Ambient Noise Is "The New Secondhand Smoke"

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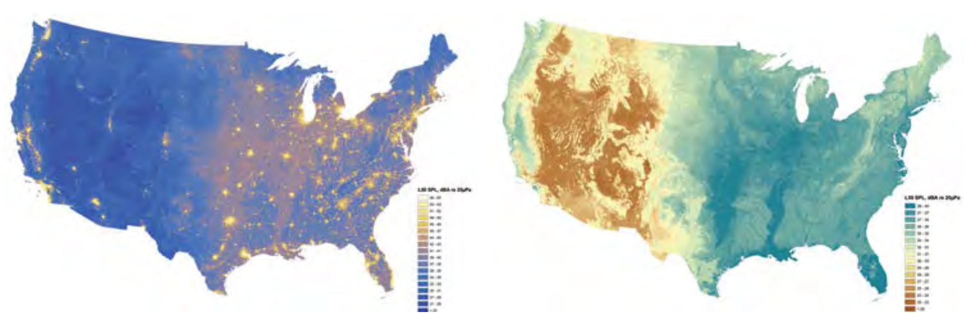
Excessive ambient noise causes hearing loss; disrupts sleep, function, and communication; and causes nonauditory health effects for millions of people.

Ambient noise is the new secondhand smoke (Fetterman, 2018). Like unwanted tobacco smoke, noise doesn't just bother people but also adversely affects human health and function. Secondhand smoke causes cancer, sudden infant death syndrome, respiratory disease in children, and coronary heart disease (Centers for Disease Control and Prevention [CDC], 2018). Similarly, unwanted single exposures to loud noise can cause hearing loss, tinnitus, and hyperacusis, whereas chronic noise exposure undoubtedly causes hearing loss and tinnitus. Noise disturbs concentration and interferes with learning. Chronic noise exposure has little known but well-documented nonauditory health effects including cardiovascular disease (Münzel et al., 2018) and increased mortality (Basner et al., 2014; Hammer et al., 2014). The sounds that matter to people are the ones reaching the tympanic membranes of the listener or perhaps the cochlear hair cells and associated peripheral nerves and central auditory processing centers.

Noise exposure is a public health problem, with noise levels in everyday life high enough to cause hearing loss (Flamme et al., 2012; Neitzel et al., 2012; Mayes, 2019). Perhaps because of this, the CDC recently reported that approximately 25% of adults aged 20-69 years had noise-induced hearing loss. Of these, 53% showed hearing loss without significant occupational noise exposure (Carroll et al., 2017). Importantly, although the nonauditory health effects of noise are small for each exposed individual, the population health impacts are large because millions of people are exposed to excessive transportation noise.

Figure 1. *National Park Service noise maps showing existing conditions (**left**) and natural conditions (**right**). Without human activity, nature is generally quiet. **Left: dark blue**, <20 dB(A); **brown**, 41-47 dB(A); **tan**, 50-54 dB(A). **Right: brown**, <20 dB(A); **yellow**, 30-31 dB(A); **dark green**, 38-40 dB(A). Noise levels are average (50%) measurements on a typical summer day, meaning that half of the time noise levels will be higher and half of the time they will be lower than those mapped. From National Park Service, 2017.*



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Nature Is Generally Quiet, with Noise Indicating Danger

The National Park Service (2017) noise maps (**Figure 1**) show that without human activity, environmental sound pressure levels are remarkably low, in the 20-30 dB(A) range. In nature, loud sounds are rare and may include thunderstorms, earthquakes, volcanic eruptions, waterfalls, and certain animal sounds. In all animals, hearing is used to obtain information about the environment, to detect danger, for communication, and for entertainment.

In nature, loud noise often indicates danger and causes "fight or flight" responses. These involuntary physiological responses involve two primitive systems, the autonomic nervous system and the neurohormonal or hypothalamic-pituitary axis. Noise causes almost instantaneous increases in blood pressure and pulse via the sympathetic nervous system (Babisch, 2014). It takes a little longer, but noise causes release of adrenocorticotropic hormone that, in turn, causes the release of steroid hormones from the adrenal gland and increases in serum epinephrine and norepinephrine levels. More recently, it has been shown that stress causes inflammation of the vascular lining (Tawakol et al., 2017) and that noise exposure specifically causes this inflammatory change (Radfar et al., 2018). These physiological effects and their clinical outcomes, best studied for transportation noise, are summarized in **Figure 2**.

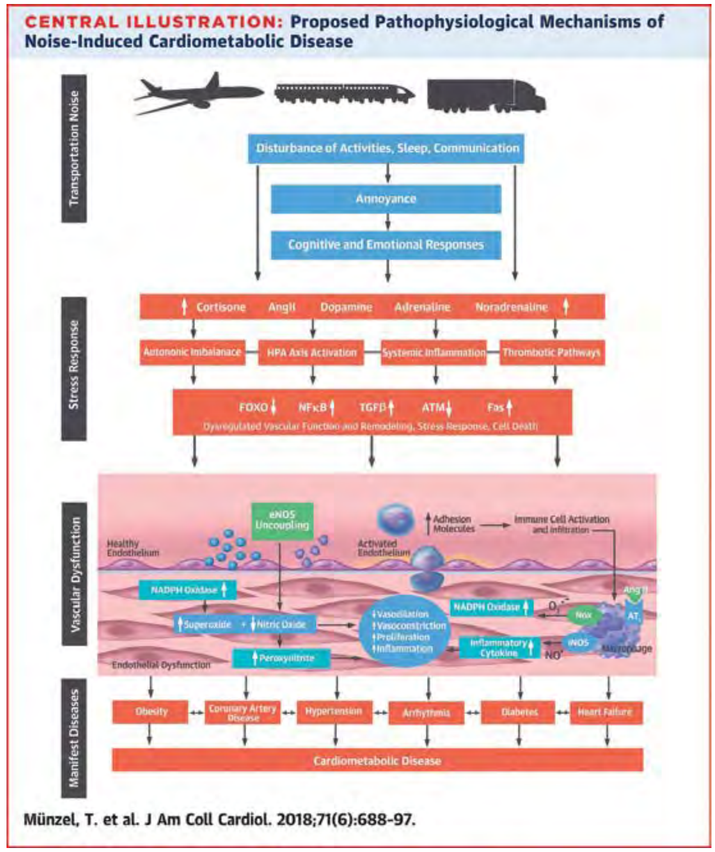

Figure 2. *Proposed pathophysiological mechanisms of noise-induced cardiometabolic disease. Noise is stressful, causing chemical changes leading to vascular dysfunction, which, in turn, leads to disease. AngII, angiotensin II, a chemical causing vasoconstriction; HPA, hypothalamic-pituitary axis. The other factors affect the stress response and cause vascular dysfunction. For more details and abbreviations, see Münzel et al., 2018. From Münzel et al., 2018, with permission.*

Specific Noise Levels Affecting Human Health and Function

It has long been known that specific noise levels affect human health and function (Passchier-Vermeer and Vermeer, 2000). These levels are based on expert systematic reviews of extensive published research. Despite their age, these specific noise levels remain valid. In some cases, such as studies of noise exposure causing hearing loss, older studies cannot be replicated because it is now unethical to endanger research subjects when the risk of harm is certain.

The National Institute for Occupational Safety and Health (NIOSH; 1998) recommended an 85 A-weighted decibel [dB(A)] equivalent continuous sound pressure level for 8 hours [$L_{Aeq(8)}$; see **Table 1** for a list of abbreviations] as the level to reduce the risk of hearing loss from occupational noise exposure in 1972 (NIOSH, 1998). The monograph by the Environmental Protection Agency (EPA; 1974), still authoritative and never rescinded, listed a 45 dB day-night-weighted sound pressure level (L_{dn}) as interfering with indoor activities, a 55 dB L_{dn} as interfering with outdoor activities, a 70 dB(A) maximum time-weighted and A-weighted sound pressure level (L_{Amax}) as an ambient-noise level interfering with speech comprehension in people with normal hearing, and a daily average of 70 dB A-weighted equivalent continuous sound pressure level for 24 hours [$L_{Aeq(24)}$] as the noise exposure level to prevent hearing loss. Moulder (1993) added 58 dB(A) L_{Amax} as the ambient-noise level interfering with speech comprehension in people with hearing loss dining in restaurants. [For ease of use, this has been rounded up to 60 dB(A) L_{Amax} in **Table 1**.] This is still much quieter than almost all restaurants in which noise levels were measured in Manhattan (Scott, 2018). In 1999, the World Health Organization (WHO) added 30 dB(A) $L_{Aeq(8)}$ as the noise level required for uninterrupted sleep, noted that 45 dB L_{Amax} will disrupt sleep, and recommended only 1 hour of exposure

Table 1. Specific noise levels affecting human health and function

Sound Level	Effect	Source
30 dB(A) [$L_{Aeq(8)}$]	Sleep disruption	WHO (Berglund, et al., 1999)
45 dB (L_{dn})	Disturbance of concentration and interference with learning	EPA, 1974; WHO (Berglund et al., 1999)
45 dB (L_{Amax})	Sleep disruption	WHO (Berglund et al., 1999)
55 dB daily average (L_{den})	Nonauditory health effects	WHO, 2018
60 dB(A) (L_{Amax})	Interference with speech comprehension for hearing impaired	Moulder (1993) for US Architectural and Transportation Barriers Compliance Board
70 dB daily average [$L_{Aeq(24)}$]	Hearing loss	EPA, 1974
70 dB(A) (L_{Amax})	Interference with speech comprehension for those with normal hearing	EPA, 1974
85 dB(A) [$L_{Aeq(8)}$]	Occupational noise exposure (recommended limit)	NIOSH, 1998
85 dB(A) [$L_{Aeq(1)}$]	Recommended exposure to prevent hearing loss	WHO (Berglund et al., 1999)

WHO, World Health Organization; EPA, Environmental Protection Agency; NIOSH, National Institute for Occupational Safety and Health; $L_{Aeq(8)}$, *A-weighted equivalent continuous sound pressure level for 8 hours;* L_{dn}, *day-night weighted sound pressure level;* L_{den}, *day-night-evening-weighted sound pressure level;* L_{Amax}, *maximum time-weighted and A-weighted sound pressure level;* $L_{Aeq(24)}$, *A-weighted equivalent continuous sound pressure level for 24 hours;* $L_{Aeq(1)}$, *A-weighted equivalent continuous sound pressure level for 1 hour. Definitions from WHO, 2018.*

to 85 dB(A) [$L_{Aeq(1)}$] to prevent hearing loss (Berglund et al., 1999). The WHO report also discussed 55 dB(A) as the level at which adverse health effects of noise occur, and this noise level [55 dB day-night-evening-weighted sound pressure level (L_{den})] has been emphasized in later reports (WHO, 2018).

Specific Noise Levels

The nine specific noise levels affecting human health and function (**Table 1**) are discussed in order of increasing sound pressure levels, with emphasis on the disability rights aspects of ambient noise and safe noise exposure levels for the public. It is important to emphasize that in the United States, there are no federal guidelines, standards, or regulations for nonoccupational or public noise exposure (Carroll et al., 2017).

Sound energy causes auditory damage and activates the stress responses to noise. The equal-energy hypothesis states that equal amounts of sound energy will produce equal amounts of hearing impairment and other effects, regardless of how the sound energy is distributed in time (Kryter, 1994; Berglund et al., 1999). The hypothesis may, however, underestimate the damage done by intermittent or impulse noise. In the United States, most noise levels affecting humans are measured in A-weighted decibels because difficulty understanding speech is the material impairment from occupational noise exposure (NIOSH, 1998). Although A-weighted decibel measurements may be relevant for speech comprehension, the total sound pressure level is likely more important for human health.

Low-frequency noise [C-weighted decibels; dB(C)] may also impact humans, specifically causing damage to hair cells in the vestibular system responsible for balance (Stewart et al., 2016). An association between hearing loss and falls has been reported, with worse hearing being correlated with increased fall risk (Lin and Ferrucci, 2012). There are no published standards for occupational or nonoccupational low-frequency noise exposure.

Thirty A-Weighted Decibel Noise Causes Sleep Disruption

Sound pressure levels as low as 30 dB(A) $L_{Aeq(8)}$ and 45 dB L_{Amax} can cause sleep disruption (Berglund et al., 1999). There are individual variations in sensitivity to sound during sleep and variations in sensitivity to sound during different phases of the sleep cycle. Even if the noise does not wake the sleeper, the sound causes electroencephalogram changes and also results in increases in heart rate (Buxton et al., 2012). Sleep is important for human health and function (Colten and Altevogt, 2006). Inadequate, interrupted, or poor-quality sleep is associated with a multiplicity of ailments, including anxiety, obesity, depression, hypertension, diabetes, dementia, and increased mortality (Cappuccio et al., 2010).

The implications for noise control are obvious. Nighttime noise sources, including heating and ventilation equipment; transportation noise; and noise from restaurants, bars, and clubs adjacent to residential neighborhoods, must be reduced to allow high-quality uninterrupted sleep. Horn-based alerts, which can be as loud as 90 dB, should be changed to electronic chirps that can be decreased in volume or turned off altogether. Better sound insulation of walls, roofs, and windows will help, but people may prefer to leave the windows open at night. Eliminating or reducing sound at the source is always better than trying to deflect, insulate, or isolate it later.

Forty-Five A-Weighted Decibels Interfere with Human Activity Including Learning

Quiet is necessary for human thought and concentration, which are disrupted at ambient sound levels of 45 dB L_{dn}. This is best researched in terms of noise interfering with learning (Bronzaft and McCarthy, 1975; Brill et al., 2018) and cognition (Clark and Paunovic, 2018a). High ambient-noise levels also decrease worker productivity and product quality (Berglund et al., 1999; Dean, 2019).

Daytime noise must also be reduced. Daytime noise particularly impacts those at home during the day, which includes vulnerable populations such as the elderly, children, those too sick to go to work or school, and an increasing percentage of the workforce working at home at least part of the time. One particularly intrusive urban and suburban noise source is the gas-powered leaf blower (Walker and Banks, 2017). Recent success in banning these in Washington, DC, provides a blueprint for action in other communities (Fallows, 2019) Again, eliminating noise at the source is preferable to increased sound insulation.

Forty-Five Decibel Noise Disrupts Sleep

Single episodes of noise at 45 dB L_{Amax} are loud enough to disrupt sleep (Berglund et al., 1999).

Fifty-Five Decibel Average Daily Noise Exposure Causes Nonauditory Health Effects

At an approximately 55 dB time-weighted average for 24 hours (L_{den}), noise exposure causes or is associated with a wide variety of nonauditory health problems including cardiovascular disease (Münzel et al., 2018), obesity (Pyko et al., 2017), diabetes (Dzambhov, 2015), reproductive problems (Ristovska et al., 2014), and mental health disorders (Clark and Paunovic, 2018b). The adverse health effects are small for each individual, but the population health impacts are large because of the large number of people affected by transportation noise. A 1 or 2 mmHg increase in systolic blood pressure is unlikely to cause problems in an individual, but if enough individuals are exposed, the average increase in blood pressure will cause some people to have heart failure, heart attacks, or strokes.

There are multiple studies in the European literature on the adverse effects of transportation noise on health. These include road traffic noise (Halonen et al., 2015), railroad noise (Seidler et al., 2016), and aircraft noise (Correia et al., 2013; Basner et al., 2017). Most experts conclude that the data are strong enough to establish causality of transportation noise exposure for the adverse health effects. (Basner, 2016) This body of research supports the recent WHO Environmental Noise Guidelines for the European Region (2018).

Again, the implications for acoustic engineering and design specifications for structures in which people work, live, and sleep are clear: sound transmission coefficients of windows, walls, and roofs must be increased and transportation noise sources must be reduced as much as possible. Effective measures include enforcement of exhaust noise regulations, requiring different combinations of road surface and tire materials, noise barriers (Rochat and Reiter, 2016), changes in aircraft flight patterns, better track and wheel maintenance, and use of rubber rather than wooden or concrete track ties. Other regulatory solutions, such as prohibiting engine braking and restricting airport operating hours, are also feasible.

Sixty A-Weighted Decibel Ambient Noise Is a Disability Rights Issue

The Americans with Disabilities Act (ADA) defines a disability as "a physical or mental impairment that substantially limits one or more major life activities," with hearing and communicating specified as major life activities (ADA National Network, 2017). People with moderate to severe auditory disorders, including not only hearing loss but also tinnitus and hyperacusis, appear to meet the ADA standard for having disabilities. High ambient-noise levels make it difficult for those with hearing loss to understand speech, worsen tinnitus, and are painful for those with hyperacusis.

Of the three auditory disorders, only hearing loss is well understood (Cunningham and Tucci, 2017. Tinnitus is commonly called ringing in the ears but technically is the perception of sound for which there is no external auditory stimulus (Bauer, 2018). Hyperacusis is a sensitivity to noise in which noise levels that don't affect most people are perceived as uncomfortable or actually painful (Baguley, 2003). People with hyperacusis often describe noise as being like a needle stuck in the ear. The most severely affected hyperacusis patients have difficulty leaving their homes, and when they do, they wear both earplugs and earmuff hearing protection.

Auditory disabilities are invisible and underappreciated. Unlike the blind, who have difficulty living independently, people with hearing loss have no problem walking or driving, shopping, preparing food, or traveling. People with hearing loss can compensate for their disability by asking someone to repeat something, cupping a hand to the ear, or seeking out quiet spaces in which to converse (Fink, 2017b). Despite this, hearing loss causes major problems in social function, leading to isolation, depression, and other problems.

There are ADA protections for the deaf and for those with profound hearing impairment (>81-90 dB decrement), including workplace modifications to allow gainful employment and mandated auxiliary aids and services, such as fire alarms with strobe lights, teletype communication devices, and sign language interpreters when needed (US Department of Justice, 2010). However, there are no ADA Access Guidelines for those with only mild (25-40 dB), moderate (41-60 dB), or severe (41-80 dB) hearing loss, and no ADA standards for ambient-noise levels in places of public accommodation (US Access Board, 2002).

High ambient-noise levels have a disproportionate impact on older people due to their high prevalence of hearing loss. Half of those over 65 and 80% of those in their 80s have at least 25-40 dB hearing decrements (Lin et al., 2011). Many older people live alone, and a restaurant meal may be the only time they converse with others.

For a variety of reasons, hearing aids do not help users understand speech in noisy places as much as desired because they primarily increase audibility but do not improve intelligibility (Lessica, 2018). As a consequence, people with hearing loss need lower ambient-noise levels to be able to understand speech. The technologies for reducing and controlling noise have been known for more than half a century. These include designing mechanical devices to be quieter or isolating, insulating, reflecting, deflecting, or absorbing the sound (Beranek, 1960). For the built environment, noise control techniques are also well understood (Harris, 1994). Relatively inexpensive items such as ceiling panels, wall hangings, carpets, and draperies can help control noise and reduce reverberation. Restaurant acoustics are reviewed by Roy and Siebein (2019). The simplest environmental modification costs nothing: turning down the volume of amplified sound.

Reducing ambient-noise levels will likely require governmental action. Laws and regulations could specify a decibel level or a functional measure, perhaps requiring indoor sound levels low enough to allow people to converse without straining to speak or to be heard. This is approximately 70-75 dB(A) for those with normal hearing and near 60 dB(A) for those with hearing loss. With appropriate enabling legislation, crowd-sourced smartphone applications, such as iHEARu (ihearu.co) and SoundPrint (soundprint.co), could provide data for local communities to initiate enforcement actions against noisy establishments.

Noise Exposure Above a 70 Decibel Time-Weighted Daily Average Will Cause Hearing Loss

The only evidence-based safe noise exposure level to prevent hearing loss is 70 dB time-weighted average for 24 hours [$L_{Aeq(24)}$], not the 85 dB(A) occupational exposure level (Fink, 2017a). Occupational exposures occur 8 hours a day, 240 days a year at work, for 40 years. (NIOSH, 1998) Noise is different from other occupational exposures such as ionizing radiation or toxic solvents because exposure continues outside the workplace, all day long, all year long, for an entire lifetime. The EPA (1974) adjusted the NIOSH-recommended exposure level (REL) for 24-hour daily exposure, 365 days a year, to calculate the daily 70 dB time-weighted average safe noise exposure level to prevent hearing loss. The EPA document carefully states that this is *not* an official regulation or standard.

The 70 dB daily average [$L_{Aeq(24)} = 70$] is probably too much noise exposure to prevent hearing loss. The EPA adjusted the REL for additional daily and annual exposure time but not for lifetime exposure. In 1967, life expectancy for a man was only 67 years. With male life expectancy now approaching 80 years in the United States, adjustment for the additional years of exposure is needed. The additional years of exposure are among the factors explaining why hearing loss is so prevalent in older people (Anderson et al., 2018).

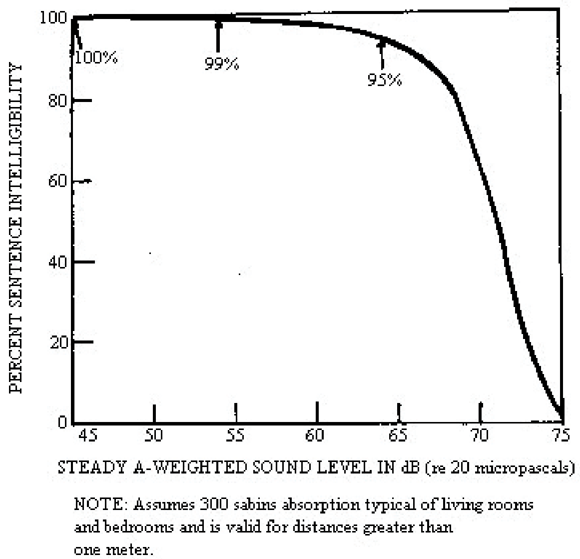

Figure 3. *Normal voice sentence intelligibility as a function of the steady background sound level in an indoor situation. At the typical conversational distance of 1 meter using normal speech volumes, people with normal hearing require 45 dB(A) ambient noise for 100% speech comprehension. Speech comprehension decreases noticeably at approximately 70 dB(A) ambient-noise levels and reaches zero at 75 dB(A). From EPA, 1974, Figure D-1.*

From a public health perspective, the NIOSH noise criteria (1998) allow an 8% excess risk of hearing loss after 40 years of occupational noise exposure. This means that workers exposed to 85 dB(A) at work have an 8% increased risk of hearing loss compared with a similar population not exposed to occupational noise. The concept of excess risk is problematic because it assumes that hearing loss is part of normal aging, which is probably not true (Fink, 2017c) and an 8% risk of injury is not acceptable for the public. The difference between occupational and public noise exposure standards was discussed in a NIOSH Science Blog post (Kardous et al., 2016). However, the principles of occupational noise control (Murphy, 2016) can be applied to the public.

Seventy to Seventy-Five A-Weighted Decibel Ambient Noise Interferes with Speech Comprehension in Those with Normal Hearing

Ambient noise also interferes with speech comprehension for those with normal hearing. This has been known since 1974, when the EPA published the graph in **Figure 3**. The text states that the maximum sound level that will permit relaxed conversation with 100% sentence intelligibility is 45 dB, but the decrement in speech intelligibility does not become meaningful for most listeners with normal hearing until ambient noise reaches 65-70 dB.

Eighty-Five A-Weighted Decibels Are an Occupational Noise Exposure Standard

The National Institute on Deafness and Other Communication Disorders (NIDCD; 2017) states that "long or repeated exposure to sound at or above 85 decibels can cause hearing loss." This statement is accurate but misleading. Eighty-five decibels or A-weighted decibels without a time limit is not a safe noise exposure level (Fink, 2017a). The auditory injury threshold is 75-78 dB(A) (Mills et al., 1981; Flamme et al., 2012) and may be as low as the effective quiet level, the sound pressure level required to recover from noise-induced temporary threshold shift, which is only 55 dB(A) (Kryter, 1994).

Unfortunately, in the absence of any federal guideline, standard, or regulation for nonoccupational noise exposure, the 85 dB sound level of the NIDCD has become the de facto federal safe noise exposure level. It is often cited as a safe volume level or as the sound pressure level at which hearing loss begins, without exposure time, by audiology experts in media reports; it is mentioned in educational materials such as the Dangerous Decibels program (bit.ly/28W7TA4) and in materials provided by the American Speech-Hearing-Language Association (ASHA) and the American Academy of Audiology and is used as a volume limit for headphones marketed as "safe" for hearing in children as young as 3 years, without specifying a time limit for exposure (Saint Louis, 2016).

At an 85 dB(A) occupational exposure, an employer must implement a hearing conservation program (OSHA, 2002). Elements of a hearing conservation program include baseline audiograms, education about noise protection, provision of hearing protection devices, annual audiograms, and meticulous record keeping. Obviously, the public has no such protections.

One Hour at Eighty-Five A-Weighted Decibels Can Cause Hearing Loss

WHO recommends only 1 hour of exposure at 85 dB(A) [$L_{Aeq(1)}$] daily for the public to prevent hearing loss (Berglund et al., 1999). An occupational noise exposure calculator will show that after only a 1-hour exposure, it is impossible for the listener to achieve the 70 dB average daily noise exposure level to prevent hearing loss. This means that noise levels in many restaurants are high enough to cause hearing loss during a typical meal lasting 1-2 hours.

Conclusion

Until the introduction of jet aircraft and the building of the interstate highway system, the United States was generally a quiet place except perhaps for a few large cities or for those living near factories, railroad yards, and tracks (Owen, 2019). The first publication about noise as a public health hazard appeared in 1969 (Ward and Fricke, 1969). As part of the nascent environmental movement, noise pollution was recognized as an environmental problem, not a health or public health problem. In 1972, the Noise Control Act (US Congress, 1972) established "a national policy to promote an environment for all Americans free from noise that jeopardizes their health and welfare." The EPA was directed by Congress to coordinate the programs of all federal agencies relating to noise research and noise control. Additional legislation included the Noise Control Act of 1978 (US Congress, 1978). Unfortunately, during the Reagan years, the attempts by the EPA to control noise pollution ran afoul of that administration's antiregulatory stance, and the EPA Office of Noise Abatement and Control (ONAC) was defunded by Congress (Shapiro, 1992). The federal government has done little about noise since then. A rare exception has been the work of the National Park Service about noise in national parks, as required by Congress.

The defunding of the ONAC led to the decline of the acoustic science and engineering professions in the United States. Noise control was left to cities and states, which lacked the funding and technical expertise to deal with noise. Several recent developments indicate that the federal government is again recognizing hearing and noise as important for the public and the nation. Reports from the National Academies of Science, Engineering, and Medicine (NASEM) include *Noise and Military Service* (Institute of Medicine, 2006), *Technology for a Quieter America* (National Academy of Engineering, 2010), and *Hearing Health Care for Adults: Priorities for Improving Access and Affordability* (NASEM, 2016). The latter led to passage of the bipartisan Warren-Grassley Over-the-Counter Hearing Aid Act in 2017 (Warren and Grassley, 2017). Finally, the Federal Aviation Administration (FAA) Reauthorization Act of 2018 includes specific mandates for studies of aircraft noise (US Congress, 2018).

This renewed federal interest in noise levels affecting the public offers an opportunity for the Acoustical Society of America and its members to stake out their rightful position as the source for information and standards for noise control, with the expertise to offer solutions to noise problems. This will help acoustic science and engineering return to relevance in the third millennium, hopefully leading to a quieter and healthier world for all.

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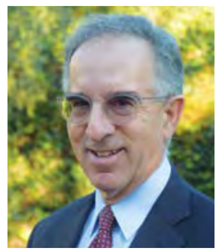
BioSketch



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