POLICY STATEMENT Organizational Principles to Guide and Define the Child Health Care System and/or Improve the Health of all Children

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Preventing Excessive Noise Exposure in Infants, Children, and Adolescents

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Noise affects people of all ages. Noise-induced hearing loss, a major problem for adults, is also a problem for young people. Sensorineural hearing loss is usually irreversible. Environmental noise, such as traffic noise, can affect learning, physiologic parameters, sleep, and quality of life. Children and adolescents have unique vulnerabilities. Infants and young children must rely on adults to remove them from noisy situations; children may not recognize hazardous noise exposures; teenagers often do not understand consequences of high exposure to music from personal listening devices or attending concerts and dances. Personal listening devices are increasingly used, even by small children. Environmental noise has disproportionate effects on underserved communities. This statement and its accompanying technical report review common sources and effects of noise as well as specific pediatric exposures. Because noise exposure often starts in infancy and effects are cumulative, more attention to noise in everyday activities is needed starting early in life. Pediatricians can potentially lessen harms by raising awareness of children's specific vulnerabilities to noise. Safer listening is possible. Noise exposure is underrecognized as a serious public health issue in the United States. Greater awareness of noise hazards is needed at a societal level.

BACKGROUND

Definitions

Sound is created by vibrations that travel through a medium, such as air or water. Characteristics of sound include frequency, intensity, periodicity, and duration.[1] Intensity is perceived as loudness; frequency is also referred to as pitch. Frequency is measured in cycles per second; the unit of this is the Hertz (Hz). Speech frequencies generally are in the range of 250 to 8000 Hz. Sound intensity is measured in Pascals (Pa) or decibels (dB). The dynamic

abstract

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range of normal human hearing extends from a minimal audible intensity of about 0.00002 Pa or about 1.9 dB (softest) to the threshold of pain at about 20 Pa or 120 dB (loudest). This range is expressed in a logarithmic scale represented in units of dB SPL (sound pressure level). The logarithmic scale means that there is a 10-fold difference in sound energy with a 10-dB difference, a 100-fold difference with a 20-point difference, and so forth.

The perceived intensity of sound varies with the frequency of the sound being heard. An equivalency curve is used to determine the measure of sound intensity, referred to as the decibel weighted by the A scale, "A-weighted dB," or "dBA." Comparisons can, thus, be made about the frequencies of sound perceived by the human ear. The loudness of human speech is approximately 50 to 60 dB SPL.

Noise is often defined as unwanted or objectionable sound.[1] Characteristics of noise include intensity (measured in dBA) and duration (length of time exposed). The meaning of sound to an individual often determines a person's reaction to the same sound. "One person's music is another's noise."[1]

Noise Categories

Occupational noise is experienced in the workplace.

Environmental noise usually refers to noise from outdoor settings generated by human activity, mostly powered by fossil fuels. Sources include vehicular traffic, railways, airplanes and airports, industrial sites, wind farms, and leaf blowers[2] and lawn mowers. Environmental noise exposure has been characterized as "one of the most important environmental stressors affecting public health throughout the world."[3]

Indoor noise sources include equipment, appliances, infant sleep machines, video games, toys, and televisions.

Recreational noise is noise sought for pleasure.[4] Sources include personal listening devices (PLDs); music at parties, dances, and concerts; sports events; and recreational firearm use.

Occupational Standards

Understanding occupational standards helps to contextualize pediatric noise exposures. Federal agencies set evidence-based recommended exposure limits (RELs) to protect workers from exposures to hazardous agents at work. The REL for occupational noise was set at 85 dBA as an 8-hour time-weighted average, with exposures greater than this considered hazardous.[5] This REL aims to protect workers from developing noise-induced hearing loss (NIHL) over a 40-year career. Because approximately 8% of workers could still develop hearing loss at this level,[6] hearing protection is recommended when levels are >85 dBA regardless of duration.[7] The occupational limit for hazardous noise exposure of ≥85 dBA over 8 hours is not meant to protect the public from general environmental noise or recreational noise, such as listening to music with earbuds or attending noisy events.[8] It also is not meant to apply to infants, children, and adolescents in their various exposure settings.

Disparities in Exposures

Studies in the United States and internationally demonstrate sociodemographic disparities in noise exposure. Most studies show that exposures are higher in people of lower socioeconomic status and in those belonging to historically marginalized racial and ethnic groups.[9,10] According to the World Health Organization (WHO), the prevalence of hearing loss in children decreases exponentially as national income increases, and there is an inverse relationship between prevalence of disabling hearing loss in children and parents' literacy rates.[11]

Excessive environmental noise exposure has been framed as a disability rights issue for people with hearing loss, tinnitus, and hyperacusis. Noisy situations worsen the ability of people with hearing impairments to understand speech; noise worsens symptoms in people with tinnitus and hyperacusis. Elevated environmental noise levels turn these disorders into disabilities in restaurants, social dance event spaces, and other venues. These sensory impairments meet the legal standard of having disabilities. Advocates have stated that legislation and regulations are needed to establish ambient noise standards that then must be enforced.[12,13]

Noise as a Public Health Issue

Noise is perceived at an individual level, but when a critical mass of individuals experiences noise that causes hearing problems, disturbs cognition, and reduces well-being, then noise becomes a public health concern.[14] Substantial evidence links noise to health effects, more than for many environmental hazards. Although commonly encountered, excessive noise exposure is treated differently than other pollutants.[15] Few communities consider health risks of noise in policy making, and noise often is not on clinicians' agendas. High noise levels at recreational and celebratory events often are accepted—and frequently sought out—rather than viewed as potentially hazardous.

CHILDREN'S UNIQUE SUSCEPTIBILITIES

Noise exposure is a pediatric issue because of the susceptibility of the developing auditory system and because effects on hearing and quality of life at early developmental stages can affect a child's life trajectory. Studies in immature laboratory animals reveal heightened susceptibilities to noise compared with adult animals, illustrating the concept of "critical periods" of vulnerability.[16] External ear anatomy in young children differs from adult anatomy; smaller ear canals more greatly intensify higher frequency sounds.[17] Children have differences in behavior and development, with long life spans during which cumulative exposures may manifest. Children and youth often have excessive exposures through PLDs. Children with developmental differences,

such as those with autism spectrum disorder, often have increased sensitivity to noise[18,19]; they may display atypical play methods with noisy toys, such as prolonged and repetitive use, potentially increasing risk of hearing damage.[20] Hyperacusis (increased sensitivity to sound at levels that would not trouble most individuals), misophonia (excessive and inappropriate emotional responses to specific "trigger" sounds), and phonophobia (phobia to specific sounds or classes of sounds) have been described in these children. Auditory processing issues are also reported in children with attention-deficit/hyperactivity disorder (ADHD), including hypersensitivity and hyposensitivity to sounds.[21,22]

NOISE EFFECTS

Hearing Loss

Sensorineural hearing loss (SNHL) is caused by damage to the hair cells of the cochlea or to the auditory nerve. Excessive noise exposure is one cause of SNHL. Damage to hair cells is permanent and usually cannot be restored with medical treatment.[23–25] NIHL can occur after high-intensity traumatic noises or after less-loud noises experienced over time. SNHL can occur after a single loud sound near the ear. Hearing loss more commonly results over time from damage caused by repeated exposures to loud sounds. The louder the sound, the shorter the amount of time it takes for damage to occur. The longer the exposure, the greater the risk for hearing loss (especially if hearing protection is not used or if there is not enough time for the ears to rest between exposures).[26] Continuous exposure to hazardous noise levels tends to cause maximum damage to high-frequency areas of the cochlea and is usually most severe around 4000 Hz.

NIHL impacts understanding of speech. Consonants are disproportionately affected in higher frequencies, whereas lower frequency vowel sounds remain relatively normal. Because softly spoken, high-frequency consonants such as "f," "s," and "h" convey more of the intelligibility of words in speech compared with vowels, an individual with NIHL can have difficulty understanding in background noise and when following higher-pitched voices.

Hearing Loss in Adults

Hearing loss is the third most common chronic physical condition in US adults. Hearing loss is linked to cognitive decline, Alzheimer disease, dementia, and Parkinson disease.[27,28] The Centers for Disease Control and Prevention analyzed data collected from adults ages 20 to 69 years using questionnaires and audiometric tests to determine the presence of audiometric notches indicative of NIHL. An audiometric notch is a deterioration in the hearing threshold (the softest sound a person can hear); high-frequency notches suggest NIHL. Nearly 1 in 4 adults (24%) had notches, suggesting a high prevalence of NIHL. People with NIHL often did not recognize this: almost one-quarter of participants reporting good or excellent hearing had bilateral (5.5%) or unilateral (18.0%) notches. This study indicates that NIHL hearing loss is a significant but often unrecognized problem in adults.[6] The high prevalence of notches (almost 1 in 5) among young adults suggests that early life interventions are needed.

Hearing Loss in Children and Adolescents

Several studies confirm that hearing loss is common in children, adolescents, and young adults. Even small amounts of hearing loss can have profound, negative effects on speech, language comprehension, communication, classroom learning, and social development.[29,30]

One study using national data examined changes in hearing loss prevalence in US children and adolescents (12 to 19 years old) from 1988 to 2010 and associated risk factors including reported noise exposures. The prevalence of hearing loss of >15 dB increased from 17.0% to 22.5% from 2007 to 2008 but decreased to 15.2% from 2009 to 2010. The most current data, thus, illustrated that about 1 in 6 middle and high school students had evidence of hearing loss. This study did not demonstrate a consistent association between exposure to loud music with an increased risk of hearing loss.[31]

Studies in youth do not consistently show positive associations between reported noise exposure and hearing loss. Adolescents and young adults, however, typically underestimate symptoms caused by loud sound, tinnitus, and temporary hearing impairment during music exposure. Youth typically underreport concern for these symptoms.[32] Although more research is needed to demonstrate the association of noise exposure with early hearing loss, it is likely that noise contributes to hearing loss in children and adolescents. Pediatricians, therefore, may play important roles in counseling about preventable noise exposures.

Nonauditory Effects

Physiologic Effects

Stress resulting from noise is believed to cause dysregulation of the autonomic nervous and endocrine systems, thus affecting long-term cardiovascular health. The pituitary-adrenal-cortical and sympathetic-adrenal-medullary axes are activated by noise, leading to a response including the release of cortisol. Noise-related effects on the cardiovascular system may also result from decreases in sleep quantity and quality. An assessment of studies conducted by the WHO revealed an association of higher road traffic noise with increased risk of ischemic heart disease in adults.[33] Research about effects on noise on children's blood pressure showed positive but not significant associations between exposure to road traffic and children's blood pressure.

Sleep

Exposure to noise leads to fragmented sleep and decreased total sleep time with reductions in daytime alertness, performance,

quality of life, and overall health. Chronically disturbed or curtailed sleep is associated with these negative outcomes; sleep disturbance is one of the most important nonauditory effects of environmental noise. Most studies in children examining the relationship of noise to sleep conclude that noise may lead to self-reports of poorer sleep.[34]

Effects on Learning

Although environmental noise is less likely to affect children's hearing—hearing loss is more likely to result from excessive recreational exposures—environmental noise affects learning. Background noise can disrupt cognitive tasks, especially short- and long-term memory.[35] Loud noise exposure has lasting effects on cognitive function (memory, attention, reaction time) even after the noise exposure is withdrawn. Noise negatively impacts speech comprehension and speech intelligibility.[36,37]

Annoyance

Annoyance is estimated as the second major health effect of noise exposure after sleep disturbance.[38] In adults, there were significant correlations between traffic noise levels and measures of annoyance. There are fewer studies in children of these relationships.

Disability-Adjusted Life Years

The WHO calculated the "burden of disease" from environmental noise in the European Union expressed in disability-adjusted life years, " … the sum of the potential years of life lost due to premature death and the equivalent years of 'healthy' life lost by virtue of being in states of poor health or disability." Conservatively estimated disability-adjusted life years lost were "61 000 years for ischemic heart disease, 45 000 years for cognitive impairment of children, 903 000 years for sleep disturbance, 22 000 years for tinnitus, and 654 000 years for annoyance in the European Union Member States and other western European countries." The WHO estimates that "at least 1 000 000 healthy life years are lost every year from traffic-related noise in western Europe."[39]

SPECIFIC PEDIATRIC EXPOSURES

Infant "sleep machines" (ISMs or "white noise" machines) produce sound in the location where the infant sleeps to soothe the infant and mask other noises. Several studies show potential benefits in ease in falling asleep, decreasing crying, and increasing pain threshold. One study of 14 ISMs, however, raised concern that sound levels of 3 machines exceeded occupational limits and that hearing damage could occur if machines were played for >8 hours. If ISMs are used, it may be safer to locate them as far away as possible from the infant, set the volume as low as possible, and limit duration of use.[40]

"Background noise exposure" occurs when the TV is on when the child is occupied with another activity. One study showed that the average child was exposed to almost 4 hours of background TV daily.[41] Researchers conclude that background TV is disruptive to young children's play even when they are not overtly paying attention to it.[42]

Toys can be excessively noisy. In 2021, 19 of 24 toys chosen for the Sight and Hearing Association's 24th Annual Noisy Toys List tested louder than 85 dB, " … the level set by the National Institute of Occupational Health and Safety (NIOSH) for mandatory hearing protection." To keep homes quieter and children's toys "ear-safe," the Sight and Hearing Association recommended adjusting volume control on toys, placing tape over speakers, removing batteries, or returning toys that are too loud. Standards for noise set for occupational settings may not be suitable to evaluate toy safety.[43]

In preschools and classrooms, noise may be especially harmful to younger children who are developing language and auditory discrimination skills.[44] Recommendations for early care and education settings include accommodating children to maintain the decibel level ≤35 dB for at least 80% of the time.[45] "Classroom acoustics"—how sounds travel in classrooms—are affected by factors including students talking and aspects of design such as ceiling type, floor rugs, and air ducts. Poor classroom acoustics can result from background noise and reverberation—how sound bouncing off surfaces acts in a room after the sound first occurs.[46,47] In the United States, recommended guidelines for an unoccupied enclosed classroom for typically developing children with normal hearing were <35 dBA according to the American National Standards Institute and <30 dBA according to the American Speech Language-Hearing Association. Actual noise levels ranged from 30 to 65.9 dBA in unoccupied classrooms and from 55 to 85 dBA in occupied classrooms. The speech intelligibility rating in many US classrooms is less than 75%, meaning that listeners with normal hearing can only understand 75% of words read from a list.[48] Even children with normal hearing suffer in these situations. Children with learning disabilities, children with auditory processing issues, and children for whom English is a second language generally have more difficulty. Young children, who are not able to "predict from context" because of their limited vocabulary and experience, are less able than older children to "fill in" missing thoughts.[48]

Personal listening devices, popular with youth, can expose listeners to hazardous noise levels. Maximum volume outputs of PLDs can be >125 dBA; average listening levels of young adults range from 71 to 105 dBA. In one study of adolescents and young adults, almost 60% of participants exceeded the 100% daily noise dose (defined as the occupational standard), particularly in the presence of background noise[49]; background noise often results in the user

increasing volume. Many younger children use headphones for entertainment and during remote learning sessions. There is no mandatory standard to restrict the maximum sound output for headphones or other listening devices sold in the United States. Many manufacturers claim to limit the volume of headphones to 85 dB, but some headphones can produce volumes high enough to be hazardous to hearing in minutes (using occupational standards).[50] Although many headphones have volume-reduction features, some have design flaws allowing children to bypass them.[51, 52] Information for parents about setting volume controls on various devices is available. Noise cancellation is another important feature, because children may turn up volume in the presence of background noise.[53]

Recreational firearm use is a high-risk situation for NIHL. Approximately 3.8 million children ages 6 to 15 years went target shooting with firearms in 2015; 1.4 million engaged in hunting activities in 2016.[54] Peak SPLs from firearms range from approximately 140 to 175 dB. Most recreational firearms generate 150 to 165 dB peak SPLs. Researchers have advocated for the development and dissemination of accurate information to support hearing loss prevention efforts for people engaging in shooting sports.[55]

Hospital settings are generally louder than most homes and offices. Noise exposure in the NICU is most studied among pediatric hospital settings. Noise sources include telephones, ventilators, pumps, monitors, incubators, alarms, air conditioners, and an infant's crying in an incubator. Preterm infants may be especially sensitive. Physiologic changes in preterm infants exposed to NICU noise include behavioral and vital sign changes,[56–58] impaired tactile learning,[59] and disrupted sleep.[60] Standards for NICU noise levels aim to promote speech intelligibility, speech privacy, physiologic stability, uninterrupted sleep, and freedom from acoustic distraction.[61] Most NICU sound reduction strategies aim to reduce the sound reaching newborn infants' ears to $<$45 dB.[61]

MRI technology, an alternative to computed tomography scanning, may pose a risk because of prolonged noise exposure generated from the polarizing gradient magnetic fields during imaging. Noise generated by loud coils,[62] characterized as "banging," "clicking," or "squawking," can be disturbing and unnerving. Hearing protection during MRI is critical, because noise in the scanner can reach the level of a jackhammer.[63]

STANDARDS FOR ENVIRONMENTAL NOISE

The WHO published guidelines to protect the public from environmental noise-induced health problems.[64] In contrast, environmental noise exposure in the United States has been less emphasized. There are no federal regulations regarding exposure to nonoccupational noise.[6] State and local governments are tasked with responding to concerns and protecting the public from exposure to excessive environmental noise.[65]

CONCLUSIONS

Much akin to knowledge and perceptions about smoking and secondhand smoke more than a half century ago, noise exposure is not generally seen as hazardous by the public.[66] More education is needed to begin changing this perception. The responsibility for raising awareness and creating safe listening environments lies with the public health community, governments, device manufacturers, and others.[67]

NIHL and other consequences of excessive noise exposure are preventable. Safer listening is possible. Pediatricians can play important roles in promoting appropriate acoustic environments, safer listening while using PLDs, and educating patients, parents, legislators, and others about hazardous exposures. It is important to emphasize that noise exposure comprises not only intensity, but that duration and frequency also must also be considered. For more background information and a summary of available research, see the accompanying technical report.[68]

RECOMMENDATIONS FOR PEDIATRICIANS

1. Preserving hearing is a lifelong endeavor. Pediatricians can incorporate information about noise and advice about preventing excessive exposure into health supervision practices.
2. The most prevalent exposure encountered is likely to be from personal listening devices. Listening to music is very important to many people. Excessive and/or prolonged exposure to high volumes, however, can result in hearing loss, tinnitus, and/or hyperacusis. Pediatricians can discuss potential hazards of PLDs during confidential adolescent interviews or when examining ears. Use of PLDs can also be discussed with parents of younger children. A child should be able to hear when spoken to and should take breaks from the device.
3. The dose of noise—the duration of exposure, not just the volume—is significant. As one increases, the other should decrease.[69] The standard of 85 dB over 8 hours used in occupational settings does not mean that this is safe for young listeners. The frequency of exposure also must be considered.
4. Advice to caregivers of young children includes avoiding or leaving excessively noisy venues, such as concerts, sporting events, or fireworks displays, or using hearing protection such as protective earmuffs, even on young infants. When parents and children attend these types of events, hearing protection is recommended regardless of the duration of exposure.[4] Using earplugs can be considered if they are properly inserted. However, earplugs can pose a choking hazard to younger children. Parents can also be encouraged to advocate for reduced noise spaces in early child care and education settings and for

using earmuffs or over-the-ear headsets for children with audio sensitivity.
5. Children should be shielded from impulse noise whenever possible. When impulse noise is expected (eg, firearms, explosives, etc), double hearing protection (ie, ear plugs and earmuffs) has been recommended to reduce the risk of hearing loss.[4]
6. Pediatricians can counsel parents who use infant sleep machines or noise machines about safe use.
7. Noise exposure can be incorporated into discussions of age-appropriate toys, video games, tablets and other devices, and screen time. Discussions can include information about volume control, frequency and duration of use, and noise-canceling technologies.
8. Adolescents employed in noisy occupations or engaged in shooting sports can be counseled about the importance of using hearing protection; adolescents attending excessively noisy events can be counseled to use ear protection or to relocate further away from the speakers.
9. Pediatricians can consider recommending formal hearing evaluations for children with a history of excessive noise exposure or for children with tinnitus or hyperacusis.
10. Hearing protection can be made available to families and health care providers in hospital settings when needed. Ear plugs can be provided for any pediatric patient undergoing an MRI scan.
11. Pediatricians involved in quality improvement initiatives to reduce noise exposure can focus on behavioral, structural, and/or operational changes based on resources and institutional needs. Noise levels can be monitored to identify specific areas or activities that produce excessive noise.
12. Pediatricians can advocate for adherence to noise abatement strategies in new hospital construction.
13. Pediatricians can encourage consideration of noise burden when purchasing new equipment.
14. Pediatricians involved in educational efforts can incorporate information about the hazards of noise exposure into medical education.
15. Where relevant, pediatricians can incorporate information about noise effects into federal, state, and local advocacy efforts.

RECOMMENDATIONS TO MEDICAL AND OTHER ORGANIZATIONS

1. Organizations should be cognizant of and monitor noise levels at national and other events to ensure that levels do not exceed recommended standards.

RECOMMENDATIONS FOR GOVERNMENT

1. Federal, state, and local governments should mount campaigns to increase the public's awareness of hazardous noise exposures. This includes promoting information directed at parents, children, and youth about the potential hazards of PLDs.
2. The federal government should set standards for the volume of toys and sleep machines used by infants and children. Volume standards should not be based solely on adult occupational standards but should consider the special vulnerabilities of infants and children.
3. Although occupational standards exist, there currently are no federal regulations or standards in the United States to protect the public from environmental noise hazards. More assertive action is needed at the federal level to protect the public. Particular attention is needed for the most vulnerable populations.

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ABBREVIATIONS

dB: decibel
dBA: decibel weighted by the A scale
Hz: Hertz
ISM: infant sleep machine
NIHL: noise-induced hearing loss
Pa: Pascal
PLD: personal listening device
REL: recommended exposure limit
SNHL: sensorineural hearing loss
SPL: sound pressure level
WHO: World Health Organization

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