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Typical noise exposure in daily life

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Abstract

Objective—Identify the distribution of typical noise levels present in daily life and identify factors associated with average sound levels.

Design—This was an observational study.

Study sample—Participants (N = 286) were 20 to 68 year old men and women, drawn from the general population of Kalamazoo County, Michigan . A total of 73 000 person-hours of noise monitoring were conducted.

Results—Median overall daily average levels were 79 and 77 $dBLeq_{A,8,equiv}$, with average levels exceeding EPA recommended levels for 70% of participants. Median levels were similar between the hours of 9 a.m. and 9 p.m., and varied little across days of the week. Gender, occupational classification, and history of occupational noise exposure were related to average noise levels, but age, educational attainment, and non-occupational noise exposures were not.

Conclusions—A large portion of the general population is exposed to noise levels that could result in long-term adverse effects on hearing. Gender and occupation were most strongly related to exposure, though most participants in this study had occupations that are not conventionally considered noisy.

Keywords

Hearing loss; noise-induced; occupational noise; environmental exposure

Typical noise exposures in contemporary daily life are not well known. Despite some efforts to address this deficiency, scientific knowledge in the area of typical noise exposure retains the limitation identified by a US House of Representatives Committee debating the Noise Control Act of 1972, which was that "…most of the information relating to noise exposures

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was concerned with specific sources, rather than typical cumulative exposures to which urban and suburban dwellers are commonly exposed." (Environmental Protection Agency, 1974, p. 8). Although source-specific assessments of noise emissions provide information useful for prioritizing noise controls and recommending the use of hearing protectors, such studies provide only limited information about the overall noise exposures of people who are exposed to a large variety of noise sources over the span of hours to weeks.

Some sources (e.g. Clark, 2008, p. 323) suggest that noise-induced temporary threshold shift (TTS) is a common event in daily life, which would imply that high degrees of noise exposure are common in industrialized societies. On the other hand, many empirical studies (Environmental Protection Agency, 1974; Johnson & Farina, 1977; Nimura & Kono, 1980; Roche et al, 1982; Thompson et al, 2003) have found that typical noise exposure levels tend to reside in the vicinity of the auditory injury threshold (AIT), which would not be expected to regularly produce significant TTS, but might yield small amounts of noise-induced permanent threshold shift (NIPTS) over an extended interval.

It is helpful to discriminate the separate but related concepts of effective quiet, the AIT, and noise dose as they pertain to the investigation of daily life noise exposures. Effective quiet is the maximum level that does not interfere with the recovery from TTS. Recovery from TTS is affected by the listener's access to levels at or below the threshold for effective quiet. The upper limit of effective quiet has been reported to be as low as 55 dBA (Kryter, 1985, p. 256–259) and as high as 65 to 70 dBA (Ward, 1976), with lower limits of effective quiet required for exposures producing greater TTS (Kryter, 1985, p. 256–259; Ward, 1976). Cumulative effects of repeated exposure to TTS-producing stimuli have been shown. In one study, sound levels as low as 48 dB SPL were shown to potentiate the TTS produced by subsequent high-level exposures in some listeners (Trittipoe, 1958). However, a follow-up study in which the TTS-producing stimulus was presented at a lower level failed to produce similar results and the effect observed by Trittipoe (1958) was considered a representation of cumulative effects of sequential exposures to stimuli producing TTS (Ward, 1960). Such cumulative effects were described by Harris (1955), who observed greater TTS for a second presentation of a TTS-producing stimulus than for the first—even when complete threshold recovery was observed prior to the second presentation. It is possible that such cumulative effects are an indication that the recovery from TTS extends beyond the time frame necessary to restore thresholds to baseline (Ward, 1960). Recent work confirms that the noise environment following high-level noise exposures influences both threshold shift and histological evidence of hair cell pathology (Tanaka et al, 2009), but the direction and magnitude of effects seems related to a variety of factors (Willott et al, 2008). The AIT is the lowest level capable of producing any threshold shift, regardless of exposure time. Based on measurements of the greatest TTS over extended exposure durations, (i.e. the asymptotic threshold shift), the AIT can be expected to occur between approximately 75 and 78 dBA (Mills et al, 1981; Nixon et al, 1977).

There is a reasonable correspondence between the amount of TTS and NIPTS produced by a sound level, even though the sites of damage might be different (e.g. Nordmann et al, 2000). The US Environmental Protection Agency (EPA) produced a report describing the levels of environmental noise requisite to protect public health and welfare (Environmental Protection

Agency, 1974). In this document, the requisite level determined to avoid adverse effects on hearing was a 75 dB 8-hour A-weighted equivalent SPL. This limit was intended to prevent a NIPTS greater than 5 dB at 4 kHz for the least susceptible 96% of the population after an exposure duration of many years. A more recent example is the ISO-1999 (1990) standard for estimating noise induced hearing impairment, which is similar to the US ANSI standard S3.44 (1996). In these examples, estimates of NIPTS cannot exceed zero at any frequency unless the A-weighted level exceeds 75 dB.

It should be noted that a small amount of NIPTS might not produce a hearing impairment leading to a disadvantage in the activities of daily living. Hearing impairments leading to a disadvantage are considered *material hearing impairments* and although the definitions of material hearing impairment have varied (Dobie, 2001; Kryter et al, 1966; National Institute for Occupational Safety and Health, 1998), they share the common goal of identifying those impairments that are likely to put the listener at a disadvantage in daily life.

As components of damage-risk criteria, estimates of noise dose are inextricably tied to the definitions of material hearing impairment used during their development. The criterion levels for estimates of noise dose must be at or above the AIT, but the extent to which they exceed the AIT is determined by the amount of NIPTS that produces a material hearing impairment in an unacceptable percentage of people exposed. Detailed reviews of damage-risk criteria are available elsewhere (e.g. Kryter et al, 1966; Environmental Protection Agency, 1974; National Institute for Occupational Safety and Health, 1998), and we have adopted the standard recommended by the National Institute for Occupational Safety and Health (NIOSH) (1998) for the purposes of this study (i.e. a recommended exposure limit of 85 dBA for an 8-hour noise exposure, based on a 3-dB exchange rate).

Exposure studies in the general population are valuable in and of themselves, and also are needed to provide a baseline against which to compare occupational exposures. A small number of studies assessing noise exposure in daily life can be found in the archival literature, including a series of studies conducted by the Air Force Aeromedical Research Lab (Johnson & Farina, 1977; Roche et al, 1982), an EPA report (Environmental Protection Agency, 1974), plus some additional smaller-scale studies (e.g. Nimura & Kono 1980, which was described in Kryter, 1985, p. 284; Thompson et al, 2003). These studies have revealed equivalent continuous levels, normalized to 8 hours, ranging between approximately 75 and 87 dBA, depending on the populations sampled, the dosimeter used, and the time frame during which the study was conducted. The average levels observed among schoolchildren tend to be greater than those for adults (Environmental Protection Agency, 1974; Nimura & Kono, 1980; Roche et al, 1982), and levels observed among workers tend to be greater than those for individuals who do not work outside the home (Nimura & Kono, 1980).

Some studies have been done with low-noise occupations and non-occupational activities of people in noisy occupations, and these studies have generally found that non-occupational noise exposures are likely to contribute little to the total noise dose of people who work in noisy jobs (Kock et al, 2004; Neitzel et al, 2004), but the levels observed in these studies indicated that non-occupational exposures can often exceed the AIT (Neitzel et al, 2004).

However, average levels observed among residents and workers in traditionally quiet jobs were often below the AIT (Kock et al, 2004).

A great deal of variability can be expected in typical noise exposure distributions, both between- and within-subjects. One can anticipate that differences associated with gender, age, occupation, lifestyle, and hobbies will exert some influence on the average levels observed for a person, and an observation period of many days would be required to capture rare but significant exposure events in both occupational and non-occupational domains. In this study, we summarize long-term dosimetry results from a large sample of participants drawn from the general population. Specifically, this study was undertaken to (1) identify the distribution of typical sound levels in daily life, (2) examine differences in these levels across time of day and day of week, and (3) identify significant factors associated with differences in daily average sound levels, including gender, age, occupational noise exposure, and non-occupational noise exposure.

Method

Participants

Participants were 210 men and 76 women participating in an ongoing study examining the magnitude and correlates of test-retest differences in pure-tone thresholds. Participants ranged in age from 20 to 68 years (mean age = 41, SD = 13), and were recruited from the population surrounding Kalamazoo, Michigan, USA. Participants were invited to volunteer by means of newsletters, flyers, announcements, and printed materials distributed to area employers, clubs, and community notice boards, and word-of-mouth. To participate in the study, volunteers were required to: (1) have hearing thresholds better than 80 dB HL between 0.5 and 8 kHz, inclusive; (2) have asymmetry of 40 dB or less at all frequencies; (3) exhibit normal middle-ear function by tympanometry; and (4) be able to read and understand the informed consent document, study questionnaires, etc., either in English or Spanish. This study was reviewed and approved by the Human Subjects Institutional Review Boards of Western Michigan University and NIOSH.

Each participant reported his or her current or most recent occupation at the time of entry into the study. These occupations were categorized into 2-digit US Bureau of Labor Statistics Standard Occupational Classification (SOC) major groups (Cosca & Emmel, 2010). The predominant occupations for men in this study were building/grounds maintenance, office/administrative support, production, computers/mathematics, education, and sales-related (Table 1). The predominant occupations for women were office/administrative support, education, life/physical/social sciences, and management.

Self-reported history of exposure to noise on the job was assessed using the following questionnaire items:

> Thinking of all the jobs you have ever had, have you ever been exposed to loud noise at work for at least three months? By loud noise, we mean noise so loud that you had to speak in a loud voice to be heard. [If yes] Did you ever wear protective devices while exposed to loud noise in that job?

Self-reported history of exposure to noise during non-work activities was assessed using the following questionnaire items:

> Outside of work, have you ever been exposed to other types of loud noise, such as a noise from power tools or loud music, for an average of at least once a month for a year? By loud noise, we mean noise so loud that you had to speak in a raised voice to be heard. [If yes] Did you ever wear protective devices while exposed to these loud noises?

Instrumentation

Noise exposure data were collected using the ER-200D personal noise dosimeter (Etymotic Research, Inc., Elk Grove Village, Illinois, USA), which performs like an ANSI (ANSI S1.25 1997) Type 2 dosimeter (Deiters et al, 2010), but has not been confirmed to meet all the specifications for a Type 2 dosimeter (e.g. vibration sensitivity, resistance to magnetic and electrostatic fields) and was not designed for impulse noise measurement. This dosimeter monitored A-weighted root-mean-square sound energy using a onesecond (slow) time constant consistent with ANSI S1.4 (American National Standards Institute, 1983) over a maximum dynamic range of 65 to 130 dBA. Sound levels were evaluated relative to the device threshold every 220 ms and integrated to produce an equivalent continuous level, which was logged to memory every 3.75 minutes (i.e. 16 logged values per hour). Data were downloaded from dosimeters using the manufacturer’s software and a USB connection.

The dosimeter was configured with a 65 dBA threshold, 85 dBA/8 hour criterion, and a 3-dB exchange rate. Note that levels below the dosimeter threshold are replaced by zeros (i.e. a value of 64.9 is replaced by a value of zero), and the resulting averages are calculated as if sounds below the threshold level were not present. For hearing conservation purposes, where average levels are expected to be 85 dBA or greater, a threshold value of 80 dBA is frequently used. This lower limit was initially specified by the limited dynamic range capabilities of early dosimeters instead of a scientific rationale. However, such a high threshold would have neglected sound levels in the area of the auditory injury threshold and prevented assessment of the amount of time participants spent in effectively quiet environments. Furthermore, replacing levels of 79.9 dBA and below with zeros would have biased downward estimates of average daily levels, which were of primary interest in this study.

The dosimeter was configured to run continuously for up to 7 days, but the average measurement run was halted after 53 hours (SD: 35 hours), when the participant returned to the research lab for audiometric testing. The time between visits to the research lab constituted a measurement run, and the subsequent run began less than 30 minutes after the completion of the prior run and while the participants were being tested in the research lab. Total durations across measurement runs ranged from 23 hours to 20 days, with a median of 9.8 days (interquartile range: 7.3 to 12.3 days). Withrawal or dismissal from the threshold reliability study resulted in total durations less than 5 days.

Procedure

Dosimeter calibration was checked before first issuing the device to a participant and after the participant's involvement in the study was completed. The dosimeter displays and the capacity to turn off the dosimeter were disabled, and participants were asked to wear the dosimeter at all times except when it could be damaged or a hazard to the wearer. It was to be placed on a nearby table while the participant slept. Based on the results of Knapp and Flamme (2009), participants were allowed to wear the dosimeter at hip level or above, as necessary for the clothing worn that day. Windscreens were not used. Although only minor effects would be expected from covering the microphone inlet with clothing (Johnson & Farina, 1977), participants were instructed to leave the microphone inlet exposed.

Data analyses

Equivalent continuous levels ($dBLeq_{A,3.75}$) were logged into the dosimeter memory 16 times per hour for the duration of each participant's involvement in the audiometry study, beginning with the enrollment meeting that took place at least 16 hours and up to 7 days prior to the first hearing test, and continuing until the participant began the last hearing test appointment, which took place no later than two weeks after the first hearing test. Therefore noise exposure data could be recorded for up to three weeks, although the longest observation interval included in the data presented here was 20 days. Dosimeters were downloaded, memory cleared, and restarted during each participant's hearing test appointments over this time period.

Individual ($dBLeq_{A,3.75}$) values were combined into daily 8-hour equivalent dBALeq ($dBLeq_{A,8,equiv}$) by determining the average Pascal-squared seconds (Pa^2s) per day in each dosimeter run, converting into decibels the ratio of the total Pa^2s in a run to the Pa^2s corresponding to a 100% noise dose for the same run interval in days, and adding this quantity to the criterion level for an 8-hour exposure (85 dBA).

$$dBLeq_{A,8,equiv}=85+10 \quad log\left(\frac{\sum Pa^2s}{(3643\times t)}\right)$$

where $\sum Pa^2s$ represents the total number of Pascal-squared seconds in the dosimeter run, 3643 represents the number of Pascal-squared seconds corresponding to a 100% noise dose, and *t* represents the number of days in the dosimeter run.

Results from questions pertaining to history of noise exposure on or off the job were transformed into a 3-level categorical variable, with values of 0, 1, and 2 assigned to those who reported no exposure, exposure but no hearing protection, and exposure with hearing protection, respectively.

A multivariable regression model was developed to identify any significant relationships between demographic variables and overall daily average levels ($dBLeq_{A,8,equiv}$), with all variables entered using indicator (i.e. dummy coded) variables. Post hoc tests of categorical variables were conducted using the Holm method, which is similar to the familiar Bonferroni procedure in that the criterion overall Type I error rate is divided over the number of comparisons to be made. However, the Holm method includes only the post-hoc comparisons with the lowest Type I error rates, thus providing greater statistical power than achieved with the Bonferroni procedure. Further explanation of the Holm method can be found in Aickin and Gensler (1996).

Results

Distributions of typical sound levels

A total of 8.37 person-years (73 000 person-hours) of exposure monitoring were included in these analyses. From men, a total of 5.63 person-years (49 000 person-hours) of exposure were obtained, while 2.74 person-years (24 000 person-hours) of exposure were obtained from women. Exposures were obtained via a total of 929 and 452 dosimeter runs for men and women, respectively, with a range of one to five runs contributed by each person (mean = 4.4; median = 5). The total duration of exposure corresponded to approximately 1.2 million A-weighted equivalent continuous levels, each of which represented a 3.75 minute measurement interval ($dBLeq_{A,3.75}$). Approximately 28% of $dBLeq_{A,3.75}$ values exceeded the 65 dBA device threshold. The preponderance of $dBLeq_{A,3.75}$ values above the device threshold were less than 85 (Figure 1), with only 1.8% of observed values above this level.

Examination of daily average levels ($dBLeq_{A,8,equiv}$) computed from each dosimeter run revealed a median $dBLeq_{A,8,equiv}$ of approximately 76 dB (Figure 2). The shapes of the cumulative distributions were similar for men and women below the median, but the distributions diverged above the median. The upper half of the cumulative distribution for men indicated greater sound exposures than were observed for women. This gender difference increased with distance from the median, with an approximate 1.5 dB difference at the 70th percentile expanding to an approximate 3 dB difference at the 95th percentile.

Within participants, daily average levels were correlated across dosimeter runs, but the relationship was far from perfect. The Pearson *r* correlations between $dBLeq_{A,8,equiv}$ values across visits ranged between .45 and .55 (mean =.51), indicating that high average levels could be expected from participants who had high average levels in prior runs. However, the strength of the correlation suggests only moderate generalizability of average levels from one run to another.

Results from the individual dosimeter runs were merged into overall daily sound levels $dBLeq_{A,8,equiv}$ for that participant by calculating the mean number of Pascal^2 seconds over the total duration of each listener's participation in the study. The cumulative distributions of those sound levels were slightly compressed relative to the distributions of individual runs (Figure 3). In addition, medians of the overall distributions were greater than observed from the individual runs. The differences were 3 and 1 dB for men and women, respectively, with an overall median of approximately 78 $dBLeq_{A,8,equiv}$. This trend extended into the higher percentiles as well, leading to the case where at levels of 82 $dBLeq_{A,8,equiv}$ the percentage of men with high-level exposures was greater than that for women by a factor of 1.5 or more (e.g. 30% of men, and 20% of women with exposures greater than 82 $dBLeq_{A,8,equiv}$). An overall daily sound level of 88 dB was exceeded by 10% of men and 2% of women.

The distribution of overall daily sound levels revealed that 65 to 70% of the participants in this study had overall daily average levels exceeding the EPA (1974) recommended limit of 75 $dBLeq_{A,8,equiv}$, and around 50% of women and 60% of men exceeded the 76.4 $dBLeq_{A,8,equiv}$ EPA-recommended limit that excludes the 1.4 dB allowance for exposures occurring outside of the conventional 2000-hour work-year. About 40% of women and 55% of men in this study exceeded the auditory injury threshold of 78 $dBLeq_{A,8,equiv}$. A substantial minority of participants (approximately 7% of women, 18% of men) had overall average daily noise levels greater than 85 $dBLeq_{A,8,equiv}$, suggesting excessive risk of material hearing impairment, as defined by NIOSH (1998).

In order to assess the times of day that contributed most to an individual's overall exposure, individual $dBLeq_{A,3.75}$ values within each dosimeter run were integrated into equivalent continuous levels over 3-hour time intervals. The results of these analyses indicated that the greatest exposures occurred between 9 a.m. and 9 p.m. (Figure 4), with median levels between 70 and 71 dB. The greatest exposures occurred during the interval ending at 6 p.m., where a median of 71.5 dB was observed. Median levels during the interval ending at 9 a.m. and midnight were somewhat lower (64.1 and 67.5 dB, respectively), and medians for time periods ending at 3 and 6 a.m. were considerably lower (48 and 44.1 dB, respectively), reflecting that most participants in the study typically slept in quiet environments during night-time hours.

The spread of observed levels differed by time of day. The smallest range was observed between 3 and 6 p.m., where the interquartile range was between approximately 67 and 76 dB. Interquartile ranges during the early morning and late evening periods were broader, spanning 10 to 15 dB. These results indicate that the second half of the typical workday contained somewhat greater amounts of sound exposure due to slightly lower variability in levels, and that the three hour intervals on either side of that time frame could contain sound levels that influence an individual's daily average.

Individual $dBLeq_{A,3.75}$ values from each participant were assessed by the day of the week to assess the degree to which an individual's exposure varied across days. The results of these analyses revealed only minor differences. Median $dBLeq_{A,8,equiv}$ values (Figure 5) ranged between 74.2 dB (Sunday) and 76.6 dB (Thursday), suggesting that small differences were found across days of the week, with the highest exposures occurring during typical workdays. The 5th percentiles varied over an approximate 7 dB range, with the lowest values of about 60 $dBLeq_{A,8,equiv}$ observed on weekends and the greatest values (65–67 $dBLeq_{A,8,equiv}$) observed during the conventional work week. The 90th percentile of the $dBLeq_{A,8,equiv}$ values was between 84 and 91 dB, with the lowest value observed on Mondays and the greatest value on Thursday.

Demographic factors associated with noise levels

Approximately 71% of men and 68% of women in this study had overall daily average levels ($dBLeq_{A,8,equiv}$) greater than the 75 dB AIT identified in ANSI S3.44 (1996). It would be of interest to clinicians and policy makers to determine whether there were simple demographic, occupational, or non-occupational factors that would identify individuals in the general population who were likely to have comparatively high levels of exposure. In these analyses, we examined the relationship between overall daily average levels ($dBLeq_{A,8,equiv}$) and gender, age in decades, educational attainment, most recent occupation, self-reported history of exposure to noise at work, and self-reported history of exposure to noise during nonwork activities.

A multivariable regression model to assess the relationships between demographic factors and average levels revealed that age, educational attainment, and self-reported history of non-occupational noise exposure were not significantly associated with overall daily average levels. The reduced model was significant and accounted for approximately one-fourth of the variance in overall daily average levels ($F_{39,224} = 1.86$; p =.003; R^2 =.25). Gender ($F_{1,224} = 4.92$; p =.028), current/most recent occupation ($F_{20,224} = 1.79$; p =.022), and self-reported history of exposure to occupational noise ($F_{2,224} = 5.13$; p =.006) were retained in the model as significant predictors. In addition, there was a significant interaction between gender and SOC job classification ($F_{16,224} = 1.79$; p =.034).

Controlling for the other factors in the model, participants reporting a history of occupational noise exposure but no use of hearing protectors tended to have slightly higher (0.89 dB) overall daily levels than those who did not report any history of occupational noise exposure, but this difference was not statistically significant ($F_{1,224} = 0.74$; p =.391). Overall daily levels for those reporting both a history of exposure to occupational noise and hearing protector use had average levels that were approximately 3 dB greater than those without occupational exposures. Post hoc testing revealed that participants reporting occupational noise exposure and hearing protector use had significantly greater overall daily average levels than both those who reported occupational noise exposure but no hearing protector use ($F_{1,224} = 4.7$; Holm-adjusted p =.031) and those who reported no occupational noise exposure ($F_{1,224} = 9.4$; Holmadjusted p =.004).

The significant interaction between gender and SOC was examined via estimation of marginal means by gender and SOC combinations (Figure 6) and post hoc tests of differences. These examinations revealed that men had significantly greater exposures than women in a few occupational categories. Significant differences between men and women remained in the *architecture and engineering* classification and in the *Production* classification after adjustment of p-values according to Holm's method. Initial p-values suggested significant differences in the *community and social services*, *life physical and social sciences*, *health practitioner and technician*, *health support*, and *office administration support* categories, but these contrasts failed to retain significance after adjustment. In each case, the gender-based difference was in the direction of greater exposure values for men within the same SOC.

The main effect of SOC was examined by identifying homogeneous subsets of classifications (i.e. occupational classifications having no significant differences with each other after controlling for the other factors in the model). Two overlapping subsets of occupational classifications were identified. The low exposure group consisted of all occupational classifications except *architecture and engineering*. The high exposure group consisted of all occupational classifications except *personal care services*. Taken together, these results suggest that men and women in *architecture and engineering* occupations can be expected to have greater average daily exposure levels than women occupied in *Personal Care Services*, but no other significant differences were found after the influence of other factors in the model were controlled.

Discussion

To our knowledge, the present study contains the widest sample of noise exposure data obtained in the general population. The results from this study indicated that 70% of men and 65% of women have overall exposures exceeding the levels recommended by the EPA to protect public health and welfare with an adequate margin of safety (Figure 3). However, both the degree of exposure and the gender difference would have been frequently underestimated if only a single dosimeter run were examined, even though the average dosimeter run duration in this study was greater than two days. This implies that episodic high-level exposures can be expected to have some influence on an individual's overall exposure, at least over a time frame of a week or two. The results of this study suggest that even though people spend much time in relatively quiet environments, a person's overall exposure is dominated by a small number of high-level exposures. For example, the median overall daily noise exposure ($dBLeq_{A,8,equiv}$) was approximately 78 dB. However, fewer than 6% of the individual samples ($dBLeq_{A,3.75}$) were above this level. The observation that relatively few individual samples were found at higher levels is consistent with Banerjee (2011), who found a 5% exceedance level for sounds logged on a 5-second interval at approximately 70 dB SPL (unweighted).

The distributions of sound levels within the day and over days in the week suggested that the largest concentration of noise exposures in daily life occur during the typical workday. The principal exposure times for the participants in this study were between 9:00 a.m. and midnight, with the greatest exposures occurring during afternoon hours (noon to 6:00 p.m.). Subtle differences were found across the days of the week, with the greatest daily average levels occurring on Thursdays and the lowest levels on Sunday. It should be noted that the lower tails of the distributions of daily sound levels were lower on the weekends than during the typical work week, perhaps supporting an assumption of greater access to auditory rest over weekends. It is also noteworthy that the upper tails of the distributions were not substantially different on weekends. This might represent the continuation of exposure profiles over weekend days for participants who worked during weekends, and it also might suggest that relatively high-level exposures occurring on weekends are generally comparable to those observed during the typical work week.

Occupation and gender were related to the overall daily noise exposures ($dBLeq_{A,8,equiv}$), and this relationship was not simple. There were significant main effects for the participant's self-reported history of working in a noisy environment, current or most recent SOC, and gender. In addition, there was an interaction between SOC and gender (Figure 6). In general, these analyses revealed that occupation plays a role in an individual's noise exposure profile, even if the occupational classification would not be considered noisy in the conventional sense. The finding of increased daily average levels among those with a history of exposure to noise on the job could indicate that people who have previously held noisy jobs tend to continue having increased noise exposures even though the person might have left the position. The sources of these increased noise exposures cannot be identified from the data available, but the absence of a significant predictive role for self-reported non-occupational noise exposure would seem to rule out a greatly increased probability of noisy non-work activities in these participants.

Gender differences in daily sound levels were apparent in the distributions of dosimeter runs, and they were expanded when data across all dosimeter runs were collapsed into overall daily sound levels averaged across the duration of participation in the study. At the level of dosimeter runs (Figure 2), gender differences are restricted to the upper half of the exposure distribution, suggesting that $dBLeq_{A,8,equiv}$ values are similar across gender for the least exposed individuals, but differ for those at higher exposure levels. After integrating the dosimetry data for each participant, greater exposures for men become apparent at lower average levels. The expansion of gender differences with increased observation duration is a consequence of increased likelihood of occasional exposure to high level sounds among men. These occasional exposures tended to occur less frequently than the duration of the average dosimeter run (53 hours), but the sound levels during these periods were sufficiently high to exert an influence on the individual’s overall daily average. This finding suggests that estimates of average daily levels obtained over periods of two days or less will tend to underestimate the average that would have been obtained over a period of one to two weeks.

As expected, the daily noise levels observed in this study are lower than those typically observed in noisy occupations. The cumulative level distributions observed in the current study and data from prior work (Humann et al, 2011; Deiters et al, 2010; Royster & Royster, 2002, Chapter 7, p. 22) are presented in Figure 7. Median levels observed in the current study were approximately 6 dB (men) to 8 dB (women) lower than median levels reported in industrial noise databases, and approximately 9 to 11 dB lower than the medians observed in studies of adolescents living in rural areas and collegelevel musicians. The general shapes of the distributions of overall exposure levels in the occupational noise databases are similar to the shapes observed in the current study, with the exception that the occupational noise exposure databases tend to have greater spread at the extreme edges. The exception to this trend was obtained from a small sample of rural adolescents (Humann et al, 2011). The distribution of values from the rural adolescents is somewhat steeper than those observed in the current study, and the reasons for this difference are unclear.

The noise exposure estimates presented here only account for signals presented to the dosimeter, and therefore exclude the exposures associated with personal music players, telephones, etc. So the percent of participants exceeding EPA recommended levels would be higher for those who listen to sound sources directly coupled to the ear, particularly at high levels or for long durations.

The results reported here were obtained from an ongoing study of the magnitude and correlates of test-retest differences in puretone thresholds. Future analyses of the dataset from this study will be conducted, including an assessment of typical noise levels after controlling for occupational category and an evaluation of the effects of recent noise exposures on pure-tone thresholds. Such results could provide useful guidance for taking typical non-occupational noise exposures into account when interpreting occupational noise exposure measurements, and in determining the optimal quiet interval prior to baseline or follow-up testing of workers involved in occupational hearing loss prevention programs.

The noise exposures of these participants were most strongly associated with the participant's occupation, whether that association was direct, through subsequent effects of previous occupational exposures, or through the different levels of noise exposure sustained by men versus women who have the same occupational classification. A sample from a group of participants within a small subset of SOC major groups would help determine whether the interaction between gender is due to men and women trending toward noisier occupations within the same SOC major group, or if gender differences persist within the same detailed SOC category. It may well be that additional factors predicting average overall sound exposure could be found in other studies. For example, potential predictive factors such as detailed SOC, preferred listening levels to music and/or television program materials, activity logs (e.g. Neitzel, 2004), and additional demographic information might be used to further explain the between-subject differences in overall average noise level.

Conclusions

Although participants spent a large percentage of time in sound levels that could not be expected to have any effect on the auditory system, overall average noise levels greater than the limit suggested by the EPA (1974) were observed in the majority of participants in this study, regardless of gender. Approximately one half of the participants in this study had overall average levels high enough to produce some degree of NIPTS over a period of years. A small but substantial minority of participants had average levels that put them at excessive risk of acquiring enough noise-induced hearing impairment to put them at a disadvantage during listening activities in daily life.

Gender, occupation, and self-reported history of exposure to noise on the job were significantly related to overall average sound levels. Age, educational attainment, and self-reported history of exposure to non-occupational noise were not significant predictors.

Participants who reported the use of hearing protectors in a noisy job tended to have higher levels of sound exposure than others, after the effects of current occupation and gender were controlled. A complex relationship existed among overall average sound levels, gender, and current occupation. Men tended to have greater overall average sound levels, and this difference was greater for men working in some occupational categories.

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Abbreviations

AIT	Auditory injury threshold

BLS	Bureau of Labor Statistics
dBA	A-weighted dB SPL
$dBLeq_{A,8,equiv}$	A-weighted equivalent continuous level, normalized to an 8-hour duration
$dBLeq_{A,3.75}$	A-weighted equivalent continuous level, 3.75 minute interval
EPA	US Environmental Protection Agency
NIPTS	Noise-induced permanent threshold shift
NIOSH	US National Institute for Occupational Safety and Health
Pa^2s	Pascal-squared seconds
SOC	US Bureau of Labor Statistics Standard Occupational Classification
TTS	Temporary threshold shift

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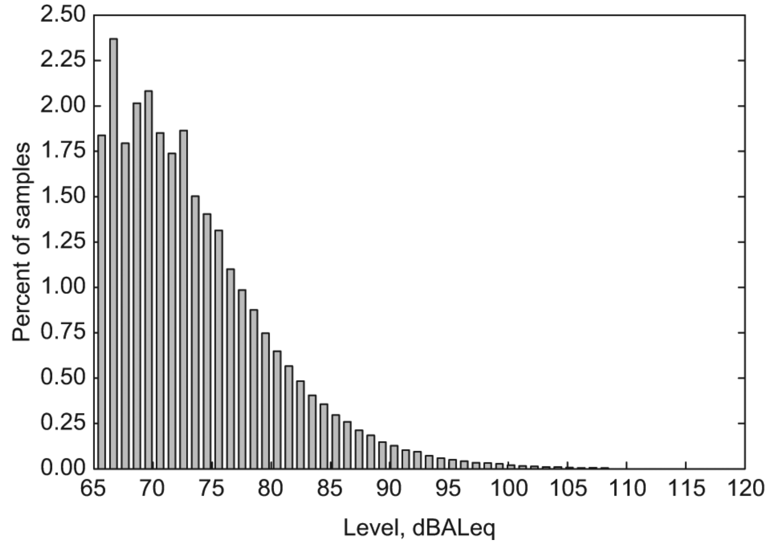

Figure 1.
Histogram of $dBLeq_{A,3.75}$ values above dosimeter threshold.

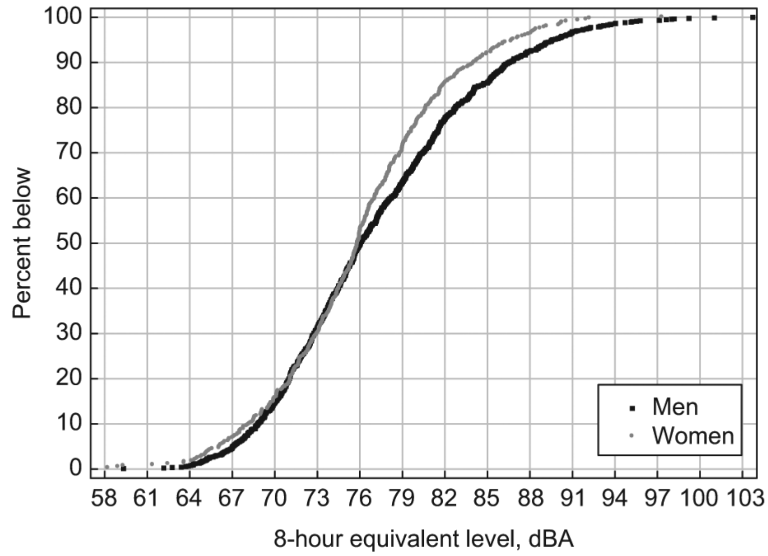

Figure 2.
Cumulative distribution of overall daily sound levels ($dBLeq_{A,8,equiv}$) estimated from dosimeter runs.

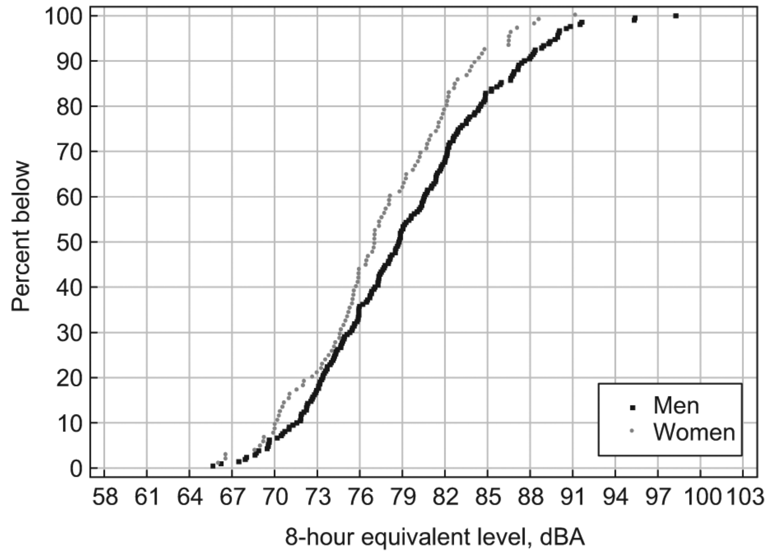

Figure 3.
Cumulative distribution of overall daily sound levels ($dBLeq_{A,8,equiv}$) from each participant.

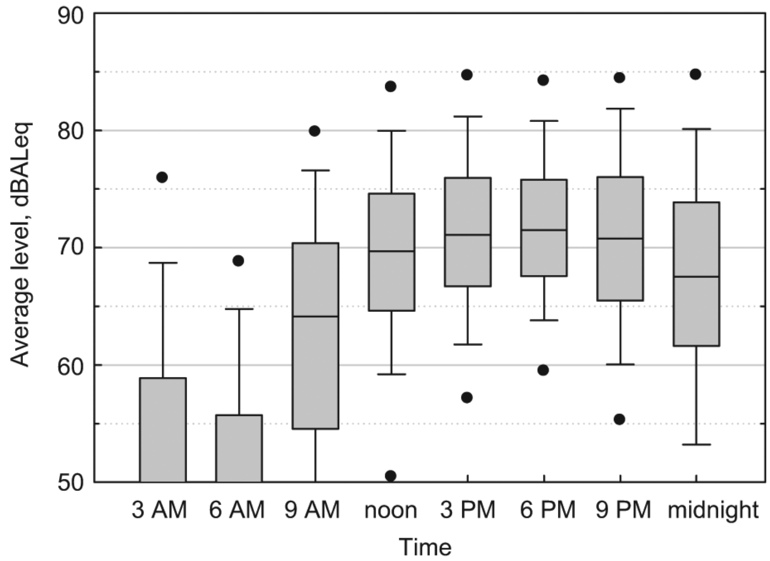

Figure 4.

Distributions of equivalent continuous levels by time of day. Shaded regions represent the interquartile range, with the median represented by the solid line within the shaded area. Error bars represent the 20th and 80th percentile points, and the filled circles represent the 5th and 95th percentiles.

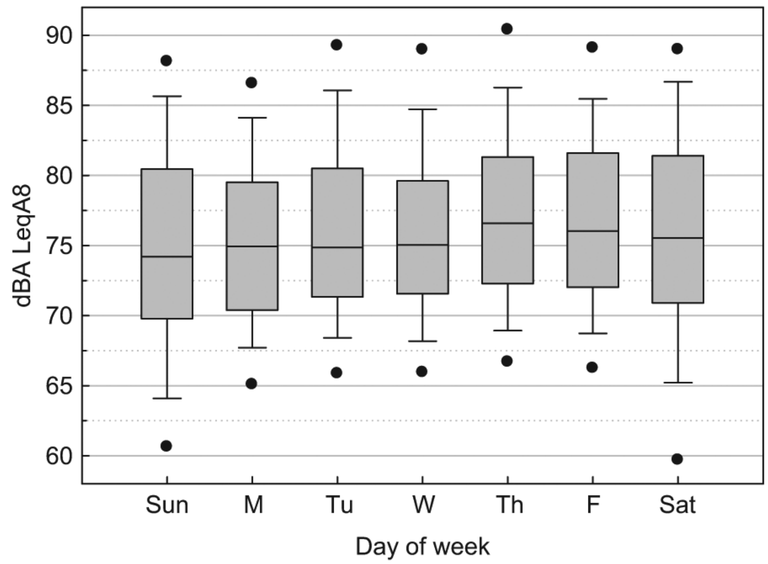

Figure 5.

Daily sound levels (dBLeqA,8,equiv) by day of week. Figure details are similar to figure 4.

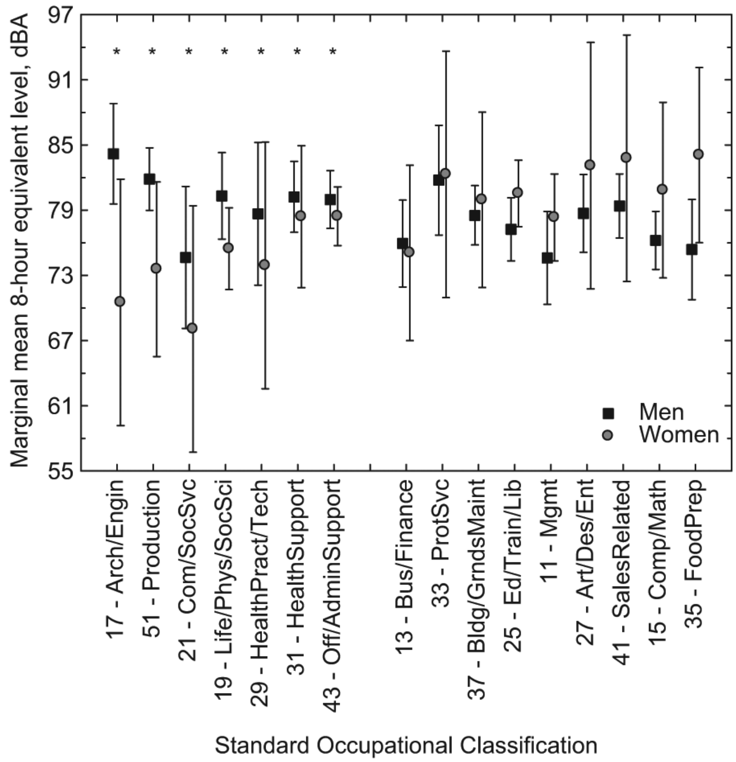

Figure 6.

Marginal mean sound levels (dBLeqA,8,equiv) by BLS Standard Occupational Classification and gender, controlling for main effects of gender and self-reported history of work in noise. Error bars represent 95% confidence intervals for means, symbols (*) indicate significant interaction effects (p =.05) by gender, after controlling for main effects.

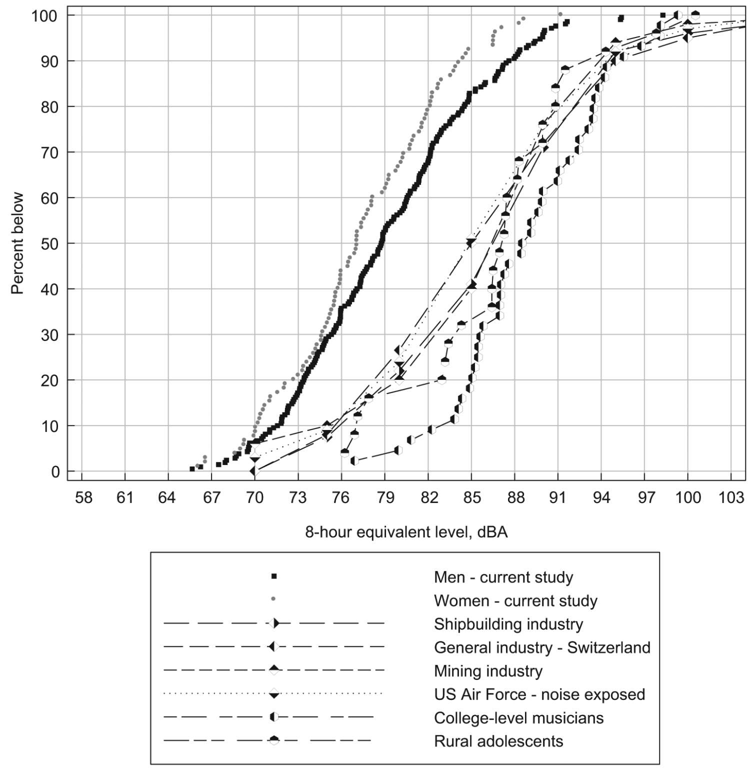

Figure 7.

Comparison of the distributions of overall average daily levels with occupational noise exposure databases and studies including specific populations. Data from musicians and rural adolescents come from Deiters et al (2010) and Humann et al (2011), respectively. Other reference databases were taken from Royster & Royster (2002).

Table 1

Numbers of participants, by gender and occupation.

		Men		Women	
BLS major group	**Description**	**N**	**%**	**N**	**%**
11	Management	7	3.3	9	11.8
13	Business and financial operations	9	4.3	2	2.6
15	Computer and mathematical	18	8.6	2	2.6
17	Architecture and engineering	7	3.3	1	1.3
19	Life, physical, and social science	8	3.8	10	13.2
21	Community and social services	3	1.4	1	1.3
25	Education, training, and library	16	7.6	16	21.1
27	Arts, design, entertainment, sports, and media	10	4.8	1	1.3
29	Healthcare practitioners and technical	3	1.4	1	1.3
31	Healthcare support	12	5.7	4	5.3
33	Protective service	6	2.9	1	1.3
35	Food preparation and serving related	7	3.3	2	2.6
37	Building and grounds cleaning and maintenance	20	9.5	2	2.6
39	Personal care and service	0	0.0	2	2.6
41	Sales and related	15	7.1	1	1.3
43	Office and administrative support	20	9.5	18	23.7
45	Farming, fishing, and forestry	1	0.5	0	0.0
47	Construction and extraction	12	5.7	0	0.0
49	Installation, maintenance, and repair	12	5.7	0	0.0
51	Production	19	9.0	2	2.6
53	Transportation and material moving	5	2.4	1	1.3
	Total	210		76	