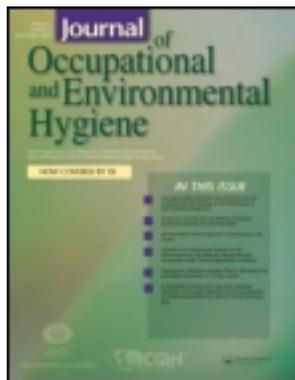


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Occupational Exposures to Noise Resulting from the Workplace Use of Personal Media Players at a Manufacturing Facility

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This study examined the contribution of noise exposures from personal media player (PMP) use in the workplace to overall employee noise exposures at a Colorado manufacturing facility. A total of 24 workers' PMP and background noise exposures were measured. Twelve PMP users worked in high-background-noise exposure (HBNE) areas, and 12 worked in low-background-noise exposure (LBNE) areas. The self-selected PMP listening level of each worker was measured using an ear simulator, and the background noise of each employee workstation was measured using a sound level meter. Workers' self-reported PMP duration of use, PMP listening exposure levels, and background noise levels were used to estimate the daily occupational noise exposures. Measured background noise levels averaged 81 dBA for HBNE workers and 59 dBA for LBNE workers. Measured, free-field equivalent listening exposure levels were significantly greater for HBNE workers (85 dBA) compared with LBNE workers (75 dBA) ($p = 0.0006$). Estimated mean daily noise exposures for both groups were below the ACGIH threshold limit value for noise of 85 dBA8-hr time weighted average (TWA), specifically 84 dBA TWA for HBNE workers and 72 dBA TWA for LBNE workers. Three of 12 (25%) HBNE workers had estimated exposures greater than 85 dBA TWA when only background noise was considered, yet when PMP use was also considered, 6 of 12 (50%) had estimated exposures greater than 85 dBA TWA, suggesting that PMP use doubled the number of overexposed workers. None of the LBNE workers had estimated exposures greater than 85 dBA TWA. The contribution of PMP use to overall noise exposures was substantially less among HBNE workers than LBNE workers due to the disproportionate selection of noise-attenuating headsets among HBNE workers compared with LBNE workers. It is recommended that the facility management either restrict workplace PMP use among HBNE workers or require output-limiting technology to prevent occupational noise-induced hearing loss.

Keywords industrial noise, noise, noise exposure, personal media players, personal stereos

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INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) has estimated that 5 to 30 million American workers are exposed to hazardous levels of noise that could contribute to occupational noise induced hearing loss (ONIHL), specifically, levels greater than 85 dBA TWA.⁽¹⁾ Given this unacceptable number of overexposed workers, NIOSH has identified hearing loss as one of the 21 priority areas for research and maintains that ONIHL continues to be a critical workplace safety and health issue. ONIHL is one of the most common occupational diseases and the second most self-reported occupational illness or injury.⁽²⁾ Machinery, equipment, and work practices are typically the sources of excessive noise in the workplace. However, workers may unknowingly contribute to their noise exposures in the workplace by using headsets to listen to PMPs such as the Apple iPod and other MP3 players; cellular phones with media listening options; and computer-based media programs listened to with headsets, especially if used to mask other occupational noise sources.

Purpose and Scope

Workers at a Colorado manufacturing facility were solicited for participation in this research. The manufacturing facility was selected because the employer permitted the indiscriminate use of PMPs by all personnel. The facility employed

workers in high-background-noise production areas and in low-background-noise office/administrative work areas. All workers within specific HBNE and LBNE work areas were questioned about their workplace PMP use. Those workers who indicated regular PMP use were solicited for participation. Workers were evaluated for background noise exposure levels, listening exposure levels, and PMP use behaviors.

Anecdotal evidence suggests there are workers in a variety of occupational sectors who use PMPs while on the job. Evidence from studies that examined non-occupational PMP use suggests that higher background noise levels may be associated with higher PMP listening levels. Thus, HBNE workers would likely listen at higher volumes than LBNE workers. The purpose of this research was to determine if workers were being exposed to hazardous levels of noise in the workplace by using PMPs and to compare the noise exposures of HBNE and LBNE PMP users.

BACKGROUND

Recently, there has been increased concern about exposure to leisure noise contributing to noise-induced hearing loss, including the use of PMPs.⁽³⁻⁶⁾ PMPs include electronic media devices such as the Apple iPod and other portable MP3 players, portable CD players, and personal computers and cellular phones that can double as PMPs when coupled with a headset. Different headset styles can influence exposure levels of PMP users. Headsets such as earbuds that are positioned at the entrance of the ear canal have been shown to result in higher at-ear sound levels than supra-aural style headsets.⁽⁷⁾ PMP users who use “sound isolation earphones” do not increase their chosen listening levels in “loud environments” to the same level as those using other types of earphones.⁽⁶⁾ Thus, the type of headset that a user chooses may influence the chosen sound listening level and noise energy delivered to the ear, especially if used in the workplace to mask other occupational noise exposures.

It was estimated in 2005 that 22 million American adults own MP3 players or iPods.⁽⁸⁾ In a 2006 survey, 11% of adults indicated that they used an Apple iPod and 12% of adults used another brand of MP3 player.⁽⁹⁾ While there is growing concern about the use of PMPs and hearing loss, there are few studies examining this association and the results have been conflicting.⁽¹⁰⁻¹³⁾

Hearing impairment risk from PMP use depends on the duration of hazardous sound exposure, chosen listening level, individual susceptibility, and non-PMP noise in the environment.⁽⁵⁾ In 2006, Fligor and Ives⁽⁶⁾ reported that in *quiet environments* 6% of subjects chose listening levels greater than 85 dBA and in *loud environments* 80% of PMP users with iPod earbud headsets or Koss over-the-ear headsets listened at sound levels greater than 85 dBA.⁽⁶⁾ In 2005, Williams⁽¹²⁾ reported that 25% of PMP users exceeded an exposure level of 85 dBA, and that the mean listening time to PMPs per day in non-occupational environments was 2.4 hours (n = 55). However, Portnuff and Fligor⁽¹⁴⁾ recently reported that

with improved technology, increased battery life, and greater music storage, PMP users could listen for longer periods compared with PMP usage in the past.⁽¹⁴⁾ Thus, users may be able to extend their PMP use at work and at home. Given these unacceptable exposure levels and those measured by others, there is clearly the potential for PMP users to exceed a TWA of 85 dBA depending on their chosen listening level and duration. Portnuff and Fligor suggested a listening level “speed limit” of 80% volume setting for 90 min per day for most headset and PMP combinations.⁽¹⁴⁾ However, the speed limit recommendation may not be practical for workplace PMP use, where duration of use and background noise levels may make it difficult for workers to adhere to this recommendation.

Meyer-Bisch⁽¹¹⁾ examined the effects that PMPs had on hearing thresholds and concluded that when listening for more than 8 hr per week, subject hearing thresholds (n = 54) were significantly higher (indicating hearing loss) than a control group. In addition, LePage and Murray’s study of more than 1700 subjects⁽¹⁰⁾ reported that otoacoustic emissions from the ear were significantly lower (indicating hearing damage) in PMP users vs. non-PMP users. They concluded, “The use of PMP headsets . . . is associated with rapid aging of the cochlea comparable with industrial noise trauma.”^(10,p. 592) In contrast, Williams, using a cross-sectional design, did not observe a correlation between the use of PMPs and self-reported hearing loss in a study of 55 individuals.⁽¹²⁾ In one of the only studies to examine noise exposures from occupational personal stereo use, Skrainar et al.⁽¹⁵⁾ found a negligible increase in the mean ONIHL risk of workers who used portable radios compared with those who did not. However, the authors noted that one-third of the subjects who used portable radios would exceed the OSHA PEL if they listened for 8 hr per day. Given the changing PMP technology and conflicting results of previous studies, the results of the present study provide important new evidence concerning PMP output and potential overexposures to noise in the workplace.

MATERIALS AND METHODS

Site and Subject Selection

A manufacturing facility in Colorado that permitted the use of PMPs by workers in industrial and office work environments was solicited for this study. Twelve PMP users in HBNE work areas and 12 in LBNE work areas participated. All aspects of this study were completed in accordance with procedures approved by the Colorado State University Institutional Review Board and the Research Integrity and Compliance Review Office.

Interview Data Collection

A validated questionnaire was administered to the subjects to collect information such as the work task performed during measurement, subject PMP and headset device details, music/sound file name and artist, and approximate volume setting of the PMP. The interviewer also recorded the type of noise attenuation, if any, of the subject’s headset. Snug-fitting,

molded canalphones (earphones that are inserted into the ear canal) and circumaural headsets (headphones that surround the pinna) that fully encompassed the ear were classified as “noise attenuating.” Supra-aural headsets (headphones that rest on the pinna) and earbud headphones (earphones that rest in the ear at the opening of the ear canal) without active noise cancellation capability were classified as “non-noise attenuating.”

Background Noise Measurement

A Quest Technologies/Metrosonics (Oconomowoc, Wis.) db-3080, Type 2, sound level meter (SLM) was used to measure background noise levels for HBNE and LBNE workers. The SLM was pre- and post-calibrated using a Quest/Metrosonics cl-304 Acoustic Calibrator. The equivalent, continuous A-weighted sound pressure level (L_{Aeq}) was measured by briefly removing the subject from her/his workstation and positioning the SLM microphone at the location normally occupied by the subject’s head. The background L_{Aeq} was measured for 2 min.

Work shift personal noise dosimetry was also conducted to measure the work shift L_{Aeq} of all HBNE subjects to account for the potential variability in noise exposure throughout the workday. Larson Davis (Provo, Utah), Type 2, Personal Noise Dosimeters 706rc and 703+ were used to measure the work shift L_{Aeq} . The dosimeters were pre- and post-calibrated using a Larson Davis CAL 150 Acoustic Calibrator. Dosimeter microphones were clipped to subjects’ shirts between the collar and shoulder on the side of the body with the highest noise exposure. Subjects were instructed not to blow on, yell into, or intentionally bump the microphone during sampling. Work shift L_{Aeq} measurements were collected and recorded for subjects on the same day that PMP listening levels and background noise levels of subjects were measured. Work shift L_{Aeq} levels measured using dosimeters were used to determine how closely the 2-min SLM L_{Aeq} measurements captured the time-variable occupational noise exposures.

Listening Exposure Level Measurement

A G.R.A.S. Sound and Vibration (Holte, Denmark) Right Ear and Cheek Simulator Type 43AG (ear simulator), connected to a Larson Davis System 824 SLM/Octave Band Analyzer, was used to measure the listening exposure levels for HBNE and LBNE workers. The ear simulator (shown in Figure 1) was calibrated using a Larson Davis CAL 200 Acoustic Calibrator.

A small cart was used to transport the ear simulator to the subjects’ work areas. Subjects were asked to remove their headsets without adjusting the volume setting of their PMP. Subject headsets were fitted to the ear simulator by the experimenter using a stationary test signal as described by Berger et al.⁽¹⁶⁾ With the subject’s media playing, the equivalent continuous sound pressure level (L_{eq}) was measured at each one-third octave band for 2 min. The measured one-third octave band L_{eq} were converted to free-field equivalent A-weighted sound pressure levels (FFL_{Aeq}) in accordance with the International Organization for Standardization (ISO) Standard 11904-2:2004.⁽¹⁷⁾ Measurements were also taken of the ambi-

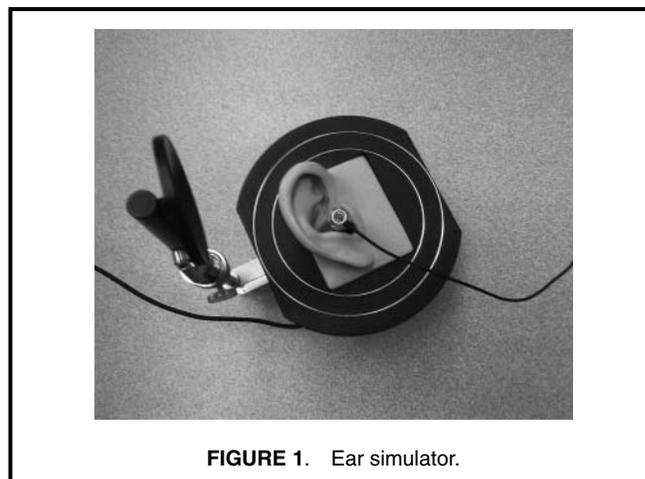


FIGURE 1. Ear simulator.

ent sound levels received in the ear simulator with no headset in place, and also with the headset in place but no signal applied. This difference between the two FFL_{Aeq} ambient sound level measurements was used to compute the headset attenuation estimate of the headset as mounted on the simulator. Because subject listening levels were measured while exposed to the background noise at employee workstations, the measured listening exposure levels were reflective of actual total noise exposure at the ear simulator (i.e., music level and attenuated background noise) and not the music level alone.

Noise Exposure Estimates

The 2-min FFL_{Aeq} listening exposure levels and the 2-min L_{Aeq} background levels were treated as discrete sound pressure level exposures and were used to calculate daily occupational noise exposure estimates. The exposure time at listening exposure level was the subjects’ self-reported duration of use. The exposure time at background level was the subjects’ shift length (not including lunch break) minus the self-reported duration of use. The maximum allowable exposure time at both FFL_{Aeq} listening exposure levels and L_{Aeq} background levels were calculated using ACGIH[®] and Occupational Safety and Health Administration (OSHA) criteria. Exposure estimates without PMP use were calculated using only the L_{Aeq} background levels.

RESULTS

Sample Population

Twenty-four subjects, 12 HBNE and 12 LBNE, were selected for evaluation in this study. The facility’s Environment, Safety, and Health Department management corroborated the findings by indicating that the workers observed using PMPs in office and productions work areas were consistent with their own observations. The average shift length, excluding the lunch period, for HBNE and LBNE subjects was 10.5 hr and 8.8 hr, respectively.

Subjects were questioned about details regarding their PMP use, including listening time, subject age, noise-attenuating headsets, and PMP device type (Table I). The mean

TABLE I. Descriptive Statistics for Personal Media Player Users

Exposure Category	Shift Length (hr) Mean (SD)	Self-Reported Daily Workplace Listening	Age (years) Mean (SD)	Proportion of Subjects Using Noise-Attenuating Headsets	PMP Device Types and Proportion of Use
		Time (hr) Mean (SD)			
High background noise (n = 12)	10.5 (0.5)	3.9 (2.3)	34.4 (4.8)	9 of 12 (75.0%)	Cellular phone 4 of 12 (33.3%) MP3 player 8 of 12 (66.7%)
Low background noise (n = 12)	8.8 (1.3)	3.4 (1.3)	36.3 (5.0)	2 of 12 (16.7%)	Personal computer 12 of 12 (100%)
P-value	0.0009	0.5051	0.3490		

self-reported workplace PMP listening time for HBNE subjects was 3.9 hr per day and ranged from 0.75 to 9 hr. The mean self-reported workplace PMP listening time for LBNE subjects was 3.4 hr per day, with a range of 1 to 5.5 hr. Mean workplace listening times for both subject exposure categories were compared with a two-sample t-test and were not significantly different (p -value = 0.5051). Assumptions of normality and homogeneity of variance were met for workplace listening times of HBNE and LBNE subjects. The combined mean workplace listening time was 3.6 hr per day.

Information about the types of PMPs and the headsets that the subjects used was gathered during listening exposure level measurements (Table I). LBNE workers exclusively chose to listen to media via computer-based PMPs because their work involved sitting at a computer workstation. Conversely, HBNE subjects exclusively chose portable PMPs. Eight of 12 (66.7%) HBNE workers used MP3 player PMPs, while 4 of 12 (33.3%) used cellular phone-based PMPs. Nine of 12 (75.0%) HBNE subjects and only 2 of 12 (16.7%) LBNE subjects chose noise-attenuating headsets.

Background Noise Levels

The mean background L_{Aeq} (Table II), measured using a SLM in LBNE areas was 59 dBA, and the mean background L_{Aeq} in HBNE areas was 81 dBA. A second set of background noise measurements was taken for HBNE workers using personal noise dosimeters (Table II), which resulted in a mean work-shift L_{Aeq} of 80 dBA.

A comparison between background L_{Aeq} levels measured by SLM and dosimetry was conducted to determine how closely a 2-min SLM measurement compared with work shift dosimetry sampling. Because dosimeter and SLM L_{Aeq} measurements were each performed on the same subjects during the same work shift, a paired t-test was conducted to compare the mean difference of the pair-wise L_{Aeq} measurements. There was no significant difference between the mean background SLM measurements and the mean dosimeter measurements (p -value = 0.6608).

Listening Exposure Levels

The mean FFL_{Aeq} listening exposure level computed for LBNE subjects was 75 dBA and for HBNE subjects was 85 dBA (Table II). A one-sided, two-sample t-test was conducted to determine if the mean FFL_{Aeq} listening exposure levels of HBNE subjects was significantly higher than the FFL_{Aeq} listening exposure levels of LBNE subjects. The mean FFL_{Aeq} listening exposure level for HBNE subjects was significantly greater than the mean FFL_{Aeq} listening exposure level for LBNE subjects (p -value = 0.0006). The assumptions of normality and homogeneity of variance were met for FFL_{Aeq} listening exposure levels for HBNE and LBNE subjects.

Effective Signal-to-Noise Ratios

The effective signal-to-noise ratio (the amount by which the FFL_{Aeq} exceeds or falls below the L_{Aeq}) indicates the degree to which PMP users increase their noise exposure while listening to PMPs. The effective signal-to-noise ratio was calculated for each subject by subtracting the SLM measured L_{Aeq} background level from the FFL_{Aeq} listening exposure level. The mean effective signal-to-noise ratio for HBNE who used noise attenuating and non-noise attenuating headsets was 3 dBA and 7 dBA, respectively (Table III). The mean effective signal-to-noise ratio for LBNE who used noise attenuating and non-noise attenuating headsets was 14 dBA and 17 dBA, respectively (Table III). The reader should note that there were only two LBNE subjects who used noise attenuating headsets.

A two-way ANOVA test was conducted to compare the mean effective signal-to-noise ratios by background exposure and headset attenuation categories. The least squares means procedure was used because there were an unequal number of subjects in each group (Table III). Results indicated a significant difference between the effective signal-to-noise ratios of HBNE and LBNE subjects (p -value = 0.0001), and no significant difference between subjects who used noise attenuating and non-noise attenuating headsets (p -value = 0.2783) (Table IV). In addition, the results did not indicate any

TABLE II. Summary of Noise Exposure Levels and Exceedances for Personal Media Player Users

Exposure Category	ACGIH Criteria										OSHA Criteria					
	Background Noise L _{Aeq} (dBA)		Listening Exposure Level FFL _{Aeq} (dBA)		Including PMP Use		Background Noise Only		Including PMP Use		Background Noise Only		Including PMP Use		Background Noise Only	
	Mean (SD)		Mean (SD)		8-Hour TWA ^A (dBA)	No. ≥ 85 dBA	8-Hour TWA ^A (dBA)	No. ≥ 85 dBA	8-Hour TWA ^A (dBA)	No. ≥ 85 dBA	8-Hour TWA ^B (dBA)	No. ≥ 90 dBA	8-Hour TWA ^B (dBA)	No. ≥ 85 dBA	8-Hour TWA ^B (dBA)	No. ≥ 90 dBA
High background noise (n = 12)	81 (4.4)		85 (6.4)		84 (4.9)	6	82 (4.6)	3	85 (4.9)	6	83 (4.5)	1	83 (4.5)	3	1	1
Low background noise (n = 12)	59 (2.5)		75 (6.4)		72 (6.9)	0	59 (2.5)	0	70 (6.5)	0	59 (2.6)	0	59 (2.6)	0	0	0
P-value	<0.0001		0.0006		<0.0001		<0.0001		<0.0001		<0.0001		<0.0001			<0.0001

^ACalculated using a 85 dBA criterion level and 3 dB exchange rate.

^BCalculated using a 90 dBA criterion level and 5 dB exchange rate.

TABLE III. Effective Signal-to-Noise Ratios and Headset Attenuation Estimates of Personal Media Player Users

Category	Effective Signal-to-Noise Ratio ^A (dBA)	Headset Attenuation Estimate ^B (dBA)	Combined Attenuation Estimate and Effective Signal-to-Noise Ratio ^C (dBA)
	Mean (SD)	Mean (SD)	Mean (SD)
High background noise exposed with noise attenuating headset (n = 9)	3 (6.2)	14 (9.6)	16 (9.2)
High background noise exposed without noise attenuating headset (n = 3)	7 (0.5)	0 (4.4)	6 (4.4)
Low background noise exposure with noise attenuating headset (n = 2)	14 (5.2)	1 (5.1)	15 (0.2)
Low background noise exposure without noise attenuating headset (n = 10)	17 (6.9)	0 (3.3)	17 (6.2)

^ADifference between listening exposure level and background noise level.

^BDifference between open-ear background noise level and headset attenuated background noise level.

^CSum of the effective signal-to-noise ratio and headset attenuation estimate. Note that the values may vary by ± 1 dBA from the sum of A and B due to rounding.

significant interaction effect between the background noise and headset attenuation categories.

Headset Attenuation Estimates

The mean headset attenuation estimate (the difference between ambient sound levels measured with and without a headset coupled to the ear simulator with no signal playing) was 14 dBA and 0 dBA for HBNE subjects who used noise attenuating and non-noise attenuating headsets, respectively (Table III). The mean headset attenuation estimate was 1 dBA

and 0 dBA for LBNE subjects who used noise attenuating and non-noise attenuating headsets, respectively (Table III). An unbalanced two-way analysis of variance (ANOVA) test was conducted to compare the mean headset attenuation estimates by background exposure and headset attenuation categories. Results indicate a significant difference between the headset attenuation estimates of HBNE and LBNE subjects (p -value = 0.0023), and a significant difference between subjects who used noise attenuating and non-noise attenuating headsets (p -value = 0.0323) (Table IV). In addition, the results did

TABLE IV. Comparison of Effective Signal-to-Noise Ratios and Headset Attenuation Estimates by Background Noise and Headset Attenuation Categories

Category	Background Noise			Headset Type			Interaction Effect P-value $\alpha = 0.05$
	HBNE (n = 12) LSMean	LBNE (n = 12) LSMean	P-value $\alpha = 0.05$	Noise Attenuating (n = 11) LSMean	Non-Noise Attenuating (n = 13) LSMean	P-value $\alpha = 0.05$	
Effective signal-to-noise ratio ^A (dBA)	4.4	15.2	0.0001	8.0	11.5	0.2783	0.8213
Headset attenuation estimate ^B (dBA)	8.2	2.9	0.0023	9.7	1.4	0.0323	0.0562
Combined attenuation estimate and effective signal-to-noise ratio ^C (dBA)	12.6	18.1	0.3985	17.8	12.9	0.2157	0.1110

^ADifference between listening exposure level and background noise level.

^BDifference between open-ear background noise level and headset attenuated background noise level.

^CSum of the effective signal-to-noise ratio and headset attenuation estimate.

not indicate any significant interaction effect between the background noise and headset attenuation categories.

The headset attenuation estimate for each subject was added to the effective signal-to-noise ratio to determine if there was a difference between the effective signal-to-noise ratios of HBNE and LBNE subjects independent of headset attenuation. The mean effective signal-to-noise ratio combined with headset attenuation level for HBNE who used noise attenuating and non-noise attenuating headsets was 16 dBA and 6 dBA, respectively (Table III). The mean effective signal-to-noise ratio combined with headset attenuation level for LBNE who used noise attenuating and non-noise attenuating headsets was 15 dBA and 17 dBA, respectively (Table III). There was no significant difference between HBNE and LBNE subjects or subjects who chose noise attenuating and non-noise attenuating headsets when the effective signal-to-noise ratios and headset attenuation estimates were combined (p -value = 0.1629 and 0.2157) as measured using an unbalanced two-way ANOVA (Table IV). There was also no significant interaction effect between the background noise and headset attenuation categories

Occupational Noise Exposure Estimates

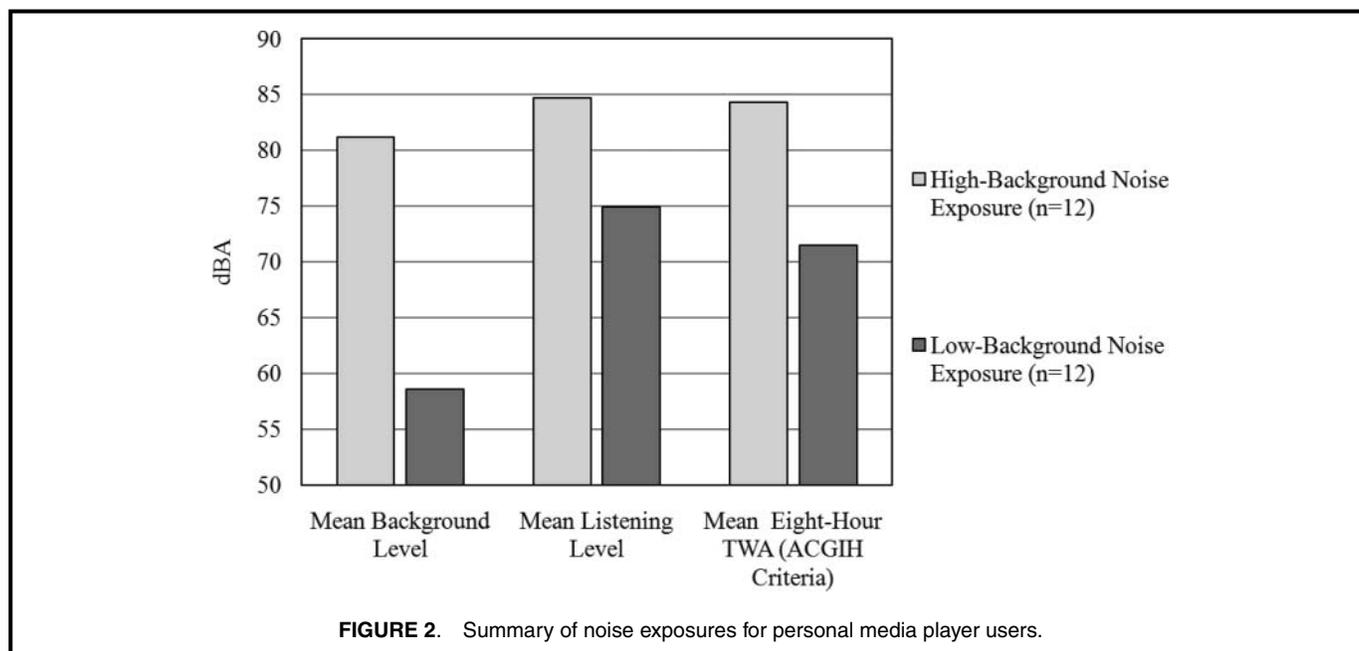
The mean nominal TWA work shift noise exposure (including background noise and listening exposure levels), calculated using ACGIH criteria, for HBNE and LBNE workers was 84 dBA and 72 dBA, respectively (Table II). Six of 12 (50%) HBNE subjects were overexposed to noise according to ACGIH criteria, while no LBNE subjects exceeded the ACGIH criteria (Table II). The mean nominal 8-hr TWA calculated using OSHA criteria, for HBNE and LBNE workers was 85 dBA and 70 dBA, respectively (Table II). One of 12 (8.3%) subjects in the HBNE areas was overexposed to noise according to OSHA PEL, and 5 of 12 (41.7%) of the HBNE subjects

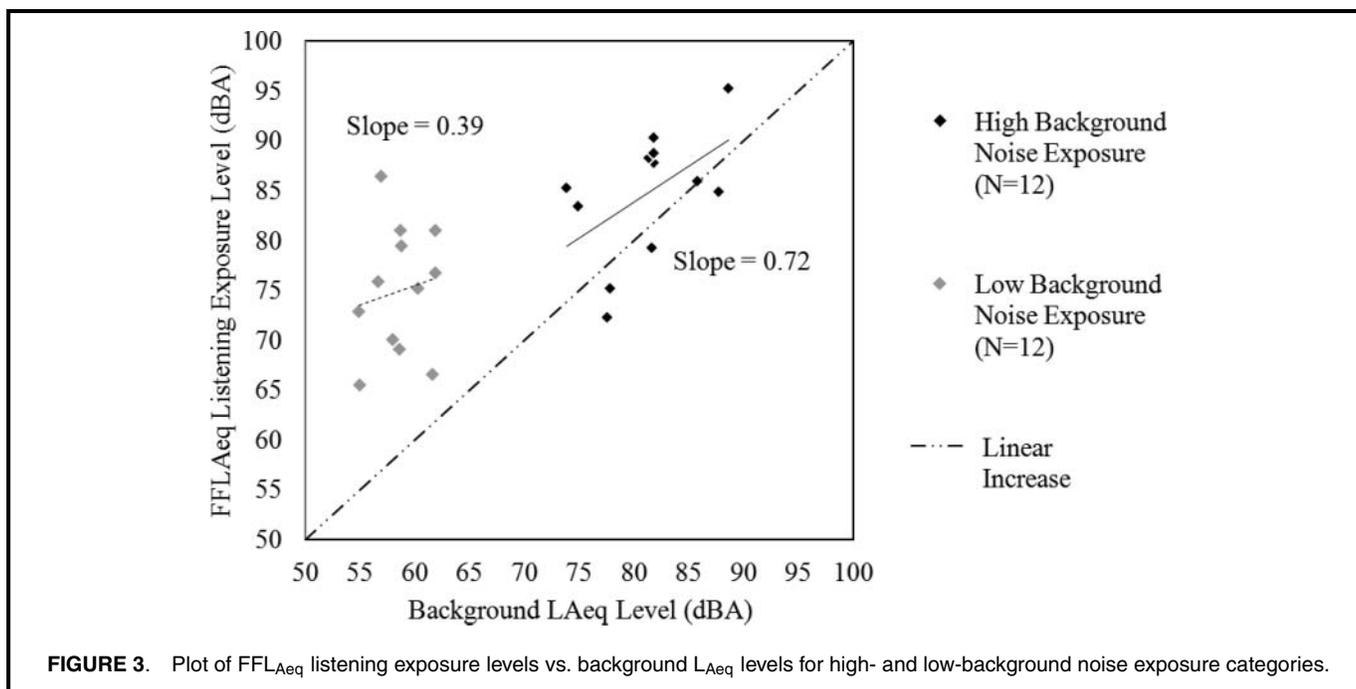
exceeded the OSHA Action Limit (85 dBA) but were below the OSHA permissible exposure limit (PEL) (Table II). No LBNE subjects exceeded any OSHA criterion (Table II).

Occupational noise exposure estimates were also calculated for HBNE subjects using only the shift length (not including lunch break) and the SLM measured L_{Aeq} background level. The mean nominal 8-hr TWA for HBNE subjects was 82 dBA and 83 dBA calculated using ACGIH and OSHA criteria, respectively (Table II). Note that the average shift lengths for both HBNE and LBNE subjects were greater than 8 hr. Thus, exposure estimates calculated using OSHA criteria appeared to be slightly more protective for this sample population compared with exposure estimates calculated using ACGIH criteria. An illustration of noise exposures for HBNE and LBNE subjects is provided in Figure 2.

DISCUSSION

The mean occupational exposure estimates for HBNE and LBNE categories were below ACGIH and OSHA occupational exposure limits. However, 6 of 12 (50%) of all HBNE subjects had exposure estimates greater than 85 dBA 8-hr TWA when both listening exposure levels and background noise were taken into account. No occupational noise exposure estimates indicated an overexposure among LBNE subjects. Additional exposure estimates without the inclusion of listening exposure levels (i.e., using background noise levels only) indicated that only 3 of 12 (25%) HBNE subjects would have been exposed to noise greater than 85 dBA 8-hr TWA. Thus, in this study, the policy allowing workplace PMP use appears to have doubled the number of HBNE subjects overexposed to noise. In addition, the number of overexposed subjects would increase further if worker listening exposure times were





extended to the entire work shift as opposed to the self-reported listening times of subjects.

Without direction from facility management, HBNE subjects were far more likely to select noise-attenuating headsets. Because HBNE subjects were working in relatively loud environments, they likely had greater motivation to select headsets that would allow them to listen to media with reduced interference from background noise. Listening exposure levels did not increase linearly with background noise levels for HBNE or LBNE subjects, as shown in Figure 3. This finding suggests that PMP users do not select their listening levels only as a function of background noise level and headset attenuation but may also base their listening level on other variables, such as personal preference, comfort, headset output potential, and media type. Regardless, given these data, one cannot assume that PMP users will increase their listening levels linearly to match increases in background noise.

There were no observed instances of workers wearing PMP headsets but not listening to music (i.e., using their headsets as hearing protection devices [HPDs]), although this potential behavior was not evaluated in this study. The results and recommendations herein assume no headset or HPD use during non-listening periods. However, it is conceivable that HBNE workers in particular may choose to wear their headsets during non-listening periods to reduce their exposure to background noise. Such behavior should be discouraged in favor of true HPDs and viewed as an opportunity for providing hearing preservation education.

The application of discrete 2-min SLM measurements proved to be a reliable work shift approximation for use in calculating occupational noise exposure estimates. The similarity between SLM and dosimeter measurement results is likely because noise sources in the facility were relatively constant and worker mobility was minimal in production areas of the facility.

Study Limitations

The use of 2-min SLM measurements in the calculation of occupational exposure estimates was successfully verified via comparison with work shift dosimetry sampling, likely because background noise exposures were relatively constant for individual workers. However, the researchers were not able to verify the FFL_{Aeq} listening exposure levels with a similar method. Consequently, the listening exposure time used in the calculation of occupational noise exposure estimates is essentially a grab sample, which may not accurately depict the true time-variable exposures. However, if subjects maintained their preferred effective signal-to-noise ratio throughout the course of their work shift by adjusting the volume setting of their PMPs, then the 2-min FFL_{Aeq} listening exposure levels would likely have been reasonably close to the true time-variable exposure, given the comparable work-shift dosimetry and 2-min SLM measurements. Furthermore, subject listening exposure level measurements were not reflective of headset output alone because a true 10 dB signal-to-noise ratio was not established for many subjects, but rather a combination of headset output and headset attenuated background noise was measured at the ear simulator.

The small and uneven sample sizes that resulted when the study population was divided into four groups (HBNE and LBNE with and without noise attenuating headsets) limited the results of the effective signal-to-noise ratio and headset attenuation estimate analysis. Larger sample sizes and a more equal sample distribution are necessary to clarify the interaction between these variables. In addition, the mean headset attenuation estimate of 0 dB for LBNE subjects who used noise attenuating headsets was surprising and likely a result of a poor seal between the subjects' headset and the ear simulator. Although subject headsets were fit to the ear simulator using the

method described by Berger et al.⁽¹⁶⁾ to aid in capturing headset output intensity as would be experienced by the PMP user, it did not aid in achieving a correct seal for headset attenuation. Both LBNE subjects who used noise attenuating headsets were female and used canalphones that were smaller than those canalphones used by the predominantly male subjects exposed to high background noise. Additional pinna sizes for the ear simulator were not available during this study but likely would have provided a better estimate of headset attenuation for the LBNE subjects. The differences between subjects who used noise attenuating headsets and those that did not were likely reduced by the potential underestimate of headset attenuation of subjects in the LBNE noise attenuating headset group.

The method by which subjects were identified and sampled is another potential limitation. The production facility was not chosen because it was representative of any particular industry or occupational sector but, rather, as a convenience sample. Subjects were asked in person whether they used PMPs at work, and although management corroborated the responses, some still may have chosen not to disclose their occupational PMP use. The researchers also moved throughout the selected work areas to solicit volunteers and conduct measurements. Thus, workers were likely aware of the researchers' approach and may have had the opportunity to adjust the listening level of their PMPs prior to the researchers' arrival at their workstation. HBNE workers may have been more likely to adjust their listening level because they may have been afraid of losing their listening privileges in HBNE work areas. The researchers' presence may also have unduly influenced the level of background noise exposures, as workers or their supervisors may have been more careful to limit loud noise sources or risky behaviors while the researchers were present.

CONCLUSIONS AND RECOMMENDATIONS

The results of this study indicated overexposures to noise among workers who used PMPs in HBNE work areas, although the mean exposure estimate was below ACGIH and OSHA occupational exposure limits. Exposure estimates from listening exposure levels and background noise levels indicated that there was a 100% increase in the number of overexposed HBNE subjects when PMP use was considered as opposed to background noise exposures alone. In addition, listening exposure level measurements indicated that 8 of the 24 total subjects (33.3%), including one LBNE subject, listened at levels greater than 85 dBA FFL_{Aeq}, although the self-reported listening exposure times did not often meet or exceed 8 hr. While HBNE subjects listened to PMPs at higher levels, they also chose to use noise-attenuating headsets much more frequently than LBNE subjects did. The preferential selection of noise attenuating headsets among HBNE subjects was likely responsible for the large discrepancy between the effective signal-to-noise ratios of HBNE and LBNE subjects.

The employer should consider feasible administrative and engineering controls to reduce hazardous noise exposures on the production floor and provide appropriate HPDs for employ-

ees overexposed to background noise as required by OSHA regulations. Although some PMP headsets appeared to provide good noise attenuation, the attenuation of headsets evaluated during this study were not tested to conform to American National Standards Institute (ANSI) standard S12.6 for HPDs.⁽¹⁸⁾ To reduce the risk of compensable ONIHL and regulatory violations, the employer should both implement and enforce a policy that discourages PMP use while promoting traditional HPD use.

As an alternative, the employer should consider providing combined HPD/PMP headsets, with output-limiting technology and properly tested noise attenuation, to allow workers to enjoy PMP listening during work without increasing their risk of hearing impairment. Before selecting any combined HPD/PMP headsets for workers, the employer should confirm that sufficient noise attenuation would be provided and ascertain any additional safety or health hazards that would be created by the workplace use of these devices. Employees should also be educated on the risks of hazardous noise exposures, including those risks from excessive PMP use.

Anecdotal evidence suggests there are a number of workers in many occupational sectors who use PMPs on the job. However, an estimate of the prevalence and magnitude of workplace PMP use should be a main objective of future research. The authors also suggest future epidemiologic research to establish the level of increased ONIHL risk, if any, associated with workplace PMP usage. Ultimately, providing information to aid in the establishment of guidelines for businesses regarding the safe workplace use of PMPs, including acceptable background noise levels and headset device types, should be a top priority for researchers.

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