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Predictors of Hearing Protection Use in Construction Workers

JANE EDELSON*, RICHARD NEITZEL, HENDRIKA MEISCHKE, WILLIAM DANIELL, LIANNE SHEPPARD, BERT STOVER and NOAH SEIXAS

Department of Environmental and Occupational Health Sciences, University of Washington, 4225 Roosevelt Way NE, Suite 100, Seattle, WA 98205, USA

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Objectives: Although noise-induced hearing loss is completely preventable, it remains highly prevalent among construction workers. Hearing protection devices (HPDs) are commonly relied upon for exposure reduction in construction, but their use is complicated by intermittent and highly variable noise, inadequate industry support for hearing conservation, and lax regulatory enforcement.

Methods: As part of an intervention study designed to promote HPD use in the construction industry, we enrolled a cohort of 268 construction workers from a variety of trades at eight sites and evaluated their use of HPDs at baseline. We measured HPD use with two instruments, a questionnaire survey and a validated combination of activity logs with simultaneous dosimetry measurements. With these measurements, we evaluated potential predictors of HPD use based on components of Pender's revised health promotion model (HPM) and safety climate factors.

Results: Observed full-shift equivalent noise levels were above recommended limits, with a mean of 89.8 ± 4.9 dBA, and workers spent an average of 32.4 ± 18.6% of time in each shift above 85 dBA. We observed a bimodal distribution of HPD use from the activity card/dosimetry measures, with nearly 80% of workers reporting either almost never or almost always using HPDs. Fair agreement (kappa = 0.38) was found between the survey and activity card/dosimetry HPD use measures. Logistic regression models identified site, trade, education level, years in construction, percent of shift in high noise, and five HPM components as important predictors of HPD use at the individual level. Site safety climate factors were also predictors at the group level.

Conclusions: Full-shift equivalent noise levels on the construction sites assessed were well above the level at which HPDs are required, but usage rates were quite low. Understanding and predicting HPD use differs by methods used to assess use (survey versus activity card/dosimetry). Site, trade, and the belief that wearing HPD is not time consuming were the only predictors of HPD use common to both measures on an individual level. At the group level, perceived support for site safety and HPD use proved to be predictive of HPD use.

Keywords: construction; hearing protectors; noise exposure

INTRODUCTION

Exposure to high noise is common in construction (Sinclair and Haflidson, 1995; Legris and Poulin, 1998; Suter, 2002), and workers are often exposed to noise that exceeds an 8-h time-weighted average exposure level of 85 dBA, the recommended exposure limit (REL) of the National Institute for Occupational Safety and Health (NIOSH) (NIOSH, 1998), and 90 dBA, the permissible exposure limit (PEL) of the Occupational Safety and Health Administration (OSHA, 1983). Studies of construction workers in Washington State have found that approximately two-thirds of measured workshifts exceed the NIOSH REL and about one-third of shifts exceed the OSHA PEL (Neitzel *et al.*, 1999; Seixas *et al.*, 2001; Reeb-Whitaker *et al.*, 2004; Daniell *et al.*, 2006). As a result of such high noise exposures, noise-induced hearing loss (NIHL) is one of the most common health conditions within the construction industry (Suter, 2002).

Although NIHL is completely preventable, hearing conservation programs are relatively rare in the construction industry. Comprehensive hearing

*Author to whom correspondence should be addressed.
Tel: +1-206-543-2384; fax: +1-206-616-6240;
e-mail: jedelson@u.washington.edu

conservation programs, required by OSHA in general industry, are lacking for the construction industry—although they are required in Washington State (WISHA, 2003). The construction industry relies almost entirely on the use of hearing protection devices (HPDs) to reduce noise exposure, but the use of HPDs among construction workers is low (Lusk *et al.*, 1998; Suter, 2002). Neitzel and Seixas (2005) found that construction workers reported using hearing protection less than one-quarter of the time that their measured noise levels exceeded 85 dBA, and that, due to poor compliance, the effective protection workers received on average was a reduction of <3 dB in their full-shift average (Neitzel and Seixas, 2005).

Workers' attitudes and beliefs toward HPDs, based on Pender's health promotion model (HPM), have been shown to be important predictors of HPD use (Lusk *et al.*, 1994, 1997). Other researchers have identified a relationship between noise annoyance (Melamed *et al.*, 1994, 1996), acculturation (Rabinowitz and Duran, 2001), and workers' individual perceptions of risk associated with noise exposure (Arezes and Miguel, 2005a) and HPD use. In addition, safety climate (Zohar, 1980), a measure of employees' shared perception of the priority safety receives in their workplace (Varonen and Mattila, 2000; Zohar, 2000), has been shown to be correlated with increased compliance with safety rules (Griffin and Neal, 2000; Garcia *et al.*, 2004) and use of HPDs (Arezes and Miguel, 2005b). Therefore, given the industry's primary reliance on HPDs for exposure reduction but low HPD usage rates, attention should be given to these predictors of HPD use.

This study evaluated HPD use among a cohort of Seattle, WA, area construction workers reported using two different self-reported measures. The theoretical model underlying the assessment was a revised version of Pender's HPM (Lusk *et al.*, 1994, 1997) adapted to include three additional constructs described in detail elsewhere (Neitzel *et al.*, 2008). HPD use based on the two measures was evaluated in relation to various potential predictors of HPD use, including individual perceptions, beliefs and knowledge, and group-level perceived site safety climate measures. The results of this study represent baseline HPD use among the cohort. Changes in HPD use following a multicomponent hearing conservation intervention delivered to the cohort will be described in a subsequent manuscript.

METHODS

Eight large unionized commercial construction sites participated in the study (Table 1). Sites were chosen based on proximity to Seattle, early stage of construction, and an adequate number of workers on-site. Seven of the eight sites had approximately the same number of workers, while one was substantially larger. Forty subjects were targeted for recruitment at each site. Subjects were drawn from general contractor and subcontractor employees expected to be on-site for a 6-month duration. Research staff provided an overview of the study procedures and protocols at scheduled site-wide safety meetings; interested volunteers then signed an informed consent form. Each subject participated in the assessment on a single workshift, and all subjects received a $20 incentive after participating in the assessment. All study procedures were approved by the University of Washington Institutional Review Board.

Table 1. Participating site characteristics

Contractor	Site	Location	No. employees	Structure type
1	A	Suburban	200	Structural steel
2	B	Urban	175	Reinforced concrete
3	E	Suburban	150	Structural steel
4	F	Urban	200	Structural steel
5	C	Urban	400	Reinforced concrete and structural steel
	G	Urban	200	Reinforced concrete
6	D	Urban	200	Reinforced concrete
	H	Urban	250	Structural steel

HPD use data were collected from each subject using two separate methods, described in detail below. The first method used a survey instrument designed to collect information regarding current and intended future HPD use and possible predictors of use. The second method was an activity card with concurrently measured noise dosimetry data designed to assess HPD use on a single workshift.

Survey measurements

Subjects completed a self-administered survey written in English at a sixth-grade reading level (Flesch-Kinkaid grade level, MS Word, Redmond, WA) which included questions about demographic information (age, gender, trade, seniority, previous education, and primary language spoken at home), health status (self-assessed hearing level and tinnitus), frequency of HPD use, perceptions and attitudes concerning HPDs, and items designed to assess hearing conservation-related knowledge. The HPD use item asked 'How often do you currently wear hearing protection in high noise' with categorical responses of <10% of the time in high noise, 10–50%, 51–90%, and >90%. Survey items addressing perceptions and attitudes about HPD use and hearing conservation knowledge were based on a revised HPM developed by Lusk *et al.* (1994, 1997). The constructs of the revised HPM used include: benefits of HPD use, barriers to HPD use, interpersonal influences on HPD use, situational influences on HPD use, self-efficacy of HPD use. To these constructs, we added two additional constructs found to predict HPD use, perceived susceptibility to NIHL and perceived severity of NIHL (Melamed *et al.*, 1996; Arezes and Miguel, 2005), as described previously (Neitzel *et al.*, 2008) as well as a construct related to hearing conservation knowledge. Multiple survey items addressed each of the HPM constructs (Appendix), and responses to each item were on a 5-point Likert scale. Survey items addressing specific HPM constructs were drawn from existing survey instruments (Lusk *et al.*, 1999; Stephenson, 2004; Svensson *et al.*, 2004; Ronis *et al.*, 2006) or developed specifically for this study. In addition to these HPM constructs, the survey included two climate constructs intended to capture workers' perceptions of management's commitment to HPD use and safety. Safety climate items were taken from Zohar and HPD climate items were modified from Zohar to specifically address perceived management attitudes toward HPD use (Zohar, 2000).

HPM construct items were analyzed on their native 5-point scales. 'Don't Know' and blank responses were coded as missing. The scoring of seven negatively worded HPM construct items was reversed to match the scale of the other items (Appendix). The cohesiveness of the items in each of the HPM constructs, as well as the HPD and safety climate items, was tested using Cronbach's α. Construct items with low cohesiveness ($\alpha < 0.6$) were analyzed separately. The item with the greatest association with HPD use from each non-cohesive HPM construct was used to represent that construct in multivariable models. A knowledge score representing the percentage of the 10 hearing conservation knowledge items answered correctly was calculated for each subject.

Demographic variables and HPM construct items and scales were described by site and trade. Nonparametric tests were used to evaluate HPM construct differences by site and trade. Differences in survey-reported HPD use by site and demographic characteristics were assessed via χ^2 tests. Differences in the HPM construct item scores by site and trade were assessed using the Kruskal–Wallis test (one-way analysis of variance [ANOVA] with ties). HPD and safety climate score differences between contractors were assessed via one-way ANOVA. For the two contractors with multiple participating sites, HPD and safety climate differences between sites were evaluated via Student's *t*-test.

Dosimetry and activity card measurements

On the same day that subjects completed their baseline survey, a full-shift noise exposure measurement was collected using a datalogging noise dosimeter (Quest Technologies, Oconomowoc, WI). Dosimeters logged the NIOSH L_{eq} metric (85 dBA criterion level, 3 dB exchange rate, 0 dBA threshold, fast response time) (NIOSH, 1998), each minute. The OSHA L_{avg}, the maximum level (L_{max}), and the highest instantaneous level (L_{peak}) were also logged but are not described here. During the measured shift, subjects reported HPD use on an activity card with ~15-min resolution throughout the day.

The dosimetry noise level data were checked for errors or minutes for which the data were unrealistic, and data were corrected or removed from the data set using previously published criteria (Seixas *et al.*, 2005). Full-shift equivalent noise levels ($L_{Aeq,\ T}$) were computed for each individual shift using the 1-min L_{eq} noise levels measured in that shift (Earshen, 2000). One-minute L_{eq} noise level data were merged with corresponding HPD use information from the activity card to allow for calculation of the percentage of shift time HPDs that were reported >85 dBA. This measure of HPD use has been validated against researcher observation and has shown a moderate level of agreement, Cohen's $\kappa \sim 0.6$. (Neitzel *et al.*, 1999; Reeb-Whitaker *et al.*, 2004; Trabeau *et al.*, 2008).

Method comparison, model development, and analysis

HPD use reported via the survey and activity card/dosimetry measures was compared using both absolute percent agreement and weighted κ. To make this direct comparison, the continuous percent of time HPDs were reported via the activity card/dosimetry measure was collapsed to match the four response categories on the survey HPD use item.

Logistic regression models were developed to evaluate potential predictors for binary recodings of the two outcome measures, survey- and activity card/dosimetry-reported HPD use (recoded to HPD use $\leq$ or >50%). Based on their *a priori*-assumed importance, site and trade were forced into the models. Other potential predictors were first tested individually for association with HPD use for both outcome measures using a likelihood ratio test (LRT) comparing models with site and trade to those with site, trade, and each additional potential predictor. Variables with $P < 0.1$ were offered into a backwards stepwise procedure, with an acceptance of $P < 0.1$. Variables tested in the stepwise procedure included years in construction, education, hearing status, the self-efficacy HPM construct, Item 2 of the HPM severity construct, Items 1, 2, and 3 of the HPM benefits construct, Items 2, 3, and 4 of the HPM barriers construct, Item 2 of the HPM interpersonal influences construct, Item 3 of the HPM situational influences construct, and percent of shift exposed to noise above 85 dBA. The stepwise procedure restricted the data set to only subjects with complete information for all variables; the final selected models were rerun with all cases.

To simplify interpretation of the safety and HPD climate scores, site-specific mean climate scores were categorized into two groups based on whether they were above (high) or below (low) the mean scores for all sites. The utility of safety and HPD climate as predictors of HPD use was evaluated by rerunning the final logistic regression model with the binary high/low climate group substituted for site.

RESULTS

Two hundred and sixty-eight subjects completed a baseline survey. Two hundred fifty-one subjects had valid dosimetry measures with matching activity cards. Data from these 251 subjects comprise the data set used for this analysis.

Ninety-seven percent of the subjects were male, with an average and standard deviation age of 37 ± 10 years. Thirty-five percent of subjects reported experiencing tinnitus at least sometimes, and 20% reported family hearing loss. These factors, along with use of a hearing aid and English as a primary language, were similar across the sites, whereas age, education, trade, and years of experience in construction differed between sites. The most common trades across all sites were carpenter (45% of subjects) and laborer (17%).

The mean full-shift $L_{Aeq,T}$ level was 89.8 ± 4.9 dBA, and the mean shift duration was 449 ± 62 min. All sites and all but one trade (plumbers) had mean full-shift equivalent noise levels above 85 dBA (Table 2). The mean percent of shift time in high noise was 32.4 ± 18.6%. Full-shift equivalent noise levels and percent of time at or above 85 dBA differed significantly across sites and trades. The loudest site had a mean full-shift equivalent noise level of 93.0 dBA and the highest average percent of time in high noise (43% of each shift). The trades with the highest full-shift equivalent noise levels were cement masons and carpenters (91.8 and 91.2 dBA, respectively), while the trades with the highest percent of time >85 dBA were ironworkers and carpenters (37.4 and 37.3%, respectively). Plumbers were the quietest group with a full-shift equivalent noise level of 84.6 dBA and spent only 14% of each shift above 85 dBA, on average.

Results for the 5-point scale survey items representing the eight HPM constructs and HPD and safety climate perceptions are shown in Fig. 1. Only one of the HPM constructs (self-efficacy) and the HPD and safety climate measures had Cronbach's $\alpha > 0.6$ and are presented as scales; all other constructs are presented by individual item. Individual items are shown grouped by construct, and item

Table 2. Full-shift equivalent noise level and percent of shift time at or above 85 dBA by contractor, site, and trade

Group	Site	*N*	Equivalent noise level ($L_{Aeq,T}$) dBA; mean (SD)[a]	Percent shift time in 85 dBA or above; mean (SD)[a]
Overall		253	89.8 (4.9)	32.4 (18.6)
Contractor				
1	A	33	87.2 (5.4)	21.8 (19.3)
2	B	31	88.7 (4.3)	29.7 (17.6)
3	E	33	91.2 (3.6)	39.4 (18.8)
4	F	38	89.5 (4.5)	32.0 (16.9)
5	C	25	90.4 (5.3)	32.8 (18.6)
	G	29	93.0 (5.1)	43.3 (16.7)
6	D	37	88.3 (4.1)	31.6 (18.7)
	H	27	90.7 (4.5)	29.7 (15.4)
Trade				
Cement mason		6	91.8 (3.6)	33.5 (20.1)
Plumber		17	84.6 (3.2)	13.7 (9.7)
Electrician		22	85.3 (4.9)	15.5 (12.7)
Operating engineer		7	87.5 (4.2)	35.9 (25.0)
Pipefitter		17	89.3 (5.2)	24.6 (17.0)
Sheet metal		14	88.7 (4.2)	30.3 (21.4)
Ironworker		17	89.9 (3.6)	37.4 (17.4)
Carpenter		113	91.2 (4.2)	37.3 (16.8)
Laborer		40	90.8 (5.2)	37.1 (17.5)

[a]$P < 0.01$ by site and trade using ANOVA.

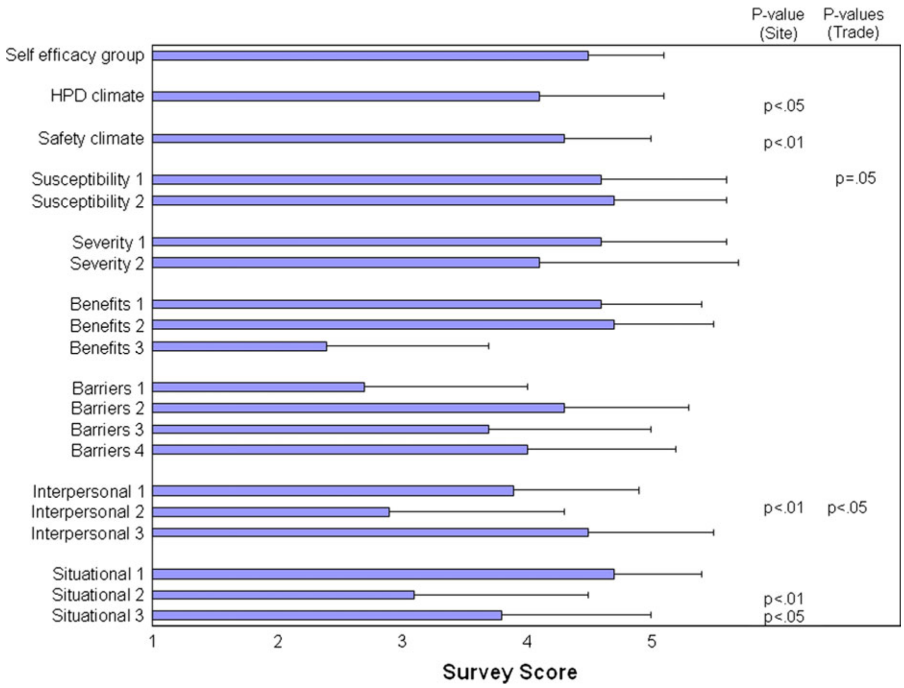

Fig. 1. Health promotion model construct performance and tests of differences between sites and trades.

numbers match those shown in the Appendix, which lists the complete wording for each item. Some individual items differed substantially from the other items within a construct; for example, Item 3 in the benefits construct (wearing HPDs can improve ability to hear machines or communicate) differed greatly from the other two benefit items. The degree to which the mean scores differed between sites or between trades was tested by the Kruskal–Wallis test and is represented by the test *P* value. Safety and HPD climate scores, as well as one item from the interpersonal influences and two items from the situational influences constructs, differed significantly between sites, while only one item pertaining to susceptibility to NIHL and one item from the interpersonal influences construct differed between trades.

Results of the safety and HPD climate constructs were relatively similar. When collapsed into binary high/low groups (data not shown), the absolute agreement between the two measures was 74%, and the Cohen's κ value was moderate (0.45). HPD climate collapsed into binary high/low groups differed significantly between sites, but not between trades, while safety climate collapsed into binary groups differed significantly between both sites and trades.

A histogram of HPD use from the activity card/dosimetry measure is shown in Fig. 2. The activity card data suggest that on a daily basis 81% of workers used HPDs either almost all (>90%) of the time or almost none (<10%) of the time in noise levels >85 dBA. The strongly bimodal distribution of activity card/dosimetry-reported HPD use was strikingly different from the distribution of survey-reported HPD use (data not shown), in which ∼15% of subjects reported wearing HPDs <10% of the time in high noise, 30% of subjects reported HPD use 10–50% of time in high noise, 35% of subjects reported HPD use 51–90% of time in high noise, and 20% reported HPD use >90% of time in high noise. Because of the bimodal distribution of activity-card/dosimetry-reported HPD use, all further analyses of both outcome variables use dichotomized variables, e.g. HPD used ≤50% of time in high noise versus >50% of time. The absolute percent agreement between the two measures of HPD use was 68.5% when both measures were treated as dichotomous, and the weighted κ was fair (0.38) and significant ($P < 0.0001$).

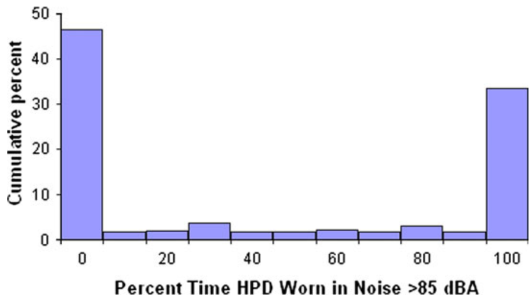

Fig. 2. Percent of subjects reporting HPD use in high noise via activity card/dosimetry measure.

Demographic variables that were significantly associated with at least one of the outcome measures using LRTs, with site and trade forced into the models, are described in Table 3. Statistically significant associations between survey-reported HPD use and trade, education, and site were observed. Significant associations between activity card/dosimetry-reported HPD use were seen for hearing status and for trade. It is also of note that HPD use (>50% of the time in high noise) was reported more often by survey than by activity card (55 versus 41%), and this difference was much more pronounced among some categories. For instance, electricians reported HPD use >50% of the time 40% more frequently by survey than by activity card, while sheet metal workers reported equally on each instrument. Those with a higher level of education reported HPD use on the survey more often than those with lower education and those who reported poor hearing had a higher discrepancy between survey and activity card reporting than those with good hearing status.

Mean survey scores are shown in Table 4. Nine individual HPM survey items and one construct group, all scored on a 5-point Likert scale, are included. The mean percent of hearing conservation knowledge items answered correctly is also shown. Statistically significant differences in survey-reported HPD use were found for items 'Value in preventing hearing

Table 3. Potential predictor variables of HPD use and differences in reporting by method

Variable	All		Survey, HPD use >50%	Activity card, HPD use >50%	Difference (survey activity)
	n	%	%	%	%
All	251	100	55	41	14
Site					
Site A	33	13	70*	42	28
Site B	31	12	58	32	26
Site C	25	10	40	24	16
Site D	37	15	68	43	25
Site E	31	12	68	58	10
Site F	38	15	53	45	8
Site G	29	12	31	45	−14
Site H	27	11	41	30	11
Trade					
Cement mason	6	2	83*	50*	33
Plumber	16	6	81	50	31
Electrician	22	9	73	32	41
Operating engineer	7	3	43	14	29
Pipefitter	16	6	63	50	13
Sheet metal	14	6	57	57	0
Ironworker	17	7	41	6	35
Carpenter	113	45	45	41	4
Laborer	40	16	60	50	10
Years in construction					
<10 years	83	33	55	39	16
10–20 years	89	35	58	43	15
>20 years	77	31	48	39	9
Education					
<HS	18	7	28*	33	–5
HS, GED	145	58	54	42	12
>HS, trade school	87	35	60	40	20
Hearing status					
Good	108	43	62	47*	15
Fair	120	48	50	38	12
Poor	19	8	47	16	31
Percent shift above 85 dBA					
<25%	102	41	62	31	31
25–50%	104	41	53	50	3
>50%	45	18	42	40	2

χ^2: *$P \leq 0.05$; **$P \leq 0.01$.

Table 4. Mean (SD) score for HPM scale items (1 = *Strongly Disagree*, 5 = *Strongly Agree*) and mean percent hearing conservation knowledge items correct by HPD use

Variable	Survey		Activity/dosimetry	
	HPD use <50% (*n* = 114)[a]; mean (SD)	HPD use >50% (*n* = 137)[a]; mean (SD)	HPD use <50% (*n* = 150)[a]; mean (SD)	HPD use >50% (*n* = 102)[a]; mean (SD)
Efficacy group	4.4 (0.7)	4.6 (0.6)	4.4 (0.6)*	4.6 (0.7)
Lost hearing problem	2.1 (1.7)*	1.7 (1.5)	2.0 (1.6)*	1.9 (1.6)
Value preventing hearing loss	4.4 (0.8)**	4.8 (0.6)	4.5 (0.8)**	4.8 (0.6)
Hearing easier with HPD	2.2 (1.3)	2.5 (1.3)	2.3 (1.3)	2.5 (1.4)
Not time consuming to use HPD	4.0 (1.2)**	4.6 (0.8)	4.2 (1.1)*	4.6 (0.9)
Not unsafe to wear HPD	3.6 (1.3)	3.8 (1.2)	3.6 (1.3)	3.9 (1.2)
HPD is not uncomfortable	3.7 (1.3)	4.3 (1.1)	3.8 (1.3)**	4.3 (1.1)
Others remind me to use HPD	2.9 (1.4)	2.8 (1.4)	2.7 (1.4)	3.1 (1.5)
Boss thinks should use HPD	3.8 (1.1)	3.8 (1.3)	3.6 (1.3)	4.0 (1.1)
	Mean % (SD)	Mean % (SD)	Mean % (SD)	Mean % (SD)
Hearing conservation knowledge	74.4 (12.6)	75.2 (11.0)	75.5 (12.0)	73.9 (11.3)

[a]*N* reduced in some variables due to missing values, by maximum of nine.
ANOVA: $*P \leq 0.05$; $**P \leq 0.01$.

loss' (HPM benefits construct Item 1) and 'Not time consuming to wear HPDs' (barriers Item 2), while significant differences in activity card/dosimetry-reported use were found for self-efficacy as well as for the items 'Lost hearing would be a problem' (severity Item 2), 'Value in preventing hearing loss' (benefits Item 1), 'HPD use is not time consuming' (barriers Item 2), and 'HPDs are not uncomfortable' (barriers Item 4). The average percent of correct responses for the 10 hearing conservation knowledge questions was ~75 ± 12% for all HPD use categories and did not differ significantly by trade or site. By trade, operating engineers had the highest mean score (81 ± 4%) and cement masons the lowest (71 ± 17%) (data not shown).

Odds ratios (ORs) for association of potential predictors of HPD use based on the survey and activity card/dosimetry are given in Table 5 for both single variables and for the final model selected by the stepwise procedure. Site and trade were forced into all models. In these models, ORs for the HPM items reflect odds of HPD use in high noise expected for a worker with a one-unit higher score on the 5-point HPM item scale, given the other variables included in the model. When ORs were estimated in both the single variable and final models, there was little difference between the OR estimates, indicating relatively robust estimates.

In the multivariable models, there were six factors (in addition to site and trade) associated with survey-reported HPD use, while only three factors (time in noise >85 dBA, HPM barriers Item 2, and HPM benefits Item 1) were associated with HPD use based on the activity card. Those with better than a high school (HS) education were estimated to have ~6-fold increase in survey-reported HPD use relative to those with no HS education. In comparison, the almost 3-fold increase in HPD use by activity card for those with better than HS education found in the individual predictors model did not enter the multivariable model. The HPM item 'HPD use is not time consuming' (barriers Item 2) was the only variable associated with both measures of HPD use.

When these two multivariable models were rerun replacing site with high versus low safety or HPD climate group, sites in the high group were more likely to report HPD use. In the activity card/dosimetry model, high HPD climate and safety climate were associated with a 1.8 (95% confidence interval [CI] 1.0, 3.3) and 2.0 (95% CI 1.1, 3.8) times greater odds of wearing HPDs. The ORs for high HPD and safety climate groups in the survey-reported HPD use model were 1.2 (95% CI 0.6, 2.3) and 1.8 (95% CI 0.9, 3.7).

DISCUSSION

This study evaluated noise exposures and use of HPDs among a cohort of construction workers from eight construction sites participating in a hearing conservation intervention study. Full-shift equivalent $L_{Aeq,T}$ noise levels averaged almost 90 dBA, and noise levels exceeded 85 dBA for almost a third of each shift on average, indicating a continuing need for noise reduction and/or the effective use of HPDs. Despite the clear need for hearing protection, HPDs were used an average of only 41% of the time that subjects were exposed to noise >85 dBA, reinforcing the need for an effective hearing conservation intervention designed to increase effective HPD use. In addition to significant differences in HPD use between sites and trades, large differences in use were also noted by level of education, perceived hearing

Table 5. Logistic regression models[a] for survey and activity card/dosimetry HPD use ≤ or >50%

Variable	Survey (n = 230)		Activity card/dosimetry (n = 249)	
	Individual predictors, OR (95% CI)	Final model, OR (95% CI)	Individual predictors, OR (95% CI)	Final model, OR (95% CI)
Demographics				
Hearing status (define)	0.6 (0.4–0.9)	—	0.6 (0.4–1.0)	—
Percent of shift noise >85 dBA (reference: ≤25%)				
>25 or ≤50	0.9 (0.5–1.7)	—	2.9 (1.4–5.9)	3.1 (1.5–6.5)
>50	0.5 (0.2–1.2)	—	1.8 (0.7–4.2)	1.9 (0.8–4.8)
Years in construction (reference: <10)				
10–20 years	0.9 (0.5–1.9)	1.3 (0.6–3.0)	1.5 (0.8–3.0)	—
>20 years	0.5 (0.2–1.0)	0.5 (0.2–1.1)	1.0 (0.5–2.1)	—
Education (reference: <HS)				
HS or GED	4.8 (1.3–17.6)	5.8 (1.5–22.6)	2.9 (0.9–9.2)	—
>HS	6.1 (1.6–23.9)	6.0 (1.5–24.9)	2.7 (0.8–9.3)	—
HPM factors				
Not unsafe to wear HPD	1.1 (0.9–1.4)	—	1.3 (1.0–1.7)	—
Others remind me to use HPD	1.1 (0.9–1.3)	—	1.2 (1.0–1.5)	—
Boss thinks should use HPD	0.9 (0.7–1.1)	—	1.3 (1.0–1.6)	—
Lost hearing problem	0.8 (0.7–1.0)	—	1.0 (0.8–1.2)	—
Easier to hear with HPD	1.3 (1.0–1.6)	1.3 (1.0–1.6)	1.2 (1.0–1.5)	—
HPD is not uncomfortable	1.5 (1.2–1.9)	1.4 (1.1–1.9)	1.5 (1.2–2.0)	—
HPD not time consuming	1.8 (1.4–2.5)	1.8 (1.2–2.5)	1.5 (1.1–2.0)	1.4 (1.0-2.0)
Self-efficacy	1.7 (1.1–2.7)	1.6 (0.9–2.7)	1.6 (1.0–2.6)	—
Preventing hearing loss important	2.6 (1.6–4.3)	—	2.2 (1.3–3.7)	1.9 (1.1–3.3)

[a]Site and trade were included a-priori in each model.

loss, and years of experience. Factors associated with HPD use on a survey asking about recent use of HPDs were found to differ from those based on a validated activity card and dosimetry method assessing HPD use on a single day of measurement.

The noise levels measured in this study were comparable to previous research. Several studies have demonstrated that laborers, operating engineers, carpenters, and ironworkers commonly have noise levels above 85 dBA (Greenspan *et al.*, 1995; Sinclair and Haflidson, 1995; Legris and Poulin, 1998; Blute *et al.*, 1999; Neitzel *et al.*, 1999; Neitzel and Seixas, 2005). Even trades often perceived as having relatively low exposures, such as electricians, plumbers, and pipefitters, have been shown to regularly exceed 85 dBA (Seixas *et al.*, 2001; Sinclair and Haflidson, 1995), as was the case here. The current study reinforces previous findings which suggest that every construction trade has the potential for exposure to excessive noise.

Previous studies of HPD use among construction workers have generally documented low usage rates. In a previous analysis of >550 workshift measurements on various construction trades, HPD use was reported only 17% of time >85 dBA on average (Neitzel and Seixas, 2005) using the activity card/dosimetry HPD use reporting method employed here. In that study, as in the current study, sheet metal workers were found to have high usage rates of HPDs; however, operating engineers were also found to have high usage rates in the previous study, a finding not duplicated here, possibly due to differences in the activities of the operating engineers in the two studies. Lusk *et al.* (1998) assessed 400 construction workers from three trades and found average HPD usage rates ranging from 18 to 49%, with carpenters having the lowest use and operating engineers the highest. Among road construction workers, 45% (±26%) reported wearing HPDs all the time—a much higher fraction than we observed here (Daniell *et al*., 2006).

Contrary to expectation, demographic characteristics and HPM constructs were largely unrelated to HPD use in this cohort. The belief that HPD use is not time consuming entered the final logistic regression models for both survey- and activity card/dosimetry-reported HPD use, while other factors, including age and hearing status, were not associated with HPD use. Only one item from the HPM constructs (‘HPD use is not time consuming,’ barriers Item 2) appeared in final model for both the survey and activity card/dosimetry measures. Education was a very strong predictor of HPD use reported via survey, but not via activity card/dosimetry, at least in the multivariable model. In previous studies, years in construction and age were significant predictors of construction workers’ HPD use in bivariate analyses (Lusk *et al.*, 1998), but not in multivariate analyses. In the current study, age did not enter the multivariable models as a predictor; however, years in construction did enter the survey-based model. Years in construction were highly correlated (r = 0.85) with age, making inclusion of both of these variables in the same model unlikely.

Pender's Revised HPM has been shown to be a useful model for explaining workers' use of HPDs (Lusk *et al.*, 1994, 1997; Kerr *et al.*, 2002; Ronis *et al.*, 2006). The survey instrument used in the current study was guided by this model and included multiple items addressing each of the model constructs. However, unlike previous research, items related to specific HPM constructs were almost uniformly found to have low cohesiveness and had to be analyzed individually, rather than as scales. A lack of cohesiveness of the HPM constructs was also found in a related study of the effectiveness of different hearing conservation training techniques (Trabeau *et al.*, 2008). The low cohesiveness among items within the same construct is at least partly due to the low number of items specific to each construct; Cronbach's α increases as the number of items in the scale increases (Landis and Koch, 1977). Previous research studies demonstrating the utility of the HPM in predicting HPD use (Lusk *et al.*, 1994, 1995, 1997; McCullagh *et al.*, 2002; Raymond *et al.*, 2006; Ronis *et al.*, 2006) have typically evaluated 4–18 items per construct, compared to the 1–4 items per construct used in the current study. It may also be that, despite being guided by the revised HPM, the survey items used in this study had low fidelity to the model. Of the possible twenty-eight items related to the HPM constructs, only five—belief that wearing HPDs is not time consuming (barrier Item 2), belief that wearing HPDs is not uncomfortable (barrier Item 4), belief that preventing hearing loss is important (Benefit Item 1), belief that wearing HPDs make it easier to hear (Benefit Item 3), and self-efficacy—were associated with HPD use in at least one of the regression models.

The activity card/dosimetry reporting measure used here has been validated against researcher observations (Neitzel *et al.*, 1999; Reeb-Whitaker *et al.*, 2004), suggesting that HPD use reported via activity card/dosimetry is the more accurate of the two measures evaluated here for assessing use of HPDs. However, it should be noted that the activity card addressed HPD use on a specific monitored day, while the survey asked about use in general. The activity card data demonstrated a highly bimodal distribution of HPD use, with ~80% of workers reporting HPD use either <10 or $>90\%$ of the time exposed >85 dBA. Thus, it would appear that the majority of workers either use HPDs essentially all the time or never use them, regardless of the noise to which they are exposed.

Neitzel and Seixas (2005) previously described substantial overreporting of HPD use via survey in comparison with the activity card/dosimetry measures. The current study confirmed these differences between the two measures and also demonstrated a stronger association of the survey with questionnaire-based predictive factors. Given that the accuracy of the activity card measure has been established, it is reasonable to suggest that the association of HPM model components with the survey-based assessment of HPD use reflects similar features of both measures. That is, personal factors associated with a positive reporting of HPD use behaviors are also associated with positive reporting on HPM factors. Alternatively, it is possible that HPD use reported via survey may provide a more accurate assessment of average, long-term behavior while the activity card is more specific to the actual day of measurement.

The relationship between safety climate and worker compliance with safety rules and requirements and with unsafe behaviors has been explored previously (Griffin and Neal, 2000; Garcia *et al.*, 2004). However, only one study appears to have evaluated the relationship between safety climate and the use of HPDs. Arezes and Miguel (2005) developed a conceptual model of HPD use from data collected on noise-exposed Portuguese industrial workers. The final linear regression model developed to explain HPD use included safety climate, in addition to perception of the risk associated with noise exposure, age, a noise exposure index, and an item representing the value workers placed on HPD use. The authors found that safety climate had little direct effect on HPD use, but instead primarily affected HPD use through indirect routes. Specifically, the effects of safety climate were largely mediated by perceived risk of noise exposure, perceived effects of noise, and value placed on HPD use by workers. Although the modeling techniques used by Arezes and Miguel differ from those employed here, the results of both studies indicate that safety climate may play an important role in the use of HPDs and also confirm the roles of noise exposure and value placed on HPD use.

In summary, our analysis of noise levels and baseline HPD use data in a cohort of construction workers identified noise levels high enough to cause hearing damage and found inadequate use of HPDs during exposure to noise at or above 85 dBA. We observed a strong bimodal distribution of HPD use in high noise for the activity card/dosimetry-based measure of HPD use, with most workers reporting either almost always or almost never using HPDs. Agreement between dichotomized survey- and activity card/dosimetry-reported HPD use measures was only fair, highlighting the need for better understanding of the performance of different measures used to assess use of personal protective equipment. Site, trade, and a perception that HPD use is not time consuming were found to be important predictors of HPD use regardless of the outcome measure used. Education level, a belief that wearing HPDs is not uncomfortable, self-efficacy, and percent of shift spent in high noise were also important predictors for one of the two outcome measures, (activity card/dosimetry) but not for both. Although the HPM has been shown to be an appropriate model for explaining use of HPDs among workers in factory (Lusk *et al.*, 1994) and construction (Lusk *et al.*, 1997) settings, low cohesiveness was observed among survey items relating to specific HPM constructs, suggesting poor performance of the HPM in explaining use of HPDs in this setting and occupational group. High site safety and HPD climate, measured at a group level, increased the odds of HPD use in the activity card/dosimetry model. These findings suggest that management support for safe work practices, including HPD use, and training on the use and importance of HPDs in preventing hearing loss seem to be important factors in influencing use of hearing protection. HPD use remains far lower than it needs to be in this population to effectively prevent hearing loss, and evaluations of interventions designed to promote effective use of HPDs are needed.

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APPENDIX

Table A1. HPM construct and HPD and safety climate items

Construct	Item	Item text
Self-efficacy	1	I can tell when I need to wear my hearing protection.
	2	I know how to wear my hearing protection correctly
	3	I am sure I can ask for help if I have a hard time wearing protection
Susceptibility	1[a]	My hearing will not be affected by noise, even if I don't wear hearing protection.
	2	I believe exposure to loud noise can hurt my hearing.
Severity of exposure	1	It would be harder for me to understand what people say if I lost some of my hearing.
	2[a]	It wouldn't be a big problem for me if I lost some of my hearing
Benefits	1	Preventing hearing loss is very important to me
	2	Wearing hearing protection protects me against hearing loss from noise
	3	Wearing hearing protection can make it easier for me to hear machinery or talk to coworkers
Barriers	1[a]	Wearing hearing protection makes it very hard to talk to people
	2[a]	It takes too much time to use hearing protection.
	3[a]	Wearing hearing protection is unsafe because it blocks out danger signals.
	4[a]	Hearing protectors are too uncomfortable for me to wear.
Interpersonal influences	1	Other workers at this site wear hearing protection when it's noisy.
	2	Other workers at this site remind me when I need to wear hearing protectors.
	3[a]	Other workers at this site make fun of me when I wear hearing protection.
Situational influences	1	It is easy for me to get hearing protectors at this site.
	2	I can choose from several types of hearing protectors at this site.
	3	My supervisor thinks I need to wear hearing protection, even when my noise exposure is short.
HPD climate	1	My supervisor sets a good example for me when it comes to hearing protection.
	2	I think preventing hearing loss from noise is very important to my supervisor.
Safety climate	1	My supervisor frequently checks to see if I am obeying the safety rules.
	2	My supervisor talks with me about how to improve safety.
	3	My supervisor reminds me to work safely if I am not doing so.
	4	My supervisor makes sure that I follow all the safety rules.
	5	My supervisor says a 'good word' to me if I pay extra attention to safety.
	6	My supervisor says I have to wear my protective equipment, even if it is not comfortable.

[a]Reversed questions for scoring.

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