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Chapter 1

Epidemiology of Hearing

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1.1 Introduction

Epidemiology is the study of the distribution and determinants (causes) of health-related states or events in specified populations in order to prevent or control health problems (CDC, 2012; Gordis, 2009). Those health-related states include disease, injury, disability and death. The focus here is on hearing conditions in the U.S. population. Surveillance is the vehicle through which much of the data necessary for epidemiological study is collected, including for hearing. Surveillance is the ongoing, systematic collection, analysis, interpretation and dissemination of health-related information for the purpose of preventing or controlling disease or injury and identifying unusual events of public health importance (Halperin & Howard, 2011; Langmuir, 1971).

Audiologists, researchers and others who work in hearing loss prevention need to be able to answer important questions. How many people have hearing conditions? Who are they — who are the high-risk groups? What are the risk factors for hearing loss? Are current prevention and treatment interventions working — do we see a reduction in hearing conditions over time? Are there emerging concerns that need to be addressed? Answering these and other questions allows those in the field to focus limited resources where they are needed most and target those at highest risk for intervention.

Epidemiology and surveillance also answer another important question. What is normal hearing? Audiologists use epidemiological data in their daily work — even though they might not realize it. Reference values for audiometric zero are rooted in epidemiological surveys conducted initially by the United States Public Health Service in 1935–1936 (Beasley, 1938) and updated later with survey and laboratory data from five countries (Jerger, 2009). Every time someone conducts a pure tone hearing test, the recorded thresholds are essentially a comparison to an epidemiological data set.

This chapter will discuss the frequency of hearing conditions and risk factors by life stage, including at birth, through childhood, adolescence and adulthood, and among the elderly. It will also discuss hearing conditions and risk factors among working adults. It is important to understand the primary sources of the information and terms that will be used throughout.

Two important terms related to surveillance are prevalence and incidence. Prevalence is the percentage or proportion of people in the population or a group with a condition or exposure. It can also be the current case count — how many have the condition. Prevalence is used to quantify the 'burden' of disease. Incidence is the percentage or proportion of new people in the population or a group with a condition or exposure. Since many hearing losses are permanent, incidence would only include the percentage of those newly diagnosed in a specified time period. It can also be the new case count. For example, how many developed tinnitus this year. Incidence is used to describe the risk of disease.

Where do the numbers come from? The statistics provided come from a variety of sources, including individual studies, each with their own strengths and limitations. Descriptions of all are beyond the scope of this chapter, but much of the data that are analyzed to generate the estimates in this chapter come from the Centers for Disease Control and Prevention (CDC) cross-sectional population surveys. Two surveys in particular have included key questions on hearing difficulty, tinnitus, use of hearing protection and noise exposures. The National Health and Nutrition Examination Survey (NHANES) collects health data on the U.S. civilian population through a household interview and physical examination. This physical examination includes pure tone audiometric testing for a subset of participants. NHANES is a representative sample of the U.S. non-institutionalized population allowing for the generation of nationally representative estimates. The National Health Interview Survey (NHIS) is another nationally representative survey which collects health data annually through household interview only. While it does not include audiometric testing, the sample is much larger, allowing for the generation of estimates by industry and occupation. Both surveys allow for the generation of prevalence and risk estimates.

With the exception of NHANES audiometric testing, the hearing-related information in these two surveys is collected via self-report. In general, research indicates that self-report is an imperfect yet valid mechanism for obtaining certain hearing-related information. Self-report is required for tinnitus (ringing in the ears), a personal and subjective condition (Heller, 2003). Related to hearing ability, for example, participants are asked: "Is your hearing excellent, good, a little trouble hearing, moderate trouble, a lot of trouble, or are you deaf?" This question has been validated against audiometric thresholds (Choi *et al.*, 2016; Schein *et al.*, 1970), although individuals sometimes under-report hearing difficulty, especially when the hearing loss is mild or primarily affects the higher frequencies (Nondahl *et al.*, 1998; Sindhusake *et al.*, 2001; Valete-Rosalino & Rozenfeld, 2005). An example of a noise exposure question is: "Have you ever had a job, or combination of jobs, where you were exposed to loud sounds or noise for four or more hours a day, several days a week? Loud means so loud that you must speak in a raised voice to be heard." Research indicates that self-reported occupational noise exposure is indeed a valid indicator (Neitzel *et al.*, 2009; Reeb-Whitaker *et al.*, 2004; Schlaefer *et al.*, 2009).

One other data source is the National Institute for Occupational Safety and Health (NIOSH) Occupational Hearing Loss (OHL) Surveillance Program, which collects longitudinal audiometric data for noise-exposed workers. It is not a representative sample of the U.S. population, but it is an incredibly large sample of millions of records allowing for examination of hearing loss by detailed industry groups, and over time. Prevalence, incidence and risk estimates have been generated using these data. In occupational settings, work-related health conditions are classified as illnesses or injuries (OSHA, 2020). OHL is usually classified as an illness because most OHLs are due to chronic exposures rather than a single traumatic injury (OSHA, 2002; Themann *et al.*, 2013).

1.2 Hearing in Infancy

Hearing loss is the most common permanent sensory impairment present at birth, affecting 1–2 of every 1,000 children born in the United States (Shave *et al.*, 2022). This equates to about 5,000–6,000 infants each year. The rate in the U.S. is consistent with the prevalence of congenital hearing loss in other countries. Worldwide, the median prevalence of permanent hearing loss identified through newborn hearing screening programs is 1.7 per 1,000 infants (Neumann *et al.*, 2020). In very highly developed countries, the prevalence of bilateral permanent hearing loss is 1.1 per 1,000 infants screened (Butcher *et al.*, 2019). Although some congenital hearing losses are conductive, the majority are sensorineural. Approximately 20–30% of congenital hearing losses are profound (Shave *et al.*, 2022). About two-thirds of hearing losses identified at birth are bilateral (Bussé *et al.*, 2020).

Early identification of congenital hearing loss is critical to ensuring that children with hearing loss achieve the best possible outcomes. Children who receive hearing aids and/or cochlear implants early in life have better language development, reading ability, academic achievement, social skills, emotional well-being, and quality of life than children whose hearing loss is not identified and treated until later (Neumann *et al.*, 2020; Williams *et al.*, 2015). Early detection and intervention benefit society as well, saving an estimated $200 million in special education costs in the U.S. each year (Grosse, 2007).

Over the past two decades, early hearing detection and intervention (EHDI) programs have led to tremendous progress in early identification and treatment of congenital hearing loss. Prior to the widespread adoption of universal newborn hearing screening, children with severe-to-profound hearing loss often were not identified until 2 or 3 years of age. Children with mild-to-moderate hearing loss frequently went undiagnosed until they entered school (JCIH, 2019). By that time, the critical period for speech and language development had passed, making it much more difficult for children to acquire these essential skills (Subbiah *et al.*, 2018). Improved technology in the 1980s and 1990s made it possible to move from risk-factor checklist screening to test-based screening using automated auditory brainstem response or otoacoustic emissions systems. Individual states began implementing universal newborn hearing screening in the 1990s, and within a few years, all states had instituted such programs (Grosse *et al.*, 2017). The percentage of infants screened for hearing loss at birth increased accordingly. In 1996, only 10% of infants were screened prior to hospital discharge. The percentage grew to 50% by 2000 and 92% by 2003 (Subbiah *et al.*, 2018). In 2019, 98% of babies born in the U.S. were screened for hearing loss within a month of birth (CDC, 2019).

The American Academy of Pediatrics Joint Committee on Infant Hearing (JCIH) recommends a set of guidelines for early identification and treatment of congenital hearing loss known as the "EHDI 1-3-6" plan. These goals target screening all newborns before one month of age (preferably before hospital discharge), diagnostic testing of infants who fail the screening by 3 months of age, and starting interventions for infants with confirmed hearing loss by 6 months of age (JCIH, 2019). While achieving the first objective is nearly met, progress towards timely diagnosis and intervention has been steady but slower. In 2007, 30% of infants who failed their initial screening received documented diagnostic testing, and 20% of the testing occurred by age 3 months. In 2019, the percentages had increased to 62% and 49% respectively, indicating substantial progress but still a need for improvement. Similarly, in 2007, 54% of babies diagnosed with permanent hearing loss received early intervention services, and 25%

were enrolled in these services by age 6 months. In 2019, the percentages were up to 62% and 45%, respectively (CDC, 2019; Subbiah *et al.*, 2018).

Infants may be lost to follow-up (LTF), meaning that they have not received diagnostic testing or intervention, or lost to documentation (LTD), meaning that they have received these services but no record is available. Reasons for LTF/D include insufficient system capacity (e.g., shortage of pediatric audiologists), lack of provider knowledge (e.g., pediatrician-recommended "wait and see" approach), obstacles to care (e.g., required insurance pre-authorization), and information gaps (e.g., poor communication across health care systems). In addition, a recent analysis found evidence of disparities in completion of diagnostic testing and intervention (though not screening) (Nicholson *et al.*, 2022). Infants whose mothers are younger than 25 or older than 50 years, have a high school education or less, and report their race as American Indian/Alaskan or Native Hawaiian/Pacific Islander are less likely to receive timely services, suggesting the need to address cultural barriers to care.

1.2.1 *Risk Factors and Etiologies*

As might be expected, the prevalence of hearing loss is higher among infants admitted to newborn intensive care units (NICUs) than infants in the well-baby population. In very highly developed countries, the prevalence of congenital hearing loss among NICU babies is estimated to be 5.9 per 1,000 infants, compared to 0.8 per 1,000 well babies (Butcher *et al.*, 2019). Globally, the difference is even greater, with prevalence among NICU infants estimated to be 15.8 per 1,000 (Bussé *et al.*, 2020). Bilateral hearing loss is also more frequent among NICU infants. 78% of NICU infants with hearing loss are affected in both ears, compared to 66% of well babies (Bussé *et al.*, 2020). The increased risk of hearing loss in the NICU population is likely related to medical conditions associated with both the hearing loss and the NICU admission, such as cranio-facial abnormalities, hyperbilirubinemia (jaundice), asphyxia requiring mechanical ventilation, and various syndromes. In addition, use of ototoxic antibiotics and high noise levels are common in many NICUs, which may affect the hearing of infants residing there (Butcher *et al.*, 2019).

Causes of congenital sensorineural hearing loss can be classified into two main types: genetic and non-genetic. Genetic causes can be further classified as either syndromic or non-syndromic. Syndromic causes account for 20–30% of genetic etiologies. Examples include Pendred syndrome (associated with thyroid problems), Usher syndrome (associated with the eye disease retinitis pigmentosa), Waardenburg syndrome (associated with pigmentation abnormalities), and branchiotorenal syndrome (associated with disorders of the neck and kidneys). Non-syndromic genetic hearing loss is much more common but highly heterogenous. More than 6,000 variants of over 100 genes have been associated with congenital hearing loss. However, half of all genetic hearing losses have been linked to two genes on the DFNB1 locus — the GJB2 and GJB6 genes which encode the connexin 26 and connexin 30 gap junction proteins (respectively) — and are thus responsible for regulating the potassium levels necessary for normal cochlear function. Most genetic hearing loss is transmitted through an autosomal recessive gene. As a result, as many as 90% of children with congenital hearing loss are born to normal-hearing parents (Mehra *et al.*, 2009; M. M. Li *et al.*, 2022; Shave *et al.*, 2022).

Non-genetic hearing loss is also quite heterogenous. Cochlear development occurs early in pregnancy, sometimes even before the pregnancy has been identified. Infections and environmental exposures during this period can lead to hearing loss in the infant. Congenital cytomegalovirus (cCMV) is the most common non-genetic cause of newborn hearing loss in the U.S. today. Approximately 1 in 200 babies is born with a cCMV infection. Most are asymptomatic at birth, but 10–15% will develop sensorineural hearing loss during childhood. Other non-genetic causes of infant hearing loss include maternal acquired immunodeficiency syndrome, toxoplasmosis, syphilis, and herpes. Maternal rubella was a common cause of congenital hearing loss in the past, but that is much rarer now due to vaccination programs (M. M. Li *et al.*, 2022; Shave *et al.*, 2022).

Other causes of infant hearing loss include complications during birth, premature birth, congenital malformations of the ear, and exposure to aminoglycoside and cyclophosmamide antibiotics. In some cases, the cause is simply unknown (Mehra *et al.*, 2009; Shave *et al.*, 2022).

1.2.2 *Interventions*

The primary goal in managing congenital hearing loss is usually to provide sufficient hearing for the normal development of speech and language. This may involve conventional hearing aids, bone-conduction hearing aids, frequency modulation (FM) systems, and/or cochlear implants. Conventional behind-the-ear hearing aids can be fit immediately upon identification, and JCIH (2019) recommends fitting no later than age 6 months. Cochlear implantation is now permitted at age 9 months, and over 65,000 U.S. children have received cochlear implants. Food and Drug Administration (FDA) trials of auditory brainstem implants are underway for cases in which cochlear implantation is not an option (e.g., severe cochlear abnormalities), with the goal of allowing this option for children as young as 18 months. In addition to amplification, all children should receive aural habilitation services to maximize aided hearing and facilitate language and cognitive development (Shave *et al.*, 2022).

1.3 Hearing in Childhood and Adolescence

Childhood hearing loss is not always present at birth. Some hearing losses may develop in early childhood due to a progressive congenital condition that does not manifest for several years (e.g., cCMV infection). Other hearing losses may be acquired during childhood and adolescence due to new illnesses or exposures (e.g., ear infections, noise exposure). Estimates of hearing loss prevalence in this population vary considerably depending on the definition of hearing impairment, ear(s) involved (i.e., one ear or both ears; better ear or worse ear), and age and scope of the group studied.

Data from NHANES III (collected from 1988–1994) indicated that 15% of children (over 7 million) aged 6–19 years had average low-frequency (500, 1,000, 2,000 Hz) or high-frequency (3,000, 4,000, 6,000 Hz) thresholds of 16 dB HL or greater in one or both ears. Most hearing losses were unilateral and "slight" (Niskar *et al.*, 1998). High-frequency hearing loss was more prevalent than low-frequency hearing loss. Nearly 5% of children had both low- and high-frequency threshold averages of 16 dB HL or more in one or both ears (Niskar *et al.*, 1998).

NHANES III data were re-analyzed for 12–19-year-olds using different definitions of hearing loss. This analysis showed that 3% of adolescents had unilateral speech-frequency hearing loss (20+ dB HL pure tone average across 500, 1,000, 2,000, and 4,000 Hz) and <1% had bilateral speech-frequency hearing loss. High-frequency hearing loss (20+ dB HL pure tone average across 3,000, 4,000, and 6,000 Hz) was more prevalent. 6% of adolescents had unilateral high-frequency hearing loss and 2% had bilateral loss. These results were compared to earlier data from 1966–1970 and more recent data from NHANES 2005–2010. As shown in Table 1.1, the prevalence of hearing loss had declined substantially since the 1960s and remained stable through the 2000s (Hoffman *et al.*, 2019).

Mehra *et al.* (2009) reviewed eight studies of childhood hearing loss prevalence conducted in the U.S. between 1958 and 1995. The studies

Table 1.1. Prevalence of speech-frequency and high-frequency hearing loss in a nationally representative sample of U.S. adolescents over time.

	Prevalence[a]					
	Speech-Frequency Hearing Loss[b]			**High-Frequency Hearing Loss**[c]		
Survey Years	**Overall (%)**[d]	**Unilateral (%)**	**Bilateral (%)**	**Overall (%)**	**Unilateral (%)**	**Bilateral (%)**
1966–1970[e]	11	7	3	33	19	14
1988–1994[f]	4	3	1	7	6	2
2005–2010[f]	5	4	1	8	6	2

[a]Prevalence of hearing loss (Hoffman *et al.*, 2019).
[b]Pure tone average threshold of 20 dB HL or greater across 500, 1,000, 2,000, and 4,000 Hz.
[c]Pure tone average threshold of 20 dB HL or greater across 3,000, 4,000, and 6,000 Hz.
[d]All estimates are rounded and may not equal the overall values.
[e]Data from the National Health Examination Survey for participants aged 12–17 years.
[f]Data from the National Health and Nutrition Examination Survey for participants aged 12–19 years.

included NHANES as well as other surveys which reached populations potentially excluded by NHANES, such as children with developmental disabilities who may not be living in their homes. Ages included in the studies ranged from 3–18 years. They reported an average prevalence of mild or worse hearing loss (pure tone average >25 dB HL across 500, 1,000, and 2,000 Hz) in one or both ears of 3% and an average bilateral mild or worse hearing loss prevalence of 1%. They also examined estimates of moderate or worse hearing impairment (pure tone average >40 dB across 500, 1,000, and 2,000 Hz) and reported a bilateral prevalence of <1% (0.3%).

Tinnitus is often considered a problem limited to adulthood but actually impacts a substantial number of youths as well. Data from NHANES (collected from 2005–2008) indicate that 8% of adolescents aged 12–19 years (2.5 million) report having been bothered by tinnitus that lasts for five minutes or more in the preceding 12 months. Chronic tinnitus (i.e., lasting for three months or longer) affects 5% of adolescents (1.6 million). Prevalence increases with age. Fortunately, very few adolescents report that their tinnitus is a severe problem (Mahboubi *et al.*, 2013).

1.3.1 *Demographic Characteristics and Risk Factors*

Most studies have shown a higher prevalence of hearing loss among boys than girls. Mehra *et al.* (2009) reported an average male to female ratio of 1.24 to 1 in the studies they reviewed. Niskar *et al.* (1998) and Hoffman *et al.* (2019) found an increased prevalence of high-frequency hearing loss in boys but no difference between boys and girls in speech-frequency hearing loss. Reported differences by race/ethnicity are inconsistent. Other factors which have been shown to influence prevalence include family economic status, history of ear infections or ear tubes, history of smoking, elevated body mass index, and exposure to continuous loud noise or music for 5+ hours per week (Hoffman *et al.*, 2019; Niskar *et al.*, 1998; Mehra *et al.*, 2009).

Unlike hearing loss, the prevalence of tinnitus is higher among adolescent girls than boys. Tinnitus prevalence does not vary by race in this age group. Risk of tinnitus is lower among adolescents who live in higher-income families. It is higher among those who have a history of recreational or firearms noise exposure, three or more ear infections in their lifetime, or have had ear tubes (Mahboubi *et al.*, 2013).

Otitis media, or middle ear infection, is a very common cause of hearing loss among young children. Half of U.S. children have had at least one ear infection by the time they are a year old, and 90% have had an ear infection by the time they turn five. Ear infections can cause conductive hearing loss, which may be temporary or chronic. Even transient ear infections can cause developmental delays and impact academic achievement (Smith & Boss, 2010). Data from the Early Childhood Longitudinal Study–Kindergarten Class of 2010–2011 (NCES, 2016) show that children who have ever had three or more ear infections have lower reading scores than children who have had 0–2 ear infections, and that the performance deficit remains over time (see Figure 1.1). There is no significant difference in scores between children who had zero and 1–2 ear infections

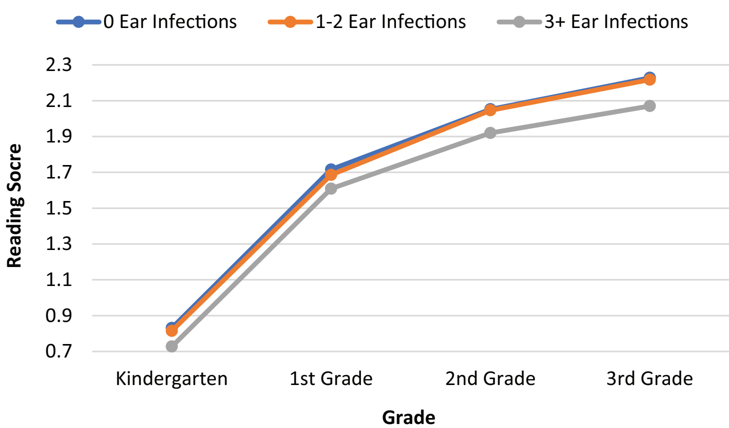

Figure 1.1. Average reading scores over time in a nationally representative sample of U.S. elementary school children based on number of lifetime ear infections. Adapted with permission from presentation "Impact of Ear Infection History and Hearing Impairment on Children's Academic Achievement in Primary School: The U.S. Early Childhood Longitudinal Study–Kindergarten Class of 2010–11 (ECLS–K:2011)" (C. M. Li *et al.*, 2022). Average reading scores have a potential range from −8 to 8 and higher numbers indicate a better reading level (NCES, 2018).

($p = 0.1411$). Scores for children who had 3+ ear infections are significantly different from those who had zero ear infections ($p < 0.0001$) and those who had 1–2 ear infections ($p = 0.0004$). Math and science scores are similarly affected (data not shown).

Noise exposure is an increasing concern among children, particularly adolescents. A recent report from the World Health Organization (2015) stated that nearly half of all teenagers and young adults (aged 12–35 years) in middle- and high-income countries are exposed to hazardous sounds from personal music players. A nationally representative survey of U.S. children under age 18 reported that more than nine million children have been exposed to noise from firearms and over 20 million have been exposed to other explosive sounds (e.g., firecrackers). Nearly six million children are exposed to very loud sounds (i.e., sounds so loud you would have to shout to be heard by someone an arm's length away) at least 10 times a year. Consistent use of hearing protection devices during any of these exposures in the preceding 12 months was poor, ranging from 6–17% (Bhatt *et al.*, 2020).

1.3.2 *Intervention and Prevention*

Hearing screening is recommended throughout childhood and adolescence to identify progressive hearing losses which were not identified by the newborn hearing screening as well as hearing losses which develop due to other causes. In addition, the U.S. is home to many immigrant children who may not have been screened at birth. Pape *et al.* (2014) estimated that more than 18,000 children with hearing loss may emigrate to the U.S. each year. Hearing screening is not included in the medical exam conducted upon entering the country. These children may not be identified until or unless they receive a hearing screening in school.

The American Speech-Language-Hearing Association (ASHA) recommends that school-based hearing screenings be provided for all children at their initial entry into school, annually from kindergarten through third grade, and again in grades 7 and 11 (ASHA, 2002). The American

Academy of Audiology (AAA) has similar guidelines (AAA, 2011). School-based screenings are mandatory in 37 states and suggested in five others. Eight states have no school screening requirement. The grades covered and screening procedures vary (ASHA, 2022). Audiologists should be aware of the screening requirements in their state and make an effort to provide screening services where gaps exist. Early identification and intervention remain important throughout childhood and even beyond.

As the saying goes, however, an ounce of prevention is worth a pound of cure. In their review, Mehra *et al.* estimated that 20% of acquired childhood cases of moderate or worse hearing loss are due to environmental causes, and that providing prevention opportunities could substantially reduce the incidence of new cases (Mehra *et al.*, 2009). Improved access to care to reduce the prevalence of ear infections, and interventions to reduce noise exposure and increase use of hearing protection among children and adolescents, have the potential to prevent many more cases of slight and mild hearing loss.

1.4 Hearing Among Adults

There is a significant burden of hearing loss in the adult population of the United States. It is the 3rd most common chronic physical health condition among adults after hypertension and arthritis, and is more prevalent than diabetes, vision trouble or cancer (Blackwell *et al.*, 2014; NCHS, 2018). 15% of U.S. adults report hearing difficulty (NCHS, 2018) and about 11% report tinnitus (Zelaya *et al.*, 2015a). Risk factors for hearing conditions among all adults include age, gender, race and recreational noise exposures.

1.4.1 *Gender and Hearing*

Hearing difficulty is more prevalent among men (19%) than women (12%) (NCHS, 2018) and males have a higher risk of reporting hearing difficulty

(Masterson *et al.*, 2016a). This is due, at least in part, to a difference in exposures. Males tend to have a greater overall average of noise exposures, and in certain occupations, males have greater noise exposures than women in the same occupation (Flamme *et al.*, 2012). Males also more frequently use firearms (Knewitz *et al.*, 2020) and have a higher prevalence of smoking (Cornelius *et al.*, 2020). However, females are less likely than males to wear hearing protection when exposed to loud noise, at least in the workplace (Green *et al.*, 2021). Tinnitus is slightly more prevalent among males than females (Masterson *et al.*, 2016a; Shargorodsky *et al.*, 2010). This is a change from adolescence, where tinnitus was slightly more prevalent among females. Males also have a higher risk of reporting tinnitus (Masterson *et al.*, 2016a; Shargorodsky *et al.*, 2010).

1.4.2 *Hearing by Age*

The prevalence and risk of hearing difficulty increases with age (Masterson *et al.*, 2016a; NCHS, 2018), due to age-related hearing loss (presbycusis) and the effects of an accumulation of harmful exposures (e.g., noise). 6% of adults aged 18–44 report hearing difficulty, compared with 18% of those aged 45–64, 32% of those aged 65–74, and 47% of those aged 75 and over (NCHS, 2018). The prevalence and risk of tinnitus also increases with age, but with much smaller increments in each age group, beginning at 5% in the 18–25 age group and increasing to 18% in the 70+ age group (Masterson *et al.*, 2016a; Zelaya *et al.*, 2015a).

1.4.3 *Race and Hearing*

Hearing sensitivity differs by race. The prevalence and risk of hearing loss decreases as pigmentation increases (Flamme *et al.*, 2019; Themann *et al.*, 2013). Hence, those of White race typically have the poorest hearing and those of Non-Hispanic Black race have the best hearing, in the absence of exposures. This may be due to a protective effect of more melanin in the cochlear hair cells of those with darker skin (Themann *et al.*, 2013). In addition to those of White race, hearing loss is often observed to be high among those in the Other race category, typically including those with mixed race or of a race group with too few participants to be counted separately. Hearing difficulty is often high in this Other race category if it includes those who are American Indian or Alaska Native (Masterson *et al.*, 2016a; NCHS, 2018). While those of Non-Hispanic Black race typically have the lowest prevalences and risks, their risks are often fairly similar to those of Hispanic and Asian races (Hoffman *et al.*, 2017; Kerns *et al.*, 2018; Masterson *et al.*, 2016a). The prevalences of hearing difficulty among U.S. adults by race are 20% (American Indian or Alaska Native), 17% (White), 11% (Hispanic or Latino), 10% (Asian), and 9% (Black or African American) (NCHS, 2018).

A similar pattern is observed for tinnitus. Tinnitus is typically highest among those with White race or Other race/ethnicity (Masterson *et al.*, 2016a; Shargorodsky *et al.*, 2010). In the Masterson *et al.* (2016a) study, Other race/ethnicity included American Indian, Alaska Native, race group not releasable (due to small sample size) and multiple race. Those of Non-Hispanic Black race, Hispanic race and Asian race typically have similar prevalences of tinnitus, all well below the prevalence for those of White race (Masterson *et al.*, 2016a; Shargorodsky *et al.*, 2010).

1.4.4 *Recreational Noise Exposure*

While some risk factors are not preventable, non-occupational (recreational) noise exposure can be reduced or avoided. In CDC population surveys, typically recreational noise exposures are measured in the two categories of firearm use and a combination of other non-occupational noise exposures. Firearm use is usually not explicitly separated from occupational firearm use and some instances of occupational weapons fire exposures may be included. Among adults aged 20–69 years, 46%

report any use of firearms, with 32% reporting some use of firearms (firing <1,000 rounds) and 13% reporting using firearms repeatedly (firing ≥1,000 rounds) (Hoffman *et al.*, 2017; Knewitz *et al.*, 2020). Firearms produce peak sound pressure levels of about 130–170 dB (Malowski *et al.*, 2022). At these sound levels, exposure to a single gunshot in the absence of hearing protection can cause tinnitus or permanent hearing loss in some individuals. Unfortunately, only 67% of adults who report firing between 1,000 and 10,000 rounds also report consistently wearing hearing protection (Bhatt *et al.*, 2017). Identifying this potentially high-risk recreational exposure creates an opportunity for audiologists to educate the patient about hearing protection and the importance of preserving their remaining hearing.

About 12% of adults aged 20–69 report having recreational noise exposure (Knewitz *et al.*, 2020). This was defined, in part, as "exposure to very loud noise or music for 10 or more hours a week" and included examples "power tools, lawn mowers, farm machinery, cars, trucks, motorcycles, motorboats or loud music" (Knewitz *et al.*, 2020). Only 11% of adults who report exposure to loud or very loud recreational noise also report always wearing hearing protection, and 62% report never wearing it during this type of exposure (Bhatt *et al.*, 2017).

1.4.5 *Overall Trends*

The prevalence of hearing difficulty in the U.S. adult population has remained fairly steady, hovering at 14–15% since 2007 (Masterson *et al.*, 2016a; NCHS, 2013; NCHS, 2018). The prevalence of tinnitus also remained relatively steady, only increasing from 10% in 2007 (Masterson *et al.*, 2016a) to 11% in 2014 (Zelaya *et al.*, 2015a), the most recent year the NHIS included a tinnitus question for analysis. The trends are more difficult to identify with firearm use and recreational noise exposure due to significant changes in the wording of survey questions over time. The prevalence of exposure to noise from firearms outside of work at least once a month among adults aged 20–69 was 6% during NHANES survey years 1999–2002 (Spankovich & Le Prell, 2013). The prevalence of those firing at least 1,000 rounds in their lifetime was 13% during NHANES survey years 2011–2012 (the latest estimates available) (Hoffman *et al.*, 2017). At first glance, it appears that recreational noise exposure decreased from 25% during NHANES survey years 1999–2002 (Spankovich & Le Prell, 2013) to 12% during NHANES survey years 2011–2012 (Knewitz *et al.*, 2020), but again the survey questions were substantially different. The earlier surveys asked about loud exposure at least once a month. The 2011–2012 surveys asked about very loud noise exposure for 10 or more hours a week.

1.5 Hearing in the Working Population

More than 90% of U.S. adults have worked sometime in their lifetime. Framed from a risk perspective, >90% have a history of exposure to work (Luckhaupt & Calvert, 2010; Masterson *et al.*, 2016a). Two important classifications of work are industry and occupation. Industry refers to the type of business (where a person works) and occupation refers to the type of work (what a person does). These concepts will become relevant in the discussion below.

Hearing loss is one of the most common work-related illnesses — on any given day, either hearing loss or skin conditions is the most common (Themann *et al.*, 2013). About 12% of the U.S. adult working population has hearing difficulty (Kerns *et al.*, 2018). Notice that this is lower than the percentage of the entire U.S. adult population with hearing difficulty (15%) (NCHS, 2018). This is due in part to the healthy worker effect. Workers usually exhibit lower overall rates of illness and death than the general population because those who are severely ill or disabled often cannot work (Farlex, 2012; Shah, 2009). Also, the retired, who are typically older than the working population, have poorer hearing. This masking of effect due to who is in or out of the population under study does not mean workers have a lower risk of hearing loss (Shah, 2009).

Approximately 24% of worker hearing difficulty is attributable to employment (Tak & Calvert, 2008). OHL is caused almost entirely by exposure to hazardous noise and ototoxic chemicals (chemicals causing damage to the auditory system) (Themann *et al.*, 2013). It is important for audiologists to recognize how common these hearing hazards are and to identify the highest risk groups for increased engagement and intervention.

1.5.1 *Ototoxic Chemical Exposures*

Ototoxic chemicals can cause OHL in the absence of noise, make the ear more susceptible to the damaging effects of noise, or both, with potential synergistic effects. A synergistic effect occurs when the combined effect of noise and a chemical or mixture of chemicals is greater (multiplicative) than the effect of simply adding the two effects. Ototoxic chemical classes include solvents, heavy metals, nitriles, pharmaceuticals, and asphyxiants (Campo *et al.*, 2013; Johnson & Morata, 2010; OSHA & NIOSH, 2018). These are common chemicals such as industrial cleaners, thinners, paints, lacquers, industrial glues, pesticides, antineoplastic drugs, lead, organic tin compounds, organic cyanides, tobacco smoke and engine exhaust. Many are commonly found in loud workplaces (Johnson & Morata, 2010).

However, there is no national prevalence estimate of worker ototoxic chemical exposure, or overall estimates by industry or occupation. Only two national estimates exist for subgroups of ototoxicants. The first is for one class of ototoxicant (solvents) from 1987, indicating that about 10 million workers are exposed to solvents (NIOSH, 1987). The second is for tobacco smoke, one type of another class of ototoxicant. Approximately 10% of workers are exposed to secondhand tobacco smoke (Dai & Hao, 2017). Industry and occupation-specific prevalence estimates are also available. The industries with the highest prevalences of secondhand smoke exposure are Construction (23%), Transportation and Warehousing (22%), and Accommodation and Food Services (18%). Occupations with the highest prevalences are Protective Service (29%), Construction and Extraction (25%), Transportation and Material Moving (24%), and Installation, Maintenance and Repair (20%) (Dai & Hao, 2017). An unknown number or percentage of workers are exposed to other ototoxicants. However, a NIOSH-funded study is expected to obtain data for the development of national estimates in the next few years.

1.5.2 *Occupational Noise Exposure*

While ototoxic chemical exposures are an important risk factor, occupational noise exposure is the predominant cause of OHL (Themann *et al.*, 2013). In the U.S., 25% of workers have a history of occupational noise exposure (41 million), with 14% exposed in the prior year (22 million) (Kerns *et al.*, 2018). More than half (53%) of these noise-exposed workers do not wear their hearing protection consistently (Green *et al.*, 2021). 58% of worker hearing difficulty cases are caused by occupational noise exposure (Kerns *et al.*, 2018). This is highlighted by the dramatic difference in the prevalence of hearing difficulty among noise-exposed workers (23%) and non-noise-exposed workers (7%) (Masterson *et al.*, 2016a). Similarly, the prevalence of tinnitus is 15% among noise-exposed workers and 5% among non-exposed workers (Masterson *et al.*, 2016a). 16% of noise-exposed U.S. workers have a material hearing impairment in one or both ears (Lawson *et al.*, 2019). This means that their hearing loss is severe enough that they have difficulty understanding speech. Noise-exposed workers with material hearing impairment have been identified in every industry sector, and no industry can be considered 'safe' from exposures that can damage hearing (Masterson *et al.*, 2013). However, there are some industries and occupations with particularly high prevalences of noise exposure. Other industries or occupations have fewer workers overall who are exposed, and among those exposed, have incredibly high numbers who do not wear their hearing protection (Green *et al.*, 2021). Both lead to increased risks for hearing loss.

1.5.3 *Exposures and Outcomes Among Industries*

As might be expected, the industries and occupations identified with more prevalent noise exposure are also typically those with the highest prevalences of hearing loss and tinnitus, and with greater losses of quality of life (negative outcomes). Focusing on industry first, Table 1.2 depicts statistics for workers in the three industry sectors consistently ranked at the top for burden and risk of hearing loss. These are compared with statistics for workers in all industries combined. The prevalences of workers exposed to noise are high. Ideally all of these noise-exposed workers would wear their hearing protection during exposure. The numbers indicate this is not happening, and for a wide range of issues beyond the scope of this chapter. What follows are high levels of hearing issues. While less information is

Table 1.2. Prevalence of occupational noise exposure, non-use of hearing protection, hearing difficulty, tinnitus, material hearing impairment, and incidence of material hearing impairment among workers in the Mining, Construction and Manufacturing sectors compared with all industries combined.

	Prevalence					Incidence
Industry	**Occupational Noise Exposure (%)**[a]	**Non-Use of HPDs (%)**[b]	**Hearing Difficulty (%)**[c]	**Tinnitus (%)**[d]	**Material Hearing Impairment (%)**[e]	**Material Hearing Impairment (%)**[f]
All Industries	25	53	12	8	16	7
Mining	61	28	23	11	24	8
Construction	51	52	14	7	25	9
Manufacturing	47	28	18	11	20	7

[a]Prevalence of self-reported occupational noise exposure among all workers (Kerns *et al.*, 2018).

[b]Prevalence of self-reported non-use of hearing protection devices (HPDs) among noise-exposed workers (Green *et al.*, 2021).

[c]Prevalence of self-reported hearing difficulty among all workers (Kerns *et al.*, 2018).

[d]Prevalence of self-reported tinnitus among all workers (Masterson *et al.*, 2015).

[e]Prevalence of material hearing impairment among noise-exposed workers defined as an average hearing threshold across frequencies 1,000, 2,000, 3,000, and 4,000 Hz of 25 dB or more in either ear, among noise-exposed workers (Lawson *et al.*, 2019; Masterson *et al.*, 2015).

[f]Incidence of material hearing impairment among noise-exposed workers for the time period 2006–2010 (Masterson *et al.*, 2015).

available for the Railroads industry, 35% of its workers report hearing difficulty, the highest of any industry (Tak & Calvert, 2008).

Quality of life is affected by hearing loss and tinnitus. Reductions in quality of life can be quantified in different ways to allow comparisons across groups. One important measure is disability-adjusted life years (DALYs), which are the number of healthy years lost due to a disease or other health conditions. The DALYs calculation assigns a "disability weight" which takes into account life limitations caused by a condition and represents a lost portion of a healthy year of life. DALYs associated with hearing loss among noise-exposed U.S. workers were estimated taking into account hearing impairment (i.e., hearing loss that affects day-to-day activities), the impact of tinnitus and mental health (Global Burden of Disease Study 2013 Collaborators, 2015; Masterson *et al.*, 2016b).

Over 2.5 healthy years are lost, each year, for every 1,000 noise-exposed U.S. workers because of hearing impairment (Masterson *et al.*, 2016b). The 13% of noise-exposed workers with hearing impairment in both ears (about 130 workers out of each 1,000 workers) share the loss of these healthy years. Over a 30-year working lifetime, about 76 healthy years are lost by these 130 workers out of each 1,000, with more highly impaired workers losing more healthy years (see Table 1.3). These workers lose even

Table 1.3. Healthy years lost because of bilateral hearing impairment among noise-exposed U.S. workers in the Mining, Construction and Manufacturing sectors compared with all industries combined (Masterson *et al.*, 2016b).

Industry	Healthy Years Lost per 1,000 Workers Each Year[a]	Bilateral Material Hearing Impairment (%)[a]	Number with Bilateral Hearing Impairment per 1,000 Workers[a]	Healthy Years Lost over a 30-Year Working Lifetime per 1,000 Workers[a,b]
All Industries	2.5	13	130	76
Mining	3.5	17	170	105
Construction	3.1	16	160	93
Manufacturing	2.7	14	140	81

[a]Among noise-exposed workers

[b]Shared among workers with bilateral impairment

more healthy years during retirement. The three industries where workers lose the greatest number of healthy years of life are Mining, Construction and Manufacturing. Mining workers lose 3.5 healthy years, each year, for every 1,000 workers. These lost healthy years are shared among the 17% of noise-exposed Mining workers with hearing impairment in both ears. Over a 30-year working lifetime, about 105 healthy years are lost by 170 workers out of each 1,000. Construction sector workers lose 3.1 healthy years, each year, for every 1,000 workers. These lost healthy years are shared among the 16% of noise-exposed Construction workers with hearing impairment in both ears. Over a 30-year working lifetime, about 93 healthy years are lost by 160 workers out of each 1,000. Manufacturing workers lose 2.7 healthy years, each year, for every 1,000 workers because of hearing impairment. These lost healthy years are distributed among the 14% of noise-exposed Manufacturing workers with hearing impairment in both ears. Over a 30-year working lifetime, about 81 healthy years are lost by 140 workers out of each 1,000. Approximately 70% of the healthy years lost by all U.S. noise-exposed workers are lost within the Manufacturing sector (Masterson *et al.*, 2016b).

Manufacturing, Construction and Mining are large industry sectors, and within each are smaller industries, each with their own prevalence of hearing loss. Often the overall prevalence for a sector is lower than some of its industries because it incorporates lower- and higher-risk industries. For example, while the overall prevalence of material hearing impairment among noise-exposed workers in Mining is 24%, the prevalence is 31% in Uranium-Radium-Vanadium Ore Mining (Lawson *et al.*, 2019). There are industries in every sector with a high burden of hearing loss, including in sectors/industries where low or no exposure would be expected. For example, the prevalence of material hearing impairment among noise-exposed workers is higher than expected in Office of Real Estate Agents and Brokers (23%), Elementary and Secondary Schools (26%), Administration of Public Health Programs (27%), Software Publishers (33%), and Depository Credit Intermediation (within Finance) (36%) (Masterson *et al.*, 2013). This illustrates that the name of the industry may alert you to potential patient exposures, but does not exclude their possibility.

1.5.4 *Exposures and Outcomes Among Occupations*

A lack of longitudinal worker audiometric data with associated occupation information has precluded the examination of incidence and material hearing impairment by occupation. However, information on self-reported occupational noise exposure, non-use of hearing protection, hearing difficulty and tinnitus are available (see Table 1.4). Installation, Maintenance and Repair, and Production are consistently occupations with higher risks for hearing loss. These are followed closely by Protective Service, Construction and Extraction, and Architecture and Engineering. Notice the high prevalence of tinnitus in the Architecture and Engineering occupation. This is more evidence that high-risk workers can be found in surprising fields.

There is an important pattern that occurs in both industries and occupations, described here using occupation. Many occupations with a higher prevalence of noise-exposed workers have more of those workers wearing their hearing protection. Conversely, occupations with fewer

Table 1.4. Prevalence of occupational noise exposure, non-use of hearing protection, hearing difficulty, and tinnitus among workers in high-risk occupations compared with all occupations combined.

Occupation	**Occupational Noise Exposure (%)**[a]	**Non-Use of HPDs (%)**[b]	**Hearing Difficulty (%)**[c]	**Tinnitus (%)**[d]
All Occupations	25	53	12	8
Installation, Maintenance and Repair	54	51	22	10
Production	55	27	17	9
Protective Service	36	57	16	7
Construction and Extraction	54	48	15	7
Architecture and Engineering	36	17	15	13

[a]Prevalence of self-reported occupational noise exposure among all workers (Kerns *et al.*, 2018).

[b]Prevalence of self-reported non-use of hearing protection devices (HPDs) among noise-exposed workers (Green *et al.*, 2021).

[c]Prevalence of self-reported hearing difficulty among all workers (Kerns *et al.*, 2018).

[d]Prevalence of self-reported tinnitus among all workers (Masterson *et al.*, 2016a).

noise-exposed workers tend to have more exposed workers not wearing their hearing protection (Green *et al.*, 2021; Tak *et al.*, 2009). Fewer workers wearing hearing protection is likely due to many factors, including a lower awareness of noise as a hazard, poorly funded or operated hearing conservation programs, and a lower priority for reducing noise among the small percentage of affected workers compared with other workplace hazards (Green *et al.*, 2021). Occupations with the highest prevalence of worker non-use of hearing protection when exposed to noise include Healthcare Support (94%), Food Preparation and Serving Related (90%), Education, Training and Library (87%), Community and Social Services (83%) and Healthcare Practitioners and Technical (82%) (Green *et al.*, 2021).

1.5.5 *Overall Trends*

The number of U.S. noise-exposed workers has remained fairly steady between study data years 1999–2004 and 2014 at 22 million each year, although affecting a lower percentage of workers (17% and 14%, respectively) (Kerns *et al.*, 2018; Tak *et al.*, 2009). There was a large increase in hearing protection non-use between study data years 1999–2004 (37%) and 2007 (56%), with a statistically non-significant reduction in 2014 (53%) (Green *et al.*, 2021; Tak *et al.*, 2009). The prevalence of hearing difficulty has remained fairly steady since study data years 1997–2003, hovering near 11–12% (Kerns *et al.*, 2018; Masterson *et al.*, 2016a; Tak & Calvert, 2008).

Among noise-exposed workers, the prevalence of material hearing impairment changed little between 1985 and 2010, decreasing from 20% to 19% (Masterson *et al.*, 2015), and currently is approximately 16% (Lawson *et al.*, 2019). The five-year incidence also changed little over 25 years, decreasing from 9% to 7% between 1986 and 2010. The overall adjusted risk for hearing loss among noise-exposed workers did decrease 46% between 1985 and 2010 (Masterson *et al.*, 2015). This was likely due to a number of factors, including the expansion of noise regulations, an overall reduction in the prevalence of smoking, and better treatment of middle ear disorders (Masterson *et al.*, 2015).

1.6 Hearing Among the Elderly

As stated earlier, the prevalence of hearing loss increases with age and is highest among the elderly. In the U.S., the prevalence of bilateral hearing loss (pure tone average of 25+ dB HL across 500, 1,000, 2,000, and 4,000 Hz) grows from 27% among adults in their 60s to 55% among adults in their 70s and 82% among adults aged 80 years and older (Goman & Lin, 2016). On average, hearing levels worsen by about 1 dB per year after age 60 (Lee *et al.*, 2005). The prevalence of tinnitus also increases with age, as does its severity (Bhatt *et al.*, 2016; Zelaya *et al.*, 2015a). Individuals aged 70 and older are more likely to discuss their hearing difficulties with their doctor than younger individuals, but only a little over half report doing so in the past five years (Zelaya *et al.*, 2015b).

Some degree of presbycusis was once considered an inevitable part of the aging process. However, a growing body of evidence indicates that it may be largely a function of cumulative lifetime exposures and health conditions. These include noise, ototoxic medications or chemicals, nutritional deficiencies, smoking or alcohol use, stress, and cardiovascular disease. Some isolated populations show hardly any hearing decline even among the very elderly (Rosen *et al.*, 1962). Several studies have indicated that age-related hearing loss accrues differently among those with and without a history of prior noise exposure (Gates *et al.*, 2000; Moore, 2021), although the evidence is conflicting (Hederstierna & Rosenhall, 2016; Macrae, 1971). The possibility that early life experiences might alter one's "hearing health trajectory" opens avenues for reducing the burden of hearing loss later in life that may warrant serious consideration by health professionals and policy makers (Davis *et al.*, 2016).

Nonetheless, genetic factors likely play some role in the development of hearing loss with age. Several genes have been identified which appear to influence susceptibility to age-related hearing loss, including KCNQ4 (which regulates potassium channels in the cochlea), ACTG1 (which encodes actin proteins necessary for outer hair cell motility), and GRM7 and GRHL2 (which manage oxidative stress). In some cases, particularly in severe cases with no other known contributing factors, what appears to

Table 1.5. Prevalence of bilateral speech frequency hearing loss by age, gender, and race/ethnicity in older U.S. adults.[a]

	Prevalence of Hearing Loss[b]					
	Gender		**Race/Ethnicity**			
Age	**Male (%)**	**Female (%)**	**Non-Hispanic White (%)**	**Non-Hispanic Black (%)**	**Hispanic (%)**	**Overall (%)**
60–69 years	39	17	27	16	29	27
70–79 years	64	48	55	41	57	55
80+ years	86	79	83	66	74	81

[a]Adapted from results reported in Goman & Lin (2016), examining data from NHANES years 2001–2010.

[b]Hearing loss is defined as a pure tone average threshold greater than 25 dB HL across 500, 1,000, 2,000, and 4,000 Hz in both ears.

be presbycusis may actually be previously undiagnosed adult-onset genetic hearing loss (M. M. Li *et al.*, 2022).

Differences in prevalence by gender and race/ethnicity follow the same pattern in the elderly as in the adult U.S. population. Prevalence of bilateral hearing loss (pure tone average >25 dB HL across 500, 1,000, 2,000, and 4,000 Hz) is higher in males than females in each age decade (see Table 1.5). Although the difference in prevalence becomes smaller at older ages, median threshold levels in men are poorer than in women in each corresponding age range. This difference is particularly evident at frequencies 2,000 Hz and above, which are the frequencies most affected by aging (Hoffman *et al.*, 2017). As with younger adults, the prevalence of hearing loss is lower in Non-Hispanic Blacks than in Non-Hispanic Whites and Hispanics (see Table 1.5).

The prevalence of hearing loss among the elderly in the U.S. has been decreasing over the past several decades. National data on hearing of individuals aged 65–74 years from 1959–1962 showed a prevalence of hearing loss (better ear pure tone average >25 dB HL across 500, 1,000, 2,000, and 4,000 Hz) of 48%. This was 59% among men and 39% among women. Comparable data from 1999–2006 found an overall prevalence of

36%, representing a 25% drop (46% among men and 27% among women). Potential reasons for the decline in prevalence could include fewer jobs involving hazardous noise, reduction in smoking prevalence, and improvements in managing chronic diseases such as hypertension and diabetes. Although the prevalence of hearing loss in the elderly is decreasing, the total number of older individuals in the U.S. is growing. Therefore, the number of older Americans with hearing loss is expected to continue to grow in the coming years (Hoffman *et al.*, 2017).

Data from the Beaver Dam Epidemiology of Hearing Loss Study and associated Beaver Dam Offspring Study, which follow a set of participants over time, paint a more detailed picture of changes in prevalence. Prevalence of hearing loss was calculated among participants in the two studies grouped into five-year categories based on their birth year from 1905–1909 to 1960–1964. The odds of hearing loss in each subsequent birth cohort were 13% lower among men and 6% lower among women. The birth cohort effect decreased with increasing age, indicating that age-related hearing loss eventually occurred but was delayed in onset. These findings support the concept of a "hearing health trajectory" established by early life experiences. Interventions aimed at reducing risk factors such as smoking, noise exposure, and cardiovascular disease at younger ages may influence hearing loss risk at older ages (Zhan *et al.*, 2010).

1.6.1 *Associations with Other Health Conditions*

Hearing health is an integral part of overall health and well-being in the elderly. NHIS data from 2011–2013 indicate that individuals aged 65 years and older who self-report hearing difficulty are significantly more likely to report fair/poor overall health and a decline in health over the past 12 months than individuals who do not report hearing loss (McKee *et al.*, 2018). The Health, Aging and Body Composition (Health ABC) Study, which enrolled over 3,000 independent, community-dwelling adults in their 70s and followed them for more than 15 years, found that those with pure tone average hearing loss of 25+ dB HL at 500, 1,000, 2,000, and 4,000 Hz had a 20% increased risk of mortality compared to those with better hearing, after controlling for cardiovascular risks (Genther *et al.*, 2015b). This study also found that risk of initial hospitalization after enrollment increased by 11% for every 10 dB increase in average hearing threshold up to 40 dB HL. Risk of subsequent hospitalizations increased by 5% with each 10 dB increase in hearing (Genther *et al.*, 2015a).

Hearing loss has been reported to be associated with a number of specific health problems. Older adults with hearing loss may be at increased risk for falls, which is a common cause of disability and mortality among the elderly. An analysis of NHANES data found that the odds of having fallen in the past 12 months increased by 1.6 for every 10 dB increase in the pure tone average of 500, 1,000, 2,000, and 4,000 Hz, after controlling for demographic variables as well as cardiovascular and vestibular risk factors (Lin & Ferrucci, 2012). Hearing and balance are related sensory systems, which could explain the association. Another hypothesis is decreased auditory awareness of the environment. Hearing loss has also been associated with increased frailty, which is another a risk factor for falling (Kamil *et al.*, 2016).

Hearing loss has been linked with a myriad of other health conditions common among the elderly, though the strength of evidence varies by condition. Some studies have linked hearing loss and cardiovascular disease, hypertension, and stroke, though conflicting evidence points to the need for better studies (Besser *et al.*, 2018; NASEM, 2016). A growing number of studies are finding associations between hearing loss and diabetes (Besser *et al.*, 2018; NASEM, 2016), obesity (NASEM, 2016, W. Li *et al.*, 2022), and chronic inflammatory diseases including arthritis (Besser *et al.*, 2018; NASEM, 2016). Depression has been associated with moderate hearing loss in the elderly, particularly in women (Li *et al.*, 2014), as well as moderately bothersome tinnitus (Loprinzi *et al.*, 2013). At least one study has reported poorer mental health among spouses of individuals with hearing loss (Wallhagen *et al.*, 2004). While more research is underway, health care providers should be aware of these potential associations and refer patients for additional evaluations when co-occurring conditions are suspected.

Evidence of a link between hearing loss and cognitive decline has received much attention recently. Mild cognitive impairment is a reduction in cognitive function that results in difficulty with complex tasks but does not interfere with independent living. It often precedes dementia, which is a more severe cognitive decline that impacts activities of daily living. Both conditions are overall terms that encompass a range of diseases, of which Alzheimer's is one of the most common (Livingston *et al.*, 2017). A combined analysis of studies which prospectively followed individuals over time to see which factors contribute to the development of incident dementia found a risk ratio of 1.9 for hearing loss (Livingston *et al.*, 2017). This means that individuals who develop hearing loss in middle age (45–65 years) are nearly twice as likely to eventually develop dementia as those who do not. The same analysis estimated that 9% of new dementia cases could be avoided if hearing loss in middle age were eliminated (Livingston *et al.*, 2017).

1.6.2 *Hearing Aid Use*

While many older adults with hearing loss could benefit from hearing aids, uptake is low. Only 14% of U.S. adults aged 50 and over with hearing loss greater than 25 dB HL in both ears (pure tone average across 500, 1,000, 2,000, and 4,000 Hz) use a hearing aid consistently, meaning at least once per day or five hours per week. In general, hearing aid uptake increases with increasing age and severity of hearing loss. Prevalence of use is less than 4% among those with mild hearing loss (pure tone average 25–40 dB HL). Prevalence of use for moderate hearing loss (pure tone average >40 dB HL) increases with each age decade from 12% among those aged 50–59 to 48% among those aged 70–79, then declines among those aged 80 and older (36%). An estimated 23 million Americans adults aged 50+ who could benefit from hearing aids do not use them (Chien & Lin, 2012).

Among those who have a better ear pure tone average (500, 1,000, 2,000 Hz) of 35+ dB HL or self-report moderate or worse hearing trouble, hearing aid use is greater among men (38%) than women (28%) and among Non-Hispanic Whites (35%) than Non-Hispanic Blacks (17%). Use increases as measures of socio-economic status increase, including better income-to-poverty ratios, higher educational attainment, and availability of external financial support. Hearing aid use also increases with decreasing time since last hearing test, although it is impossible to know whether acquisition of hearing aids resulted from having a hearing test, or the more recent hearing test resulted from seeking hearing aids (Bainbridge & Ramachandran, 2014). Some evidence that hearing aid uptake may be slowly increasing has been reported (Reed *et al.*, 2021).

Reasons for the low uptake of hearing aids among older individuals include not recognizing a hearing problem, perceptions that hearing aids will not help, associated stigma, high cost, and poor coverage by insurance programs (Chien & Lin, 2012; NASEM, 2016). Age-related hearing loss is an uncovered condition under most U.S. insurance plans. Traditional Medicare does not pay for routine hearing tests or hearing aids. Medicare Part B only covers hearing tests when ordered by a physician as part of a medical work-up. Some Medicare Advantage or private insurance plans provide limited hearing aid coverage. State Medicaid programs are not required to offer coverage for hearing aids in adults. Nearly half offer no coverage and those that do vary considerably in eligibility criteria and extent of benefit (Arnold *et al.*, 2017). A hearing loss that unquestionably would qualify for assistance with amplification and aural rehabilitation services through insurance or government programs when it occurs in a child frequently is ineligible for similar assistance when it occurs in an older adult (NRC, 2014). However, economic obstacles are unlikely to be the primary barrier to hearing aid use among older adults, as uptake is not much better in countries which provide hearing aids at low or no cost through national insurance programs (NASEM, 2016).

The U.S. has recently taken several steps to improve hearing aid use among adults. In 2016, the FDA eliminated the long-standing requirement that adults receive clearance from a physician (or sign a waiver) prior to seeking a hearing aid. In 2022, the FDA authorized the sale of over-the-counter hearing aids to adults without the need to consult a hearing health professional as part of the process. The hope is that simplifying the route for obtaining a hearing aid and offering a more affordable class of devices will remove some of the barriers which have prevented older adults from improving their hearing and overall quality of life through amplification.

A recent review found that hearing aids effectively improve hearing-related quality of life (i.e., ability to participate in events of daily living) as well as general health-related quality of life among adults with mild to moderate hearing loss (Ferguson *et al.*, 2017). Preliminary studies indicate that use of hearing aids may reduce incident cognitive decline among individuals who still have normal cognitive function (Chern *et al.*, 2021). No studies have yet investigated whether use of hearing aids can reverse or slow the progression of cognitive decline in individuals who are already affected.

1.7 Conclusions

The results presented here indicate that some progress in hearing loss identification and/or prevention has occurred for people in nearly every life stage and in the workplace, but many challenges still exist. Epidemiologic data can be leveraged in clinical practice to improve outcomes. "Healthy People" is the federal public health agenda for the United States. Established in 1979, the Healthy People Program was developed to reduce the burden of disease by promoting healthy behaviors. Each decade, the Healthy People Program establishes measurable 10-year goals across a broad spectrum of health issues, including hearing loss. In addition, the Program promotes tools and resources to enable progress toward identified goals.

Healthy People 2030 contains 10 hearing-related objectives which target issues in diagnosis, treatment, and prevention for infants, children, and adults. Most of the hearing objectives are in the Hearing and Other Sensory and Communication Disorders (HOSCD) topic area, which also includes objectives related to balance, voice, speech, and language, and taste and smell. The Occupational Safety and Health (OSH) topic area includes one additional hearing objective (see Table 1.6).

Table 1.6. Hearing-related objectives in Healthy People 2030 (CDC, 2020a; CDC, 2020b).

Objective Number	Objective	Baseline (%)[a]	Target (%)[b]
HOSCD[c]-01	Increase the proportion of newborns who are screened for hearing loss by no later than 1 month of age	95.0	97.0
HOSCD-02	Increase the proportion of infants who did not pass the hearing screening test that receive diagnostic audiologic evaluation for hearing loss no later than 3 months of age	75.0	79.2
HOSCD-03	Increase the proportion of infants with confirmed hearing loss who are enrolled for intervention services no later than 6 months of age	53.0	62.9
HOSCD-04	Reduce frequent ear infections (otitis media) in children (under age 17 years)	48.0 children per 1,000	43.2 children per 1,000
HOSCD-06	Increase the proportion of adults (aged 20–69 years) who have had a hearing examination within the past 5 years	21.8	24.4
HOSCD-07	Increase the proportion of adults (aged 18 years and older) with hearing loss who use a hearing aid	24.4	26.4
HOSCD-08	Increase the proportion of adults (aged 20–69 years) who use hearing protection devices when exposed to loud sounds or music	66.7	71.4
HOSCD-09	Reduce the proportion of adults (aged 20–69 years) who have bilateral hearing loss due to noise exposure	97.8 adults per 1,000	79.0 adults per 1,000
HOSCD-10	Increase the proportion of adults (aged 18 years and older) with onset of bothersome tinnitus in the past 5 years who have seen a health care specialist	61.8	74.2
OSH[d]-06	Reduce new cases of occupational hearing loss	1.7 cases per 10,000 full-time workers	1.4 cases per 10,000 full-time workers

[a]Most recent statistic prior to 2021 used for comparison to future statistics to determine whether the target (goal) has been achieved.

[b]Goal for 2030.

[c]Hearing and Other Sensory and Communication Disorders topic area.

[d]Occupational Safety and Health topic area.

Although the Healthy People objectives are national in scope, they can only be achieved by individuals working towards them at a more local level. Audiologists can contribute to the success of the Healthy People Program by setting specific objectives relevant to their own clinical practice, implementing strategies towards improvement, and tracking progress. For example, an audiologist could ascertain the proportion of hearing aid candidates in their practice who have been successfully fit with some form of amplification, paying particular attention to disparities. National data could be used as a guide to set appropriate targets for increasing successful device fittings. By implementing existing evidence-based strategies to increase uptake, building partnerships within the community, and continually measuring outcomes to assess the impact of interventions, progress can be made over time. A good model for this approach is the *Oyendo Bien* program in southern Arizona, which targeted the needs of older Hispanic adults who have the lowest hearing aid use rate in the United States. Despite multiple barriers to care, 50% of participants in the pilot program had obtained a hearing aid or other assistive device within a year of the program (Marrone *et al.*, 2017).

While most patients are already presenting with an issue that needs treatment, prevention is a critical part of clinical practice. Those fitted with hearing aids will likely have the same exposures and repeat the same behaviors that led to their initial hearing loss without education and course correction. As hearing worsens, so does quality of life. Understanding risk factors and identifying high-risk groups can help audiologists identify patients for intervention so that no additional hearing is lost.

Disclaimer

The findings and conclusions in this chapter are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, United States of America.

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