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## Why Are Noise Exposure Guidelines So Complex?

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Almost all noise-induced hearing loss (NIHL) is preventable. However, once acquired, NIHL is permanent and irreversible. In addition to hearing loss, evidence shows that prolonged or repeated exposure to high levels of noise is associated with other health effects, such as heart disease, hypertension, and insomnia.<sup>1</sup> The World Health Organization (WHO)<sup>2</sup> and the United Nations Environmental Programme (UNEP)<sup>3</sup> attest that exposure to loud sounds (noises) adversely affects the lives of millions of people at home, at work, and in the community. If just 20% of NIHL was prevented among working-age individuals, \$123 billion could be obtained from increased earnings, an economic impact excluding costs associated with health care, special education, and reduced quality of life.<sup>4</sup> Noise is the most common modifiable environmental cause of hearing loss among young and middle-aged adults, and the most common self-reported cause of hearing loss among men.<sup>5</sup>

Several recommendations for limiting noise exposure to avoid adverse effects have been developed over the years. However, noise exposure guidelines vary. Four main factors contributing to differences across noise exposure guidelines are:

- exposure definitions – how exposure is measured (e.g., averaging characteristics, exchange rate, weighting scales)
- health outcomes – what health effects are covered (e.g., auditory, non-auditory, annoyance)
- target group – who is being protected (e.g., the general population, workers, children)

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#### DISCLOSURE:

The findings and conclusions are those of the authors and do not necessarily represent the views of the Centers for Disease Control and Prevention/the Agency for Toxic Substances and Disease Registry.

- allowed risk – what proportion of the target group might still develop the outcome due to differences in sensitivity to noise effects.

In this article, we describe how these factors, and other considerations, make developing and applying noise exposure guidelines difficult. We will use the following noise limit criteria as examples to illustrate how these factors and considerations are applied:

- The 70 dB(A)  $L_{eq(24)}$  environmental exposure limit recommended by the Environmental Protection Agency (EPA)<sup>6</sup>
- The 80 dB(A) maximum of 40 hours per week recommended by the WHO<sup>2</sup>
- The 85 dB(A) Recommended Exposure Limit (REL) published by the National Institute for Occupational Safety and Health (NIOSH)<sup>7</sup>
- The 100 dB(A) venue and event upper limit standard by the WHO.<sup>8</sup>



## EXPOSURE DEFINITIONS

First, let's look at definitions of exposure. The criteria used to define noise limits are complicated by the intrinsic complexities and nuances of sound measurement. Generally, exposure to continuous noise is measured using the frequency dependent A-weighted decibel scale (dB[A]). However, using the C-weighted scale (dB[C]) or unweighted (sound pressure level) scale may be appropriate for noise sources with a large proportion of low-frequency components, very intense levels, and/or high intensity impulse noise. Few exposures are constant and unvarying; therefore, most exposure limits are based on a Time Weighted Average (TWA) which sums energy over time. This involves specifying

an exchange rate. An exchange rate is the increase in allowable exposure level with each halving of exposure duration. Most guidance specifies a 3-dB exchange rate based on the “equal energy” principle (i.e., sound energy doubles with every 3 dB increase in level). Some noise limits use a higher exchange rate (e.g., 5-dB) to allow for intermittency which reduces risk. The exchange rate substantially influences measured exposure and risk. Other exposure characteristics may also be used to quantify exposure. These include time (e.g., 24-hour, day/night), intermittency, frequency spectrum, and kurtosis (“peakedness”) of the sound source.

Differences in exposure definitions explain some of the variability across the noise criteria above. All are measured on the dB(A) scale and use a 3-dB exchange rate. However, the EPA 70 dB(A) exposure limit is set to cover a 24-hour time period ( $L_{eq(24)}$ ), the 80 dB(A) recommended by the WHO is for a maximum of 40 hours per week, and the 85 dB(A) NIOSH REL is based on an 8-hour workday. The 100 dB(A) WHO limit for venues and events is averaged over only 15 minutes. As you can see, exposure limits generally become lower as exposure periods become longer, accounting for part of the differences across recommendations.

## HEALTH OUTCOMES

Next, let’s consider the health outcomes addressed in various guidelines. Noise exposure limits may be set to protect against auditory outcomes, such as hearing loss and tinnitus, or to prevent adverse non-auditory effects (e.g., heart attack, stroke, sleep disturbance, and injury avoidance). The EPA 70 dB(A), WHO 80 dB(A), and the NIOSH 85 dB(A) REL exposure limits were established to prevent hearing loss. However, the definition of “hearing loss” is very different across the guidelines. The NIOSH REL aims to protect workers from developing a material hearing impairment (i.e., hearing loss substantial enough to impact understanding speech) over their working lifetime (assumed to be 40 years). The EPA limit seeks to protect against a hearing change of more than 5 dB at 4K Hz—a much more stringent hearing loss criterion, which results in a lower recommended exposure limit. The WHO 80 dB(A) guideline was set at a level to avoid any increased risk of permanent hearing impairment due to environmental noise exposures. In contrast to these recommendations, the WHO 100 dB(A)  $L_{eq(15min)}$  limit aims to prevent hearing loss only indirectly by reducing “unnecessarily hazardous sound levels” at venues and events. The WHO acknowledges that this 100 dB(A) limit “does not, and cannot, eliminate all risk of an individual audience member suffering sound-induced hearing injury.” Interestingly, some noise exposure guidelines are set to avoid annoyance. EPA recommendations include additional limits of 45 dB(A) for indoor spaces and 55 dB(A) for outdoor spaces and are designed to prevent “activity interference and annoyance.”

## TARGET GROUP

A third element that varies across noise exposure criteria is the target group. The NIOSH REL is clearly targeted toward workers, whose exposures typically last 8 hours a day, 5 days per week. The EPA 70 dB(A) and WHO 80 dB(A) recommendations target the general population, whose exposures can occur 24 hours a day, 7 days per week, but with more

presumed intermittency. The WHO venue and event guidelines are targeted toward adults attending concerts and other loud events. WHO recommends that the limits be set lower for children: at least 94 dB(A)  $L_{eq(24)}$  for events targeted specifically for children; 90 dB(A) if the event targets very young children.

Nearly all current noise exposure recommendations were developed for adults. Although there is currently no consensus on the established acceptable risk of NIHL in children, a recent literature review suggested that a 75 dBA 24-hour continuous average sound level would protect 99% of children from hearing loss (> 5 dB at 4 kHz) after 18 years of noise exposure.<sup>9</sup> Another literature review regarding a nonoccupational criterion to eliminate the risk for NIHL in any exposed person recommended a 24-hour equivalent continuous exposure limit of 70 dBA.<sup>10</sup>

## ACCEPTABLE RISK

The fourth factor that creates differences across noise exposure guidelines is the level of acceptable risk incorporated into the recommendation. Lower noise limits generally protect more people; however, individuals differ in their susceptibility to noise. The 70 dB(A) EPA limit was set to protect 96% of the population. At exposures equivalent to the REL, NIOSH estimates that 92% of workers exposed 240 days/year for 40 years would be protected from developing a material hearing impairment. The WHO 80 dB(A) maximum of 40 hours per week is presumed to protect 100% of the population. As noted previously, the WHO venues and events guidelines acknowledge that some participants may acquire hearing damage even at venues meeting the criterion. The WHO did not lower the criterion further because reducing the sound to a limit that would eliminate hearing risk would be unacceptable for both performers and spectators.

## REGULATIONS AND RECOMMENDATIONS

One additional consideration for noise exposure guidelines is enforcement. Some noise limits have the force of law. For example, U.S. regulatory agencies such as OSHA and EPA create legally enforceable noise regulations and standards which set limits on exposure to hazardous noise. The EPA Office of Noise Abatement and Control was phased out in 1982 leaving noise control to state and local governments without the presence of a federal program.<sup>11</sup> State and local governments may pass legislation to regulate noise exposure. Legislation may include noise level limits, zoning laws, time of day restrictions, and nuisance ordinances.<sup>12</sup> In contrast, other governmental, professional, or standards organizations propose voluntary guidelines and recommendations on noise exposure limits. Recommendations do not carry the force of law. For example, the WHO has published guidelines on community noise limits<sup>13</sup> and road traffic noise levels.<sup>14</sup> Though not legally enforceable, these recommendations often represent best practices and are intended to assist health care and other professionals, stakeholders, and the general public with making informed decisions.

New or updated noise limits have been published periodically and vary due to differences we have described. In 1999, the WHO recommended community noise limits of 55 dB(A)

$L_{eq}$  for outdoor living areas to prevent serious annoyance. They also recommended a limit of 70 dB(A)  $L_{eq}$  for industrial, commercial shopping, and traffic areas (indoors and outdoors) to prevent hearing loss.<sup>13</sup> In 2018, the WHO Regional Office for Europe strongly recommended that noise levels produced by road traffic be reduced to < 53 dBA  $L_{den}$  to prevent adverse health effects. Further, they suggested a reduction to below 45 dB(A) at night to prevent impaired sleep.<sup>14</sup> In 2019, the WHO and the International Telecommunication Union (ITU) recommended a reference exposure limit of 80 dBA for 40 hours a week to reduce the risk of hearing loss among users of personal audio devices (including smartphones and audio players).<sup>15</sup>

Noise exposure guidelines, recommendations, and regulations need to be based on sound, ethical science and include high-quality, relevant information. Guidelines and recommendations need to be clear, valid, and transparent and based on the highest level of scientific evidence obtained through a systematic review of the literature.<sup>16</sup> An intra-agency workgroup formed within the National Center for Environmental Health (NCEH) in the Centers for Disease Control and Prevention (CDC) endeavors to assist in this effort by conducting research and providing public health education materials. The workgroup is comprised of CDC staff members from NCEH, the National Center for Chronic Disease Prevention and Health Promotion, the National Center on Birth Defects and Developmental Disabilities, and NIOSH.<sup>17</sup> In addition, staff from the National Institute on Deafness and Other Communication Disorders in the National Institutes of Health collaborate with the workgroup on activities of mutual interest. Workgroup members collaborate to address the risks of exposure to hazardous noise levels. This is accomplished through educational campaigns; partnerships with academic and hearing associations and organizations; supporting national and international standards development; and exploring additional research opportunities to enhance public health protection.

By working with various stakeholders and engaging in ongoing research, CDC and the workgroup hope to adequately address the complexities of creating and instituting noise exposure guidelines.

## Biographies

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