Evaluation of the effects of exposure to organic solvents and hazardous noise among US Air Force Reserve personnel

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Abstract
Hearing loss affects many workers including those in the military and may be caused by noise, medications, and chemicals. Exposures to some chemicals may lead to an increase in the incidence of hearing loss when combined with hazardous noise. This retrospective study evaluated the risk for hearing loss among Air Force Reserve personnel exposed to occupational noise with and without exposures to toluene, styrene, xylene, benzene, and JP-8 (jet fuel). Risk factors associated with hearing loss were determined using logistic and linear regression. Stratified analysis was used to evaluate potential interaction between solvent and noise exposure. The majority of the subjects were male (94.6%) and 35 years or older on the date of their first study audiogram (66%). Followed for an average of 3.2 years, 9.2% of the study subjects had hearing loss in at least one ear. Increasing age (odds ratio [OR] = 1.03 per year of age) and each year of follow-up time (OR = 1.23) were significantly associated with hearing loss. Low and moderate solvent exposures were not associated with hearing loss. Linear regression demonstrated that hearing loss was significantly associated with age at first study audiogram, length of follow-up time, and exposure to noise. Hearing decreased by 0.04 decibels for every decibel increase in noise level or by almost half a decibel (0.4 dB) for every 10 decibel increase in noise level.

Keywords: Hazardous noise, hearing loss, military, noise, organic chemicals, solvents

Background
It is well-known that exposure to hazardous levels of noise causes hearing loss, also known as noise-induced hearing loss. Exposure to noise, a growing body of the literature suggests that exposure to chemical substances (primarily organic solvents) may be an additional cause of hearing loss with and without concurrent noise exposure. Current data on the combined effects of exposure to noise and toxic substances in the occupational or military setting are inconclusive, but suggest a possible interactive effect especially for exposures to styrene and noise. For example, one recent study found that styrene exposure had a greater adverse effect on hearing loss in subjects with noise exposure less than 85 dBA, whereas among those exposed at 85 dBA and above, the effect of styrene exposure was less pronounced.

Some noise-exposed workers in military settings were concurrently exposed to different types, concentrations and mixtures of organic chemicals including jet fuel (JP-4 and/or JP-8) and solvents such as benzene and toluene. These exposures as well as other workplace chemical exposures were below the established occupational exposure limits (OELs), thus providing an opportunity to evaluate the independent and joint effects of noise and solvents. This study was conducted to evaluate the risk for hearing loss among Air Force Reserve personnel who were routinely exposed to occupational hazardous noise with and without occupational exposures to the study chemicals of interest (toluene, styrene, xylene, benzene or JP-8 jet fuel).

Methods
Data were collected retrospectively from existing audiometric examinations, industrial hygiene documentation such as workplace hazard and exposure assessments and purchasing records for the study chemicals of interest for the period January 1, 2001, to December 31, 2007. The population consisted of civilian and military (full-time and part-time) personnel who met one of two inclusion criteria.
criteria: (1) Individuals with a reference audiogram plus at least one annual audiogram during the study period (2001-2007). For example, a subject with only two audiograms on file who received a reference audiogram in 2006 during the pre-placement occupational health examination and an annual audiogram 1 year later met the inclusion criteria; or (2) individuals who received at least two annual audiograms during the study period and whose reference audiogram was performed before the study start date of January 1, 2001, were also included. In addition, inclusion criteria required that medical records be available. Four general exposure profiles were sought: Noise with solvents, noise alone, solvents alone and neither noise nor solvents.

Workplaces (jobs) included aircraft maintenance, flightline operations, air operations (aircrew), plumbing, electrical, carpentry, painting, heating, ventilation and air conditioning, warehouse operations, vehicle maintenance, security and firefighting.

The study population was identified through the site occupational hearing conservation program (HCP). Study individuals were followed from the date of their first audiogram up until the date of their last audiogram during the study period. Part-time military personnel were expected to have incidental exposure to hazardous noise (greater than or equal to 85 dB) for more than 25 days/year. However, some part-time personnel who did not have incidental exposure to hazardous noise for more than 25 days also received annual audiograms. Some personnel received audiograms without regard to their noise exposure due to policies or other regulatory requirements. These individuals provided a population who had no routine noise exposure, but were receiving audiograms during the study period.

Data sources included an audiogram repository database, medical records (audiograms), industrial hygiene records (workplace exposure summaries) and purchasing records. Exposure data, both noise and solvent, were derived from workplace exposure summaries contained in the industrial hygiene records for each workplace.

Using audiometric data from medical records and the electronic audiogram repository database, audiogram results were ascertained for each study subject. Workplace identifiers were used to link subjects to the appropriate workplace and corresponding exposure data.

Noise exposure data
The industrial hygiene noise exposure monitoring data were used to identify workplaces with sound pressure levels that were ≥85 dB and to document the equivalent cumulative level (ECL) for noise previously determined by the site industrial hygienist. The ECL represents the average of the sound pressure levels as a function of time-varying sound levels during the observation period for a given workplace or activity. Based on the ECL, the workplaces were classified into four noise exposure groups (A-D): (A) <85 dBA; (B) 85-89 dBA; (C) 90-94 dBA; and (D) ≥95 dBA. For dichotomous analyses, workplaces were coded as unexposed if the ECL was less than 85 dBA (Group A) and exposed if the ECL was equal to or greater than 85 dBA (Groups B, C, D).

Organic solvent and JP-8 exposure data
Chemical sampling and survey documentation were reviewed for each workplace. Workplace narratives that mentioned exposures to study chemicals of interest (toluene, xylene, styrene, benzene and JP-8) were verified by at least one other source. The additional sources included industrial hygiene monitoring and sampling data or results, survey reports and chemical purchasing records. When sampling or monitoring was not conducted and no sampling data were available for activities that used very small amounts of chemicals (such as stenciling), the presence and quantity of any study chemicals in the workplace were verified using the purchasing records.

Workplaces were considered as solvent-exposed if the workplace narrative listed any of the study chemicals and sampling data were available or the purchasing records indicated the chemical was purchased for the workplace. None of the documented solvent concentrations exceeded the established exposure limits; therefore, three exposure categories were used: (1) No solvent exposure — solvents were not present or the documentation did not meet the criteria to confirm the presence of the solvents; (2) Low solvent exposure — solvent concentrations were below established exposure limits and were used rarely or in very small quantities, like stenciling or infrequent cleaning of small parts; and (3) Moderate solvent exposure—solvent concentrations were below established exposure limits and were used in moderate quantities or used in enclosed or confined spaces, such as a paint booth or fuel cell. For dichotomous analyses, subjects with low and moderate exposures were compared with those with no exposures.

Audiometric examination data
Audiogram results in one or both ears may indicate no change (zero difference), a positive change (hearing loss), a negative change (improved hearing) when compared with the reference audiogram. Each audiogram was evaluated for changes in hearing as well as for hearing loss that is a standard threshold shift (STS). STS was defined as a change in hearing sensitivity that was equal to or exceeded an average of 10 dB or more at 2000, 3000 and 4000 Hz in either ear, compared with the reference audiogram.

For each ear a continuous variable was created to represent the average change in hearing in decibels for the frequencies 2000, 3000 and 4000 Hz over the study period. These values were further classified into categorical variables to describe
the overall average change in hearing in each ear. The three categories were: STS (≥10 dB), some hearing loss (>0 to <10 dB) and No hearing loss (≤0 dB). The latter category included individuals with zero or no change in hearing as well as those whose hearing improved over the study period. The “Some” category was excluded in the bivariate analyses and only the “STS” and “No” categories were compared.

Results

The study population consisted of 503 workers from two Air Force Reserve sites who received 2,219 audiograms to detect changes in hearing during the study period. 41 subjects did not meet the study inclusion criteria.

Most of the subjects (66%) were 35 years or older on the date of their first audiogram during the study period; however, of those who were younger than 35 years old, almost all were less than 25 years old. A very large proportion (94.6%) was male. Based on historical industrial hygiene records and knowledge of the site industrial hygienists, approximately 47% were full-time employees, 39% were part-time and employment status was unknown for about 14%. Population demographics are summarized in Table 1.

Age was not normally distributed, therefore, the non-parametric Wilcoxon test was used to determine if there were differences in hearing loss between those who were aged less than 35 versus 35 years or older at the time of their first study audiogram. Hearing loss was significantly increased among those who were 35 years or older compared with those less than 35 years of age (Chi-square 6.22; P-value 0.01). This analysis was adjusted for length of time between the first and last audiograms during the study period.

The overall incidence of hearing loss that is at least one STS in either ear, was 9.2% (46/503) and 2.6% of study subjects developed STS in both ears. Approximately, 22% of study subjects had no hearing decrement in either ear. Hearing changes in decibels (dB) among the population are described in Table 2. Overall, the average change in hearing in decibels for the left and right ears was very similar for the entire cohort. The maximum decrease in hearing sensitivity was 38 dB in the left ear for one subject and 52 dB in the right ear for another subject.

The distribution of the study population by exposure group is described in Table 3. Over half of the subjects (56.7%) were exposed to either low or moderate levels of solvents. When subjects were categorized by combined noise and solvent exposure profiles, most of the subjects (73.1%) were in the noise-exposed groups (43.7% noise and solvents; 29.4% noise without solvents), which was expected.

The characteristics of the workplace exposure groups are shown in Table 4. The solvent only-exposed group was slightly older and also received fewer audiograms compared to the other exposure groups. The proportion with hearing loss in the left ear was slightly higher for the noise group without solvent exposure. For the right ear, the group with no noise and no solvent exposure had the highest percentage of individuals with hearing loss.

Exposure to noise and organic solvents

As shown in Table 5, the crude relative risk (RR) relating noise exposure to hearing loss in the left ear was minimally elevated (RR = 1.1; 95% CI = 0.9-1.4); and no difference was found in the right ear (RR = 1.0; 95% CI = 0.8-1.3). The crude relative risks relating hearing loss to solvent exposure were the same (RR = 0.8) for both right and left ears.
Stratified analyses were conducted to evaluate the association between noise exposure and hearing loss in the presence or absence of organic solvents. The crude relative risks relating hearing loss to noise exposure in the presence of solvents ranged from 1.0 to 1.2, for the right and left ears, respectively, whereas in the absence of solvents, the crude relative risks were similarly close to the null and non-significant. Inversion of the stratified risk estimates in the middle row of Table 5 to evaluate the relative risk for hearing loss in the absence of noise exposure ≥85dBA yields CRRs of 0.8-1.0. Because the left ear showed the stronger associations with hearing loss for noise and solvents, only the left ear results were considered in the regression analyses.

### Logistic regression

According to the logistic regression model [Table 6], increasing age at first audiogram during the study period was significantly, but weakly associated with the odds of hearing loss (OR = 1.03/year of age, 95% CI = 1.01-1.05). Study follow-up time was associated with a substantial increase in the odds of hearing loss (OR = 1.23, 95% CI = 1.12-1.35) for every year increase in follow-up time. Hearing loss was not associated with increasing noise levels (dB) and the odds ratios for low and moderate solvent exposures were less than 1.0. Also, no associations were found for hearing loss when using categorical variables for noise and solvent exposure groups. Finally, no interactions were evident to indicate that solvents were ototoxic in the presence or absence of noise exposure at or above 85 dBA.

### Linear regression

The relationship among the variables was also examined using linear regression; this analysis explained very little of the variance (4%) for hearing loss among the study population. Except for noise exposure, the results were similar to those seen in the logistic regression. The degree of hearing loss in the left ear was significantly \((P < 0.05)\) associated with age at first audiogram, follow-up time and noise level exposure. Low and moderate solvent exposures were not associated with hearing loss among the population.

Based on the results of the model, hearing worsened by 0.06 dB with every year increase in age at first study audiogram and by 0.25 dB for every year increase in follow-up time during the study period. In addition, hearing decreased by 0.04 dB for every decibel increase in noise level or by almost half a decibel (0.4 dB) for every 10 decibel increase in noise level. The results of the linear regression are shown in Table 7.

### Discussion

Noise as a risk factor for hearing loss has been widely studied; however, the risk of hearing loss from solvent exposure with and without noise exposure remains an important area of inquiry.

Over half of the study subjects were 35 years or older on the date of the first audiogram during the study follow-up period. The incidence of hearing loss was more frequent in subjects who were 35 years or older at the time of their first study audiogram compared with their younger counterparts. Although employment history data were unattainable for this study, the age at first audiogram during the study period may serve as a proxy for individuals who entered the workforce or military before robust HCPs were in use. Therefore, it is possible that an increased incidence of hearing loss seen among the older study subjects may be explained by less emphasis on hearing prevention during the earlier part of their careers.
Overall results of the study demonstrated that hearing loss was associated with age at first study audiogram, length of follow-up time and exposure to noise. No additional risk was found for hearing loss among those exposed to noise and solvents or solvents only.

Multivariable linear regression revealed that the strongest predictors were follow-up time and age at first study audiogram. Age is well-documented as a risk factor for hearing loss in many published studies[43-49] and increasing age as a risk factor for hearing loss, is correlated to cumulative years of noise exposure as well as the aging process.[18,36,50-52] Therefore, the association of advancing age and increasing follow-up time with hearing loss was expected.

Another important and well-documented predictor of hearing loss is exposure to noise.[53-55] Although some of the study subjects were routinely exposed to hazardous levels of noise (≥85 dB) with or without exposures to solvents, the incidence of hearing loss may have been reduced by the use of hearing protection such as ear plugs and/or ear muffs. The linear regression model showed that the degree of hearing loss was associated with increasing noise levels; however, the effect of noise exposure was relatively weak. Hearing sensitivity was reduced by 0.04 dB for every decibel increase in noise exposure level (equivalently, by almost a half a decibel (0.4 dB) for every 10 dB increase in noise exposure). The logistic model did not identify noise exposure as a significant predictor of dichotomous hearing loss.

Although many animal[56-60] and some human[9,10,28,34,35] studies have suggested associations between solvent exposure and hearing loss, including studies with current exposures below OELs,[29,37] no association was found in this study. Neither were any interactions seen indicating an ototoxic effect of solvents in the presence or absence of noise exposure at or above 85 dBA. This finding may relate to the low levels of exposure to organic solvents and/or jet fuel for this study population. However, hearing loss from solvent exposure below OELs may not be apparent in the presence of noise exposure.

In this study, all the solvent exposures were documented as below OELs or under detectable limits. As of the date of this study, none of the study solvent OELs list the ear as a potential target organ and are still based on other toxicological endpoints or target organs. This may be due to the limited data available on known or suspected ototoxins, especially for mixtures or at very low levels of exposure.

The study represents a large number of workers from a homogeneous population. The mean follow-up time of 3.2 years was long enough to detect changes in hearing.

### Table 5: CRR of hearing loss by noise and solvent exposure

| Entire study population | Left ear (n=234) | Right ear (n=225) |
|-------------------------|-----------------|-----------------|
| Noise exposure (≥85 dBA ECL) | CRR 95% CI | CRR 95% CI |
| Noise exposure (≥85 dBA ECL) | 1.1 (0.9-1.4) | 1.0 (0.8-1.3) |
| Solvent exposure | 0.8 (0.6-1.2) | 0.8 (0.5-1.2) |
| Solvent exposed group | Left ear (n=139) | Right ear (n=123) |
| Noise exposure (≥85 dBA ECL) | 1.2 (0.9-1.5) | 1.0 (0.8-1.4) |
| No solvent exposed group | Left ear (n=95) | Right ear (n=102) |
| Noise exposure (≥85 dBA ECL) | 1.1 (0.7-1.5) | 1.0 (0.7-1.4) |

Individuals with hearing changes >0 to <10 dB were excluded from this analysis. CRR=Crude relative risk, CI=Confidence interval, ECL=Equivalent cumulative level

### Table 6: Effect of age at first study audiogram and follow-up time on hearing loss among study subjects (logistic regression), (n=503)

| Variable | Beta | SE | Chi-square | P value | OR | 95% CI |
|----------|------|----|------------|---------|----|--------|
| Intercept | −1.0723 | 1.2313 | 0.7584 | 0.3838 | 1.09-1.58 |
| Age at first study audiogram (years) | 0.0306 | 0.0111 | 7.6635 | 0.0056 | 1.031 | 1.009-1.054 |
| Follow-up time (years) | 0.2081 | 0.0469 | 19.7030 | <0.0001 | 1.231 | 1.123-1.350 |
| Noise level (ECL continuous, dBA) | 0.0003 | 0.0129 | 0.0007 | 0.9793 | 1.000 | 0.975-1.025 |
| Solvent-low versus none | −0.1393 | 0.2113 | 0.4347 | 0.5097 | 0.870 | 0.575-1.316 |
| Solvent-moderate versus none | −0.3842 | 0.2815 | 1.8630 | 0.1723 | 0.681 | 0.392-1.182 |

dB=Decibels, SE=Standard error, CI=Confidence interval, OR=Odds ratio, ECL=Equivalent cumulative level

### Table 7: Relationship of independent variables to degree of hearing loss in dB (linear regression), (n=503)

| Source | Degrees of freedom | Sum of squares | Mean square | F value | P value |
|--------|--------------------|----------------|-------------|---------|---------|
| Full-model | 5 | 320.85 | 64.17 | 4.95 | 0.0002 |
| R-square | 0.047 | Adj. R-square | 0.038 |
| Variable | Parameter estimate | r value | P value |
| Intercept | −4.119 | −1.94 | 0.054 |
| Solvent-low versus none | −0.009 | −0.03 | 0.980 |
| Solvent-moderate versus none | −0.888 | −1.84 | 0.067 |
| Age at first audiogram (years) | 0.0593 | 3.20 | 0.002 |
| Follow-up time (years) | 0.247 | 3.11 | 0.002 |
| Noise level (ECL continuous, dBA) | 0.044 | 1.97 | 0.049 |

dB=Decibels, ECL=Equivalent cumulative level
However, current literature suggests that the latency period for developing hearing loss from solvent exposures varies from 2 to 3 years of exposure\[^{10,61}\] to 5 or more years.\[^7\] Thus, it is possible that latency was not adequate to detect solvent-induced hearing loss among these study subjects.

In addition to the study size, the stability of the population and the low personnel turnover rates were study strengths. Thus, the subjects were part of the workforce long enough to receive multiple annual audiograms, which increases the ability to detect changes in hearing among a worker population over time.\[^62\] In addition, the population was relatively young — with 94% of the subjects less than 60 years old. Although hearing loss is associated with increasing age, it is unlikely these study results were influenced substantially by age-related hearing loss that often accelerates at older ages, especially, for those older than 60.\[^{62}\]

Several considerations may have affected the internal validity of this study, including missing or incomplete medical record (audiogram) data, incomplete data on employment status, other sources of exposure and disease misclassification and confounders such as non-occupational exposures. Missing audiogram records could be a source of selection bias if they were associated with hearing loss. However, most missing records were unavailable because they were not maintained on site due to personnel locations, deployments or training and not due to hearing loss status. Therefore, the potential for selection bias due to missing or incomplete audiogram data is believed to be minimal.

Because of incomplete data on employment status, the analysis could not account for full-time and part-time employment. Therefore, the part-time personnel (39% of the study population) with less exposure time on average than full-time personnel (47% of the study population), may have diluted the apparent effects of exposures to hazardous noise and/or organic solvents on hearing loss in this study. This exposure misclassification would be non-differential by hearing loss status.

These results might have limited generalizability to non-Air Force workplaces given the types of industrial operations and industrial hygiene practices and degree of hearing protection use at these two sites. Lastly, due to medical military entrance requirements the study population may be younger and healthier than non-military worker populations.

**Exposure misclassification for noise and solvents**

Ambient workplace noise exposure data may overestimate the true exposures to noise among the subjects. Hearing protection devices are used to reduce noise exposures to acceptable levels below 85 dB for the 8-h time weighted average. Occupational standards and regulations mandate HCPs and require employees with exposures to hazardous noise to use hearing protection devices.

Because noise-exposed study personnel were most likely wearing hearing protection when exposed to hazardous occupational noise sources, the differences in true exposures between the study’s four noise groups may have been modest, therefore diminishing the ability to detect a difference in hearing loss between exposure groups. The use of hearing protection devices was not evaluated in this study due to time and resource constraints; therefore, it is not known whether individuals wore adequate hearing protection and if so, whether it was worn correctly.

As noted in the historical industrial hygiene workplace summaries, most of the solvent exposure data were below the OEL or were not quantified by the industrial hygienists or laboratories. Sampling was not typically conducted for solvents used infrequently or in very small amounts. Thus, available data may not have provided good estimates of duration, concentration or intensity of solvent exposure. Similar challenges have also been noted in other occupational health studies.\[^{10,64-65}\] Secondly, most of the solvent exposure levels were determined from historical occupational industrial hygiene records and purchasing records. Exposure levels (none, low and medium) were estimated based on the amount of study solvent annotated in workplace exposure summaries, ordered and/or used in each workplace and were not necessarily based on individual monitoring. It is possible that exposures to solvent levels may have been over- or underestimated when grouping the solvents into three groups (none, low, or moderate). In addition, most personnel who are exposed to moderate solvent levels such as during fuel cell entry are required to wear personal protective clothing such as gloves and overalls.

**Disease misclassification**

Other types of tests or examinations such as bone conduction, otoscopy or immittance audiometry may be useful to detect changes in hearing in addition to pure tone audiometry.\[^{21,66}\] The primary purpose of an audiogram is to detect hearing loss before it becomes permanent, identify hearing changes and trends among workers and provide an opportunity to educate and train workers about hearing protection and conservation. Other or additional clinical or audiologic tests may be more sensitive for assessing the possible toxic effects of solvents on the ears.

**Confounding**

The linear regression model showed age at first audiogram, years of follow-up and noise exposure to explain only 4% of the variance for hearing loss, indicating that other factors account for the outcome variability in this study population. Some of the effects of noise or solvents may be masked by confounders present in the population;\[^{67}\] as others have noted,\[^{10,21}\] it is difficult to account for these numerous confounding factors. Without detailed questionnaires or survey tools, the effects of non-occupational noise sources and known ototoxins are very
difficult to differentiate from occupational hearing loss.\[68\] Combinations and mixtures of various chemicals such as engine exhaust and carbon monoxide that were not accounted for may also affect hearing. Subjects may have been exposed to mixtures of solvents and depending on the composition of the mixtures the toxicological effects may have differed even within a similar exposure group. In addition as noted in various studies, it is difficult to tease out individual exposures when mixtures of solvents or chemicals are present in the workplace.\[17,69,70\] Significantly more resources would have been necessary to account for all of the chemicals present in each workplace.

Other risk factors that may play a role include individual susceptibility to noise and solvents, genetic risk factors,\[71\] tobacco\[64,72-75\] and alcohol use, infectious diseases and concurrent medications.\[76\] Medications that are known or suspected ototoxins such as certain antibiotics and chemotherapy drugs also affect hearing; however, with the widespread use of antibiotics the use of these drugs most likely occurs equally in both the non-exposed and exposed groups.\[63,70,77-81\] The effects of ototoxic medications along with the effects of occupational noise would potentially have the same clinical implications as solvent exposures and may appear the same on an audiogram.\[76,81,82\] Hearing loss may also result from non-occupational exposures to noise from firearm use, construction activities, yard work and wearing headphones while listening to music. Due to limited resources, information about non-occupational or incidental occupational exposures to noise and study solvents were not evaluated among study subjects.

**Conclusion**

Among the study population, hearing loss was associated with age at first study audiogram, length of follow-up time and exposure to noise. The study results provide insight into the incremental effects of noise exposure and show that workers who are exposed to increasing levels of noise gradually lose hearing sensitivity over time. Although this study did not find evidence that low or moderate exposures to solvents were associated with hearing loss in the absence or presence of noise, solvent exposure may still be a risk factor. The effects of solvent exposure may be less evident with noise exposures at or above 85 dBA. In addition, even though the overall sample size had sufficient study power, the no noise exposure groups, with and without solvent exposure, may have been too small to detect a statistically significant difference in hearing loss for low or moderate solvent exposures.

Uncontrolled confounders and possible misclassification due to employment status may introduce some degree of uncertainty. Another uncertainty originates from qualitative and not quantitative solvent exposure assessments for each workplace, which may reduce specificity in classifying solvent exposures and mask dose-response relationships. Adequately assessing the solvent exposures that are below the existing OELs is important for future studies as well as the establishment of OELs for known or suspected ototoxins and other solvents with the ear as a target organ for toxicity.

However, even with routine exposure to occupational hazardous noise, the incidence of hearing loss found in this study was below the incidence found in other studies with similar populations.\[33,67\] The relatively low incidence of hearing loss suggests the effectiveness of an occupational HCP in reducing noise-induced hearing loss among workers. These findings are encouraging and emphasize that employers should continue to implement HCPs to protect against noise-induced hearing loss among those who are routinely exposed to occupational hazardous noise.

Industrial workplaces are encouraged to continue to prevent noise-induced hearing loss by implementing multi-pronged HCPs that include monitoring for noise levels, implementing engineering and administrative controls, conducting routine audiometric examinations and trend analysis, requiring personal hearing protection devices, conducting on-going education and training, ensuring accurate recordkeeping as the basis for recurring program evaluation. In the absence of OELs for suspected or known ototoxins with the ear as a toxic endpoint, it is important to protect workers from exposures to organic solvents with and without noise exposure. Quantifying the effect of low level solvent exposures and additional non-occupational risk factors on hearing loss remains a challenge and warrants further investigation.

**Acknowledgments**

This research was conducted in partial fulfillment of the requirements for a doctoral degree. We thank Steven Godio, Christine Englmann, Lee (Grant) Lynch and Peggy Lebruny for providing their expertise and assistance in reviewing chemical and noise surveys and interpreting industrial hygiene records and workplace exposure summaries. We also thank the commanders and individuals from the sites for taking their time to provide data related to the study. **Disclaimer:** The conclusions and opinions expressed are those of the authors. They do not reflect the official position of the U.S. Government, Department of Defense, the United States Air Force or the United States Air Force Reserve.

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How to cite this article: Hughes H, Hunting KL. Evaluation of the effects of exposure to organic solvents and hazardous noise among US Air Force Reserve personnel. Noise Health 2013;15:379-87.

Source of Support: Nil, Conflict of Interest: None declared.
