Effects of Common Agricultural Tasks on Measures of Hearing Loss

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Background *Among agricultural populations, hearing loss caused by excessive noise exposure is common. However, examinations of associations between exposure to agricultural tasks and hearing loss are limited.*
Methods *Audiometry and lifetime exposure to 11 agricultural tasks were analyzed among 1,568 participants. Gender stratified multivariable linear regression was used to estimate associations between exposure duration and three hearing loss metrics.*
Results *Among men, significant associations were observed between hearing loss and hunting or target shooting, all-terrain vehicle (ATV) or motorcycle riding, chain saw use, electric or pneumatic tool use, living on a farm, and all agricultural tasks combined. When all significant exposure metrics were included in a single model, associations remained for hunting or target shooting, electric or pneumatic tool use and living on a farm. Significant associations were sparse among women, and in all cases paradoxical.*
Conclusions *Despite imprecise estimation of noise exposure, specific agricultural tasks were associated with hearing loss.* Am. J. Ind. Med. 55:904–916, 2012.

KEY WORDS: hearing loss; occupational health; agricultural health; risk factors; noise

INTRODUCTION

Farmers are more likely to experience hearing loss than other occupational groups. Among adult farmers, the prevalence of hearing loss has been shown to be almost double that of non-farmers [Brackbill et al., 1994; Marvel et al., 1991]. A detailed assessment of the hearing thresholds of 1,727 farmers and farm residents reported hearing loss prevalence between 9% and 47%, with the highest prevalence being for high-frequency hearing loss [Gomez et al., 2001]. Among farmers, hearing loss commonly occurs between 4,000 and 6,000 Hz, indicating that noise is the relevant exposure [Plakke and Dare, 1992; Varchol and Wilkins, 1998].

Members of farming populations frequently engage in noisy tasks [Karlovich et al., 1988; Marvel et al., 1991; Knobloch and Broste, 1998; Hwang et al., 2001]. Specific agricultural practices, such as driving tractors and working around grain bins have been associated with hearing loss [Marvel et al., 1991; Beckett et al., 2000; Hwang et al., 2001; McBride et al., 2003]. Hazardous levels of noise have been documented around grain dryers, tractors, and livestock, indicating that those tasks have the potential to

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Contract grant sponsor: NIOSH Heartland Center for Occupational Health and Safety; Contract grant number: T42OH008491;
Contract grant sponsor: NIOSH Great Plains Center for Agricultural Health; Contract grant number: U54OH007548.
Disclosure Statement: The authors report no conflicts of interests.
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Accepted 12 May 2012
DOI 10.1002/ajim.22077. Published online 5 June 2012 in Wiley Online Library (wileyonlinelibrary.com).

cause noise-induced hearing loss [Broste et al., 1989; May et al., 1990; Marvel et al., 1991; Beckett et al., 2000; Hwang et al., 2001].

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 [Schenker et al., 2002; Gates and Jones, 2007]. In addition to limited use of hearing protection, farmers and rural residents are also more likely to engage in recreational activities that are associated with substantial noise exposure, such as hunting and riding all-terrain vehicles [Axelsson and Prasher, 2000; Nondahl et al., 2000].

While previous studies have shown associations between common farm practices and hearing loss, they have not provided task-specific hearing loss information to guide intervention strategies. The goal of this study was to examine associations between years spent performing common agricultural tasks and measures of hearing loss among farmers and rural residents. Specifically, this study was conducted to (i) measure and compare the hearing loss among members of a rural agricultural population and (ii) examine associations between years participating in common agricultural tasks and measures of hearing loss.

METHODS

Study Sample

Audiometric and agricultural exposure data were collected from participants enrolled in the Keokuk County Rural Health Study (KCRHS). Keokuk County, located in southeast Iowa, is a rural county as defined by the US Census Bureau, with no town having a population >2,500 residents. The 2000 United States Census reported the population at 11,400, with a gender distribution of 51% female and 49% male. The Census Bureau also estimated the median age of Keokuk County residents to be 40 years and the mean family size to be 2.5 persons [United States Census Bureau, 2009]. There were 1,163 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 [United States Department of Agriculture, 2007].

The KCRHS is a prospective cohort study of rural residents that began in 1994. The methodology used to collect KCRHS cohort data has been published previously [Stromquist et al., 1997; Merchant et al., 2002]. In brief, the KCRHS cohort is a stratified random sample of all occupants (regardless of age) of households located in Keokuk County. Data collection was conducted in three phases or "Rounds."

All eligible households that agreed to participate after invitation were enrolled in the study. Although the investigators planned to stop enrollment once 1,000 households agreed to participate, during both rounds a few additional households were enrolled past the 1,000th household. Human subjects review and approval was provided by The University of Iowa's Institutional Review Board. Furthermore, all participants signed written informed consent documents upon enrollment into the study.

Data collection during Round 1 was conducted from 1994 to 1999. From 2,496 eligible households a total of 1,004 participated, representing 2,284 individuals. Of the original 1,004 households enrolled in Round 1 of the KCRHS, 707 continued into Round 2 (2000–2006). An additional 2,471 eligible households were recruited for Round 2. Of these households, 295 participated, resulting in a total of 1,002 households participating in Round 2, and representing 2,164 individuals. At entry into the study, each participant 8 years or older completed a set of standard clinical screening tests, including pure tone audiometry. In addition, standard questionnaires were administered by trained study personnel to participants age 18 years or older about health status, injuries, demographics, occupational exposures, and recreational activities.

Data Collection

For this study, audiometric, agricultural exposure, and covariate information from Round 2 of the KCRHS were analyzed. Of the 2,164 participants with data from Round 2, 1,924 completed standard audiometric testing. Participants under the age of 18 years (N = 352) were not included in the analyses resulting in 1,572 participants. Four participants had impossible exposure values (i.e., exposure durations greater than age) and were excluded from all analyses, resulting in a final sample size of 1,568 participants. A few participants were missing thresholds at required audiometric frequencies. Because of this, the numbers of participants available for frequency-specific analyses varied slightly depending on which audiometric summary variables were used.

Audiometric data

At the time of health screening, standard pure tone audiometry (PTA) was conducted following American National Standards Institute guidelines with a calibrated Maico MA-800 audiometer in a sound proof chamber (Maico Diagnostics, Eden Prairie, MN) installed in the KCRHS testing facility [American National Standards Institute, 1996a]. Testing was conducting at 500, 1,000, 2,000, 3,000, 4,000, 6,000, and 8,000 Hz, with a repeat of the test at 1,000 Hz. The repeatability of the subject's responses was deemed valid if the threshold of the

1,000 Hz retest was within 5 dB of the initial 1,000 Hz test. To identify factors that may have affected hearing function, subjects were asked about recent noise exposure and underwent otoscopic examination administered by a trained KCRHS staff nurse.

For purposes of data analysis, pure tone audiograms were reduced to three continuous summary variables of hearing loss as a function of decrements in acuity (in units of dB) at specific frequencies of the audiogram. The first summary metric was based on methods developed by National Institute for Occupational Safety and Health (NIOSH) and was calculated as the arithmetic mean of hearing acuity decrements at 1,000, 2,000, 3,000, and 4,000 Hz (*NIOSH PTA*) [NIOSH, 1998]. The second and third summary variables were designed to separately capture low- and high-frequency hearing losses. Specifically, low-frequency hearing loss was calculated as the arithmetic mean of decrements at 500, 1,000, 2,000, and 3,000 Hz (*low-frequency PTA*) and high-frequency hearing loss was calculated as the arithmetic mean of decrements at 3,000, 4,000, and 6,000 Hz (*high-frequency PTA*). The three PTA thresholds used in this study (NIOSH PTA, low-frequency PTA, and high-frequency PTA) are among those recommended by either the American National Standards Institute [1996b] or the International Standards Organization [1990]. Hearing loss was characterized separately for the left and right ears. For each participant, the ear with the greater loss was used in the analysis.

Agricultural exposure data

Standard questionnaires were administered by trained study personnel on the same day as audiometric testing to collect occupational and agricultural exposure information. The questionnaires were created from previously published surveys [Merchant et al., 2002].

Specifically, the total lifetime years engaged in 11 agricultural or rural activities was obtained. The 11 agricultural exposure variables and the corresponding questions in the KCRHS questionnaire are provided in Table I.

An additional agricultural exposure metric, *total lifetime years engaged in all agricultural tasks*, was created by summing the total years engaged in the 11 individual agricultural tasks into a single variable. In addition, for descriptive purposes only, participants were classified as farmer or non-farmer. A participant who reported one or more total years working on a farm were classified as *farmer*.

Data Analysis

Because the distributions of mean years engaged in each the 11 agricultural exposure tasks had almost no overlap between men and women, all analyses were stratified by gender and conducted separately, Participants were stratified by farmer or non-farmer when examining hearing loss among the study sample. Associations between agricultural exposure task variables and the three PTA hearing loss summary variables were estimated using multiple linear regression analysis. To control for potential confounding, a set of base model covariates for each gender were identified and included in all multivariable models. All analyses were conducted with SAS, version 9.2 (SAS Institute, Inc., Cary, NC).

Selection of base model covariates

Nine covariates (i.e., years worked in a noisy job other than farming; age; alcohol consumption; smoking; military service; marital status; education; income; financial assets) were identified a priori as potential confounders of

TABLE I. Agricultural Exposure Variables and Corresponding Questions From the Keokuk County Rural Health Study Questionnaires

Exposure variable (total lifetime years engaged in)	Question
Hunting or target shooting	Have you EVER gone hunting or done target shooting? This does not include bow hunting. If yes, for how many years?
All-terrain vehicle or motorcycle riding	Have you EVER ridden a motorcycle or an all-terrain vehicle? If yes, for how many years?
Chain saw use	Have you EVER used a chain saw? If yes, for how many years?
Electric or pneumatic tool use	Have you EVER used electric or pneumatic tools? If yes, for how many years?
Living on a farm	IN YOUR LIFETIME, how many years did you live on a farm?
Working on a farm	IN YOUR LIFETIME, how many years did you work on a farm?
Use of tractor without a cab	Have you EVER ridden in a tractor WITHOUT cab? If yes, for how many years?
Use of tractor or combine with a cab	Have you EVER ridden a tractor, a combine or a harvester with a cab? If yes, for how many years?
Grain dryer, feed mill, hay chopper use	Have you EVER worked around a grain dryer, grain feed-mill, or forage or hay chopper? If yes, for how many years.
Livestock work	Have you EVER worked with livestock in buildings? If yes, for how many years?
Hog confinement building work	Number of years worked with (hogs) in confinement?

the association between agricultural exposures and hearing loss. Age and years worked in a noisy job other than farming were selected because of their known association with hearing acuity. Alcohol drinks per day, years smoked, and past military job involving use of firearms were included because they have been shown in the literature to be associated with hearing loss [Marvel et al., 1991; Hwang et al., 2001; Crawford et al., 2008]. The remaining covariates, that is, marital status, education, income, and household financial assets were included as indicators of socioeconomic status.

Initially, the nine covariates were entered simultaneously into separate linear regression models for each of the three PTA hearing loss summary variables. A backward stepwise 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 *P*-value of <0.10. Once backward selection was completed, Spearman correlation coefficients were calculated between all pairs of remaining covariates. Pairs with correlations >0.30 were identified and the variable with the lower *P*-value was retained in the base model while its correlated variable was removed. Once base model covariates were identified for each of the three PTA audiometric summary variables, a standard base model of all covariates associated with any of the three PTA audiometric summary variables ($P < 0.10$) was created. The standard base model covariates were included in all multivariable analyses of the three PTA hearing loss outcomes.

Multivariable regression analysis

The first step of the multivariable regression analysis was to estimate associations, separately, between each of the agricultural exposure variables and the three hearing loss outcomes controlling for standard base model covariates. For the agricultural exposure variable *all agricultural tasks combined*, only the individual association between this variable and the three hearing loss outcomes (controlling for the standard base model covariates) was examined, that is, in a separate model. Because the relationship between duration of exposure to agricultural tasks and hearing loss may not be linear, each continuous agricultural task exposure variable was categorized. Among men (with the exception of *hog confinement building work*), all exposure variables were categorized into quintiles (due to some clustering of the data, some categories may not have exactly equal numbers of participants). Because approximately half of the participants reported no hog confinement building work, this one exposure variable was dichotomized (ever vs. never).

Exposure durations were shorter among women than men and resulted in unacceptably small cell sizes when categorized into quintiles. Therefore, with the exceptions of *years lived on a farm* and *total lifetime years engaged in all agricultural tasks combined*, exposure variables were dichotomized (ever/never) among women. Durations were sufficiently long for *years lived on a farm* and *total lifetime years engaged in all agricultural tasks combined* for categorization into quintiles.

After estimating standard base model adjusted associations between each of the 11 individual agricultural exposure variables and the three hearing loss outcomes, full multivariable linear regression models were created in which all agricultural exposure variables with a $P < 0.20$ in the individual analyses were included simultaneously in multivariable linear regression models along with the standard base model covariates. A backwards elimination procedure was then used to remove agricultural exposure variables with *P*-value >0.10. Because the exposure variable, *all agricultural tasks combined*, was the arithmetic sum of the individual task exposure durations, it was not included in any of the full multivariable regression models, as doing so would result in over-adjustment of the model. Regression diagnostics were performed to verify the assumptions of the linear regression analysis. Studentized residuals were observed to be approximately normally distributed. Residual, leverage, and Cook's D values was also used to identify possible outliers and influential values. Specifically, values with Studentized residuals with absolute value >2, leverage >0.015 for men and >0.016 for women and Cook's D > 0.006 for men and >0.005 for women were identified as possible outliers. All values identified as possible outliers were compared to values recorded in the original data collection instruments. None were found to be miscoded and all were retained in the analyses.

RESULTS

Demographic Characteristics

The demographic and agricultural exposure characteristics of the study sample are presented in Table II. Of the 1,568 participants, 686 were men and 882 were women. The average age of participants was 55 years with men having a mean age of 55.3 years (SD = 16.4) and the women having a mean age of 54.9 years (SD = 16.2). A statistically significantly greater proportion of farmers were men than were women (59.3% vs. 40.6%, $P < 0.01$).

Men spent significantly more years than women engaged in the 11 agricultural tasks ($P < 0.01$). Except for age, the means and proportions of all reported covariates were significantly different between men and women. In particular, the men were less educated than the women, had higher incomes, and higher values of household assets. The men were also more likely than the women to

TABLE II. Characteristics of Study Population for All Participants Overall and Stratified by Gender

Characteristics	All subjects, mean (SD) or % (N = 1,568)	Men, mean (SD) or % (N = 686)	Women, mean (SD) or % (N = 882)	*P*-value
Total lifetime years engaged in				
Hunting or target shooting	8.9 (15.9)	19.1 (19.1)	1.0 (4.6)	<0.01
All-terrain vehicle or motorcycle riding	5.3 (9.4)	8.8 (11.5)	2.5 (5.9)	<0.01
Chain saw use	6.5 (11.5)	14.2 (13.8)	0.5 (2.6)	<0.01
Electric or pneumatic tool use	10.7 (15.5)	22.1 (16.5)	1.8 (5.9)	<0.01
Living on a farm	27.2 (24.1)	29.8 (25.2)	25.1 (23.0)	<0.01
Working on a farm	14.3 (18.5)	23.0 (20.6)	7.6 (13.2)	<0.01
Use of a tractor without a cab	12.5 (16.1)	20.4 (18.3)	6.4 (10.7)	<0.01
Use of a tractor/combine with a cab	5.8 (9.9)	10.0 (11.9)	2.6 (6.2)	<0.01
Grain dryer, feed mill, hay chopper use	7.1 (11.7)	12.1 (13.9)	3.1 (7.5)	<0.01
Livestock work	7.8 (13.0)	11.1 (15.2)	5.3 (10.2)	<0.01
Hog confinement building work	4.1 (9.0)	6.5 (11.2)	2.2 (6.1)	<0.01
Noisy job other than farming	4.8 (9.9)	7.6 (12.3)	2.7 (6.8)	0.02
Age (years)	55.1 (16.2)	55.3 (16.4)	54.9 (16.2)	0.64
Farming status				
Non-farmer	61.1	17.1	55.9	<0.01
Farmer	38.9	82.9	44.1	
Marital status				
Not married	22.5	17.9	26.1	<0.01
Married	77.5	82.1	73.9	
Education				
Some high school	8.4	10.5	6.7	<0.01
High school graduate	44.6	48.7	41.5	
Some college	29.0	25.4	31.8	
College graduate	18.0	15.4	20.0	
Income				
<$40,000	38.6	35.9	40.7	<0.01
$40–79K	36.9	38.1	36.0	
≥$80K	15.6	20.8	11.5	
Don't know/refused	8.9	5.2	11.8	
Total household assets				
<$80K	22.4	19.8	24.4	<0.01
$80–299K	36.9	39.7	34.7	
≥$400K	25.4	32.8	19.7	
Don't know/refused	15.3	7.7	21.2	
Military experience				
No	87.6	72.3	99.4	<0.01
Yes	12.4	27.7	0.6	
Alcohol drinks per day				
Do not drink	37.1	30.2	42.4	<0.01
<One drink	54.3	54.7	54.1	
One drink or more	8.6	15.1	3.5	
Years smoked				
Never smoked	62.4	50.2	71.9	<0.01
<14 years	12.7	16.3	9.9	
≥14 years	24.9	33.5	18.2	

SD, standard deviation.

have past military experience, consume alcohol, and smoke.

Use of hearing protection by participants when engaging in the 11 agricultural tasks was limited. Among a subset of participants with data on hearing protection use, 65% reported never using hearing protection when hunting or target shooting and 73% reported never using hearing protection when using electric or pneumatic tools. For the remaining agricultural tasks, over 75% of participants reported never using hearing protection.

Unadjusted Analysis

Mean hearing acuity for the three PTA hearing loss summary variables (in dB) is presented by age group, farmer status, and gender in Table III. For the full study sample (i.e., all ages combined), the mean hearing loss was greater among (i) male farmers than among male non-farmers and (ii) female farmers than among female non-farmers for all three PTA summary variables. The difference was statistically significant ($P \leq 0.05$) for male farmers versus male non-farmers for the NIOSH PTA summary variable, and for male farmers versus male non-farmers and female farmers versus female non-farmers for the high-frequency summary method.

Base Model Covariates

Among the men, years worked in a noisy job other than farming, age, education and total household assets were associated ($P < 0.10$) with one or more of the three PTA outcome measures and used as base model covariates for all multivariable regression analyses among male participants. Among the women, age, marital status, education, total household assets, and number of alcohol drinks per day were associated ($P < 0.10$) with one or more of the three PTA outcome measures and used as base model covariates for all multivariable regression analyses among female participants.

Multivariable Regression Analysis

Adjusted individual associations

Among the men, base model adjusted individual associations between each agricultural exposure variable (including *total lifetime years engaged in all agricultural tasks combined*) and the three hearing loss summary variables are presented in Table IV. For most of the exposure variables, the highest exposure category was associated with the largest effect size, most of which achieved statistical significance ($P \leq 0.05$). As expected, for all three PTA summary variables, the highest category of years of all agricultural tasks combined had larger effect sizes than

TABLE III. Mean (SD) Decibels of Hearing Loss Stratified by Age Group, Gender, and Farming Status Using NIOSH, Low-and High-Frequency PTA Calculations

Age group	NIOSH PTA				Low-freq. PTA				High-freq. PTA			
	Male (N = 685)		Female (N = 882)		Male (N = 686)		Female (N = 882)		Male (N = 684)		Female (N = 882)	
(years)	Farmer (N = 568)	Non-farmer (N = 117)	Farmer (N = 389)	Non-farmer (N = 493)	Farmer (N = 569)	Non-farmer (N = 117)	Farmer (N = 389)	Non-farmer (N = 493)	Farmer (N = 567)	Non-farmer (N = 117)	Farmer (N = 389)	Non-farmer (N = 493)
<50	19.4 (13.9)	19.9 (14.0)	10.1 (10.0)	9.6 (10.3)	14.1 (11.5)	14.5 (11.5)	8.7 (8.3)	8.9 (9.6)	29.4 (19.1)	30.7 (18.9)	16.1 (11.9)	14.5 (11.5)
50–59	28.0 (15.1)	26.5 (12.7)	16.1 (9.3)	13.9 (9.2)	19.7 (12.8)	19.2 (11.0)	13.6 (8.1)	12.3 (8.5)	44.3 (19.9)	41.4 (16.0)	**24.8 (11.4)**	**20.7 (10.7)**
60–69	41.1 (17.0)	39.3 (18.3)	21.6 (13.0)	25.1 (17.0)	30.8 (14.8)	28.8 (16.2)	18.9 (12.3)	21.6 (16.0)	57.2 (20.2)	58.8 (20.1)	30.1 (14.4)	34.3 (18.7)
≥70	48.4 (15.1)	45.7 (20.1)	35.1 (18.4)	35.4 (15.4)	37.3 (14.7)	36.5 (19.2)	30.4 (17.5)	30.8 (14.8)	65.9 (14.9)	63.2 (18.8)	47.0 (19.6)	48.6 (16.2)
All ages	**32.6 (19.3)**	**28.3 (18.8)**	20.0 (16.4)	18.3 (16.2)	24.3 (16.4)	21.2 (16.2)	17.3 (14.8)	16.2 (14.7)	**46.9 (23.8)**	**42.2 (23.1)**	**28.5 (18.9)**	**26.0 (19.2)**

SD, standard deviation; PTA, pure tone average.
Values in bold indicate mean decibels of hearing loss between farmers and non-farmers for each gender are statistically different, student's *t*-test *P*-value (<0.05).

TABLE IV. Individual Associations of Each Agricultural Exposure Variable and Decibels of Hearing Loss Adjusted for Base Model Covariates (Age, Education Level, Household Assets, and Years at Noisy Job Other Than Farming) Among *Men* Only

Exposure		NIOSH PTA		Low-freq. PTA		High-freq. PTA	
(total lifetime years engaged in)	N	β	*P*-value	β	*P*-value	β	*P*-value
Hunting or target shooting							
0	101	0.00	—	0.00	—	0.00	—
>0–5	159	3.36	0.06	2.17	0.18	5.30	0.02
6–19	121	5.25	0.01	4.38	0.01	6.35	0.01
20–38	159	4.19	0.02	2.21	0.18	7.33	<0.01
>38	146	4.39	0.02	2.39	0.16	7.80	<0.01
All-terrain vehicle or motorcycle riding							
0	160	0.00	—	0.00	—	0.00	—
>0–<1	120	−0.35	0.84	0.34	0.83	−2.14	0.32
1–5	120	0.96	0.60	0.78	0.64	1.04	0.64
6–18	145	1.55	0.38	1.74	0.27	0.63	0.77
>18	141	3.17	0.04	3.31	0.04	2.58	0.24
Chain saw use							
0	49	0.00	—	0.00	—	0.00	—
>0–4	204	3.33	0.15	1.96	0.34	4.04	0.15
5–16	158	3.71	0.12	1.89	0.37	4.50	0.12
17–26	141	3.41	0.16	1.91	0.38	5.04	0.09
>26	134	6.04	0.01	3.63	0.10	8.12	0.01
Electric or pneumatic tool use							
<3	135	0.00	—	0.00	—	0.00	—
3–18	132	2.67	0.15	2.77	0.09	1.72	0.44
19–24	95	3.89	0.05	3.02	0.09	4.04	0.09
25–37	178	3.64	0.03	2.85	0.06	3.02	0.14
>37	146	4.04	0.01	4.36	0.02	3.28	0.13
Living on a farm							
0	149	0.00	—	0.00	—	0.00	—
>0–17	100	−0.69	0.71	0.73	0.66	−3.41	0.13
18–38	162	−0.46	0.78	0.03	0.98	−2.44	0.22
39–54	131	1.00	0.59	1.02	0.54	−0.77	0.73
>54	144	4.69	0.02	4.08	0.03	2.98	0.24
Working on a farm							
0	117	0.00	—	0.00	—	0.00	—
>0–9	135	−1.59	0.38	−0.90	0.58	−1.92	0.38
10–29	153	−0.14	0.94	−0.40	0.80	−1.38	0.52
30–45	142	0.38	0.84	0.05	0.98	−0.75	0.75
>45	139	2.83	0.19	1.90	0.33	3.06	0.25
Use of tractor without a cab							
0	113	0.00	—	0.00	—	0.00	—
>0–9	143	0.29	0.87	0.57	0.72	−0.27	0.90
10–24	150	1.10	0.54	0.35	0.83	1.10	0.62
25–38	135	−0.25	0.90	−0.65	0.71	−1.22	0.61
>38	145	3.76	0.06	2.94	0.10	2.80	0.25
Use of tractor or combine with a cab							
0	251	0.00	—	0.00	—	0.00	—
>0–4	98	−1.18	0.50	−0.77	0.62	−1.46	0.49
5–14	108	−0.13	0.94	0.18	0.91	−2.51	0.23
15–24	98	0.53	0.77	0.26	0.88	0.40	0.86
>24	131	2.09	0.23	1.71	0.27	1.13	0.59

(*Continued*)

TABLE IV. (*Continued*)

Exposure (total lifetime years engaged in)	N	NIOSH PTA		Low-freq. PTA		High-freq. PTA	
		β	*P*-value	β	*P*-value	β	*P*-value
Grain dryer, feed mill, hay chopper use							
0	226	0.00	—	0.00	—	0.00	—
>0–5	118	−0.81	0.62	−0.07	0.96	−2.52	0.21
6–17	113	1.17	0.49	0.38	0.81	0.38	0.85
18–28	114	0.24	0.89	0.23	0.88	−0.19	0.93
>28	115	3.11	0.08	2.50	0.12	1.54	0.48
Livestock work							
0	286	0.00	—	0.00	—	0.00	—
>0–6	103	−0.74	0.66	0.31	0.84	−2.46	0.23
7–15	107	0.01	0.99	0.66	0.65	−0.99	0.62
16–29	86	3.73	0.04	3.74	0.02	2.52	0.26
>29	104	3.22	0.07	3.00	0.06	1.97	0.36
Hog confinement building work							
Never	394	0.00	—	0.00	—	0.00	—
Ever	292	1.61	0.18	1.76	0.10	0.13	0.93
All agricultural tasks combined							
0–56	136	0.00	—	0.00	—	0.00	—
57–114	138	1.38	0.43	0.37	0.81	1.16	0.58
115–216	137	1.17	0.51	−0.26	0.87	1.60	0.45
217–292	138	0.30	0.87	0.58	0.73	−0.51	0.82
>292	137	6.70	<0.01	4.46	0.01	7.20	<0.01

PTA, pure tone average; Freq., frequency.

any of the individual agricultural exposure variables. Interestingly, the three intermediate exposure categories of all agricultural tasks combined were essentially unassociated with the PTA summary variables and showed no discernible effect trend. Furthermore, the analyses did not reveal a clear dose–response pattern with increasing hearing loss by increasing years engaging in agricultural tasks.

Among the women, base model adjusted individual associations between each agricultural exposure variable (including *total lifetime years engaged in all agricultural tasks combined*) and the three hearing loss summary variables are presented in Table V. A statistically significant paradoxical association was observed between *all-terrain vehicle (ATV)* or *motorcycle riding* and hearing loss, as well as an the exposure category (27–53 years) of *all agricultural tasks combined* (i.e., significant better hearing was observed among participants with exposure). Otherwise, no significant associations were observed between any individual agricultural activity and hearing loss among the women.

Fully adjusted associations

For the NIOSH PTA hearing loss outcome, *years hunting or target shooting, years of chain saw use, years of electric or pneumatic tool use, years living on a farm, years use of tractor without a cab, years of livestock work and years of hog confinement building work* met the probability criterion (Type III sum of squares $P < 0.20$) for inclusion in the initial full multivariable linear regression model (data not shown). For the low-frequency PTA hearing loss outcome *years hunting or target shooting, years of electric or pneumatic tool use, years living on a farm, years of livestock work and years of hog confinement building work* met the probability criterion (Type III sum of squares $P < 0.20$) for inclusion in the initial full multivariable linear regression model (data not shown). For the high-frequency PTA hearing loss outcome *years hunting or target shooting, years of chain saw use, years living on a farm* met the probability criterion (Type III sum of squares $P < 0.20$) for inclusion in the initial full multivariable linear regression model (data not shown).

The final adjusted multivariable linear regression models for the men are presented in Table VI. *Years hunting or target shooting* and *years living on a farm* were retained in multivariable models of NIOSH PTA and high-frequency PTA hearing loss. Interestingly, all non-zero categories of *years hunting or target shooting* were associated with the NIOSH and high-frequency PTA hearing loss outcome variables whereas only the highest category

TABLE V. Individual Associations of Each Agricultural Exposure Variable and Decibels of Hearing Loss Adjusted for Base Model Covariates (Age, Marital Status, Education Level, Household Assets, and Drinks per Day) Among *Women* Only

Exposure variable		NIOSH PTA		Low-freq. PTA		High-freq. PTA	
(total lifetime years engaged in)	N	β	*P*-value	β	*P*-value	β	*P*-value
Hunting or target shooting							
Never	647	0.00	—	0.00	—	0.00	—
Ever	235	0.55	0.57	−0.02	0.98	1.08	0.31
All-terrain vehicle or motorcycle riding							
Never	355	0.00	—	0.00	—	0.00	—
Ever	527	−2.43	0.01	−2.74	$<$0.01	−2.11	0.04
Chain saw use							
Never	779	0.00	—	0.00	—	0.00	—
Ever	103	1.08	0.41	−0.01	0.99	1.86	0.21
Electric or pneumatic tool use							
Never	625	0.00	—	0.00	—	0.00	—
Ever	257	−0.15	0.88	−0.88	0.32	0.44	0.68
Living on a farm							
0	192	0.00	—	0.00	—	0.00	—
1–15	148	−0.48	0.73	−0.40	0.75	0.44	0.78
16–24	180	−1.52	0.25	−1.51	0.22	−0.97	0.52
25–46	178	−1.95	0.15	−2.10	0.10	−1.97	0.19
$>$47	184	−0.19	0.90	−0.84	0.55	0.84	0.62
Working on a farm							
Never	493	0.00	—	0.00	—	0.00	—
Ever	389	−0.59	0.49	−0.88	0.28	−0.24	0.96
Use of tractor without a cab							
Never	320	0.00	—	0.00	—	0.00	—
Ever	561	0.42	0.64	0.28	0.74	0.17	0.87
Use of tractor or combine with a cab							
Never	574	0.00	—	0.00	—	0.00	—
Ever	307	0.14	0.88	−0.37	0.68	0.57	0.59
Grain dryer, feed mill, hay chopper use							
Never	637	0.00	—	0.00	—	0.00	—
Ever	245	−0.15	0.88	−0.80	0.37	0.02	0.99
Livestock work							
Never	537	0.00	—	0.00	—	0.00	—
Ever	344	0.62	0.48	0.36	0.66	0.53	0.59
Hog confinement building work							
Never	697	0.00	—	0.00	—	0.00	—
Ever	182	1.00	0.35	0.80	0.42	1.10	0.36
All agricultural tasks combined							
0–6	179	0.00	—	0.00	—	0.00	—
7–26	172	0.22	0.87	−0.37	0.77	0.92	0.54
27–53	179	−2.95	0.03	−3.14	0.01	−3.53	0.02
54–98	176	−0.72	0.60	−1.06	0.40	−0.20	0.89
$>$99	176	−0.30	0.83	−1.20	0.37	0.14	0.93

PTA, pure tone average; Freq., frequency.

TABLE VI. Final Multivariable Linear Regression Model of Agricultural Exposure Variables and Hearing Loss Adjusted for Base Model Covariates (Age, Education Level, Household Assets, and Years at Noisy Job Other Than Farming) Among *Men* Only

Exposure variable	NIOSH PTA		Low-freq. PTA		High-freq. PTA	
(total lifetime years engaged in)	β	*P*-value	β	*P*-value	β	*P*-value
Hunting or target shooting						
0	0.00	—	—	—	0.00	—
>0–5	3.49	0.05	—	—	5.60	0.01
6–19	5.61	<0.01	—	—	6.96	<0.01
20–38	4.62	0.01	—	—	8.05	<0.01
>38	4.54	0.02	—	—	8.33	<0.01
Electric or pneumatic tool use						
<3	—	—	0.00	—	—	—
3–18	—	—	2.77	0.09	—	—
19–24	—	—	3.02	0.09	—	—
25–37	—	—	2.85	0.06	—	—
>37	—	—	4.36	0.01	—	—
Living on a farm						
0	0.00	—	—	—	0.00	—
>0–17	−1.12	0.54	—	—	−4.10	0.07
18–38	−0.88	0.59	—	—	−3.22	0.11
39–54	0.50	0.79	—	—	−1.86	0.41
>54	4.64	0.03	—	—	2.74	0.27

PTA, pure tone average; Freq., frequency.

of *years living on a farm* was associated with NIOSH PTA outcome. Only *years of electric or pneumatic tool use* was retained in the low-frequency PTA multivariable model, and the only association between hearing loss was for the highest exposure category.

Because only one agricultural exposure variable met criteria for inclusion in the final multivariable model among women, no additional fully adjusted models (i.e., simultaneous modeling of multiple agricultural exposures) were required.

DISCUSSION

In the current study, statistically significant adjusted individual associations were observed between several of the agricultural exposure task variables and pure tone audiometry, a standard, quantitative, objective metric of hearing acuity. When agricultural exposure task variables were combined into a final covariate-adjusted multivariate model, statistically significant associations were observed for *years hunting or target shooting*, *years of electric or pneumatic tool use* and *years lived on a farm*. As expected, the effect sizes of *all agricultural tasks combined* were greater than the effect sizes of each of the individual component exposures. Consistent with current knowledge of noise induced hearing loss, this observation indicates that each additional noisy agricultural exposure contributed to the overall magnitude of observed hearing loss.

Comparisons of the current study to the published literature are difficult due to the use of a wide range of PTA threshold calculations for the hearing loss summary variables and differences in agricultural exposures analyzed. Regardless, the findings from the current study are consistent with some previously published results. In the published literature, statistically significant association between agricultural tasks (i.e., agricultural exposure variables) and hearing loss have been observed for: lifetime exposure to farm equipment (in hours), livestock farming, years driving a tractor, years of grain dryer exposure, pesticide spraying, operating a tractor without a cab, metal work, chain saw use, firearm use, years worked in agriculture, and other noisy jobs [Marvel et al., 1991; Beckett et al., 2000; Hwang et al., 2001; McBride et al., 2003].

Although these published studies did not examine exactly the same agricultural exposure variables, it is reasonable to assume that variables in the current study, such as *years of electric or pneumatic tool use, years lived on a farm* and *all agricultural tasks combined* are similar to some of the agricultural exposures variables in the literature observed to have a statistically significant association with hearing loss. The main inconsistency between the current study and the published literature is that agricultural exposure variables similar *to years hunting or target shooting* in these studies were either not associated with hearing loss or a paradoxical association was observed (i.e., exposure was associated with better hearing acuity) [Marvel et al., 1991; Beckett et al., 2000; Hwang et al., 2001; McBride et al., 2003].

Reasons for these inconsistencies include differences in exposure estimation methods and differences in methods used to ascertain and summarize hearing loss. Because lifetime agricultural noise dosimetry is not feasible, most studies examining associations between hearing loss and agricultural exposures have used questionnaire-based instruments to quantify lifetime exposure. Unfortunately, no standard, widely-used questionnaire has been developed for this purpose. Consequently, differences across questionnaires may lead to differences in observed associations across studies. In addition to differences in exposure estimation, differences in hearing loss summary variables may also lead to inconsistent associations. As noted above, some studies have used questionnaires to assess hearing loss. It is likely that error is introduced with this method [Gomez et al., 2001]. Even when pure tone audiometry was used to assess hearing loss, differences in data reduction procedures, that is, specific PTA hearing loss calculations and analyses of continuous versus dichotomized hearing loss outcomes would add further heterogeneity to the literature.

The current study is consistent with the published literature in that hearing loss was greater among farmers than non-farmers and that the effect was most apparent in the higher frequencies of the audiogram [Broste et al., 1989; Brackbill et al., 1994; May et al., 1990; Marvel et al., 1991; Plakke and Dare, 1992; Varchol and Wilkins, 1998; Beckett et al., 2000; Gomez et al., 2001; Hwang et al., 2001; Choi et al., 2005]. Furthermore, these observations are consistent with previously published results from Round 1 of the KCRHS [Flamme et al., 2005; Merchant et al., 2002].

In the current study, analyses were conducted separately for men and women. This was done to (i) allow for estimation of effects without confounding by gender and (ii) eliminate the appearance of modification of effects by gender resulting from possible gender-based differences in true noise exposure per reported year of task duration. Examination of the distributions of duration of exposure to agricultural tasks showed that women spent substantially fewer years performing agricultural tasks than men. Furthermore, a large proportion of the women reported never engaging in many of the tasks. Therefore, when men and women were analyzed together, the referent group for each agricultural exposure task was nearly all women and the higher exposure groups were nearly all men. Compounding this problem is the fact that the amount of noise energy delivered to each participant per year of reported task duration may have differed systematically between men and women (i.e., 1 year of reported chain saw use among women may not represent the same noise energy as 1 year of reported chain saw use among men). Hence, controlling for the effect of gender in multivariate models and including a gender by exposure interaction term would have produced potentially biased results.

Except for *hunting or target shooting*, statistically significant fully adjusted associations (Table VI) between the agricultural task variables and hearing loss were observed exclusively among male participants in the highest quintile of exposure. This was also observed for the individual association (Table IV) between *all agricultural tasks combined* and hearing loss. One possible reason could be that the actual noise exposure per year of reported task duration varied systematically over time, with each year of noise exposure experienced in the past delivering more noise energy than each year of exposure experienced more recently. If true (i.e., that farming was noisier in the past), then those with longer durations of exposure would have experienced disproportionately greater noise energy those with shorter durations of exposure.

Limitations

Several methodological limitations may have affected the results of the current study. Although hearing loss was measured with a gold-standard method, that is, pure tone audiometry, the metric of exposure was less precise. As noted above, years of exposure to specific agricultural tasks was used as the metric of noise exposure. However, it is likely that considerable random variability in true noise exposure occurred per year of reported task duration. If such error occurred equally across participants, regardless of hearing acuity, then it would attenuate the observed association in comparison to the true association (i.e., non-differential misclassification).

Another important limitation of the current study was the lack of useful information on use of hearing protection, a modifier of the effect of ambient noise exposure. Hearing protection use by some participants would decrease their noise exposure and increase the heterogeneity of true noise delivered per reported year of task duration. Therefore, it is possible the effects of the agricultural exposures on hearing loss were different among participants who did and did not use hearing protection. However, farmers are known to use hearing protection infrequently and the contribution of hearing protection to a reduction in actual noise exposure is likely small [Karlovich et al., 1988; Broste et al., 1989]. Furthermore, previous research found hearing protection use among farmers working around noisy farm equipment was not associated with a reduced risk of hearing loss [Hwang et al., 2001].

Additional limitations of the current study included a participation rate lower than expected and, compared to women, a larger proportion of men having current or past agricultural exposures (i.e., prior to gender stratification, the referent group for each agricultural exposure was nearly all women). These limitations have been identified previously [Merchant et al., 2002]. It is uncertain if the lower than expected participation rate introduced any error or affected the generalizability of the results. An examination of non-participants from the study region found only slight demographic differences from KCRHS participants [Merchant et al., 2002]. There is no reason to believe that study participation was a function of the joint distribution of noise and hearing function, however, and thus we believe that the associations reported in this article are not likely the result of sampling bias.

Strengths

In comparison to other published studies, the large sample size and use of established audiometric methods to formally ascertain hearing loss are strengths of the current study. Prior studies using audiometric measurements have typically been small [Karlovich et al., 1988; Broste et al., 1989; Marvel et al., 1991; Plakke and Dare, 1992; Gomez et al., 2001; Solecki, 2002]. The large sample size in the current study allowed for greater statistical power and more stable estimation of effects. Furthermore, the large sample was obtained by random sampling of rural residents making the results generalizable to other rural and agricultural populations. In comparison to self-reported hearing loss, use of audiometric measurements of hearing loss reduces both differential and non-differential misclassification. Measurement error was controlled by using calibrated equipment, standard procedures, and trained technicians. Any modest audiometric error was expected to be non-differential, affecting all study participants equally, and resulting in attenuation of observed associations.

Public Health Significance

The results of this study provide insight into a public health approach to prevent or reduce hearing loss among farmers and rural residents. Several tasks were identified that should be the focus of interventions to reduce lifetime noise exposure and ultimately hearing loss. Specifically for men, agricultural exposures common to both farmers and rural residents (i.e., *years hunting or target shooting*, and *years of pneumatic or electric tool use*) were associated with hearing loss. It is likely that male farmers and male rural residents have similar noise exposure histories. Therefore, public health education and/or intervention strategies to prevent hearing loss should not focus exclusively on obvious farm tasks (i.e., driving tractors, working around grain bins, or working around livestock).

From a public health perspective, of considerable concern is the low rate of hearing protection use observed in the current study (and in many previously published studies). For short-term exposures such as hunting or target shooting and use of electric or pneumatic tools, it is important that farmers and rural residents who engage in these activities use hearing protection.

Despite limitation in exposure assessment (i.e., use of exposure expressed in years engaging in agricultural tasks rather than actual task noise dosimetry) which likely resulted in extensive misclassification, this study shows associations between some specific agricultural tasks and loss of hearing acuity. This association was especially prominent among individuals who reported engaging in these tasks for the greatest number of years. Future studies to determine the actual noise exposures associated with agricultural tasks would contribute substantially to the understanding and prevention of hearing loss among farmers and agricultural workers.

In summary, evidence from the current and other studies suggests that hearing loss is associated with agricultural tasks and efforts to prevent noise exposure, either by engineering or personal protective equipment should be emphasized.

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