
looking for tools	working on shop and talking on phone
miscellaneous work In shop	

Loading and unloading pickups/trailers

hooking up trailer to pick up	unloading pickup at other shop
loading construction tools into pickup	unloading trailer at farm site
loading trailer	unloading trailer at field
loading trailer	

Maintenance on equipment

adjusting brakes	maintenance on lawn mower
at workbench and tractor working on hydraulics	maintenance on planter
changing oil in the field	maintenance on sprayer
changing oil on tractor	maintenance on tractor
changing oil on tractor	moving/maintenance on semi
checking hydraulic hose (grain truck repair)	repairing combine header
checking hydraulic line, filling hydraulic fluid	repairing grain truck
fixing combine	routine maintenance on combine
fixing combine header	swapping out auger on grain truck
fixing corn picker	walking on implement (lifter)
fixing grain vacuum hose	working on boat (rec equip)
fixing ripper/digger	working on combine
fixing/repairing combine	working on header
greasing semi-trailer	working on implements (beet lifter)
maintenance (mainly looking/planning maintenance)	working on planter in yard
maintenance on air seeder tank	working on semi
maintenance on combine	working on sprayer
maintenance on combine header	working on trailer
maintenance on drill	working underneath grain truck
maintenance on fender?, removing bolts	working in shop, maintaining combine
maintenance on grain truck	working on implement (digger) in shop
maintenance on implement (lifter)	working on implement In shop

Maintenance on structures

maintenance of bin auger	prepping room for taping (checking screws)
working on bin fans	working on bin fans/maintenance on storage structures
taping and mudding sheetrock	working on bin fans

Miscellaneous work around farm

around farm	miscellaneous activities on farm site
around farm site	looking at airplanes
miscellaneous	standing around farm site
miscellaneous work around planter/tractor	working in yard
miscellaneous work around farm getting semi unstuck	working out in yard, picking corn

Miscellaneous work in field	
checking crops for aphids	standing in field
checking fields	standing in field next to semi
checking moisture in wheat field	standing in field waiting to load truck
in tractor waiting for rain to pass	waiting in field
lighting field on fire (tractor nearby)	burning corn fields

Operating ATV	
driving 4 wheeler	driving 4 wheeler, setting corn fields on fire

Operating grain cart	
driving grain cart	emptying grain cart
driving grain cart to farm/field	operating grain cart
driving tractor pulling grain cart	pulling grain cart
driving tractor/grain cart to field (operating grain cart)	unloading grain cart into semi

Operating tractor other field work	
driving tractor/shredding stocks	pulling out stuck tractor

Picking up parts, fertilizer, miscellaneous at store	
at elevator getting fertilizer	paperwork at elevator
at elevator ordering fertilizer	stop at gas station
at repair shop	stop in grocery store
getting fertilizer at minn-kota	

Planting grain crops	
driving tractor planting	planting
driving tractor planting beets	planting wheat
driving tractor planting soybeans	testing planter in field
planting corn	

Plowing, digging, ditching fields	
chisel plowing field	plowing digging field
digging field	plowing field
driving tractor digging field	scrapping field driving tractor
driving tractor plowing	scrapping field driving tractor/ditching

Prepping equipment	
fueling/prepping truck	prepping truck
prepping digger	prep work outside
prepping tractor	working/prepping versatile tractor
prepping tractor/digger	

Prepping for combining

prep work/maintenance on combine	prepping combine while talking outside a lot
Prepping combine	prepping combine/checking combine

Prepping for planting

changing out planter boxes	miscellaneous work infield, loading corn & fertilizer
emptying air seeder tank	moving seed
loading fertilizer into planter	swapping out planter boxes
loading planter	prepping tractor and planter
loading seed into planter	prepping planter
prepping planter and tractor	

Prepping for spraying

filling pesticide tank	loading sprayer
filling pesticides	prepping sprayer
filling water tanks	prepping sprayer filling tank
loading chemical into sprayer	Reticulating fertilizer on flatbed
loading chemical onto semi	prepping/loading sprayer

Spraying fields

driving tractor and spraying corn	spraying field
driving tractor/applying anhydrous	spraying herbicide on field
driving tractor/spreading fertilizer	spraying soybeans

Talking to employees, family members, neighbors

at farm on phone, deciding which field to do next	talking to neighbor
in shop talking with salesman	on phone
talking to other farmer (about 20 yards from tractor)	talking to other farmer in shop
on steps talking on phone	talking to uncle on roadside
outside talking to employees	talking with employee outside
talking in yard	talking with equipment dealer
talking to contractor	talking with other farmers at farm site
talking to farmer in field	having lunch or break outside

Unloading grain at elevator

loading seed at cenex	unloading corn at elevator
unloading at elevator	unloading semi at elevator
unloading at elevator	unloading semi at elevator (outside)
unloading at elevator (out of truck)	

Unloading grain/loading grain bins at farm	
emptying combine hopper	unloading grain truck
emptying grain bin	unloading grain truck at farm
loading corn	unloading semi
loading grain	unloading semi
loading grain into truck	unloading semi at farm
loading semi	unloading soybeans
unloading corn	unloading truck
unloading corn from bin	unloading truck at farm
unloading from truck into grain bin	unloading truck/loading bin
unloading grain into bin	

Waiting in grain truck/semi	
waiting at elevator	waiting in line at elevator (in truck)
waiting at elevator in truck	waiting in line at elevator (outside)
waiting in cab for truck to load	waiting in line at semi
waiting in field for truck to load	waiting in semi
waiting in field with truck	Waiting in truck
waiting in line at elevator	waiting to load grain truck

Working around grain bins	
adjusting corn dryer	prep work around bins, moving auger
checking bins	starting/working with grain dryer
checking grain dryer	working around dryer
checking moisture at grain bins	working around elevators-this is really bins
getting grain auger assembled	working inside grain bin, emptying
hooking up auger	checking soybeans in bin with dryer for moisture
hooking up augers	working on starting grain dryer
dismantling grain vacuum	

APPENDIX D: TASKS NOT POOLED AND POOLED INTO COMBINED TASK CATEGORIES

Tasks from the original 41 task categories not pooled into combined categories

Operating grain vacuum	Planting grain crops
Unloading/loading grain bin at farm	Operating grain cart
Changing tires on vehicles and implements	Spraying fields
Checking equipment/field/crops during field work	Plowing/digging/ditching fields
Working around grain bins	Driving tractor non-field work
Unloading grain at elevator	Unaccounted work time
Operating ATV	

Tasks from the original 41 task categories pooled into a combined task category

Combined Task Category	Original Task Category
Operating other equipment	Operating other equipment Operating skid steer/bobcat
Operating tractor-other field work	Operating tractor-other field work Mowing ditches
Driving pickup/personal vehicles	Driving pickup/personal vehicles Loading/unloading pickups/trailers
Maintenance on equipment	Maintenance on equipment Cleaning equipment
Driving grain trucks	Driving grain trucks Driving semi
Miscellaneous work in field	Miscellaneous work in field Waiting in grain truck/semi
Combining grain crops	Combining grain crops Driving combine
Working in shop	Working in shop Maintenance on structures
Prepping Equipment	Prepping for crop spraying Prepping for planting Prepping for combining Fueling equipment Attaching/moving implements and vehicles
Miscellaneous work around farm	Miscellaneous work around farm Picking up parts/fertilizer/miscellaneous at store Talking to employees/family/neighbors In house or office In shop not working

REFERENCES

1. Srivastava AK, Goering CE, Rohrbach RP, Buckmaster DR. *Engineering principles of agricultural machines.* 2nd ed. St. Joseph Michigan: ASABE; 1993.

2. Cooper MR, Barton GT, Brodell AP. *Progress of farm mechanization.* Miscellaneous Publication No. 630. Washington, DC: US Dept. of Agriculture; 1947.

3. Olmstead AL, Rhode PW. Reshaping the landscape: the impact and diffusion of the tractor in American agriculture, 1910–1960. *J Econ His*. 2001;61(03):663-698.

4. Nelson DI, Nelson RY, Concha-Barrientos M, Fingerhut M. The global burden of occupational noise-induced hearing loss. *Am J Ind Med*. 2005;48(6):446-458.

5. Sataloff RT, Sataloff J. *Occupational hearing loss.* Boca Raton, FL: CRC Press; 2006.

6. Nadol JB. Hearing loss. *N Engl J Med*. 1993;329(15):1092.

7. Adams PF, Benson V. Current estimates from the National Health Interview Survey, 1989. *Vital Health Stat.* 1990;10(176):1-221.

8. Occupational Safety and Health Administration. Occupational Noise Exposure: Title 29, Chapter XVII, CFR Part 1910.95. Federal Register 1971; 36:10518, No. 105.

9. NIOSH *Criteria for a Recommended Standard, Occupational Noise Exposure, Revised Criteria 1998.* NIOSH, US Department of Health and Human Services, Cincinnati, OH: DHSS (NIOSH); 1998. Publication No. 98.-126

10. International standards organization: determination of occupational noise exposure and estimation of noise-induced hearing impairment. Geneva, Switzerland . International Standards Organization.; ISO-1999.

11. American national standard: determination of occupational noise exposure and estimation of noise-induced hearing impairment. New York, NY: American National Standards Institute, Inc., ANSI S3.44-1996.

12. AAO-HNS. American Academy of Otolaryngology/Head and Neck Surgery committee on hearing and equilibrium, and the American Council of otolaryngology Committee on the medical aspect of noise. "Guide for the evaluation of hearing handicap". *JAMA*. 1979;241(19):2055-2059.

13. Clark JG. Uses and abuses of hearing loss classification. *ASHA*. 1981;23(7):493-500.

14. Mathers C, Smith A, Concha M. *Global burden of hearing loss in the year 2000*. GBD 2000 Working Paper 2000. Geneva Switzerland: World Health Organization: 2003.

15. Pleis JR, Lethbridge-Cejku M. Summary health statistics for U.S. adults: National Health Interview Survey, 2006. *Vital Health Stat*. 2007;*10*(235):1-153.

16. Agrawal Y, Platz EA, Niparko JK. Prevalence of hearing loss and differences by demographic characteristics among US adults. *Arch Intern Med*. 2008;168(14):1522-1530.

17. Cruickshanks KJ, Wiley TL, Tweed TS, et al. Prevalence of hearing loss in older adults in Beaver Dam, Wisconsin: The epidemiology of hearing loss study. *Am J Epidemiol*. 1998;148(9):879-886.

18. Gopinath B, Rochtchina E, Wang JJ, Schneider J, Leeder SR, Mitchell P. Prevalence of Age-Related Hearing Loss in Older Adults: Blue Mountains Study. *Arch Intern Med*. 2009;169(4):415-416.

19. Flamme GA, Mudipalli VR, Reynolds SJ, et al. Prevalence of Hearing Impairment in a Rural Midwestern Cohort: Estimates from the Keokuk County Rural Health Study, 1994 to 1998. *Ear Hear*. 2005;26(3):350-360.

20. Tak SW, Calvert GM. Hearing difficulty attributable to employment by industry and occupation: An analysis of the National Health Interview Survey-United States, 1997 to 2003. *J Occup Environ Med*. 2008;50(1):46-56.

21. Prince MM, Stayner LT, Smith RJ, Gilbert SJ. A re-examination of risk estimates from the NIOSH Occupational Noise and Hearing Survey (ONHS). *J Acoust Soc Am*. 1997;101(2):950-963.

22. Hwang SA, Gomez MI, Sobotova L, Stark AD, May JJ, Hallman EM. Predictors of hearing loss in New York farmers. *Am J Ind Med*. 2001;40(1):23-31.

23. Gomez MI, Hwang SA, 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.

24. Brackbill RM, Cameron LL, Behrens V. Prevalence of chronic diseases and impairments among US farmers, 1986-1990. *Am J Epidemiol*. 1994;139(11):1055-1065.

25. May JJ, Marvel M, Regan M, Marvel LH, Pratt DS. Noise-induced hearing loss in randomly selected New York dairy farmers. *Am J Ind Med*. 1990;18(3):333-337.

26. Plakke BL, Dare E. Occupational hearing loss in farmers. *Public Health Rep*. 1992;107(2):188-192.

27. 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.

28. Choi SW, Peek-Asa C, Zwerling C, et al. A comparison of self-reported hearing and pure tone threshold average in the Iowa Farm Family Health and Hazard Survey. *J Agromed*. 2006;10(3):31-39.

29. Beckett WS, Chamberlain D, Hallman E, et al. Hearing conservation for farmers: source apportionment of occupational and environmental factors contributing to hearing loss. *J Occup Environ Med*. 2000;42(8):806.

30. Marvel ME, Pratt DS, Marvel LH, Regan M, May J. Occupational hearing loss in New York dairy farmers. *Am J Ind Med*. 1991;20(4):517-531.

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

33. 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.

34. Varchol K, Wilkins III J. Farm residence increases risk of hearing loss among youth. *American J.Epidemiology*. 1998;147(11 Suppl):516.

35. 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.

36. Cocchiarella L, Andersson GB, eds. *Guides to the evaluation of permanent impairment.* 5^{th} ed. Chicago, IL: AMA Press; 2001.

37. Berger EH, Royster LH, Driscoll DP, Royster JD, Layne M, eds. *The noise manual.* 5th ed. Fairfax, VA: American Industrial Hygiene Association Press; 2003.

38. Pearson JD, Morrell CH, Gordon-Salant S, et al. Gender differences in a longitudinal study of age-associated hearing loss. *J Acoust Soc Am*. 1995;97:1196-1205.

39. Melamed S, Kristal-Boneh E, Froom P. Industrial noise exposure and risk factors for cardiovascular disease: Findings from the CORDIS study. *Noise and Health*. 1999;1(4):49-56.

40. Melamed S, Bruhis S. The effects of chronic industrial noise exposure on urinary cortisol, fatigue, and irritability: a controlled field experiment. *J Occup Environ Med*. 1996;38(3):252-256.

41. van Dijk FJ, Souman AM, de Vries FF. Non-auditory effects of noise in industry. VI. A final field study in industry. *Int Arch Occup Environ Health*. 1987;59(2):133-145.

42. Melamed S, Luz J, Green MS. Noise exposure, noise annoyance and their relation to psychological distress, accident and sickness absence among blue-collar workers--the Cordis Study. *Isr J Med Sci*. 1992;28(8-9):629-635.

43. Wilkins PA, Acton WI. Noise and accidents - a review. *Ann Occup Hyg*. 1982;25(3):249-260.

44. Axelsson A, Prasher D. Tinnitus induced by occupational and leisure noise. *Noise and Health*. 2000;2(8):47-54.

45. Clark WW. Hearing: the effects of noise. *J Otolaryngol Head Neck Surg*. 1992;106(6):669-676.

46. DiNardi SR eds. *The Occupational environment: Its evaluation, control, and management.* Fairfax, VA: American Industrial Hygiene Association Press; 2003.

47. Mine Safety and Health Administration. Compliance Guide to MSHA's Occupational Noise Exposure Standard. Available at: http://www.msha.gov/REGS/COMPLIAN/GUIDES/NOISE/GUIDE303COVER.HTM. Accessed 12/3/2009, 2009.

48. ACGIH. 2003. TLVs and BEIs: Threshold limit values for chemical substances and physical agents biological exposure indices. American Conference of Governmental Industrial Hygienists. Cincinnati, OH.

49. 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):23-37.

50. Holt JJ, Broste SK, Hansen DA. Noise exposure in the rural setting. *Laryngoscope*. 1993;103(3):258-262.

51. Lander LI, Rudnick SN, Perry MJ. Assessing Noise Exposures in Farm Youths. *J Agromed*. 2007;12(2):25-32.

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

53. Milz SA, Witherspoon MKM, Ames ALM, Wilkins III J. Noise Exposure Assessment of Three Adolescents Living on Farms in Northwestern Ohio. *Semin Hear* . 2008;29(1):42-48.

54. Firth H, Herbison P, Bride DM. Dust and noise exposures among farmers in Southland, New Zealand. *Int J Environ Health Res*. 2006;16(2):155-161.

55. Dennis JW, May JJ. Occupational noise exposure in dairy farming. In: McDuffie HH, Dosman JA, Semchuk KM, Olenchock S, Senthilsevan A., eds. *Agricultural Health and Safety: Workplace, Environment, Sustainability*. Boca Raton, FL: Lewis Publishers; 1995:363-367.

56. Solecki L. Evaluation of annual exposure to noise among private farmers on selected family farms of animal production profile. *Ann Agric Environ Med*. 2005;12(1):67-73.

57. Solecki L. Characteristics of annual exposure to noise among private farmers on family farms of mixed-production profile. *Ann Agric Environ Med*. 2006;13(1):113-118.

58. Susi P, Goldberg M, Barnes P, Stafford E. The use of a task-based exposure assessment model (T-BEAM) for assessment of metal fume exposures during welding and thermal cutting. *Appl Occup Environ Hyg*. 2000;15(1):26-38.

59. Verma DK, Cheng WK, Shaw DS, et al. A simultaneous job- and task-based exposure evaluation of petroleum tanker drivers to benzene and total hydrocarbons. *J Occup Environ Hyg*. 2004;1(11):725-737.

60. Warren ND, Marquart H, Christopher Y, Laitinen J, Van Hemmen JJ. Task-based Dermal Exposure Models for Regulatory Risk Assessment. *Ann Occup Hyg*. 2006;50(5):491-503.

61. Reames GJ, Brumis SG, Nicas M. Task-specific lead exposure during residential lead hazard reduction projects. *Appl Occup Environ Hyg*. 2001;16(6):671-678.

62. Eduard W, Bakke B. Experiences with task-based exposure assessment in studies of farmers and tunnel workers. *Nor Epidemiol*. 1999;9(1):65-70.

63. Goldberg M, Levin SM, Doucette JT, Griffin G. A task-based approach to assessing lead exposure among iron workers engaged in bridge rehabilitation. *Am J Ind Med*. 1997;31(3):310-318.

64. Methner MM, McKernan JL, Dennison JL. Occupational health and safety survelillance task-based exposure assessment of hazards associated with new residential construction. *Appl Occup Environ Hyg*. 2000;15(11):811-819.

65. Susi P, Schneider S. Database needs for a task-based exposure assessment model for construction. *Appl Occup Environ Hyg*. 1995;10(4):394-399.

66. Benke G, Sim M, Fritschi L, Aldred G. Beyond the job exposure matrix (JEM): the task exposure matrix (TEM). *Ann Occup Hyg*. 2000;44(6):475-482.

67. O'Shaughnessy PT, Donham KJ, Peters TM, Taylor C, Altmaier R, Kelly KM. A task-specific assessment of swine worker exposure to airborne dust. *J Occup Environ Hyg*. 2010;7(1):7-13.

68. Depczynski J, Franklin RC, Challinor K, Williams W, Fragar LJ. Farm noise emissions during common agricultural activities. *J Agric Saf Health*. 2005;11(3):325-334.

69. Franklin RC, Depczynski J, Challinor K, Williams W, Fragar LJ. Factors affecting farm noise during common agricultural activities. *J Agric Saf Health*. 2006;12(2):117-125.

70. Milz SA, Wilkins JR, Ames AL, Witherspoon MK. Occupational noise exposures among three farm families in northwest Ohio. *J Agromedicine*. 2008;13(3):165-174.

71. Humann MJ, Sanderson WT, Flamme GA, et al. Noise exposures of rural adolescents. J Rural Health [serial online]. Available from: DOI: 10.1111/j.1748-0361.2010.00306.x

72. Hager LD. Sound exposure profiling: a noise monitoring alternative. *Am Ind Hyg Assoc J*. 1998;59(6):414-418.

73. Reeb-Whitaker CK, Seixas NS, Sheppard L, Neitzel R. Accuracy of task recall for epidemiological exposure assessment to construction noise. *Br Med J*. 2004;61(2):135-142.

74. Seixas NS, Sheppard L, Neitzel R. Comparison of task-based estimates with full-shift measurements of noise exposure. *Am Ind Hyg Assoc J*. 2003;64(6):823-829.

75. Virji MA, Woskie SR, Waters M, et al. Agreement between task-based estimates of the full-shift noise exposure and the full-shift noise dosimetry. *Ann Occup Hyg*. 2009;53(3):201-214.

76. Seixas NS, Ren K, Neitzel R, Camp J, Yost M. Noise exposure among construction electricians. *Am Ind Hyg Assoc J*. 2001;62(5):615-621.

77. Neitzel R, Seixas NS, Camp J, Yost M. An assessment of occupational noise exposures in four construction trades. *Am Ind Hyg Assoc J*. 1999;60(6):807-817.

78. Meijster T, Tielemans E, Schinkel J, Heederik D. Evaluation of peak exposures in the Dutch flour processing industry: implications for intervention strategies. *Ann Occup Hyg*. 2008;52(7):587-596.

79. Preller L, Heederik D, Kromhout H, Boleij JSM, Tielen MJM. Determinants of dust and endotoxin exposure of pig farmers: development of a control strategy using empirical modelling. *Ann Occup Hyg*. 1995;39(5):545-557.

80. Ross AS, Teschke K, Brauer M, Kennedy SM. Determinants of exposure to metalworking fluid aerosol in small machine shops. *Ann Occup Hyg*. 2004;48(5):383-391.

81. Hansen DJ, Whitehead LW. The influence of task and location on solvent exposures in a printing plant. *Am Ind Hyg Assoc J*. 1988;49(5):259-265.

82. Nieuwenhuijsen M, Schenker MB, Samuels S, Farrar J, Green SS. Exposure to dust, noise, and pesticides, their determinants, and the use of protective equipment among California farm operators. *Appl Occup Environ Hyg*. 1996;11(10):1217-1225.

83. Pfeiffer S, Graham TE, Webb RD, Wilson BA, Rivington-Moss EG, Fisher-Ingram LM. Aspects of physical fitness and health in Ontario dairy farmers. *Can J Public Health*. 1984;75(3):204-211.

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

85. Schenker MB, Orenstein MR, Samuels SJ. Use of protective equipment among California farmers. *Am J Ind Med*. 2002;42(5):455-464.

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

87. Axelsson A, Jerson T, Lindberg U, Lindgren F. Early noise-induced hearing loss in teenage boys. *Scand Audiol*. 1981;10(2):91-96.

88. Nondahl DM, Cruickshanks KJ, Wiley TL, Klein R, Klein BEK, Tweed TS. Recreational firearm use and hearing loss. *Arch Fam Med*. 2000;9(4):352-357.

89. Stromquist AM, Merchant JA, Burmeister LF, Zwerling C, Reynolds SJ. The Keokuk County rural health study: methodology and demographics. *J Agromedicine*. 1997;4(3):243-248.

90. United States Census Bureau. American FactFinder. Available at: http://factfinder.census.gov/home/saff/main.html?_lang=en. Accessed 12/5/2009, 2009.

91. United States Department of Agriculture. 2007 Census of Agriculture: County Level - Iowa. Available at: http://www.agcensus.usda.gov/Publications/2007/Full_Report/Volume_1,_Chapter_2_County_Level/Iowa/index.asp. Accessed 12/5/2009, 2009.

92. American national standard: specification for audiometers. New York, NY: American National Standards Institute, Inc., ANSI S3.44-1996.

93 Merchant JA, Stromquist AM, Kelly KM, Zwerling C, Reynolds SJ, Burmeister LF. Chronic disease and injury in an agricultural county: the Keokuk County Rural Health Cohort Study. *J Rural Health*. 2002;18(4):521-535.

94. Choi SW, 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.

95. Solecki L. Hearing loss among private farmers in the light of current criteria for diminished sense of hearing. *Ann Agric Environ Med*. 2002;9(2):157-162.

96. Burgess GL, Dippnall WM, Ravandi MRG, Cherry NM. Retrospective noise estimates for British nuclear workers using an alternative approach. *Ann Occup Hyg*. 2004;48(2):117-127.

97. Seal A, Bise C. Case study using task-based, noise-exposure assessment methods to evaluate miner noise hazards. *Mining Eng*. 2002;54(11):44-48.

98. Neitzel R, Yost M. Task-based assessment of occupational vibration and noise exposures in forestry workers. *Am Ind Hyg Assoc J*. 2002;63(5):617-627.

99. Seixas NS, Neitzel R, Sheppard L, Goldman B. Alternative metrics for noise exposure among construction workers. *Ann Occup Hyg*. 2005;49(6):493-502.

100. Van Dyke MV, LaMontagne AD, Martyny JW, Ruttenber AJ. Development of an exposure database and surveillance system for use by practicing OSH professionals. *Appl Occup Environ Hyg*. 2001;16(2):135-143.

101. Benke G, Sim M, Fritschi L, Aldred G. A task exposure database for use in the alumina and primary aluminium industry. *Appl Occup Environ Hyg*. 2001;16(2):149-153.

102. Becker P, Flanagan ME, Akladios M. Development of an ACGIH construction industry silica exposure database overview. *Appl Occup Environ Hyg*. 2001;16(8):781-783.

103. LaMontagne AD, Herrick RF, Van Dyke MV, Martyny JW, Ruttenber AJ. Exposure databases and exposure surveillance: promise and practice. *Am Ind Hyg Assoc J*. 2002;63(2):205-212.

104. Morgan DA. Occupational exposure databases and their application for the next millennium: symposium framework and workshop introduction. *Appl Occup Health Environ*. 2001;16(2):111-114.

105. United States Department of Agriculture. 2007 Census of agriculture county profile: Wilkin County Minnesota. Available at: http://www.agcensus.usda.gov/Publications/2007/Online_Highlights/County_Profiles/Minnesota/cp27167.pdf. Accessed 07/10, 2010.

106. United States Department of Agriculture. 2007 census of agriculture county profile: Richland County North Dakota. Available at: http://www.agcensus.usda.gov/Publications/2007/Online_Highlights/County_Profiles/North_Dakota/cp38077.pdf. Accessed 7/10, 2010.

107. National Agricultural Statistics Service. 2*007 Census of Agriculture*. Publication No. AC-07-A-51. Washington, DC: US Dept. of Agriculture; 2007.

108. Unge J, Hansson G, Ohlsson K, et al. Validity of self-assessed reports of occurrence and duration of occupational tasks. *Ergonomics*. 2005;48(1):12-24.

109. Van der Beek AJ, Braam ITJ, Douwes M, et al. Validity of a diary estimating exposure to tasks, activities, and postures of the trunk. *Int Arch Occup Environ Health*. 1994;66(3):173-178.

110. United States Department of Agriculture. 2007 Census of agriculture county profile: Ramsey County North Dakota. Available at: http://www.agcensus.usda.gov/Publications/2007/Online_Highlights/County_Profiles/North_Dakota/cp38071.pdf. Accessed 09/15, 2010.

111. Keil CB, Wil F, TR Anthony, eds. *Mathematical models for estimating occupational exposure to chemicals.* 2nd ed. Fairfax, VA: American Industrial Hygiene Association Press; 2009.