# Chapter 69
# The Prevention of Tinnitus and Noise-Induced Hearing Loss

Larry E. Roberts, William Hal Martin, and Daniel J. Bosnyak

**Keypoints**

1. Although tinnitus is more common in older individuals, it can occur at any age. Because tinnitus in most individuals is associated with hearing impairment, prevalence may be increasing among youthful populations owing to exposure to environmental and recreational sound.
2. At present, there are no effective medical treatments for chronic tinnitus. Because hearing loss is a major risk factor, primary prevention is possible. Primary prevention is effective in other health domains, although it takes time for such programs to have impact.
3. Public education programs, role modeling by parents, cooperation from employers and industry, awareness campaigns, education of health professionals about avoidable risk factors, legislated standards for sound-emitting devices, and protection strategies that are acceptable to the young as well as adults, all have a role to play.
4. "Dangerous Decibels" is an example of a successful program aimed at reducing noise-induced hearing loss and tinnitus among school-aged children and young adults.
5. Epidemiological research tracking the prevalence of hearing loss and tinnitus at all ages, and research on intervention approaches, can provide essential information about effectiveness and long-term trends.

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**Abbreviations**

| | |
|---|---|
| HL | Hearing level |
| TEN | Threshold equalizing noise test |
| DPOAE | Distortion product otoacoustic emissions |
| ABRs | Auditory brainstem responses |
| NIOSH | National Institute for Occupational Safety and Health |
| NIHL | Noise induced hearing loss |
| WHO | World Health Organization |
| OMSI | Oregon Museum of Science and Industry |

## Introduction

It is a common perception that tinnitus is an affliction of older individuals, which is to a significant extent true. Although reported prevalence varies widely among studies (see Chap. 5), it has been estimated that between 8 and 20% of individuals over the age of 60 report a persisting tinnitus, and among these individuals approximately 25% describe their tinnitus "moderate" and another 6.6% as "severe" [1] implying an adverse effect on quality of life in the latter group, which translates into millions of Americans and many more around the globe. However, it is well documented by national surveys [2] and confirmed by clinical experience that persisting tinnitus can occur at any age. Because in most individuals tinnitus is associated with hearing impairment, prevalence may be increasing among youthful populations owing to exposure to environmental and recreational sound in our electronic age.

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This state of affairs is by itself sufficient cause for concern among those who formulate public health policy. However, the problem is compounded by the fact that while treatments exist that often can reduce the impact of chronic tinnitus on individual lives, elimination of the disturbing tinnitus sensation itself remains largely beyond the reach of medicine (see Section V of this book). It is especially worrisome that although tinnitus experienced by younger individuals after noise exposure often subsides, tinnitus may return later in life as changes in brain function related to aging unmask a hidden vulnerability. The prospect of a growing cohort in future years calls not only for intensified research into the causes of tinnitus and its treatment but also for programs aimed at its prevention.

Programs and policies aimed at primary prevention have worked in other domains (see Fig. 69.1). In the three decades following publication of the US Surgeon General's Report on Smoking and Health in 1964, the incidence of smoking (a major preventable cause of respiratory and cardiovascular disease) in the United States declined from 42% of adults in 1964 to 26% in 1998, with this decline being particularly steep among men more of whom smoked (53%) than did women (33%) in 1964, compared to 28% and 23%, respectively, in 1998 [3]. Public education, anti-smoking campaigns, government restrictions on advertising and conditions of use, and litigation have undoubtedly contributed to this outcome, which (although it is not a simple matter to quantify health benefits) is an important medical success story. Use of seat belts in automobiles and helmets for cyclists have also doubtlessly reduced the risk of injury and subsequent social and health costs associated with driving and cycling. These well-known examples illustrate some of the key ingredients of successful prevention. Public awareness is essential, and cooperation from industry (sometimes resisted) is needed. When the need is urgent, government policies, law making, and legal action can mobilize interventions to reduce risk. The personal costs associated with prevention including convenience and expense must be acceptable. Persistence and patience over the long haul are required, and monitoring is needed to gauge effectiveness.

It must be acknowledged that prevention of tinnitus does not have the same urgency as that associated with tobacco use or passenger protection, which are examples that address risks affecting a substantial proportion of the population and if ignored can have catastrophic personal consequences. However, for millions of individuals severely affected, tinnitus is a debilitating and costly condition for which no effective medical treatments are currently available. Tinnitus also shares in common with these examples evidence of a role for a causal and tractable factor that makes prevention of new cases of tinnitus a practical goal. Epidemiological and neuroscience studies indicate that among the many benefits of preserving normal hearing is likely to be the prevention of tinnitus.

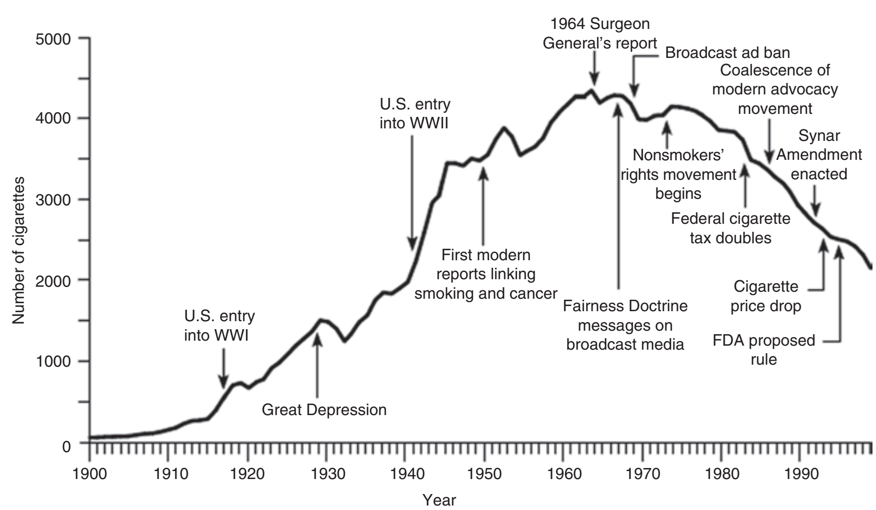


**Fig. 69.1** Adult per capita cigarette consumption and major smoking and health events, United States 1900–1990. From the report of the US Surgeon General (2001) *Women and Smoking*

## Tinnitus and Hearing Loss

One of the highest risk factors for tinnitus is noise exposure. Individuals who regularly worked in loud sound situations or were frequently exposed to impulse noise were nearly three times more likely to have tinnitus than those who did not have regular, loud sound exposures [4]. Henry et al. [5] noted that prolonged sound exposure and noise trauma represented the most commonly known factor associated with the onset of tinnitus. The Oregon Tinnitus Data Registry reported that sound exposures represented the most commonly reported onset factor in a tinnitus clinic population of 2,503 individuals [6]. Tinnitus has also been found to be an early indicator of permanent sensory neural hearing loss in work settings with prolonged loud sound exposure [7]. When measured within individuals, there is a close correspondence between the frequencies that are present in the tinnitus sensation and the sound frequencies at which hearing loss is present in the audiogram [8–11]. The nature of this relation is that ratings of sound frequencies for their similarity to tinnitus increase incrementally at the audiometric edge and continue to increase with the depth of threshold shift up to about 12 kHz [10, 11] (see Chap. 13). Konig et al. [12] reported that tinnitus is associated with steeper slopes of hearing loss, and also noted a strong relationship between the frequency with the steepest slope and the dominant tinnitus pitch for tonal cases. Restoration of hearing is often associated with a decrease in tinnitus, provided that the tinnitus has not been present for too long. It is commonly reported in the clinic and confirmed by systematic study [13] that many individuals with tinnitus experience a reduction of their symptoms when fitted with a hearing aid (see Chap. 74).

However, many people have hearing loss without having tinnitus, and many people who have "normal" hearing according to their audiograms have tinnitus. For example, Barnea et al. [14] found that 8% of their patients suffering from tinnitus had normal hearing thresholds (<25 dB HL) up to 8 kHz, and Roberts et al. [15] reported that 8 of 32 individuals with tinnitus (25%) had normal hearing similarly defined. However, in the latter study, all 32 individuals with tinnitus had hearing thresholds exceeding 25 dB HL when measured above 8 kHz, underscoring the need for more thorough audiometric assessments. In a subsequent study, Roberts et al. [11] measured hearing thresholds up to 16 kHz in two groups of individuals with tinnitus: one consisting of individuals aged 50 years or older ($n=40$) and the other aged less than 50 years ($n=7$). As expected, the older group exhibited threshold elevations commencing above about 2 kHz, but the younger group had normal hearing thresholds up to 10 kHz (see Fig. 69.2). However, when the people in these tinnitus groups were compared to age-matched controls without tinnitus, both tinnitus groups had

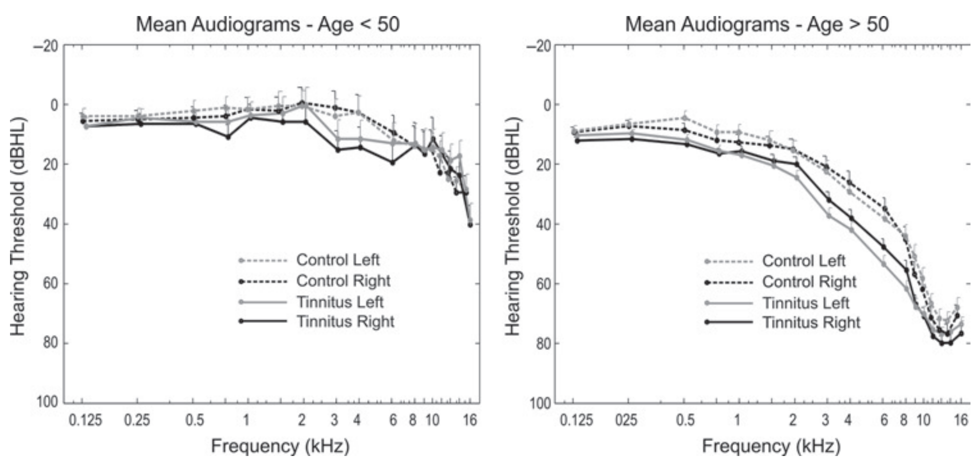


**Fig. 69.2** Hearing thresholds in individuals with and without tinnitus, matched for age above (*right panel*) or below 50 (*left panel*) years. Hearing thresholds are elevated between 2 and 8 kHz in tinnitus subjects compared to age-matched controls in both age groups, even though the audiograms for the younger tinnitus group were in the normal range up to 10 kHz. From Roberts et al. [11]

hearing thresholds that were elevated by approximately 11 dB compared to controls over the frequency regions corresponding to their tinnitus. These findings suggest that tinnitus and hearing impairment are related and that the degree of impairment needed to increase the risk for tinnitus is not large [16].

An alternative interpretation of the results of Fig. 69.2 is that the threshold elevations seen in the audiograms of individuals with tinnitus do not reflect reduced hearing, but confusion of the test sound with their tinnitus, which overlaps the same frequency range. Measures other than the conventional audiogram provide another approach. Tests for off-frequency listening can indicate the presence of cochlear dead regions that may lead to the development of tinnitus. Weisz et al. [17] administered the Threshold Equalizing Noise (TEN) test for off-frequency listening in individuals with tinnitus who were selected for study because their audiometric thresholds were within the normal range. Evidence was found for circumscribed cochlear damage in the frequency ranges that were rated as being similar to the tinnitus percept. Cochlear dead regions also appear to influence the shape of tinnitus spectra when band-limited noises differing in center frequency are used to measure these spectra, implying that individuals with tinnitus are listening off frequency to sounds in the stimulus where hearing thresholds are better preserved [11]. Measurement of distortion product otoacoustic emissions (DPOAEs) is another approach to detecting changes in hearing. Shiomi et al. [18] found significant decreases in DPOAE amplitudes over limited frequency ranges in 93% of ears in individuals with tinnitus and normal audiograms, in 96% of ears in patients with tinnitus and hearing impairment, and in only 15.4% of control ears. Similarly, Gouveris et al. [19] found decreased amplitudes in the 1,650–2,400 Hz range and increased amplitudes in the 4–6.3 kHz range in tinnitus patients. These studies point to some degree of impairment of outer hair cell function in tinnitus. Studies of auditory brain stem responses (ABRs) have provided more ambiguous results, with some authors reporting shortened wave V latency [20], others prolongations of waves I, III, and V [21, 22], and others no effects on the latency of waves I–V [14, 23].

If it is accepted that hearing loss is a substantial risk factor for tinnitus, how is tinnitus generated when hearing impairment occurs? Neuroscience studies have begun to answer this question (for a review see Chap. 13). Briefly, hearing loss induced by experimental noise trauma in animals leads to a reorganization of tonotopic maps in the primary auditory cortex, as thalamocortical input to the affected region is impaired [24–26]. This reorganization likely occurs because when thalamocortical input is reduced, neurons in the hearing loss region begin to express the frequency tuning of their unaffected neighbors via horizontal connections in the tonotopic map. It has also been found that the spontaneous firing rate of the affected neurons is increased and that there is an increase in neural synchrony (temporally coupled neural activity, sometimes called temporal coherence) in the region of hearing impairment [24]. Evidence from physiological, psychoacoustic, and human brain imaging studies suggests that increased neural synchrony in the hearing loss region may underlie the tinnitus sound [27].

Notwithstanding these lines of research pointing to a role for hearing loss in tinnitus, it is undeniable that there are individuals who have hearing loss but not tinnitus (see the older control group of Fig. 69.2). This is a puzzle to be explained. One factor that might distinguish between individuals with and without tinnitus despite the presence of hearing impairment is a difference in the prevalence of cochlear dead regions in the two groups. To date, this possibility has not been investigated. Age-related changes in intracortical inhibition [28, 29] may also play a role, with lags favoring normal tonotopic structure and conferring a benefit in preventing tinnitus. Some older individuals who have high-frequency hearing loss without tinnitus may eventually come to experience tinnitus, reducing the disparity between the two phenomena. Nevertheless, what protects many elderly individuals with hearing loss from tinnitus is presently unknown.

## Hearing Loss in the Young

Noise exposure, which can lead to hearing loss, is an increasing problem among children. Blair et al. [30] reported that at some time during their young lives, 97% of 273 third graders surveyed had been exposed to sound levels that are regarded to be hazardous to their hearing. Another recent study indicated that 16% of 14- to 18-year-olds listen to their personal stereo systems at levels exceeding the recommendations of the National Institute for Occupational Safety and Health (NIOSH) on a daily basis [31]. Thirty percent of the students said they sometimes participated in other noisy activities (such as shooting firearms or attending auto races); however, only 5.5% of the students ever used hearing protection while engaged in these activities. Sources of excessive sound exposure for children include loud music [32, 33], real or toy firearms [34], power tools [35, 36], fireworks [37], loud toys [8, 38], and snowmobiles or other loud engines such as jet skis or motorcycles [39]. The World Health Organization reported that North American children "may receive more noise at school than workers from an 8-h work day at a factory"[40]. Surveys of junior high and high school students have identified large deficiencies in their knowledge about normal hearing as well as hearing loss, and that students know little about the damaging effects of noise exposure [41, 42]. Results from the third National Health and Nutrition Examination Survey indicated that 12.5% of 6- to 19-year-olds in the United States (5.2 million) have documented evidence of elevated hearing thresholds directly attributed to noise exposure [43]. Early exposure to noise causes cumulative damage that accelerates age-related changes and long-term consequences [44].

The good news is that nearly all noise-induced hearing loss (NIHL) and related tinnitus can be prevented. Educational interventions can increase knowledge about NIHL issues. One study that evaluated the effectiveness of hearing conservation education in high school students found an average increase of 16% correct responses after participation in an educational program [45]. A second study presented an educational program on hearing conservation to elementary school children and found that their knowledge regarding NIHL improved by an average of 23% [46]. Recent work using resources from the Dangerous Decibels program (see below) has shown that several interventions, including classroom programs, museum exhibits, and online interactives can improve knowledge, attitudes, and intended behaviors related to sound exposure and use of hearing protection strategies [47–49]. Knowledge of potentially dangerous sounds, their consequences, and simple ways to protect oneself are all significant factors in prevention of NIHL and tinnitus. Public education can promote hearing health and behavior to reduce noise-induced hearing loss, a fully preventable condition.

## Dangerous Decibels

The health behavior literature has shown that attention to specific components of an intervention affects the success of that intervention. Strategies that tailor messages to the target group [50–53], use interactive not passive instruction [54], and incorporate teaching skills and self-efficacy [52, 53, 55, 56] have been most effective. *Dangerous Decibels*® is an exemplary program that has been built on health promotion theory applied to hearing loss and tinnitus prevention.

The Dangerous Decibels partnership began in 1999 and has been locally, regionally, nationally, and internationally active in hearing health promotion [48, 57]. The total number of individuals reached by Dangerous Decibels activities, including the museum exhibition at Oregon Museum of Science and Industry (OMSI), classroom education, web-based activities, OMSI Science Festivals at county fairs, and educator training workshops, approaches one million annually. It is the most extensively developed, disseminated, and evaluated hearing loss and tinnitus prevention program in the world with materials in 46 US States and 17 different countries. Between 2001 and 2006, 4,634 elementary and middle school students and adults participated in the formative and summative evaluation process for the Dangerous Decibels interventions. The results showed that the interventions were effective at changing knowledge, attitudes, and behaviors regarding exposure to loud sound and use of appropriate hearing protective strategies [47].

The Dangerous Decibels resources include the following components, some of which are illustrated in Fig. 69.3:

- A permanent Dangerous Decibels exhibition at the OMSI including 12 components covering over 2,000 $ft^2$ and providing information to approximately 670,000 visitors each year 70,000 of whom are K-12 students on school group field trips.
- A virtual Dangerous Decibels museum exhibition at the Dangerous Decibels website (www.dangerousdecibels.org).
- An interactive, inquiry-based classroom program targeting kindergarten through 12th grade students covering the physics of sound, normal hearing function, the pathophysiology and functional consequences of noise exposure, and tinnitus and hearing loss protective strategies.
- Educator training workshops that fully equip and certify individuals to present the classroom program in a manner proven to be effective, plus a Teachers Resource Guide with activities, images, and graphics intended to supplement the classroom program.


**Fig. 69.3** Dangerous Decibels. (**a**) Fourth grade students playing "Whatta ya know?" (*left panel* and "How loud is too loud?" (*right panel*), two of the of the exhibit components at the Oregon Museum of Science and Industry. (**b**) Image from the Dangerous Decibels Virtual Exhibit game "How loud is too loud?" conducted over the Web. (**c**) Dangerous Decibels classroom program being delivered to fourth grade students (hair cell function is being illustrated here). (Photos by Genevieve Y. Martin)

- The "Jolene" system for measuring the sound pressure levels generated by personal music systems through headphones. The *Jolene Cookbook* [58] describes how students can make their own version of a Jolene.

These and other Dangerous Decibels activities are designed to communicate information about three questions important for the protection of hearing: (1) What are sources of dangerous sounds? (2) What are the consequences of being exposed to dangerous sounds? (3) How can I protect myself from dangerous sounds? Tinnitus is one of the potential consequences, and information about the role of hearing loss in tinnitus is essential to prevention.

## Conclusion

Noise-induced hearing loss and tinnitus prevention activities have historically been emphasized in, or perhaps even limited to, occupational and military settings with the assumption that those settings provided the highest risks. However, recent epidemiologic evidence [59] indicates that cumulative hearing loss in the population has not declined over the past 30 years despite expected decreases in NIHL due to mandatory hearing conservation programs in occupational settings, suggesting that sound-related hearing loss may be resulting from exposures in non-occupational settings. Teaching individuals from an early age to cherish and protect the gift of hearing and equipping them to do so provides the highest likelihood of reducing the incidence of tinnitus.

Primary prevention takes time (Fig. 69.1), and education about noise exposure, while fundamental to success, is not the only factor that may bring benefits. Role modeling by parents, cooperation from employers and from industry, public awareness campaigns, education of health professionals about avoidable risk factors, legislated standards for sound-emitting devices, and protection strategies that are acceptable to the young as well as adults, are needed for a successful outcome. Epidemiological research into the prevalence of hearing loss and tinnitus at all ages, and research on the effectiveness of intervention approaches, can provide essential information about the magnitude of the problem and long-term trends. In addition to reducing the incidence of tinnitus, other benefits of hearing protection are reductions in health care costs and in disability claims as well as improved social and workplace communication. Primary prevention is especially important for tinnitus, because while some treatments exist that may reduce the impact of tinnitus on individual lives, elimination of the tinnitus sensation itself remains largely beyond the reach of medicine.

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