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Hearing conservation program for agricultural students: Short-term outcomes from a cluster-randomized trial with planned long-term follow-up

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ABSTRACT

Objectives. (1) To conduct a contemporary analysis of historical data on short-term efficacy of a 3-year hearing conservation program conducted from 1992 to 1996 in Wisconsin, USA, with 753 high school students actively involved in farm work; (2) to establish procedures for assessment of hearing loss for use in a recently funded follow-up of this same hearing conservation program cohort.

Methods. We analyzed a pragmatic cluster-randomized controlled trial, with schools as the unit of randomization. Thirty-four rural schools were recruited and randomized to intervention or control. The intervention included classroom instruction, distribution of hearing protection devices, direct mailings, noise level assessments, and yearly audiometric testing. The control group received the audiometric testing.

Results. Students exposed to the hearing conservation program reported more frequent use of hearing protection devices, but there was no evidence of reduced levels of noise-induced hearing loss (NIHL).

Conclusion. Our analysis suggests that, since NIHL is cumulative, a 3-year study was likely not long enough to evaluate the efficacy of this intervention. While improvements in reported use of hearing protection devices were noted, the lasting impact of these behaviors is unknown and the finding merits corroboration by longer term objective hearing tests. A follow-up study of the cohort has recently been started.

Introduction

Agriculture is an industry with among the highest recorded exposures to dangerous levels of noise (National Institute for Occupational Safety and Health, 2001). Studies have demonstrated an increased prevalence of noise-induced hearing loss (NIHL) among children who were actively involved in farm work (Broste et al., 1989; Renick et al., 2009). The Occupational Safety and Health Administration (OSHA) mandates implementation of hearing conservation programs in industries where noise levels equal or exceed 85 dB averaged over eight working hours (OSHA, 2002). However, most agricultural worksites are exempt from OSHA regulations, so alternative strategies to promote hearing conservation among farm youth must be identified and evaluated.

From 1992 to 1996, a cluster-randomized trial was conducted to evaluate the efficacy of a 3-year hearing conservation program involving high school students who were working in agriculture (Knobloch and Broste, 1998). To date, this is the *only* existing randomized trial that examines NIHL prevention in the farm population (El Dib et al., 2006) and data from the trial remain an important reference. However, previous analyses of this randomized trial considered only the intermediate end point of self-reported use of hearing protection devices and not objective measures of hearing acuity (Knobloch and Broste, 1998).

The purpose of this paper was to present new analyses of historical data from the original trial. Our research group was recently funded to conduct a long-term follow-up of hearing loss among participants in the original trial. This new study will evaluate objective audiometric measures of long-term hearing loss based upon contemporary clinical standards. Such an analysis had never been conducted on short-term outcomes as part of the

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original trial. During the last decade, new standards have been developed for the conduct and reporting of cluster-based randomized controlled trial standards (Campbell et al., 2004). The current report is based upon contemporary standards for such trials that were not available historically.

Methods

Specific objectives and hypotheses

Our objective was to determine whether a hearing conservation program directed at students who were actively involved in farm work resulted in (i) a reduced prevalence of NIHL at 3-year follow-up and/or (ii) an increased use of hearing protection devices, as compared with similar groups of students who did not receive the program. We hypothesized that the hearing conservation program would lead to a lower prevalence of NIHL, as well as increased use of hearing protection devices.

Participants

The study comprised 34 rural schools in the state of Wisconsin, USA. Inclusion criteria for schools were as follows: (i) located in rural Wisconsin, (ii) had an active vocational agriculture program as identified by the state Department of Public Instruction, and (iii) agreement by school administrations to participate, be randomized, and adhere to requirements of the trial protocol. Target students (i) were enrolled in grades 7–9 at the time of recruitment, (ii) worked or resided on a farm and were "*active and regular participants in farm work*," (iii) were members of the National FFA (a youth agricultural education organization [http://www.ffa.org/]) or taking vocational agricultural classes, (iv) expected to remain in their current school system through the end of the study, and (v) provided assent (students) and informed consent (parents or guardians). There were no specific exclusions. The Institutional Review Board of Marshfield Clinic Research Foundation approved the study.

Noise exposure history

Participants were given a baseline questionnaire and parental consent forms. Following consent, students were asked to complete the questionnaire with their parents. The questionnaire focused on past medical history, history of hearing problems, exposures to specific types of farm work, exposures to recreational sources of noise, and use of hearing protection devices. This noise exposure questionnaire was re-administered after 3 years.

Audiometric testing

Site visits were made to each of the 34 schools. Audiometric examinations were performed by trained technicians, using a truck-mounted mobile testing unit with a specially designed testing booth. Ambient noise levels were measured using a sound level meter. When noise levels exceeded permissible limits, the testing vehicle was moved or testing was halted until the background noise levels were acceptable. Students were instructed to avoid noisy situations in the 24 hours prior to testing and were supplied with ear plugs to use if they could not avoid such exposures. Audiometers were calibrated per American National Standards Institute (ANSI) standards and a Hughson–Westlake modification of the ascending threshold technique was used to determine hearing levels (ANSI, 1978).

If the study team felt that the audiometric testing identified clinically important, undetected hearing loss, or the subject reported unusual symptoms (e.g., dizziness, ear pain, drainage, unilateral tinnitus, change in tinnitus, sudden change in hearing), an audiologist was consulted, and the parents were sent a letter recommending that the student follow-up with a physician.

Educational intervention

For students in the intervention schools, a hearing conservation program was implemented after baseline testing. The intervention incorporated elements of an ideal industrial hearing conservation program (Royster and Royster, 1990) and included the following: (i) classroom instruction at each school, (ii) distribution of hearing protection devices to each student, (iii) direct mailings to the student's home, (iv) noise level assessments at the student's home, and (v) yearly audiometric testing.

The intervention began with classroom instruction by the study's health educator and included basics of anatomy and physiology of the ear, videotaped testimonials by young farmers with impaired hearing, and demonstrations of music with missing frequencies. Proper fit and use of hearing protection devices were also demonstrated and students were given ample time to practice with ear plugs and ear muffs. A variety of hearing protection devices were provided free to students and were replaced regularly throughout the study (nine scheduled distribution times over 3 years). The intervention message was reinforced periodically via direct mailings to the student's home (11 mailings over 3 years). Students were given an opportunity to use an inexpensive sound level meter to measure noise levels of equipment and activities around their own farms. Finally, yearly audiometric testing provided an opportunity to reinforce and encourage hearing protection behaviors.

Primary and secondary outcome measures

All outcomes were assessed at the individual student level. Primary outcome measures were audiometric threshold changes from baseline to the 3-year follow-up in (i) the individual frequencies (500, 1000, 2000, 3000, 4000, and 6000 Hz), (ii) the high-frequency average (3000, 4000, and 6000 Hz), (iii) the low-frequency average (500, 1000, and 2000 Hz), and (iv) OSHA standard threshold shift, representing an increase of 10 dB or greater in the average for 2000, 3000, and 4000 Hz in either ear (yes or no). Measures (i)–(iii) were calculated for the left and right ears separately, but the primary analyses were based on the maximum change of the two ears. In addition, we analyzed a newly developed audiometric outcome, the "bulge depth statistic" (Dobie, 2005), which specifically targets NIHL and is defined as the difference between the mean audiometric values at 2000, 3000, and 4000 Hz, and the mean values at 1000 and 6000 Hz. This difference in means quantifies linearity across the thresholds as a way of assessing the often-cited NIHL "notch." It is similar to the "notch index" defined by Rabinowitz et al. (2006), but substitutes 6000 Hz for 8000 Hz (8000 Hz was not available in the original study).

The planned secondary outcome measure was self-reported use of hearing protection devices when exposed to noisy environments or activities. The latter were assessed using three-point Likert-type scale (*never*, *sometimes*, *always*/*almost always*).

Sample size

Enrollment for the trial represented a convenience sample based on the availability and participation of eligible schools. The original goal was to enroll enough schools to provide projected initial numbers of 400 per group. An 86% retention rate would result in a total sample size of 690 subjects at 3 years. Based on the observed variability and intraclass correlations, this sample size provides over 90% power to detect a 1.5 dB mean group difference in the low-frequency average, and provides over 90% power to detect a 1.25 dB mean group difference in the high-frequency average (two-sided tests, $\alpha = 0.05$).

Randomization

In total, 34 schools were recruited. A cluster-randomized design was used, with schools as the unit of randomization. Schools were first stratified by projected student numbers into larger and smaller schools and were subsequently randomized by the statistical support staff to either the intervention or control group separately within these two strata. Given that the intervention involved education and distribution of hearing protection devices and that intervention and control schools were geographically separated, it was not possible or necessary to blind either subjects or support staff in the trial.

Statistical methods

The individual audiogram frequencies were each analyzed as a maximum (left or right) change from baseline using logistic regression to compare the study arms. Prior to analysis, high changes were pooled such that at least 10 responses per study arm occurred in the highest category. A cumulative logit parameterization assuming proportional odds was fit to the resulting ordinal scale (e.g., 0, 5, 10, 15+) measures. The OSHA standard threshold shift was analyzed using binary logistic regression to compare study arms.

Audiogram summary measures were each analyzed as a maximum (left or right) change from baseline using a linear model to compare the study arms. The measures were first transformed (Box and Cox, 1964) to provide better approximate normality and improved statistical properties. Statistics were returned to the original scale for presentation. Residuals from these analyses were examined for outliers and overly influential observations. Both the Spearman rank correlation statistic and analysis of covariance models were used to evaluate potential associations between measures of noise exposure, the use of hearing protection, and the audiogram summary measures.

All models were adjusted for the randomization by school, since the results for students within a school may be correlated due to conditions during testing and/or regional similarities in farm characteristics. A school indicator was used in the models to estimate and adjust for this potential correlation (the intraclass correlation coefficient, ICC). Models incorporating the ICC are called "random effects" or "mixed" models.

Analyses included all available data following intention-to-treat principles. References to statistical significance are based on the 5% level of significance ($p<0.05$) in two-sided tests. No adjustment for multiple comparisons was utilized in the preplanned analyses. However, secondary analyses of associations for audiometric tests with noise exposure and hearing protection were required to show both significance at a high level ($p<0.001$) and consistency across adjacent frequencies.

Table 1
Demographic characteristics at baseline and year 3 for intervention and control group (Wisconsin, USA, 1992–1996).

	Baseline		Year 3	
	Control	Intervention	Control	Intervention
Schools (n)	17	17	17	17
Students (n)	378	375	341	349
Male (%)	65.3	76.3	63.9	75.9
Median age (yr)	14.5	14.6	17.4	17.6
Minimum	12	12	15	15
Maximum	17	16	20	19
Live on farm (%)	81.7	76.5	79.5	72.2
Work on farm (%)	93.4	94.4	86.2	86.5
School yr median (hr/wk)	11.0	10.5	20.0	19.0
Minimum	0	0	0	0
Maximum	80	100	100	79
Summer median (hr/wk)	30.0	30.0	40.0	42.0
Minimum	1	0	1	0
Maximum	105	112	160	120
Operate tractor (%)	78.0	78.7	79.5	78.2
School yr median (hr/wk)	2.0	1.0	3.0	2.0
Minimum	0	0	0	0
Maximum	50	80	40	100
Summer median (hr/wk)	10.0	10.0	20.0	15.0
Minimum	0.5	0.5	0	0.5
Maximum	100	107	140	100

Results

Recruitment and participant flow

Representatives from the 34 schools agreed to participate in the study (Fig. 1). Geographically, these schools covered a large area of central and western Wisconsin. Seventeen schools were randomized to each study arm, resulting in 375 students in the intervention arm and 378 students in the control arm.

The study protocols, intervention or control, were successfully implemented at all 34 schools, and all 34 schools remained active throughout the planned three years of study (Fig. 1). Follow-up questionnaires and hearing exams were completed by 349 students in the intervention group (93%) and 341 students in the control

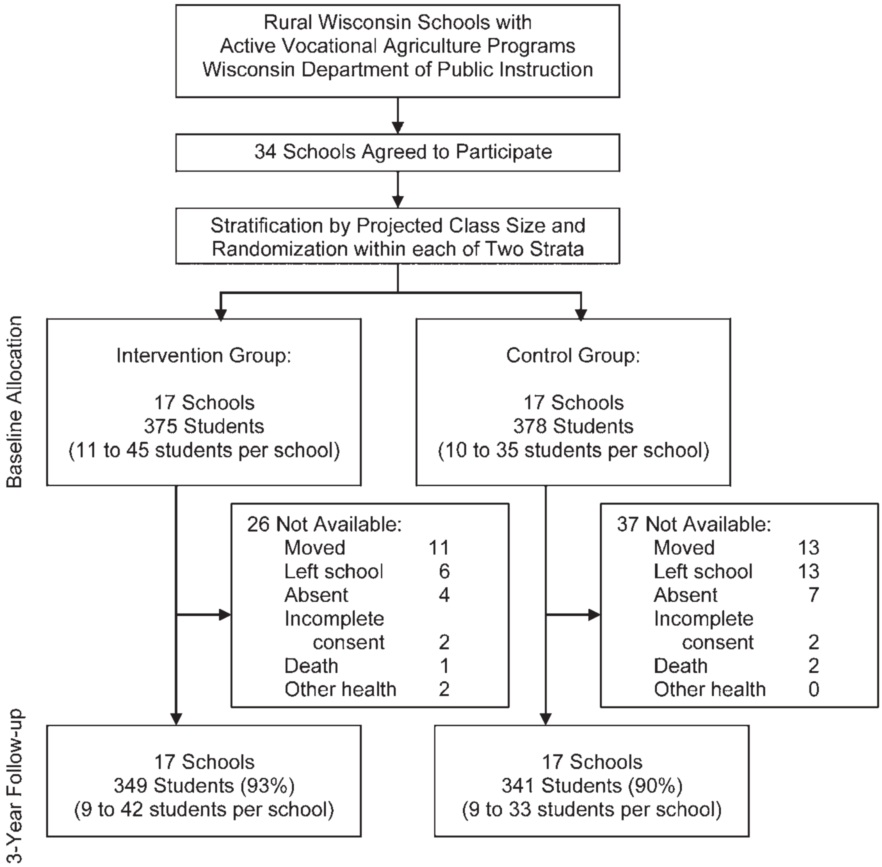

Fig. 1. Flow diagram of schools and participants in the cluster-randomized trial (Wisconsin, USA, 1992–1996).

Table 2

Reported use of hearing protection devices at baseline versus year 3 for intervention and control group[a] (Wisconsin, USA, 1992–1996).

Control	Year 3			Intervention	Year 3		
	Never	Sometimes	All/almost all		Never	Sometimes	All/almost all
Baseline	*n* (%)	*n* (%)	*n* (%)	Baseline	*n* (%)	*n* (%)	*n* (%)
(A) When working in a noisy area							
Never	**197 (57.8)**	51 (15.0)	6 (1.8)	Never	**51 (14.6)**	191 (54.7)	26 (7.4)
Sometimes	24 (7.0)	**48 (14.1)**	8 (2.3)	Sometimes	8 (2.3)	**46 (13.2)**	19 (5.4)
All/almost all	0 (0)	2 (0.6)	**5 (1.5)**	All/almost all	0 (0)	5 (1.4)	**3 (0.9)**
(B) When shooting firearms							
Never	**119 (52.9)**	33 (14.7)	7 (3.1)	Never	**71 (30.2)**	71 (30.2)	22 (9.4)
Sometimes	19 (8.4)	**28 (12.4)**	5 (2.2)	Sometimes	9 (3.8)	**38 (16.2)**	15 (6.4)
All/almost all	1 (0.4)	8 (3.6)	**5 (2.2)**	All/almost all	0 (0)	4 (1.7)	**5 (2.1)**

Numbers in bold show students with the same degree of use at both time points.

[a] The number of students and group percent is shown for each combination of baseline with year 3.

group (90%). Students were lost to follow-up primarily due to families moving (24 students) or to the students otherwise leaving school (19 students). Three student deaths, unrelated to the study, were reported in the study period, and there were no adverse health events reported. In total, 47 students received medical referral letters based on audiometric testing (23 students in the intervention, 24 students in the control).

Descriptive data

Table 1 presents a summary of participant characteristics for the 753 students at baseline and for the subset of 690 who were also studied at three years. Initial ages ranged from 12 to 17 years and were well balanced by group. Seventy percent were male, and this was somewhat higher in the intervention group (76% vs. 65%). High percentages of these students lived (79%) and/or worked (94%) on farms, and the farm work often involved some operation of tractors larger than a lawn tractor (78%).

By the study's end, students were 15 to 20 years of age. Characteristics of those completing the study were similar to the full group at randomization (Table 1), although there was some decrease in the percentages living (76%) and working (86%) on farms.

Outcomes and estimation

Reported use of hearing protection devices

Table 2A summarizes the reported use of hearing protection devices while in a noisy area at baseline (rows) and year 3 (columns) by randomized group. The same degree of use at both time points was reported by 73% of the control group but by only 29% of the intervention group. The most pronounced difference among groups was the large percentage of intervention group who changed from

Table 3

Analysis of changes in reported use of hearing protection devices and changes in audiometric threshold tests from baseline to year 3[a] for intervention and control group (Wisconsin, USA, 1992–1996).

(A) Use of hearing protection devices (HPD)							
	Showing increased use		Odds ratio	95% confidence interval		*p* value	Intraclass correlation
	Control (%)	Intervention (%)		Lower	Upper		
HPD use in noisy area	19.1	67.6	7.73	4.98	11.99	<0.001	0.04
HPD use with firearms	13.2	30.9	3.09	2.03	4.71	<0.001	0.01

(B) Individual audiometric frequencies							
	With some hearing loss		Odds ratio	95% confidence interval		*p* value	Intraclass correlation
	Control (%)	Intervention (%)		Lower	Upper		
500 Hz	50.4	45.0	0.91	0.52	1.61	0.747	0.11
1000 Hz	47.5	37.5	0.77	0.47	1.25	0.279	0.07
2000 Hz	40.5	41.8	1.00	0.64	1.57	0.999	0.06
3000 Hz	46.9	42.4	0.88	0.58	1.34	0.543	0.04
4000 Hz	50.7	59.0	1.55	0.89	2.69	0.115	0.09
6000 Hz	76.2	73.9	0.98	0.61	1.55	0.913	0.06

(C) Standard threshold shift							
	With 10 dB or greater loss		Odds ratio	95% confidence interval		*p* value	Intraclass correlation
	Control (%)	Intervention (%)		Lower	Upper		
	2.1	2.6	1.18	0.41	3.40	0.748	0.00

(D) Audiometry summary metrics							
	Adjusted means		Mean difference	95% confidence interval		*p* value	Intraclass correlation
	Control	Intervention		Lower	Upper		
Low-frequency average	5.0	4.6	0.35	−0.54	1.29	0.443	0.12
High-frequency average	7.8	7.9	−0.09	−0.90	0.78	0.837	0.05
Bulge depth	2.6	3.2	−0.58	−1.47	0.31	0.192	0.04

[a] In all models, school was modeled as a random effect. Outcomes in A, B, and C were modeled using logistic regression with control.

reporting "never" using hearing protection devices to using it "sometimes" (55% of the intervention group, 15% of the control group). Among students who used firearms, there was also a greater proportion in the intervention group who changed from "never" used hearing protection devices when shooting to using it "sometimes" (30% for the intervention group, 15% for the control group; Table 2B). Analyses of the changes in reported use of hearing protection devices showed highly significant group differences ($p<0.001$) both for use in a noisy area and for use with firearms (Table 3A).

Audiometric threshold testing

Raw audiometric results showed similar distributions in the two study groups, both at baseline and three years later (Figs. 2A and B). Little change in hearing was observed over the 3 years of the study (Figs. 2A to B). Individual results varied greatly, with some subjects showing nearly ideal hearing at both time points, others showing marked hearing loss at both times, and a few showing substantial declines over the 3-year study.

Analyses of the thresholds verified the presence of underlying gender differences in hearing, as reported by others (Sato et al., 1991; McFadden, 1993; Morlet et al., 1996; Phillips et al., 2001; Nageris et al., 2007). As shown in Fig. 3, both the low- and high-frequency baseline averages tended to be higher in males, but asymmetrically. In girls, the left and right ears were quite similar and were also similar to the right ears of boys. In boys, the left ear thresholds were on average 3 dB higher (less acute) than those for right ears. These differences could not readily be explained by reported noise exposures (farm machinery, power tools, firearms, recreational vehicles, music). Gender comparisons were not the focus of this trial, but given the fact that randomization by school left some residual imbalance by group, it was critical to adjust our primary analyses for gender.

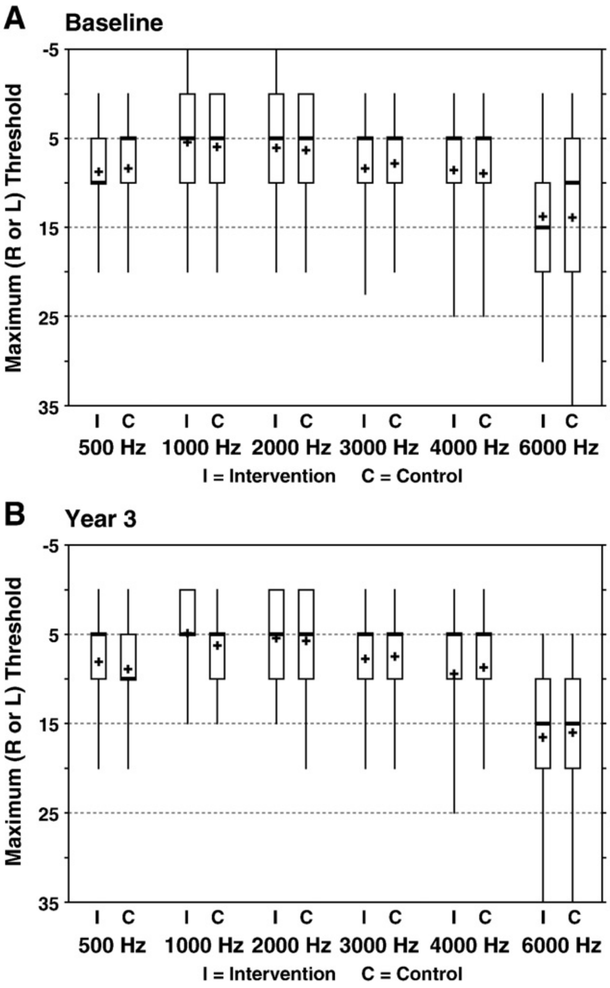

Fig. 2. Audiometric threshold test results at baseline and year 3 for intervention and control group. Boxes extend from the 25th to 75th percentiles, with a midline at the median, and "+" at the mean. Vertical lines extend to the 5th and 95th percentiles (Wisconsin, USA, 1992–1996).

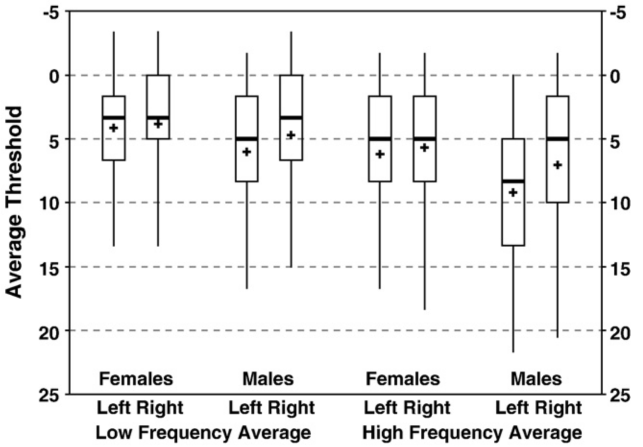

Fig. 3. Low- and high-frequency average audiometric threshold test results by gender and ear. Boxes extend from the 25th to 75th percentiles, with a midline at the median, and "+" at the mean. Vertical lines extend to the 5th and 95th percentiles (Wisconsin, USA, 1992–1996).

Group comparisons of the audiometric thresholds are summarized in Table 3B. No significant differences were observed between intervention and control, and no consistent trend was observed across the thresholds. The largest group difference observed was at 4000 Hz, where the odds ratio was 1.55, in the direction of worse hearing in the intervention group at 3 years, but even this result was not significant upon appropriate adjustment for the cluster-randomization and gender ($p=0.115$). Similarly, the standard threshold indicator of changes in the range 2 to 4 kHz gave no indication of group differences (Table 3C, $p=0.748$).

Comparisons of the hearing summary metrics are presented in Table 3D. As with the raw thresholds, no significant group differences were observed. Means adjusted for the design and gender were very similar by group for the low- and high-frequency averages and for the bulge depth statistic. The mean bulge depth was slightly higher in the intervention group (in the direction of more curvature across the thresholds in the intervention group), but the difference was not statistically significant ($p=0.192$).

Secondary analyses of associations with noise exposure

In addition to recording the use of hearing protection devices, study questionnaires included information on exposure to various sources of noise commonly found on farms (Table 4). Both the use of hearing protection devices and reported noise exposures were evaluated in secondary analyses for associations with the audiometric testing. Responses were found to be strongly associated with gender, with males consistently showing higher noise exposures but also showing lower use of hearing protection devices. Analyses to evaluate noise exposure and to evaluate hearing protection devices as a modifier of noise exposure were therefore stratified by gender.

The noise exposures were evaluated singularly and in combination, both in their raw form as reported on the questionnaire and after applying weights based on the reported duration of exposure and approximate decibel ratings based on published sources (Table 4). The observed correlations (data not shown) were generally low and only weakly suggestive that noise exposure was associated with decreased hearing acuity in this young farm population which had not yet experienced substantial NIHL. Similarly, greater reported use

Table 4
Percentage of children exposed to agricultural and recreational noise of different decibel levels (dB), by gender for intervention and control group (Wisconsin, USA, 1992–1996).

	Males		Females	
	Control (%)	Intervention (%)	Control (%)	Intervention (%)
Highest noise levels (>90 dB)				
Tractor with no cab[a]	86.2	87.4	60.3	48.3
Combine[b]	11.5	9.2	2.5	0.0
Chainsaw[a]	53.4	48.6	9.2	5.6
Snowmobiles, ATVs, motorcycles[c]	87.4	85.3	74.0	66.3
Firearms[c]	87.4	85.3	38.9	27.0
Intermediate levels (85–90 dB)				
Silo blower[d]	59.6	57.9	19.5	9.9
Haybine[d]	46.8	48.0	14.4	9.9
Field chopper[d]	31.9	41.8	11.0	6.2
Elevator[d]	80.9	78.8	55.1	59.3
Silo unloader[d]	66.4	63.4	40.7	37.0
Woodworking[a,f]	71.7	75.9	36.6	31.5
Lawn mowers[a]	97.6	98.6	91.6	93.3
Lowest noise levels (<85 dB)				
Barn cleaner[d]	68.1	69.2	52.5	43.2
Milking equipment[a]	66.0	72.9	69.5	58.0
Loud music[e]	87.9	86.7	91.6	93.3

[a] Lander et al. (2007).
[b] Jones and Osler (1968).
[c] Neitzel et al. (2004).
[d] National Farm Medicine Center (1999).
[e] Williams (2005).
[f] Depcyznski et al. (2005).

of hearing protection was associated with better audiometric test results, but the observed correlations were low.

Discussion

This cluster-randomized controlled trial examined the efficacy of a hearing conservation program directed at students who were actively involved in farm work. The major study finding was negative, in that there was no documented evidence of a reduced level of NIHL over 3 years among students from schools that were randomized to the hearing conservation program. Consistent with the original findings of Knobloch and Broste (1998), students exposed to the hearing conservation program reported more frequent use of hearing protection devices.

Internal validity

Common sources of bias that would affect the internal validity of this trial warrant comment. The first of these is selection bias. Schools and youth who participated in the study were not purported to be representative of students involved in farm work. However, selection of study participants was made independently of the outcomes under study. Further, response rates at the school and student levels were both extremely high, and loss to follow-up was low and consistent between the intervention and control arms of the trial. Therefore, there is no reason to suspect that the findings in this randomized trial are attributable to selection bias.

With respect to potential confounding, comparisons suggested that some baseline differences existed between the intervention and control participants. Baseline differences were observed by gender (Table 1) and farm operational characteristics (data not shown). These differences are likely attributable to insufficient numbers of schools being randomized to ensure balance between groups. Gender differences were noted (Fig. 3) and analyses were adjusted accordingly. Further stratification of the randomization scheme by regional farming type may have led to improved balance of the trial arms with respect to potential confounders. However, the observed imbalances were unlikely to mask meaningful differences in the study outcomes when the overall changes in hearing were limited at three years. Should outcome differences emerge in future analysis of the ongoing follow-up study, it will be important to evaluate potential associations with other baseline characteristics.

The fact that hearing loss was actively measured in both groups may have also limited the potential effect of the intervention, as provision of screening on three occasions to controls may have led to subtle changes in hearing conservation practices among controls. Further, by necessity, this was an unblinded study at both the participant and investigator levels. Our reliance on objective measures of hearing function via audiograms, however, should have minimized the potential for differential errors in the assessment of the NIHL.

External validity

Results from this cluster-randomized trial are likely generalizable to populations of young people who share similar cultural and exposure experiences as the students studied. However, study findings should be generalized neither to other (e.g., nonrural) populations nor beyond the 3-year time window due to the progressive nature of NIHL. Caution is also warranted in the generalization to contemporary farm youth due to changes in farm operations and youth noise exposures over time.

General interpretation

Findings from this cluster-randomized trial suggest that a focused hearing conservation program aimed at rural students led to some increase in reported use of hearing protection devices. This is encouraging because hearing protectors reduce noise levels approximately 10 dB in field studies (Berger et al., 1996). However, there was no evidence of decreased rates of NIHL at 3 years among young people assigned to the intervention and little evidence of NIHL from the audiometric testing performed on 690 students that completed the full trial protocol. The risk of NIHL increases with age and length of exposure to noise; yet most noise-related damage occurs within the first 10 years of high noise exposures (Meyer, 2003). Three years is a short time interval, perhaps too short to make definitive conclusions about the efficacy of this intervention.

Secondary findings that emerged from the analysis included the observed asymmetry in hearing for male, but not for female participants. Hearing among boys was significantly less acute in the left ear, particularly at high frequencies. It is unclear whether this finding is attributable to differences in biology, exposures to farm production activities, or other sources of noise such as gunfire. However, noise exposures as measured in this study did not explain the gender difference in asymmetry. Past studies have identified high levels of hearing loss among children involved in farm work and attributed these to production activities. Our findings may call into question this conclusion, specifically for studies that did not appropriately account for the confounding influence of gender and noise exposures that are different between males and females.

While improvements in reported use of hearing protection devices were noted in the intervention arm, the long-term impact of these behaviors remains unknown. The level of evidence at this point would be modest at best to recommend the routine implementation of such an intervention. This might change with time. Hence, participants in this trial are currently being recruited in order to repeat the audiometric testing some 16 years after baseline testing.

Future analysis of results from the long-term follow-up study will mirror the methods presented here and notably will include adjustment for gender differences. Objective, long-term measurement of hearing function via audiogram and analysis of the same hearing loss metrics as used for the original trial should permit a more comprehensive and accurate assessment of the efficacy of the hearing conservation program. Furthermore, with over 10 additional years of noise exposure, we expect to see more subjects with hearing loss, and this will allow us to better evaluate potential causative factors. Assessment of noise exposures subsequent to the original trial will provide new information on the natural history of NIHL in farm youth as they pursue careers both inside and outside of agriculture.

Conflict of interest statement

The authors declare that there are no conflicts of interest.

Acknowledgments

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