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A multi-component intervention to promote hearing protector use among construction workers

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Abstract

Hearing protection devices (HPD) remain a primary method of prevention of noise-induced hearing loss despite their well-known limitations. A three-pronged intervention to increase HPD use was conducted among construction workers and included a baseline hearing loss prevention training, follow-up 'toolbox' (TB) reinforcement trainings, and use of a personal noise level indicator (NLI). A total of 176 subjects on eight sites completed three assessments. Prior to intervention, HPDs were used an average of 34.5% of the time and increased significantly, up about 12.1% after intervention and 7.5% two months after interventions were completed. The increase in HPD use was greatest among the group receiving both TB and NLI interventions; up about 25% from baseline, and this group was about two times more likely to use HPDs than the BL (baseline) training only group. This study demonstrates the mild impact of a well-constructed HPD use training and provides support for the additional use of a personal NLI to increase use of HPDs among construction workers. The most effective procedures for using such instruments require further exploration.

Sumario

Los instrumentos para la protección de la audición (HPD) siguen siendo el método primordial para la prevención de las pérdidas auditivas inducidas por ruido, a pesar de sus bien conocidas limitaciones. Se ha propiciado una intervención de tres facetas para incrementar el uso de los HPD por parte de los trabajadores de la construcción que incluyen un entrenamiento básico para la prevención de problemas auditivos, un conjunto de herramientas (TB) de seguimiento para reforzar los entrenamientos y el uso de un indicador personal de niveles de ruido (NLI). Completaron las tres evaluaciones un total de 176 sujetos en ocho sedes. Antes de la intervención, se usaron los HPD con un promedio de 34.5% del tiempo y aumentaron significativamente hasta alrededor del 12.1% después de la intervención y 7.5% dos meses después de que se completaron las intervenciones. El incremento en el uso de HPD fue mayor entre el grupo que recibió las intervenciones TB y NLI, hasta cerca del 25% a partir de la línea de base y este grupo fue usuario de HPD, cerca de dos veces más que el grupo que solo recibió el entrenamiento BL. Este estudio demuestra el ligero impacto de un entrenamiento bien estructurado del HPD y proporciona apoyo para el uso adicional de un NLI personal para incrementar el uso de HPDs en trabajadores de la construcción. Los procedimientos más efectivos para el uso de estos instrumentos, requiere un análisis adicional.

Despite wide recognition of the high levels of noise exposure in the construction industry (Sinclair & Haflidson, 1995; Legris & Poulin, 1998; Suter, 2002), the high prevalence of noise-induced hearing loss among long-term construction workers (Daniell et al, 2002; Hong, 2005), and the potential effectiveness of hearing protection devices (HPDs) (Berger et al, 1996; Toivonen et al, 2002), especially when used as part of a comprehensive hearing loss prevention program (HLPP) (Brink et al, 2002; Davies et al, 2008; Rabinowitz et al, 2007), use of HPDs among construction workers remains frustratingly low. Previous work by our group has observed usage rates less than 25% of the time while workers were exposed to noise levels greater than 85 dBA, the nominal 'high noise' level at which risk of hearing loss increases steeply. Further, when the attenuation achieved by typical foam insert ear plugs is factored in with the time of use and exposure levels at those times, the average reduction in exposure is less than 3 dBA over a full work shift. While both noise exposure level and HPD use appear to vary substantially by trade, all trades observed have a substantial fraction of their full shift exposures above 85 dBA, even after adjusting for HPD use (Neitzel & Seixas, 2005). Other researchers have documented similarly low use of HPDs among construction workers (Lusk et al, 1998; Daniell et al, 2006).

Improving the prevention of hearing loss among construction workers may be accomplished through a variety of strategies. Reducing the noise emitted from construction tools and machines through

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Abbreviations

BL	Baseline (training)
HLPP	Hearing loss prevention program
HPD	Hearing protection device
HPM	Health promotion model
L_{eq}	Sound pressure level using a 3 dB exchange rate, in decibels
NLI	Noise level indicator
PPE	Personal protective equipment
TB	Toolbox (training)

'buy quiet' campaigns and incentives shows significant promise as a long-term solution (NIOSH, 1998; Driscoll & Royster, 2000), as does the application of engineering controls to existing equipment (Driscoll & Royster, 2000). Increasing distance between the noise source and the workers, or adding barriers to prevent the propagation of noise to worker-occupied areas can also reduce exposures. While specific hearing loss prevention program (HLPP) requirements are well-defined for general industry (OSHA, 1983), they are completely absent from the federal construction industry regulation (OSHA, 1971). Recommended standards for hearing loss prevention in construction, which include effective use of hearing protection have been developed in the US (ANSI/ASSE, 2007), but have not been promulgated into regulations. Further, enforcement of the existing regulations has historically been, and continues to be quite lax, with very few regulatory inspections and even fewer citations (Suter, 2002). Financial incentives to employers for assuring adequate protection could perhaps be achieved through emphasis and education regarding the high observed rates of workers' compensation claims (Daniell et al, 2002; McCall & Horwitz, 2004). However this mechanism is problematic given the chronic nature of hearing loss and the typical employment of workers by multiple sequential employers, and the frequent lack of serial audiometric test data documenting the timing and development of an individual's hearing loss. Despite the potential contribution of each of these mechanisms to reduce noise exposures among construction workers, it is unlikely that the industry will achieve adequate noise reduction for many workers without relying on the use of hearing protection devices. Thus, finding ways to improve the utilization of HPDs among construction workers remains an important goal.

Use of personal protective equipment (PPE) including HPDs requires active participation by the individual; thus strategies which help motivate and support the desired behaviors are integral to effective PPE programs. In particular, efforts to educate workers on the importance of using the HPDs, and training on effective means of using the devices are required. However, education and training alone have not proved to be generally effective means of behavioral change. A variety of health behavior models have been proposed to improve the effectiveness of training by identifying key aspects which influence behavior. The health promotion model (HPM), for instance, incorporates cognitive-perceptual concepts such as perceived self-efficacy, perceived benefits of and barriers to a particular behavior, as well as modifying factors such as individual, interpersonal, and situational (organizational) barriers to implementing a behavior (Pender et al, 1990; Pender, 1996; Lusk et al, 1997). Although the HPM has been effectively used to explain and motivate use of HPDs in past studies (Lusk et al, 1994, 1999a, 1997; Ronis et al, 2006), this model does not include risk perceptions around hearing loss due to noise exposure. Melamed and col-

leagues demonstrated that constructs from other value-expectancy models such as the health belief model also significantly predict HPD use (Melamed et al, 1996). In particular the perceived threats of noise exposure (i.e. perceived susceptibility to noise and perceived severity of the consequences of noise exposure) were related to HPD use.

The conceptual model that guided the current intervention was a revised version of the HPM which also included perceived threats of noise exposure as constructs that were predicted to be directly related to intentions to use HPDs. Emphasis was placed on increasing workers' perceived benefits and efficacy beliefs around wearing HPDs while simultaneously decreasing perceived barriers to use. To enhance self-efficacy around hearing protection the intervention includes the use of a miniature electronic noise level indicator (NLI) as a means of providing real-time feedback on noise-levels. We hypothesized that the use of the NLI would increase self-efficacy beliefs by making it much easier for workers to recognize and act upon unsafe noise levels. In addition to increasing self-efficacy beliefs, continuous monitoring of risk can also be a 'cue to action,' a concept commonly integrated into the HPM and other behavior change models.

In this study, we examine the potential for three interventions to motivate behavior change resulting in adoption of the use of HPDs among construction workers: (1) a comprehensive one-time baseline (BL) training designed on the basis of HPM constructs, (2) subsequent brief refresher 'toolbox' trainings (TB) designed to reinforce the key messages delivered in the baseline training program, and (3) use of a NLI that provides the worker with individual information in real time on their exposure level, thus reminding and prompting the worker to adopt the desired behavior and use the HPDs when needed.

Methods

Study design

The three interventions were delivered on eight construction sites. Sites selected had to be of sufficient size that they would have an adequate number of workers on site for the duration of the six-month intervention and assessment period, and were therefore large commercial construction sites with unionized labor. In order to accommodate the three interventions within the confines of a limited number of worksites, the one-time baseline (BL) training was delivered to all subjects at each site following a pre-intervention assessment period. Subsequently, half (four) of the sites were selected to receive follow-up toolbox (TB) training, and half of the subjects on each site were randomized to receive the noise level indicator (NLI). Thus, the design included a pre-post evaluation for the baseline training, a group- (site-) randomized intervention for the TB training, and an individually randomized intervention within each site for the NLI.

Subject selection

About thirty subjects were recruited for participation at each of the sites and all participants were recruited through an informed consent process approved by the University of Washington Institutional Review Board. Subjects were given $20 each time they completed either a questionnaire or full shift exposure assessment. Volunteers were recruited for the pre-intervention assessment period, and after being informed of the study procedures and signing an informed consent letter, were given a pre-intervention questionnaire and exposure assessment. Within one month of recruitment, we returned to the

site to deliver the BL training and randomize individuals for use of the NLI, which was assigned to half (approximately 15) workers on each site. Only subjects who returned for BL training are included in the study sample.

The intervention period lasted for two months beginning with the delivery of the BL training. During this two month period, subjects on the TB sites were given a short (5–7 minute) reinforcement training every two weeks (four trainings total), and subjects who had received NLIs were instructed to wear the device daily for this period of time. At the end of the two-month intervention period, the TB trainings were discontinued and the NLIs were retrieved from the participants. At this time, a second assessment was conducted, including dosimetry and task card, and a questionnaire. Approximately two months after the interventions were discontinued, a post-intervention exposure and HPD-use assessment was again conducted for each subject. As a result, we obtained a pre-intervention, a two-month post-intervention, and a final assessment two months subsequent to the end of the interventions (four-months subsequent to the BL training). These three assessments on each subject form the basis of this report.

Two additional assessments using only the questionnaire were conducted; one immediately after the baseline training, and one about ten months after the baseline intervention (six months subsequent to the last dosimetry-based assessment). The results of these two additional questionnaires are not reported here because, based on earlier work, we have determined that the questionnaire assessment of HPD use is inaccurate (Neitzel & Seixas, 2005; Edelson et al, 2009), and therefore inadequate to evaluate changes in HPD use related to the interventions. We have found that individuals are likely to over-report their use of HPDs on the questionnaire compared to the task-card evaluation of HPD use, and to our own direct observation. This pattern of over-reporting was found again in the current study, and we believe that changes in questionnaire-reported HPD use includes a substantial social desirability bias, and may indicate that training increases individual's likelihood of reporting HPD use, while actual use may not change.

Interventions

The BL training program's development and delivery has been described previously (Neitzel et al, 2008). Briefly, we adopted a modified version of the HPM (Pender et al, 1990; Pender, 1996) and designed the training program around the original HPM elements of self-efficacy, benefits to prevention, barriers to prevention, interpersonal and situational influences, as well as elements addressing perceived susceptibility and perceived severity (Melamed et al, 1996). In addition, the program addressed specific knowledge about hearing loss prevention and HPD use. These concepts were developed using plain language, and were delivered using situational examples relevant to the construction setting, as well as common perceptions and misperceptions about noise and hearing. Two hands-on demonstrations also provided specific training on proper use and fitting of insert hearing protection devices, and simple noise control techniques (sound barriers and distance). The format was designed for simple delivery on a construction site, using a set of flip-chart posters with simple graphics, and was designed to be delivered in one or two sessions for a total of approximately one hour. Study sites preferred delivery in a single session to avoid additional scheduling challenges. One study team member (RN) delivered all of the trainings using a uniform approach and style. A pilot test of the effectiveness of the training indicated increases in knowledge and intent to use hearing protection (Neitzel

et al, 2008). Subjects who reported using HPDs regularly in the pre-intervention period were more likely to report higher self-efficacy, greater benefits from HPD use, fewer barriers to HPD use, and higher noise exposures (Edelson et al, 2009).

Study participants on the four sites selected for reinforcement TB training were provided with a series of four additional 'toolbox' style onsite training sessions delivered every other week by one study team member (RN). The TB training focused on four key areas covered in the basic training; 'Construction noise and when to wear hearing protection,' 'Five things you can do to lower your noise exposure,' 'Using hearing protection correctly,' and 'Issues with hearing protection.' The reinforcement training was delivered orally and used a one-page hand-out with key concepts presented graphically, with minimal text derived from the baseline training materials. The BL training presentation, and TB training handouts are available on our website (http://staff.washington.edu/rneitzel/hc_training.pdf for the BL training, and http://staff.washington.edu/rneitzel/hc_toolbox.pdf for the TB training).

Half of the subjects on each site were randomly selected to participate in the third arm of the intervention, use of the noise level indicator (NLI). The NLI was a small (1.5 × 2 × 0.5 inch) sound level meter which was under development (by Quest Technologies, which was subsequently purchased by 3M, Oconomowoc, WI) and worn clipped to the participant's clothing or fall protection harness on the individual's chest or shoulder (see Figure 1). The indicator was preset to alarm with LED lights at 85, 95, and 105 dBA, and

Figure 1. Prototype NLI as used in the intervention study.

to vibrate and provide a blinking visual LED at 115 dBA. Subjects were instructed at the time they were provided with the NLI to wear it every day while at work, and instructed on the need for HPD use whenever noise levels exceeded 85 dBA. During the two-month intervention period, subjects wearing the NLI were visited by study staff approximately weekly to check that the indicator was functioning and to replace batteries.

Assessments

Each subject was given a pre-intervention survey addressing demographic factors, knowledge and attitudes about hearing protection for each of the HPM constructs, and site-specific safety and HPD climate factors, as described previously (Edelson et al, 2009). HPD climate was based on a series of questions concerning supervisory support for use of HPDs, analogous to standard safety climate questions. Each of these constructs was addressed using a five-point Likert scale and were used in the current analysis as potential covariates in the analysis of use and change in use of HPDs.

Noise exposure and HPD use was assessed for each subject on a single shift in the pre-intervention and at the 2-month and 4-month follow ups. Noise exposure was assessed as previously described (Edelson et al, 2009, Neitzel et al, 2008, Reeb-Whitaker et al, 2004). Briefly, a dosimeter (Quest Technologies NoisePro DLX or Q-300, Oconomowoc, WI) was provided to each subject, and logged the sound pressure level as L_{eq}, according to criteria specified by NIOSH (3 dB exchange rate, 80 dBA threshold, 85 dBA criterion level, slow response) (NIOSH, 1998) for each minute of the workshift. The dosimeter was downloaded at the end of the shift into a database of minute-long noise levels. During each monitored shift, each subject was asked to fill out a detailed task card recording the time at which specific activities were conducted, and including the time at which HPDs were in use. These HPD use reports from the task cards were matched by time with the dosimetry measurements as described previously (Neitzel & Seixas, 2005). Using the dosimetry and HPD use information, the percent of time during which the sound pressure levels exceeded 85 dBA in each shift, and in which the worker also reported using HPDs, was calculated. Based on these data, HPD use was quantified in two ways. The primary indicator of HPD use was the percent time in high noise (e.g. ≥ 85 dBA L_{eq}) in which HPDs were used. However, because previous analysis (Edelson et al, 2009) indicated that the distribution of HPD use was bimodal—with a large percentage of workers either reporting 0 or 100% HPD use while in high noise—we also created a binary variable indicating those subjects that used HPDs more or less than 50% of the time at or over 85 dBA L_{eq}. Note that use of hearing protectors for less than 50% of the time spent in high noise provides minimally effective protection from noise (Berger, 2000; Neitzel & Seixas, 2005).

Analysis

Given the design of the study, the analysis addressed four groups and three time points, or two change periods. The groups were defined as: (1) those that received BL training, (2) those that received BL training and TB training, (3) those that received BL training and the NLI, and (4) those that received all three interventions: BL, TB, and the NLI. Change in HPD use was assessed from the pre-intervention period to the two-month post-intervention assessment, and from pre-intervention to the four-month post-intervention assessment. In order to assure comparability of all factors, the analysis was restricted to those that had assessments conducted at all three time points. Table 1 shows

Table 1. Number of subjects by survey and intervention group.

	Intervention group				
	No noise indicator		Noise indicator		
Number of sites	4		4		8
Number of workers	Baseline	Baseline and toolbox	Baseline	Baseline and toolbox	Total
Enrolled	77	78	57	59	271
Enrolled at randomization	65	66	56	59	246
Missed one or more F/U (%)	19 (29)	22 (33)	11 (20)	18 (31)	70 (28)
Complete data	46	44	45	41	176

these four groups and the number of subjects enrolled in each, and included in the analysis.

Prevalence of HPD use ($>$50% of time in high noise) was calculated on a group basis, and changes in prevalence were evaluated using a McNemar's chi-square for paired data, acknowledging that some individuals who used HPDs at baseline did not at follow-up, and vice versa. In addition, average change in the percent time that HPDs was used, and the change in this percent from pre-intervention to two- and to four-month follow-up was calculated. The percent time using HPDs was assessed by intervention group, and by factors measured at baseline including demographic characteristics, HPM constructs, and safety climate factors. The HPM constructs were represented by single items from the questionnaire except for self-efficacy which was represented by the mean of the three self-efficacy questions, following the findings at baseline (Trabeau et al, 2008; Edelson et al, 2009) Each of the demographic and HPM constructs were classified into two to four levels, based on their distribution and the need to provide an adequate number of subjects in each group. The change in HPD use was evaluated between groups using analysis of variance (ANOVA).

Finally, models were developed to consider the effect of the intervention within each group, and possible precision, confounding, or effect modification variables. First, logistic transition models were considered with the binary 'HPD use $>$50 percent of the shift' at either the two-month or four-month assessment as the outcome variable. In these models, HPD use at the pre-intervention period was included as a covariate. However, because these models do not estimate the average change in use from pre-intervention to follow-up period, continuous regression models for change in use (as a continuous variable for percent time) were also developed. In these later models, precision, confounding, and effect modification covariates were also considered. Each potential covariate was first considered independently for association with change at two- or four-months. If the variable was associated ($p < 0.1$) with the outcome (precision), or if they substantially changed the primary effect of intervention group (confounding) they were added to the model stepwise. Interaction was also considered between the intervention groups and these covariates.

Results

A total of 271 subjects at eight sites were enrolled and underwent exposure assessment prior to randomization and intervention (Table 1). Twenty five of these subjects did not return for baseline

training, and were therefore excluded from randomization, leaving a total of 246 subjects available for study. Thirty-four of these subjects did not complete either of the follow-up assessments, and an additional 36 completed only one follow-up. Thus, we have restricted our primary analyses to those 176 subjects that completed all three assessments, distributed roughly equally across the four intervention groups. A comparison of baseline characteristics between the 176 subjects included in the analysis and the 70 who dropped out subsequent to randomization indicated no significant differences in age, trade, years in construction, and HPD use between the two groups.

Demographic characteristics of the four intervention groups are given in Table 2. Only slight and non-significant differences were observed in the distribution of age and educational achievement and

Table 2. Subject demographics* at baseline by intervention group.

	Intervention group				
	No noise indicator		Noise indicator		
	Baseline	Baseline and toolbox	Baseline	Baseline and toolbox	Total
	N (%)	N (%)	N (%)	N (%)	N (%)
Number of subjects	46	44	45	41	176
Age					
<=30	12 (26)	17 (39)	7 (16)	13 (32)	49 (28)
>30–40	14 (30)	10 (23)	17 (38)	12 (29)	53 (30)
>40–50	15 (33)	11 (25)	13 (29)	11 (27)	50 (28)
>50	5 (11)	6 (14)	8 (18)	5 (12)	24 (14)
Education					
<High school	3 (7)	4 (9)	1 (2)	4 (10)	12 (7)
High school	26 (59)	28 (65)	29 (69)	24 (59)	107 (63)
> High school	15 (34)	11 (26)	12 (29)	13 (32)	51 (30)
Missing	2	1	3	0	6
Hearing status*					
Good	16 (36)	25 (57)	15 (34)	21 (51)	77 (45)
Fair	23 (52)	18 (41)	27 (61)	16 (39)	84 (48)
Poor	5 (11)	1 (2)	2 (5)	4 (10)	12 (7)
Missing	2	0	1	0	3
Trade					
Electrician	9 (20)	3 (7)	6 (13)	2 (5)	20 (11)
Carpenter	14 (30)	21 (48)	20 (44)	21 (51)	76 (43)
Laborer	10 (22)	9 (20)	5 (11)	6 (15)	30 (17)
Other	13 (28)	11 (25)	14 (31)	12 (29)	50 (28)
Construction years					
<10	11 (27)	16 (37)	10 (24)	14 (40)	51 (32)
10–20	18 (44)	13 (30)	15 (37)	10 (29)	56 (35)
> 20 years	12 (26)	14 (33)	16 (39)	11 (31)	53 (33)
Missing	5	1	4	6	16
Others remind me to use HPDs[†]					
1	14 (31)	12 (28)	15 (35)	6 (15)	47 (27)
2–3	16 (36)	18 (42)	16 (37)	10 (24)	60 (35)
4–5	15 (33)	13 (30)	12 (28)	25 (61)	65 (38)
Missing	1	1	2	0	4
Boss thinks I should use HPDs[†]					
1–2	3 (7)	5 (13)	9 (20)	6 (15)	23 (14)
3–4	28 (67)	19 (50)	18 (41)	13 (32)	78 (47)
5	11 (26)	14 (37)	17 (39)	22 (54)	64 (39)
Missing	4	6	1	0	11

Chi-Sq: [†]p <0.05, *p <0.01.

trades between the four groups. Subjects on the sites receiving TB training had slightly better self-reported hearing and less experience working in construction. About a third of the subjects were classified as 'other' trades, which included iron workers (n = 8), plumbers (n = 12), pipefitters (n = 10), sheet metal workers (n = 10), operating engineers (n = 7), and cement masons (n = 3). HPD climate scores were higher among workers receiving the NLI (data not shown). This finding is similarly reflected in responses to HPM questions concerning co-worker and supervisory support for using HPDs (last two items in Table 2). No significant differences were found between intervention groups with respect to the other HPM factors (self-efficacy, benefits, barriers, susceptibility, and severity).

Table 3 presents full shift noise levels measured on the study group. Overall, the average full shift L_{eq}s were about 90 dBA, with about 30 to 40% of the time during the shifts over 85 dBA. There were small differences in the average noise levels between intervention groups. A slight but consistent downward trend for noise levels was observed over time. This trend may be due to behavioral changes in response to the interventions or the novelty of being monitored for the first time, but we believe the most likely reason is change in the work processes on sites over time.

Table 4 presents HPD use as the percent time in which HPDs were used (mean and standard deviation, SD) and the number (and percent) of workers using HPDs more than 50% of the time in noise at or above 85 dBA. Both measures are presented because of the highly bimodal distribution observed in HPD use, as reflected in the large standard deviations in the average percent time HPDs were used (upper half of Table 4). The change in these two measures of HPD use between pre-intervention and each follow-up is also presented. Overall, the percent of time HPDs were used in high noise went up from 34.5% pre-intervention to 46.7% at the conclusion of the intervention period, and then reduced to 42% at the four-month follow-up, indicating a small and statistically non-significant increase in HPD use over the study period. Similarly, 35% of workers wore HPDs at least 50% of the time in high noise prior to intervention, which rose to almost 49% of workers at the end of the two month intervention period, and decreased to 40% at the end of the post-intervention period. Thus overall, the intervention was associated with a 12.1 or 14% increase in use of HPDs at the end of the intervention period, settling to a 7.5 or 6% increase two months later, for percent time using HPDs, or percent of workers using HPDs, respectively.

When these results were stratified by intervention group, some significant differences were observed in HPD use at the pre-intervention assessment; those receiving the BL and TB trainings had the highest HPD use (50% of workers using HPDs 50% of the time or more in high noise), and those receiving all three interventions (BL, TB, NLI) had the lowest use (22%). These differences appear to indicate problems with initial randomization, however all four intervention groups used HPDs substantially less frequently than desired, allowing for improvement in all four groups. All four groups did improve their HPD use at two months post-intervention, although this increase was only sustained to a significant degree among those receiving the BL, TB, and NLI interventions. The group receiving BL and TB training, paradoxically, appears to have decreased their use at four months in comparison to the pre-intervention period. Despite the low use at pre-intervention among the BL, TB, and NLI group, workers in this group had the highest use (49%) at the four month follow-up, and this change was significant (p <0.05). The overall results indicating change in percent of workers using HPDs over the intervention periods are illustrated in Figure 2, which demonstrates the increase at two months post-intervention and decline

Table 3. Noise levels by intervention group and observation.

| | Intervention group | | | | |
| | No noise indicator | | Noise indicator | | |
	Baseline	*Baseline and toolbox*	*Baseline*	*Baseline and toolbox*	*Overall*
N	46	44	45	41	176
Pre-intervention					
Leq	89.0 (5.9)	89.8 (4.2)	87.3 (4.4)	90.5 (4.8)	89.1 (5.0)
% Shift ≥85 dB*	38.1 (20.9)	43.3 (17.7)	35.7 (22.0)	40.1 (18.7)	39.3 (20.0)
2 month					
Leq	87.2 (5.8)	89.7 (4.0)	86.5 (4.4)	88.3 (4.8)	87.9 (4.9)
% Shift ≥85 dB	29.7 (18.2)	35.5 (16.8)	28.5 (19.2)	37.1 (20.3)	32.6 (18.8)
4-month					
Leq	87.1 (3.9)	88.2 (3.5)	85.4 (5.0)	88.3 (5.5)	87.2 (4.7)
% Shift ≥85 dB	28.7 (15.7)	36.8 (17.2)	27.5 (19.1)	35.7 (20.6)	32.1 (18.5)

*Mean (SD) of percent of shift time in which Leq ≥85 dBA.

at four months among the BL only and BL and TB groups, and the sustained increase at two and four months among the two groups using the NLI.

Table 5 presents HPD use and change in use as a percent of time in high noise by demographic factors. Younger workers, those with higher educational achievement, those employed in 'other' trades, and those with poorer self-reported hearing, appear to have increased their use of HPDs compared to their co-workers. Laborers in particular appear to have increased their use by 26.4% at two months, but did not sustain this change two months post intervention. Paradoxically, those reporting lower safety and HPD climate scores preintervention, also appear to have increased their HPD use. In part this may be due to the fact that those with higher climate scores were already using HPDs at a higher rate prior to intervention.

A similar pattern is seen in Table 6 which provides HPD use and change in use, by elements of the HPM. In general, workers with low scores prior to intervention were more likely to adopt HPD use over the study period. For instance, the three items related to barriers to using HPDs indicate increasing levels of HPD use among those with a more positive attitude toward HPD use at baseline. However, it is those with more negative responses and low use rates at baseline that show the greatest increase in use in response to the interventions. Conversely, those with a higher degree of self-efficacy at baseline had higher HPD use, with significant increases at least for those rating self-efficacy in the middle of the range.

Table 7 presents the results of the logistic transition model at the two- and four-month follow-up assessments. Workers who reported using HPDs greater than 50% of the time in high noise prior to intervention were much more likely to continue wearing them in the follow-up period (OR = 5.3 and 7.6 at two months and four months, respectively). Compared to HPD use among those in the BL-only group, there were no statistically significant differences among the other three groups. However, at the four-month follow-up, those in the BL, TB, and NLI group were over two times (95% CI: 0.9 to 6.0) more likely to use HPDs than those in the BL only group.

Linear models estimating the change in HPD use from pre-intervention to two- and four-month follow-up are presented in Table 8. The base model, including only intervention group as a predictor of

Table 4. HPD use prior to intervention and change at two and four-month follow-up by intervention group.

| | | | 2-month follow-up | | 4-month follow-up | |
	N	*Pre-intervention Using HPDs*	*Using HPDs*	*Change from pre-intervention[#]*	*Using HPDs*	*Change from pre-intervention[#]*
% of time HPD used		Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
All groups	176	34.5 (42.8)	46.7 (43.8)	12.1 (46.3)**	42.0 (43.6)	7.5 (46.5)[†]
BL Only	46	30.0 (40.1)	43.3 (43.3)	13.4 (44.8)[†]	35.5 (41.1)	5.5 (40.9)
BL and toolbox	44	48.5 (46.9)	50.3 (44.5)	1.8 (48.8)	41.2 (43.8)	−7.3 (54.8)
BL and NLI	45	33.7 (43.3)	43.8 (44.4)	10.1 (40.3)[‡]	42.4 (44.3)	8.8 (37.6)
BL, toolbox, NLI	41	25.5 (38.3)	49.6 (44.1)	24.1 (49.9)*	49.8 (45.5)	24.3 (7.4)*
Workers using HPD 50% of the time		N (%)	N (%)	%	N (%)	%
All groups	176	61 (35)	86 (49)	14*	71 (40)	6
BL only	46	15 (33)	21 (46)	13	17 (37)	4
BL and toolbox	44	22 (50)	25 (57)	7	16 (36)	−14
BL and NLI	45	15 (33)	19 (42)	9	18 (40)	7
BL, toolbox, NLI	41	9 (22)	21 (51)	29*	20 (49)	27*

[#]Tests for change: paired t-test for change in % of time; McNemar's test for matched proportions for workers using HPD >50% of time: [‡]p<0.1, [†]p<0.05, *p<0.01, **p<0.001.
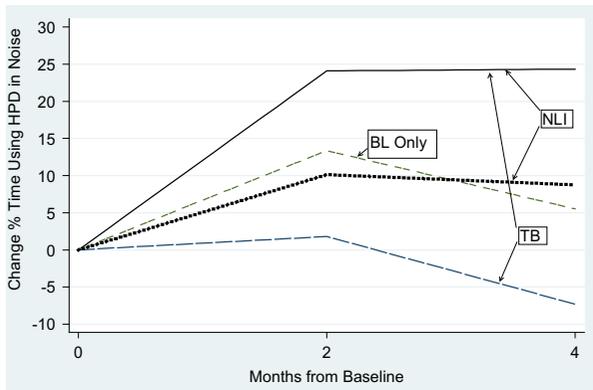
Figure 2. Change in percent of time workers used HPDs at two-month (end of intervention period) and four-month assessments by intervention group.

change in HPD use, indicates a 13.4% (two-month) and 5.5% (four-month) increase in HPD use among the BL training only group, with an additional 10.7 (two-month) and 18.8% (four-month) in the BL, TB, and NLI group. Thus, based on this model, the full intervention group had about a 25% increase (5.5 + 18.8) in HPD

use on average. When covariates were tested for significant contributions for both the two- and four-month follow-up, several variables contributed additional precision (p <0.1) and/or confounding. These variables included 'hearing is easier with HPDs' (item from the HPM barrier construct), the self-efficacy HPM construct, and HPD climate score. When interactions were tested between these covariates and the intervention groups, no significant interaction was observed. With these three variables added to the model, the model r^2 increased to 18% (two-month) or 19% (four-month). In the final model including these three covariates (lower half of Table 8), there was a substantial increase in the coefficient for the BL, TB, and NLI intervention group, going from 10.7 ± 9.9 (base model) to 17.7 ± 9.6 for the two-month follow-up, and from 18.8 ± 9.8 to 25.9 ± 9.6 in the four-month assessment. For HPD climate, those with a higher rating at baseline had a smaller increase in HPD use at follow-up. For the other two factors, the coefficients did not show a consistent monotonic pattern.

Discussion

Despite the availability of more permanent solutions to preventing noise-induced hearing loss, effective use of hearing protection devices remains a primary strategy, especially in complex work environments with intermittent noises, such as those found in the

Table 5. HPD use prior to intervention and change at 2- and 4-month follow-up by group and demographic characteristics.

	N	Pre-intervention % Using HPDs (SD)	2-month follow-up		4-month follow-up	
			% Using HPDs (SD)	Change from pre-intervention	% Using HPDs (SD)	Change from pre-intervention
All groups	176	34.5 (42.8)	46.7 (43.8)	12.1 (46.3)**	42.0 (43.6)	7.5 (46.5)†
Age						
< = 30	49	29.7 (42.6)	44.1 (44.8)	14.4 (49.1)†	40.9 (46.4)	11.2 (53.0)
>30–40	53	26.4 (39.1)	41.3 (43.3)	15.0 (43.5)†	37.7 (39.1)	11.3 (41.5)‡
>40–50	50	42.3 (45.3)	47.6 (42.8)	5.3 (45.4)	42.9 (42.7)	0.6 (42.4)
>50	24	46.1 (43.3)	61.7 (44.3)	15.6 (49.5)	52.3 (43.7)	6.2 (51.6)
Education						
< High school	12	21.4 (39.3)	30.6 (37.3)	9.3 (25.1)	25.8 (38.2)	4.4 (25.5)
High school	107	35.8 (43.8)	46.3 (45.1)	10.5 (45.5)†	43.5 (44.7)	7.7 (48.7)
> High school	51	35.7 (42.0)	47.5 (42.8)	11.8 (50.8)	41.6 (42.0)	5.9 (46.8)
Hearing status						
Good	77	38.7 (44.4)	47.3 (45.4)	8.7 (51.0)	45.1 (44.1)	6.4 (48.7)
Fair or Poor	96	30.2 (40.8)	45.5 (42.5)	15.3 (42.9)**	38.9 (42.8)	8.7 (45.5)‡
Trade						
Electrician	20	29.8 (43.2)	41.4 (43.0)	11.7 (37.5)	36.1 (43.2)	6.4 (49.0)
Carpenter	76	33.1 (43.9)	35.1 (41.3)	1.9 (46.7)	37.6 (44.1)	4.5 (43.9)
Laborer	30	37.1 (40.9)	63.6 (41.6)	26.4 (49.5)*	38.8 (40.3)	1.7 (46.8)
Other	50	36.9 (43.2)	56.2 (44.9)	19.3 (44.5)*	53.1 (44.0)	16.1 (49.3)†
Construction years						
< 10	51	37.8 (45.2)	49.3 (44.7)	11.5 (51.9)	43.6 (45.4)	5.8 (47.2)
10–20	56	29.8 (41.0)	40.1 (43.4)	10.3 (43.6)‡	40.1 (42.6)	10.3 (46.0)*
> 20 years	53	35.1 (42.7)	46.5 (42.9)	11.4 (45.7)‡	40.3 (42.6)	5.2 (49.1)
HPD climate#						
Low <4	53	33.5 (44.5)	52.9 (44.5)	19.3 (46.0)*	47.2 (45.4)	13.7 (50.2)‡
Med 4-<5	60	20.1 (32.6)	36.3 (42.5)	16.1 (41.2)*	34.0 (41.3)	13.9 (40.3)*
High 5	61	47.4 (45.5)	50.0 (43.3)	2.5 (50.7)	44.6 (43.9)	2.8 (47.5)
Safety climate#						
Low <4.5	80	27.0 (39.1)	43.2 (43.8)	16.3 (39.7)**	37.1 (42.2)	10.2 (40.4)†
High 4.5–5	95	40.2 (44.8)	49.0 (43.8)	8.8 (51.2)‡	45.6 (44.5)	5.4 (51.3)

One sample t-test: ‡p<0.1, †p<0.05, *p<0.01, **p<0.001.
#Scale refers to Likert scale values: 1 = Strongly disagree, 3 = Not sure, 5 = Strongly agree.

Table 6. Percent time in high noise HPD used prior to intervention and change at 2- and 4-month follow-up by HPM construct responses[#].

	N	Pre-intervention % using HPDs (SD)	2-month follow-up		4-month follow-up	
			% using HPDs (SD)	Change from pre-intervention	% using HPDs (SD)	Change from pre-intervention
Interpersonal influences: Others remind me to use HPDs						
1	47	26.7 (41.2)	41.7 (43.1)	15.0 (53.8)[‡]	38.8 (42.9)	12.1 (51.6)
2–3	60	34.5 (41.8)	46.9 (44.9)	12.4 (39.8)[†]	36.0 (41.8)	1.5 (44.5)
4–5	65	39.3 (44.2)	49.3 (43.7)	10.0 (47.8)[‡]	48.3 (45.0)	8.9 (44.6)
Situational influences: Boss thinks should use HPDs						
1–2	23	28.8 (41.5)	39.3 (42.4)	10.4 (50.8)	35.3 (39.6)	6.5 (43.0)
3–4	78	26.6 (40.1)	42.2 (43.8)	15.6 (38.8)**	38.6 (44.0)	12.0 (44.1)[†]
5	64	43.6 (44.4)	51.7 (43.3)	8.1 (53.4)	49.1 (44.3)	5.4 (48.7)
Severity: Lost hearing is a problem						
1	127	38.1 (44.5)	49.8 (44.2)	11.7 (48.2)*	46.2 (44.1)	8.0 (46.3)[‡]
2–5	49	25.2 (37.0)	38.5 (42.0)	13.4 (41.4)[†]	31.4 (40.7)	6.2 (47.2)
Benefits: Hearing is easier with HPDs						
1	68	28.9 (41.5)	52.4 (43.9)	23.5 (40.6)**	45.6 (43.8)	16.7 (42.6)*
2	43	43.7 (44.1)	38.1 (43.9)	5.6 (39.2)	35.5 (43.1)	8.2 (51.0)
3–5	63	33.8 (42.6)	45.7 (43.5)	12.0 (53.4)[‡]	41.9 (44.0)	8.1 (45.8)
Benefits: Value preventing hearing loss						
1–4	49	14.8 (31.7)	31.0 (41.3)	16.1 (41.3)*	27.7 (40.4)	12.9 (43.1)[†]
5	127	42.1 (44.2)	52.7 (43.4)	10.6 (48.1)[†]	47.6 (43.7)	5.5 (47.7)
Barriers: Not unsafe to wear HPD						
1–2	38	18.5 (34.8)	43.7 (41.0)	25.2 (48.5)*	41.6 (41.7)	23.1 (50.7)*
3–4	71	34.3 (41.9)	40.9 (44.9)	6.7 (45.4)	40.3 (44.5)	6.1 (47.0)
5	66	43.1 (45.5)	53.8 (43.6)	10.7 (45.4)[‡]	43.3 (44.0)	0.2 (42.1)
Barriers: HPDs are not uncomfortable						
1–3	44	15.4 (31.9)	35.3 (43.9)	19.9 (49.2)*	25.2 (38.8)	9.8 (48.9)
4	50	35.2 (40.8)	48.2 (43.6)	13.0 (38.8)[†]	41.0 (43.8)	5.8 (44.6)
5	81	43.7 (45.9)	51.3 (43.3)	7.6 (49.0)	51.2 (43.5)	7.4 (47.1)
Barriers: Not time consuming to use HPDs						
1–3	29	8.7 (21.8)	27.4 (39.6)	18.6 (39.7)[†]	33.7 (44.1)	25.0 (46.7)*
4	41	32.1 (40.9)	36.9 (43.6)	4.8 (38.0)	34.6 (43.5)	2.5 (39.2)
5	104	42.1 (45.3)	55.8 (42.7)	13.7 (51.0)*	47.2 (43.0)	5.0 (48.6)
Self efficacy construct: Mean of three items						
1–4	44	27.0 (40.2)	31.6 (42.6)	4.6 (47.0)	27.1 (38.8)	0.1 (42.8)
4.1–4.9	55	28.5 (41.7)	56.9 (41.5)	28.3 (42.0)**	50.6 (43.0)	22.1 (47.6)**
5	77	43.1 (44.1)	47.9 (44.2)	4.9 (46.4)	44.4 (44.9)	1.4 (45.8)

T-test: [‡]p<0.1, [†]p<0.05, *p<0.01, **p<0.001.
[#]Scale refers to Likert scale values: 1 = Strongly disagree, 3 = Not sure, 5 = Strongly agree.

construction industry. Regulations for hearing loss prevention programs, as well as industry-based strategies, are largely based on HPD use, and the training, enforcement and audiometric surveillance necessary to support such behaviors. However, in many sectors of

Table 7. Logistic transition models for use of HPDs ≥ 50% of time (vs. <50% of time) at two- and four-month follow-up.

	2-month follow-up		4-month follow-up	
Variable	OR (SE)	95% CI	OR (SE)	95% CI
Pre-intervention HPD use	5.3 (1.9)	2.6, 10.7	7.6 (2.8)	3.60, 16.0
Intervention group (ref: BL)				
BL and toolbox	1.2 (1.0)	0.50, 3.04	0.6 (0.3)	0.24, 1.70
BL and NLI	0.8 (0.1)	0.34, 2.05	1.2 (0.4)	0.45, 2.97
BL, toolbox and NLI	1.5 (1.0)	0.63, 3.82	2.3 (1.2)*	0.88, 5.96

*p<0.1.

industry, notably construction, HPD use remains low, and changing the culture of the industry to increase HPD use has been slow. In this intervention study, standard approaches including comprehensive training and reinforcement 'toolbox' training were implemented along with a novel noise level indicator worn by individual subjects. The NLI provided workers with real-time feedback about their own noise exposure levels, thus reminding them of the information transmitted during the training, and cueing them to the current need to protect themselves. While the BL training improved HPD use at the end of the two-month intervention period by about 14%, the effect was largely lost over the subsequent two months of observation, resulting in an average increase of only about 6%, which was not statistically significant. On the other hand, when training was combined with use of the NLI, the effect was much more dramatic—a 24% increase at the end of the NLI use period. Even more importantly, this change in use was sustained over the subsequent two months without any further use of the NLI.

The study design included both group- and individually-randomized components. For the most part, site and individual randomization was successful, with little systematic differences between

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Table 8. Linear model for change in percent HPD use by group.

	2-month follow-up		4-month follow-up	
Variable	B (SE)	95% CI	B (SE)	95% CI
Base model: r^2	0.03		0.057	
Constant	13.4 (6.8)	−0.022, 26.7	5.5 (6.7)	−7.72, 18.8
Intervention group (ref: BL only)				
BL and toolbox	−11.6 (9.7)	−30.7, 7.58	−12.8 (9.6)[†]	−31.8, 6.11
BL and NLI	−3.2 (9.6)	−22.3, 15.8	3.2 (9.5)	−15.6, 22.1
BL, toolbox and NLI	10.7 (9.9)	−8.8, 30.2	18.8 (9.8)	−0.48, 38.1
Final model: r^2	0.18		0.19	
Constant	25.0 (10.3)	4.57, 45.4	14.4 (10.3)	−5.87, 34.7
Intervention group (ref: BL only)				
BL and toolbox	−9.03 (9.43)[†]	−27.6, 9.6	−9.03 (9.37)*	−27.5, 9.47
BL and NLI	−4.08 (9.38)	−22.6, 14.4	3.37 (9.32)	−15.0, 21.8
BL, toolbox, and NLI	17.7 (9.61)	−1.24, 36.7	25.9 (9.55)	7.10, 44.8
Hearing is easier with HPDs (Ref: 1)[#]				
2	−33.4 (8.79)*	−50.7, −16.0	−29.7 (8.74)*	−47.0, −12.4
3–5	−12.8 (7.72)	−28.0, 2.47	−10.2 (7.67)	−25.3, 4.97
Self efficacy (ref: <4)[#]				
4	24.5 (8.91)[†]	6.93, 42.1	23.0 (8.86)[†]	5.53, 40.5
5	6.60 (8.66)	−10.5, 23.7	8.97 (8.61)	−8.03, 26.0
HPD climate (ref: <4)[#]				
4– <5	−8.89 (8.53)[†]	−25.7, 7.96	−7.20 (8.48)[†]	−23.9, 9.55
5	−23.0 (8.85)	−40.5, −5.51	−25.1 (8.80)	−42.5, −7.72

Variable p-value: [†]$p<0.05$, *$p<0.01$.
[#]Scale refers to Likert scale values: 1=Strongly disagree, 3= Not sure, 5= Strongly agree.

groups. However, despite randomization, some differences were seen between groups. Of greatest importance was that HPD use was lower prior to intervention among the BL, TB, and NLI group (about 25%) compared to the other three groups (about 30 to 50%). This failure of randomization could have significant ramifications on the generalizability of the study findings, since the interventions in general seemed to be most effective among subgroups of the cohort for whom use was lowest at baseline.

Accurate measurement of HPD use is difficult. Consistent with previous studies in our group (Neitzel & Seixas, 2005; Edelson et al, 2009; Trabeau et al, 2008), we again observed a positive bias in self-reported HPD use using a questionnaire compared with a task card filled out on the day of use. We have previously evaluated the task card method against direct observation and found it to be highly accurate (Neitzel et al, 1999, Reeb-Whitaker et al, 2004). As a result, we were unable to rely on the survey-based responses on usual HPD use. However, this also meant that we could not assess the continued effectiveness of the intervention over a longer period of time (twelve months), as originally intended.

The task card assesses HPD use only on the day it is used, rather than assessing a worker's usual practice. Due to the inherent variability in use and reporting, a worker that reports using HPDs on one day, has a finite but unknown probability of not reporting use on the following day. As a result, some portion of our findings, that those with low initial use had higher use after intervention, may result from this inherent variability and regression to the mean.

This phenomenon is likely the primary reason that the BL and TB group ended the study with a lower HPD use rate than prior to the intervention. Note that even though their HPD use went down, it was still higher than the BL-only group at the four-month follow-up. In addition, the low observed use among the BL, TB, and NLI group

prior to intervention could be a factor in the 'success' of the NLI intervention. However, a sustained positive response was also seen among the BL and NLI group even though they did not have a low use rate prior to intervention. Further, while use was lower in the BL, TB, and NLI group prior to intervention, HPD use in this group ended up higher than any of the other groups by the end of the study.

Other studies have generally found that hearing loss prevention interventions among construction workers have generally increased use of hearing protection devices. Lusk and colleagues (Lusk et al, 1999b) found that a single one hour training increased HPD use significantly (from 44 to 53% of time) 10–12 months post-training. Dineen and colleagues (Dineen et al, 1998) found that HPD use increased significantly (from 23% to 35%) four months post-training. It is important to note that each of these studies have relied on self-reported HPD use information collected via questionnaire. Our comparison of questionnaire data to validated task card reports of HPD use indicates that HPD use is overstated when reported via questionnaire (Edelson et al, 2009, Neitzel & Seixas, 2005), suggesting that the intervention effects described in these earlier studies may be optimistic.

The HPD and safety climate factors, as well as specific HPM questions concerning supervisory and social support for HPDs, were associated with HPD use prior to intervention, and with change in use subsequent to the intervention. However, this change was not in the expected direction; that is, those reporting a more positive climate were less likely to change subsequent to intervention. We have previously described a highly bimodal use of HPDs, with construction workers using HPDs nearly all the time, or none of the time, and relatively fewer individuals using them inconsistently (Edelson et al, 2009). As a result, increasing use of HPDs can only

be seen among those individuals who are not using them to begin with. Those with positive management and social support for using HPDs may have already adopted this practice, while among those with a lower level of support, there remain a number of workers who would use them given appropriate support. We suspect that the interventions described here have the greatest effect on those individuals who are not yet using HPDs, but are open to it. This group appears to be about 15 to 25% of the population included in this study. While this gain is modest, added to those who have already adopted HPD use, it results in a substantial fraction, i.e. 40–50% of the exposed population, using HPDs during a meaningful portion of their exposure. Some fraction of those remaining unprotected may require other approaches such as tailored training (Lusk et al, 2003), incorporation of audiometric test results into training (Zohar et al, 1980), or other techniques.

To obtain some perspective on the apparent success of the NLI in changing behavior, a brief survey was conducted among the NLI users at the conclusion of the four-month follow-up on the last site in the study. All seventeen workers assigned an NLI who were present on site at the final assessment answered the survey and a very high percentage of them (60–95%) provided positive feedback about the utility of the NLI. For instance, 60% reported that the NLI helped them 'a lot' to be aware of noise, 71% had recommended the NLI to co-workers, and 88% had used the NLI to 'test' sound levels from specific pieces of equipment. These responses corroborate the apparent effectiveness of the NLI in increasing awareness and interest in noise exposure, changing HPD use patterns, and helping to sustain use over time—even after stopping use of the NLI.

In conclusion, delivery of a hearing loss prevention training, designed following specific components of the health promotion model, increased use of HPDs among construction workers. However, the change in behavior was most pronounced, and only sustained over time, among workers also using a noise level indicator, which gave them real-time information about noise levels, and reminded them of the need to wear HPDs during noisy activities. We do not have information about how long a worker would have to use the NLI to have the desired effect, although, based on worker feedback, it is likely that the two-month period of use in this intervention study was more than needed. It would seem quite reasonable to distribute NLIs to workers as a component of a comprehensive hearing loss prevention program for periods of one to two weeks. Workers may also benefit from a 'refresher' use of an NLI for a brief period every six months or year. While use of NLIs represents one component of a comprehensive program, including a positive HPD and safety climate indicative of management support for HPD use, additional approaches may be needed to protect all workers exposed to noise.

Acknowledgments

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