Environmental and Occupational Noise Pollution in the US: How Bad is the Problem and What Can We Do About It?

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ABSTRACT

The relationship between chronic exposure to high levels of noise and noise-induced hearing loss (NIHL) has been known for hundreds of years. There is now a growing body of evidence linking noise to additional adverse health effects, including heart disease and stress. The US has no national plan to reduce environmental noise pollution, but standards designed to protect human health do exist for environmental and occupational noise.

In this paper we provide national estimates of exposure from common noise sources by updating previous estimates with current census and research data. For example, we estimate that 104 million individuals had annual 24-hour equivalent continuous average levels >70 dBA in 2013 and were at risk of NIHL and heart disease.

We describe approaches to the assessment of noise exposures in the US at the community level as well as at the level of the individual, and outline potential ways in which environmental and occupational noise can be integrated into our assessments of noise exposure.

Based on the number of noise-exposed individuals in the US and the potential impact of noise-related health effects, we conclude that greater integration of environmental and occupational health noise exposures will likely improve our ability to protect public health and quality of life.

INTRODUCTION

Noise, or unwanted sound, is a ubiquitous byproduct of the human activities of modern life in the United States. It is an undesirable and hazardous environmental pollutant in the same sense that chemical and radiological contaminants in air and water are considered pollutants, but has historically been treated differently than these other agents. Noise is one of the most common environmental exposures in the US and in other developed nations because exposure levels are spread across a large portion of the population. In 1981, EPA estimated that nearly 100 million people in the US (about 50% of the 1981 population) had annual exposures to traffic noise that were high enough (>55 A-weighted decibels, or dBA, or louder than a normal conversation in quiet surroundings) to be potentially harmful (EPA 1974). Chronic environmental noise causes a wide variety of adverse health effects, including sleep disruption, annoyance, stress, cardiovascular disease, and hearing loss (Hammer, Swinburn, and Neitzel 2013). While noise-induced hearing loss is the outcome typically associated with chronic exposure to noise, recent evidence suggests that the substantial burden of disease from noise-induced hearing loss may be exceeded

by the impact of the non-auditory health effects associated with noise, and particularly those associated with cardiovascular disease (Münzel et al. 2014).

This paper describes environmental and occupational exposure standards currently in pace in the US, estimates the prevalence of potentially harmful noise exposures in the US using existing data, and briefly explores public policy approaches that can better synchronize noise measurement with health protection standards.

Exposure limits

In 1974, the EPA recommended a 24-hour exposure limit of 55 A-weighted decibels (dBA) to prevent any long-term adverse effects on the public, including health and quality of life issues (EPA 1974). This recommended limit is 24-hour average noise level covering both day- and night-time periods, and is hence referred to as a day-night noise limit (L_{DN}). Levels measured between the hours of 10 PM and 7 AM ("night) are artificially increased by 10 dB to account for the potentially disruptive effects of noise during this period on sleep. Daytime levels are not artificially increased. While this standard was developed to specifically to protect and promote public health in America, the 55 dBA exposure limit is only a recommendation, and therefore is unenforceable.

In 1974 the EPA also issued a recommended 24-hour exposure limit of 70 dBA (EPA 1974). This second limit was intended to prevent any exposed individual from developing any measurable hearing loss, and as such may be considered a truly "safe" standard for the prevention of hearing loss. Unlike the 55 dBA LDN designed to prevent any long-term health effects, the 70 dBA limit does treats noise during day- and night-time periods as equivalent – i.e., no penalty is applied to night-time noise. The 70 dBA limit is a 24-hour equivalent continuous average exposure level, or $L_{AEQ(24)}$. This 24-hour exposure limit is considered equally harmful to an 8-hour workday exposure (which would be termed an $L_{AEQ(8)}$ when considered in this way) with effectively no noise exposure for the remainder of the 24-hour period.

When considered in terms of an 8-hour exposure, the EPA's limit intended to prevent hearing loss (expressed as an $L_{AEQ(8)}$) can be directly compared to the current 8-hour Permissible Exposure Limit (PEL) of 90 dBA enforced by the US Occupational Safety and Health Administration (OSHA) (OSHA 1971). The EPA 75 dBA $L_{AEQ(8)}$ recommendation is intended to protect against any hearing loss in any exposed individual, and includes a 5 dB margin of safety to insure that even the most susceptible or vulnerable individuals are protected (EPA 1974). Conversely, exposure at the enforceable OSHA 90 dBA 8-hour PEL – which is often assumed to be inherently "safe" (it is, after all, a federal regulation nominally designed to protect worker health!) – is expected to result in one in four workers developing a material hearing impairment after 40 years of exposure at work (NIOSH 1998). Given this evidence, the US occupational regulation for noise is a health standard that cannot be considered "safe" in any way. Certainly there are no other occupational or public health exposure limits which treat as acceptable a 20-30% excess risk of a health affect among exposed individuals; by contrast, exposure limits designed to protect against other health outcomes, including cancer, typically set the acceptable risk at 1 case per 100,000 or per 1 million exposed individuals. Best practice recommendations for occupational noise exposure in the US – for example, the National Institute for Occupational Safety and Health (NIOSH) 85 dBA 8-hour Recommended Exposure Limit (NIOSH 1998) – are still not as protective as the EPA

standard, but reduce the excess risk of noise-induced hearing loss to 1 in 10 or 12 workers.

Levels of noise exposure assessment: community vs. individual

There are two levels at which noise exposure sources may be assessed: at the individual level and at the community level. Assessment of the contributions of specific noise sources at these two levels often takes different forms. When assessing noise exposure at the community level, assessment is typically conducted through short-term measurements (typically on the order of minutes to hours) of specific sources (e.g., industrial sites, roads and freeways) from fixed indoor and outdoor receiver locations using a sound level meter. These measurements are then compared to standards or regulations specifying the permissible sound emission from that source (e.g., community noise guidelines, Federal Aviation Administration limits) over a time period of up to 24 hours. These permissible levels are typically L_{DN} levels that penalize nighttime noise exposures more than daytime exposures. Source data are relatively easy and inexpensive to obtain, and can be used to compare the fraction of exposures in a population which exceed a given threshold level due to each of these sources. While assessing noise from a source perspective has some utility, it is important to acknowledge that this approach has a substantial inherent limitation because the public health impact can be misleading when there is no holistic assessment of exposures across sources.

When considering individual (personal) noise exposure, the gold standard of exposure assessment is quantification of an individual's noise exposure through repeated, long-term personal noise measurements using integrating devices called noise dosimeters. This approach integrates exposures over a short period of time (typically 8-24 hours) and produces an estimate of L_{AEQ} received by the measured individual across all of the monitored activities. This noise dose is then compared to an acceptable health standard (e.g., a 24-hour recommended L_{AEQ} for public health purposes and an 8-hour recommended L_{AEQ} for occupational health purposes). Health standards developed for long-term protection of health are usually based on annual exposure levels assumed to occur over an extended exposure period (typically 40 years). To create these standards, measured daily exposures are often extrapolated to annual exposures, so health-based recommended exposure limits for community noise often refer to annual L_{DN} exposures – in other words, the average daily day-night noise level experienced by individuals over a one-year period. From a public health perspective, the more useful of the two levels of exposure assessment is the individual level. By evaluating dosimetry measurements made on individuals conducting a wide variety of occupational and non-occupational (e.g., recreational and transport) activities in different settings and environments, we can assess the percentage of a population which is at potential risk of adverse health effects resulting from chronic exposures at different noise levels. It is also possible, with sufficient detail on the monitored activities, to begin to attribute these risks to specific activities or environments with either high noise levels or extended exposure durations. However, while individual-level data represent the gold standard data source for public health risk assessment, as with all quantitative measurements of personal environmental characteristics, they are difficult and expensive to obtain.

Given these dual levels of assessment, two lists of potentially important noise sources can be created. While the lists share several important sources of noise, including surface transportation (e.g., road and rail traffic), air transportation, occupational/industrial activities (including construction), and noisy recreational

activities (including concerts, sporting events, races), important additional sources at the individual level include amplified music, consumer products (including household electronics, toys, and appliances) and firearms (Suter 1992). Amplified music appears to be an especially important individual source of exposure for both adults and adolescents. Important additional noise sources at the community level include power generation (e.g., power plants, wind turbines), landscaping and yard maintenance equipment, and emergency warning signals. Note that some of these sources – especially amplified music and concerts – may not qualify as "noise" in the sense of being unwanted sound, but adverse health effects from sound may occur even if the sound is perceived as desirable.

METHODS AND RESULTS

Community-level prevalence of harmful noise exposure

While noise is commonly acknowledged to be a ubiquitous environmental stressor, current quantitative local-, regional-, and national-level estimates of the prevalence noise exposures in the US are not available. The last national-scale estimates of noise exposure in the US were prepared in 1981 (EPA 1981). Those dated and likely obsolete estimates are unfortunately the only data from which the current prevalence of exposure can be estimated, as we have done below.

As Figure I illustrates, we estimate that 43.8 million people (13.9% of the total 2013 US population) are currently exposed to annual noise levels at or above 65 dBA L_{DN} from a variety of different community noise sources, and are therefore at risk of health effects, including heart disease, hypertension, and sleep disruption. We developed this estimate by taking EPA estimates from 1981 for specific sources (EPA 1981), and updating them to reflect the current US population (315 million in 2013, as compared to 200 million in 1981) (Hammer, Swinburn, and Neitzel 2013).

Note that this approach assumes no changes in exposures other than the reduction in air-transportation noise. Annual air transport noise exposures >65 dBA L_{DN} have seen a roughly 90% reduction since 1981 (from about 8 million, or 4% of the 1981 population, to 0.5 million in 2007, or 0.001% of the 2013 population) despite a six-fold increase in number of people-miles travelled by air in the US. This dramatic decrease in noise can be attributed in large part to government requirements, and technological improvements driven by these requirements, for quieter jet engines (Waitz IA, Bernhard RJ 2007).

Overexposures associated with the other noise sources in Figure I have not enjoyed the same reduction over time. The largest single source of community noise, road traffic, exposed 19.3 million people (9.7% of the population) to annual levels >65 dBA L_{DN} in 1981 (EPA 1981). This fraction has likely increased due to growth in population and traffic, but at a minimum, assuming no change in noise levels, 30.4 million people had exposures that likely exceeded this level in 2013. The number of people exposed to high levels of railroad and urban-rail noise is also likely higher today than it was in 1981, when 2.5 million people were estimated have annual exposures >65 dBA L_{DN}. This increase is due to growth in both population and rail traffic volume. Finally, in 1981, an estimated 2.1 million people (0.1% of the population) were exposed annually to construction noise >65 dBA L_{DN}, and 470,000 (0.002% of the population) were exposed to industrial noise above this level. An analysis of occupational noise exposures between 1998 and 2008 indicated no downward trend in exposures over that period. If we assume that there has been no long-term downward trend in construction and industrial noise since 1981, an

estimated 3.3 million people are exposed>65 dBA L_{DN} annually from construction noise, and an estimated 740,000 are exposed annually above that level from industrial noise in 2013. Overall, the estimates in Figure I suggest that a substantial portion of the US population may be at risk of adverse noise-related health effects.

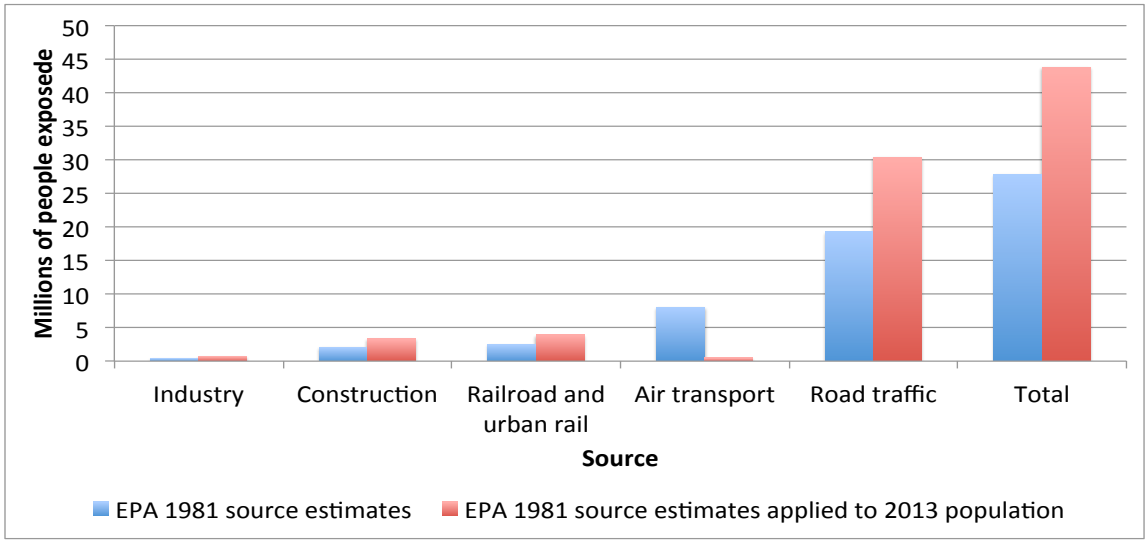

Figure 1: Estimated exposures >65 dBA LDN in US by source and overall

Individual-level prevalence of harmful noise exposure

Figure I tells us little about cumulative individual-level exposures across sources. An example of the importance of comparing community- and individual-level exposures is use of firearms. Some authors suggest that using firearms – a common pastime in the US – is the single biggest risk factor for noise-induced hearing loss, making this source of noise vitally important at the individual level, though there is no widely accepted method for integrating firearms noise exposure into an annual average exposure estimate. Conversely, at the community level, the number of people potentially exposed to excessive levels of firearms noise is small – likely limited only to military, law enforcement, and firing range personnel and private gun enthusiasts.

Recent studies of individual noise exposures in the US adult population suggest a high potential for exposures capable of harming hearing. Several studies (Flamme et al. 2012; Neitzel et al. 2012) have indicated that a sizeable fraction of US adults are exposed daily in excess of the EPA 70 dBA $L_{AEQ\ (24)}$ recommended limit. Neitzel et al (2012) sampled over 4500 men and women who lived or worked in New York City (NYC) and estimated annual noise exposures associated with occupational activities, use of mass transit, non-occupational activities (e.g., riding motorcycles, attending commercial sporting events and concerts, playing in a band, etc), listening to music, and time spent at home and doing other miscellaneous activities. Nine out of ten individuals in the sample were estimated to exceed the EPA/WHO recommended exposure limit of 70 dBA.

By combining US census data with the NYC estimates created by Neitzel et al (2012), we can estimate the prevalence of annual exposures >70 dBA $L_{AEQ(24)}$ (Hammer, Swinburn, and Neitzel 2013). There are 16 metropolitan statistical areas in the US with >4 million population. These areas comprised a total population of 80,621,123 in 2012 (http://www.census.gov/popest/data/metro/totals/2012/tables/CBSA-EST2012-01.xls,

accessed 16 April 2013), or 25.6% of the US population. Assuming that the personal exposure estimates for New York City residents and workers are applicable to these 14 largest urban agglomerations in the US, an estimated 72.6 million US residents are exposed to annual $L_{AEQ(24)}$ levels that exceed 70 dBA (Figure 2). By comparison, the EPA estimated that over 66 million people (33% of the total population) in the US were exposed above a 70 dBA annual $L_{AEQ(24)}$ in 1981 due to non-occupational activities (e.g., riding motorcycles, snowmobiles, and other equipment; using power tools; using consumer products, using common transportation, etc) alone (EPA 1981); that translates to 104 million overexposed individuals in 2013, again assuming no change in annual noise levels between 1981 and 2013. Based on the study by Neitzel et al (2012), over one in 5 Americans may be exposed in excess of a yearly 70 dBA $L_{AEQ(24)}$ from music alone, and about 6% of Americans have exposures exceeding this level due to occupational and non-occupational activities. Overall, the data presented in Figure II suggest that a substantial fraction of the individuals in the US may be at risk of hearing loss due to exposures associated with specific activities, as well as from their cumulative exposure across all activities. Occupational noise, historically the major source of exposure to a majority of the US population, now appears to contribute less to the burden of noise exposure in the US population than do nonoccupational and music exposures. However, it is important to note that, while a larger fraction of the population may be exposed to nonoccupational noise and music, the exposure levels associated with occupational noise tend to be much higher, and that the burden of hearing loss associated with occupational exposures is likely much greater on an individual level than that associated with nonoccupational exposures and music (Lewis, Gershon, and Neitzel 2013).

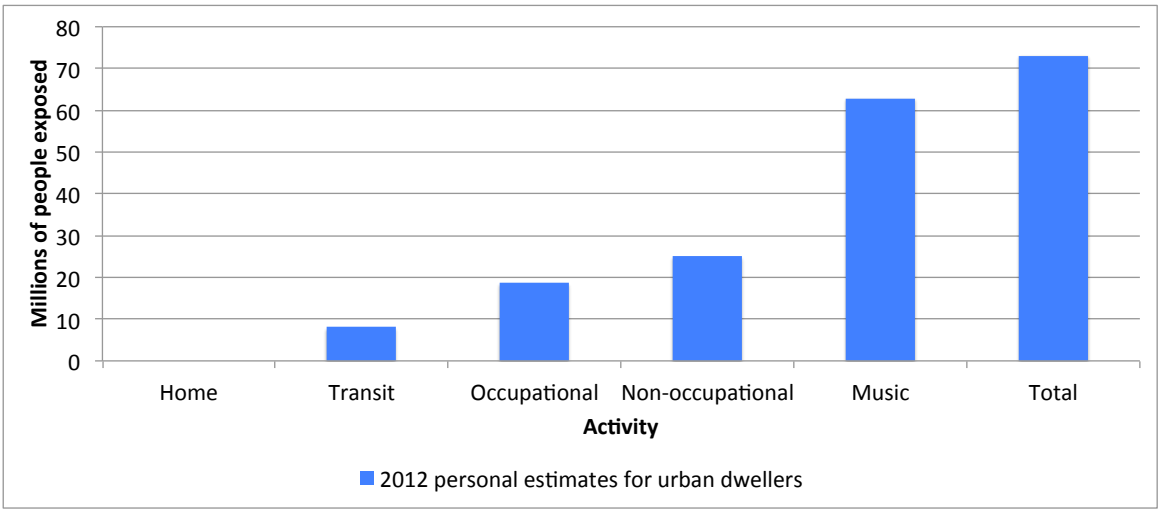

Figure 2: Estimated personal exposures >70 dBA $L_{AEQ(24)}$ by activity and overall

APPROACHES TO INTEGRATE NOISE EXPOSURE MEASUREMENT WITH HEALTH PROTECTION STANDARDS

Given the substantial estimated exposures to noise in the US population and the severity of negative health consequences associated with these exposures, there is a clear need for policy aimed at better characterizing and ultimately reducing noise exposures. We believe that US health protection standards should be synchronized and should ultimately guide how noise exposures are measured.

Currently, the *de facto* national approach to environmental noise exposure assessment in the US depends on source-level exposure estimates drawn from

EPA's 1981 document (EPA 1981). With the exception of a few cities – notably New York City and San Francisco – there are no regional or local governmental efforts underway to update these dated estimates. Other than a few recent large-scale research studies on environmental noise exposure (e.g., (Flamme et al. 2012; Neitzel et al. 2012), there appear to be no ongoing US efforts to estimate environmental noise exposures at the individual level. As a result, it is possible to make inferences about the prevalence of exposures to different environmental noise sources, as we have done here, but individual-level inferences are difficult.

With regards to occupational noise exposure in the US, the situation is reversed; there are few industry-level efforts to assess noise exposure, and virtually all exposure assessment activity occurs at the individual level within workplaces. It is therefore possible to make inferences about the numbers of individuals who may be exposed to excessive levels of noise, but it is very difficult to estimate overexposures at the industry level. The disparity between environmental and occupational noise exposure assessment is further increased by the marked differences between the exposure limits applied to the two settings, as described above.

We propose that better integration of environmental and occupational noise exposures is needed in order to protect public health against auditory and non-auditory health effects associated with noise. Synchronization of the recommended and enforceable exposure limits for noise would reduce the complexity of assessing noise exposures according to multiple limits. This would preferably involve lowering (i.e., making more protective) the occupational exposure limit for noise, but could also involve relaxing the environmental limit – perhaps by eliminating the 5 dB margin of safety and acknowledging that it may not be feasible to protect the most susceptible individuals from any measurable hearing loss from noise. Such a step would help move the US towards a more comprehensive system for noise exposure assessment.

A second effort to improve public health would focus on holistic noise exposure assessment – e.g., the consideration of both occupational and nonoccupational exposures at the individual level. While challenging, this effort represents a way to unify the currently divergent and non-integrated approaches to exposure assessment for the community (e.g., source-level assessment) and the workplace (e.g., individual-level assessment). A large-scale and ongoing research and/or surveillance effort would be needed to develop nationally-representative estimates of individual-level exposure, but such an effort would allow for the evaluation of the relative contribution of occupational vs. non-occupational noise sources to the burden of noise-related disease in the US. The US National Children's Study may represent one avenue through which this approach could be employed on a trial basis.

Finally, it is unlikely that meaningful progress will be made at reducing noise exposures in the US without the establishment of additional, enforceable regulations designed to reduce noise at the source. Such regulations already exist for a handful of noise sources that were regulated by the EPA Office of Noise Abatement and Control prior to the defunding of that agency in 1981. The EPA maintains the regulatory authority to establish new source control regulations, and with renewed funding could begin to research and develop additional regulations on some of the sources described above. Such regulations could have a dramatic impact on both environmental and occupational noise exposures, and represent the most direct path towards noise reduction in the US.

CONCLUSIONS

Updated national-level estimates of individual noise exposures are needed to better characterize the prevalence of exposures and the relationship between noise and a host of health effects. Even considering the limitations in our current knowledge, however, we believe that the existing body of research is sufficiently well-developed to demonstrate the need for immediate noise-reduction policies and interventions. Synchronizing the environmental and occupational exposure limits in the US, adopting a holistic exposure assessment approach, conducting more detailed noise exposure assessments, and establishing and enforcing noise control regulations are all actions that could be part of a comprehensive plan towards reducing noise exposure and improving public health in the US.

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