Noise induced hearing loss in children; a “less than silent” environmental danger.

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ABSTRACT
A review of the problems of noise induced hearing loss in children, especially related to recreational music and the use of personal entertainment devices. The patho-physiology of noise induced hearing loss, and associated problems (e.g. tinnitus) are discussed. The evidence for an increase in noise induced hearing loss in children and young people is reviewed. Some practical advice (for clinicians, caregivers, and children) about hearing loss prevention is provided.

Introduction

Pollution experts and environmental toxicologists warn us constantly about chemical and other air-born factors that can be a danger to health, but one problem that is rarely mentioned in the context of environmental hazards is noise induced hearing loss. It is time that we seriously consider the dangers of exposure to excessive and chronic noise, and the growing evidence that it can cause irreversible hearing loss. Historically our focus on the problems of acoustic trauma has been largely related to adults, for example hearing loss in soldiers from the battlefields of world wars, workers in noisy industrial factories, and the elderly for whom a life-time of noise exposure can hasten the onset of presbyacusis (age related hearing loss). However, since the advent of amplified sound in the music and entertainment industries, and the growing popularity of portable music and gaming devices in our younger population, noise induced hearing loss in children is a serious and growing concern.

This paper is written to inform healthcare professionals more about noise induced hearing loss in children. I will briefly describe the patho-physiology of the hearing loss, and explain what structures of the inner ear are vulnerable and can be damaged by loud noise exposure. I will review the current literature that relates to noise induced hearing loss in our youth and discuss the practical consequences of reduced hearing ability in children (e.g. in relation to education and quality of life). Finally I will describe some educational tools and guidelines that can help to inform us (clinicians, teachers, caregivers) and children about the risks of noise induced hearing loss, and offer some practical advice on hearing loss prevention.

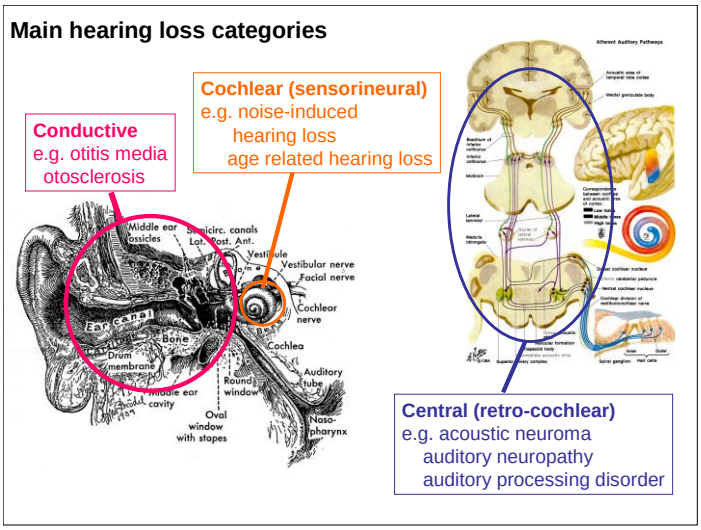

Figure 1. A broad classification of types of hearing loss. Whilst noise induced hearing loss is usually categorized as a cochlear or sensorineural hearing loss, it may also be combined with a conductive loss, and will also impact on central auditory processing.

What is noise induced hearing loss?

As figure 1 illustrates, there is a common categorization of types of hearing loss, which distinguishes conductive loss, cochlear or sensorineural loss, and central hearing disorders. A conductive loss is anything that reduces the transmission of acoustic signals to the cochlea; this can be simply wax or other obstruction in the ear canal, or fluid build up in the middle ear. Pediatricians will of course be familiar with the conductive hearing loss that can accompany otitis media. In relation to noise exposure, it is possible to have an intense acoustic trauma that damages the ear drum or the middle-ear ossicles, but this is rather unlikely in infants and children (unless they live in a war zone). For the most part, noise

induced hearing loss involves the damage to delicate structures of the inner ear, particularly the haircells, and is thus categorized as a cochlear, or sensorineural hearing loss. The third category of hearing loss is that relating to a central auditory system disorder. I would point out that we cannot absolutely separate a cochlear hearing loss from central loss because any reduction or degradation of the peripheral auditory input will have consequence for central auditory function. Importantly, health care professionals dealing with infants should also recognize that in early life, the activity patterns that are present at the cochlear level are important for the development of the central auditory brain, and that cochlear disorders and even conductive loss may have significant impact on the development of (central) mechanisms of hearing (1, 2).

Turning attention now to noise induced hearing loss or acoustic trauma, figures 2 and 3 show what can happen to the delicate haircells of the cochlea after physical insult. The left panels of figure 2 show normal hair cells, and a diagram (for one cell) showing how the stereocilia (hairs) are organized. These stereocilia, when deflected by acoustic signals cause an excitation (depolarization) of the haircell that leads to neural activity in cochlear afferent neurons that make up the auditory (8th cranial) nerve. For each cell, the stereocilia are neatly organized in a bundle. The individual "hairs" are cross-linked, and when the whole bundle is displaced by sound signals, some of these links pull open membrane ion channels on the surface of the hairs. Flow of ions (mainly potassium) though these membrane channels changes the haircell receptor potential. I mention these details to emphasize that the micromechanical arrangements of stereocilia, their linkages, and the membrane ion channels are delicate and can be damaged by acoustic over-stimulation.

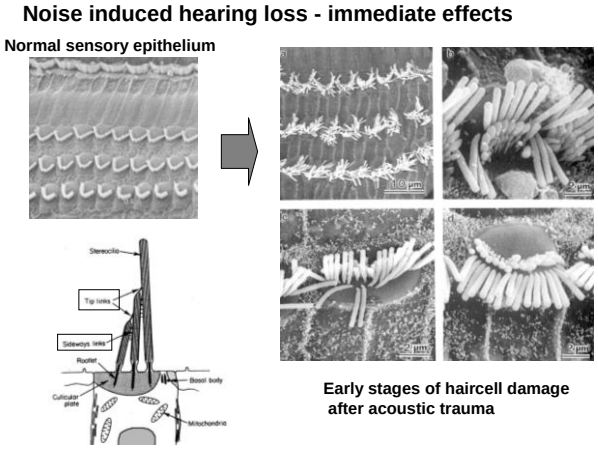

Figure 2. Scanning electron images illustrating normal cochlear haircells (left) and immediately after noise trauma (right). The lower left diagram shows the normal linkages between stereocilia that are disrupted or broken in noise induced hearing loss.

Some of the first obvious signs of acoustic over-stimulation are illustrated in right hand images of figure 2. Note how the stereocilia appear to loose their rigidity and become splayed apart. Clearly when this happens the linkages between the hairs are broken and can no longer mediate the opening and closing of membrane ion channels; the haircells can no longer work as sensory receptors. Importantly, the cells ***cannot recover*** from this state, and soon after this degree of damage, the cell self-destructs, (apoptosis sets in; lysosomal activity "eats-up" the cells). In the right-hand images of figure 3 we can see how the stereocilia start to be "digested" back into the cell; there is no recovery.

In addition to the direct mechanical trauma that loud sounds can cause to the haircells, there are also secondary effects that can cause further damage. Just as with a brain injury (e.g. stroke) there can be initial restricted lesion, but then cellular by-products that are released e.g. oxidative free radicals, or excessive amounts of neurotransmitter, can cause more extensive further damage. It is also possible that prolonged acoustic over-stimulation can lead to local vascular damage and a cochlear hypoxia which in turn can cause damage to haircells (3).

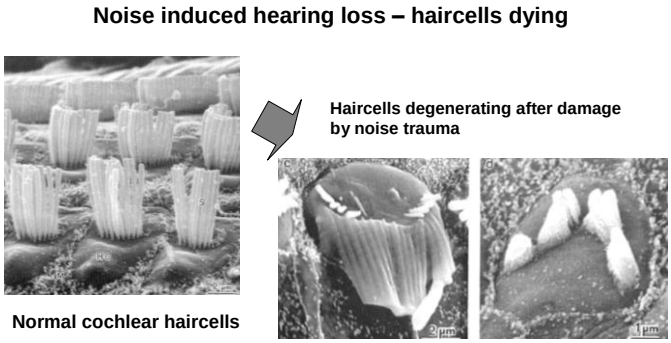

Figure 3. The stereocilia of healthy cochlear haircells (left) compared with cells after acoustic trauma, and in the process of complete degeneration (right). There is no natural regeneration of haircells in the mammalian cochlea.

We are all born with a fixed number of cochlear haircells. In humans (and all other mammals) they do not regenerate and so we should take preventative care of these cells. In some vertebrates, for example in birds, similar haircells do regenerate after damage. Actually new haircells develop from local supporting cells which act like a type of stem cell. There is evidence that in our vestibular sense organs, the haircells are capable of regenerating from supporting cells, but in the cochlea this does not happen. There is presently a considerable research effort to determine if cochlear haircells can be made to regenerate, either by providing suitable growth hormones, or by finding a genetic switch to turn on

the cell differentiation process (e.g. 4, 5, 6). Presently however the fact remains that if we kill haircells by noise exposure, they are lost forever.

Temporary threshold shift and tinnitus

Other than the loss of hearing sensitivity, there are two other common symptoms related to noise induced hearing loss. One is temporary threshold shift (commonly referred to as TTS), the other is tinnitus, or ringing in the ears. Regarding the former, after exposure to a period of loud sound there can be a "temporary" mild hearing loss. We have all experienced this after a long air flight or bus journey, or following a loud music concert. It is a period when everything sounds quieter (your car might sound better, at least until the next day). We tend not to worry about such experiences, in part because there appears to be a full recovery. However, it is widely supposed that repeated episodes of TTS can result in permanent changes. It is likely that the noise exposure causing TTS is altering the delicate micromechanics of the cochlea, including those linkages between haircell stereocilia, and that the reversibility of such insults may not be 100%. Personally I would try to avoid any noise exposure that leads to TTS.

There are a number of types of tinnitus, and not all result from cochlear damage. Often tinnitus is transient, and indeed it is normal to occasionally hear a brief ringing in the ear which dies away within a few seconds. However when chronic tinnitus is experienced after exposure to loud sounds, it is not just a warning sign but a clear manifestation of cochlear injury. Consider the ringing sound to be caused by haircells and neurons actually in the process of dying. Such cells generate a neural injury discharge because the cell membrane breakdown causes repeated depolarization (excitation) and/or uncontrolled release of neurotransmitter. In the case of a severe acoustic trauma, tinnitus can persists and becomes permanent. It has been suggested that the initial neural injury discharge sets up (synaptic) connections in a network of auditory neurons at a more central (cortical) brain level, and that these cells continue to fire spontaneously (perhaps because a local positive feedback circuit is established, or because local inhibitory neuron activity is reduced). Chronic tinnitus can be as devastating on quality of life as a hearing loss. Clearly any recreational activity that induces tinnitus should be avoided.

Noise induced hearing loss is a growing problem.

I briefly review here some of the current literature on the noise induced hearing loss in children and young adults. This is not an exhaustive or systematic review, but a representative sample of studies which all point to the growing problem. In terms of general population studies, a report from a large-scale US national health survey indicates that 12-15% of school age children have some hearing deficits attributable to noise exposure (7). In Canada we have had no large surveys that specifically address noise induced hearing loss. Statistics Canada data indicate that 13% of children (up to 14 years) have some hearing disability, but does not separate out specific etiology. Worksafe BC (Workers Compensation Board of British Columbia), in a large survey of young workers entering the workforce, report that over 20% have some early signs of hearing loss, but again this includes all causes of hearing loss, not just noise induced loss.

We may not have much Canadian data, but there is plenty from other countries. In a Scandinavian study (8) hearing testing of 538 teenage boys revealed a hearing loss (>15dB) in 15%. The characteristics of the loss indicated that the majority were related to noise exposure. Similarly, a German review of clinical data (9) estimates that one in ten adolescents has some degree of noise induced hearing loss from "leisure time noise". In a recent Chinese study of 120 young users of "personal listening devices", impaired hearing (>25dB loss) was found in 14% of ears (10). A French audiometric survey of 1364 young subjects found evidence of hearing problems in 12% of the general population, and in a sub-group that often attended rock concerts, or used "personal cassette players" (> 7 hr/week), 66% had a hearing loss (11). A similar finding was reported in a smaller group (N=24) of German teenagers (12). Many studies describe the increase in the use of personal entertainment devices and attendance of concerts where amplified sounds are enough to cause noise induced hearing loss (e.g. 13).

Recognizing that there is a real problem, many studies have focused on some of the specific causes, such as very loud signals from some cordless telephones (14), the types of headphones or earphones used in personal entertainment devices (15) and the actual levels of sound that are generated by earphone transducers (16). In addition there are numerous other reports on other possible sources of noise trauma for children, including very noisy toys, cap guns and fireworks. Other research has assessed the risks of noise induced hearing loss at specific entertainment venues such as rock concerts (17) and "urban music clubs"(18). There is even a published report with the title "Can hockey playoffs harm your hearing?"; from a Canadian research team of course (19). All of these reports and studies confirm that there is a potential problem with noise induced hearing loss at certain entertainment events. In noise induced hearing loss from very high-level sound exposures, tinnitus is often reported. For example in a Swedish study of 55 boys (ages 8-20) who were seeking help for tinnitus, the majority were found to have been exposed to excessive noise, mostly from recreational music (20). One study suggested that after short-term exposure to (over-) amplified music, tinnitus may be more of a problem than any hearing deficit (21).

To balance the evidence, some studies have concluded from their data that there is no clear link between recreational

noise exposure and hearing loss. For example, one research group concluded that ***most*** young users of personal listening devices are at low risk for noise induced hearing loss (22). However these authors cautiously admit that their study group did not include certain high risk populations with greater noise exposures, and go on to strongly recommend educational sessions about the dangers of noise exposure. An extensive Australian survey (23) also concluded that there was "no widespread hearing loss caused by recreational noise", but do warn that "if recreational patterns remain the same" the teenagers will be at high risk for noise induced hearing loss by their mid twenties. Indeed there is a strongly held view (which this author also holds) that noise exposure effects are

cumulative. Thus, in the short term, the effects of noise over-stimulation may not be obvious, but the accumulated effects of damaging episodes eventually lead to significant hearing deficits. An important point here concerns the redundancy of haircells in the cochlea. There are many more sensory elements than we need, and so considerable cell loss can occur before there are clinical signs of a problem. However with repeated insults, our fixed complement of haircells eventually runs out. This is one reason why noise induced damage in early years may not be immediately manifest, but may become a problem in later life.

To summarize on a cautious note, a recent general review of the issue of noise induced hearing loss in relation to school aged children (24) concludes that it is a major cause of hearing loss (in the US), and that hearing impairment among children and teenagers is on the increase due mostly to "voluntary exposure" to loud noise (i.e. using personal entertainment devices or attending amplified sound concerts).

What are the full consequences of hearing loss in children?

For most healthcare professionals, hearing loss is largely described by the results of clinical tests such as the audiogram or speech threshold measures. The general categories of loss range from mild, to moderate, to severe, to profound (and each has a specific audiometric definition). In infants, hearing can be assessed objectively using auditory evoked potentials or oto-acoustic emissions. Typically a deficit will be described as a hearing threshold loss in decibels (dB). It is important to point out that such basic measures, whilst useful, do not always reflect a hearing problem. It is common to have a child with normal hearing thresholds but with significant problems in understanding speech. In other words the ability to understand complex sounds can be reduced before pure tone audiometric thresholds are apparent. I would advise clinicians to recommend a comprehensive hearing evaluation including speech discrimination tests.

Beyond clinical tests results there are broader ways of looking at hearing disability. The World Health Organization (WHO) has a scheme for assessing and describing hearing problems (see figure 4, left-hand panel). This model distinguishes [1] ***impairment*** [2] ***disability*** and [3] ***handicap***. Impairment is the actual loss of sensory function such as quantified by the clinical tests mentioned above. Disability is the "activity limitation" of an individual that results from the impairment (e.g. a patient might not understand what you say, and needs to ask you to repeat words). Handicap is a measure of "participation restriction", i.e. activities that a child may not be able to do because of the hearing problem. This might include making friends, keeping up at school, or being excluded from training for a certain career. Another "holistic" approach to measuring a hearing disability is illustrated in figure 4 (right panel). Here one can separately consider the core, one-on-one interactions of a subject with mother, a sibling, teacher etc. Then in the wider circle there is the task of communication and interactions more broadly with family and friends. Finally there is the impact of the subjects hearing impairment on society (including economic issues, educational achievement, employability, and quality of life).

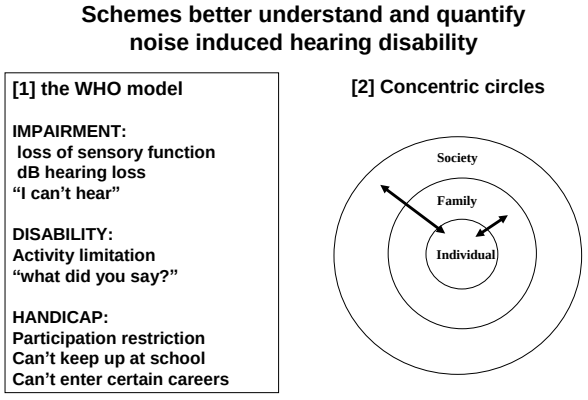

Figure 4. The consequences of a hearing loss should be considered in broader terms than just the clinical measures of hearing threshold loss.

For a child with noise induced hearing loss, the degree of deficit is likely to be mild or moderate as opposed to severe or profound. However such a loss might still be a barrier to effective communication, especially in noisy environments such as the school classroom. We should also recognize that mild to moderate hearing losses may not be immediately apparent to a child (in the same way that many older persons do not recognize that they have age related hearing loss). Parents and clinicians should be vigilant, and it is worth repeating that measures of speech discrimination will more accurately reveal a hearing problem than simple audiogram or hearing screening test. In a very young child, hearing problems can delay language development, and certainly if information is being missed at school, educational achievements can be reduced. For adolescents,

communication difficulties can lead to social isolation, and there have been reports of suicide resulting from such situations. If hearing aid use is warranted, the adolescent may also have problems with the cosmetic appearance of the device or the stigma attached. The child may decide not to use the aid, or choose to retreat to a small group or social isolation. In any case we can assume that there will be quality of life implications.

In public advocacy and education campaigns by The Hearing Foundation of Canada (25), one strategy for promoting hearing loss prevention in children, is to say "save your hearing for the music" (see figure 5). In other words if you love listening to your music now, you will loose that pleasure if you damage your hearing. The quality of life impact may also be felt at a later age when job opportunities are restricted because of the hearing problem itself, or a reduced educational attainment. The impact may well also be an economic one.

Practical advice about noise induced hearing loss

The noise in our environment is no longer all "natural" and there numerous sources of amplified sounds that can damage hearing. In (western based) industry, business and the military, there is legislation, or guidelines and safety factors relating to noise exposure. In the areas of public entertainment (discos, rock concerts, sports stadiums) and personal entertainment devices (MP3 or CD players, electronic games) regulations are not in place, and even if they were it would be difficult to achieve compliance. However, we do have some public awareness campaigns on the dangers of noise exposure, and there are a few educational programs in schools that teach children that hearing loss can result from listening to loud sounds (by analogy, just as many of us were told at school not to look directly at the sun!). The Hearing Foundation of Canada (THFC; see website (25)) has introduced a successful program called "Sound Sense" (26) into many schools, where age appropriate materials provide kids with the facts, and encourage prevention. This foundation and others attempt to get the prevention message out via web based information portals and advertisements Another instructional website is named "Dangerous Decibels", and is a joint project between the Oregon Museum of Science and Industry and the Oregon Hearing Research Center (27).

Figure 5 is an informative poster distributed by The Hearing Foundation of Canada (25), and provides a guide to the levels of sounds that are a potential risk. This "Sound Sense" poster is targeted toward children and young people. Note on the table of various levels of example sounds there is also an indication of how long an exposure to that sound can be considered safe. This is an important concept with regard to noise induced hearing loss. It is not just the sound intensity, but also the duration of the exposure that determines its potential to cause cochlear damage.

In recent years, the manufacturers and distributors of personal entertainment devices have been providing (in package) warnings and practical advice relating to the risks of noise induced hearing loss. I would like to think that this was good corporate responsibility, as opposed to just being a hedge against possible litigation. In any case, such instructions if attended to can help prevent noise induced hearing loss. One such warning suggests setting the device output to "below 85 dB" (decibels sound pressure level). Unfortunately we do not all have access to a decibel sound level meter, so it is not clear how one can practically make such an adjustment.

Figure 5. Sound Sense poster from the Hearing Foundation of Canada (25,26), targeting young people with the slogan "Save your hearing for the music".

Many parents (and children) have concerns about the levels of sound exposure from personal entertainment devices, and the risks of hearing loss. One common problem is a tendency to turn up the device volume to overcome surrounding noise, which itself can be substantial. I suggest that one adjusts the device output in a quiet environment, to a level that is comfortable, and then try to avoid increasing the volume even in noisy settings. Our general auditory experience can

tell us what is comfortable and what is too loud; perhaps parents should help younger children find that level. Some other useful advice is to get a child into the habit of checking if others nearby can also hear the music. If so it may be set too loud, although this of course will depend on the type of earphone in use (see below). Mention was made above of the notion that it is not just the intensity of noise that is a problem, but also the duration of exposure. In this regard, for a young person who is constantly listening to music it is advisable to take periodic 15-20 minute breaks, to allow the inner ear to "recover".

Another issue relates to the type of earphone or headphone used. The least risky in terms of the potential to do damage are the loose fit ear-buds that do not insert tightly into the ear canal. They are typically small transducers and do not output acoustic energy directly into the confined space of the ear canal. On the other hand, the listener is not insulated from the environmental noise and thus there is often a tendency to increase volume accordingly. Perhaps for the "careless" child this type of earphone is best. If the child is more responsible, then I recommend a type of earphone that blocks outside noise, and can thus present the ear with a better quality sound and obviate the need to increase volume to compete with environmental noise. These can be ear-buds that fit snugly right into the ear canal, or a larger headphone that fits against or around the ear. The downside for these transducers is that they can actually produce very intense signals either because sound energy is transmitted into a closed space or because of the size of the transducer diaphragm in the case of large headphones. For the serious music lover, active noise-reduction earphones are a nice luxury, but I am not sure that they are very practical for children, and may isolate an individual too much from the outside world!

Other potential noise dangers for children include powered garden and domestic equipment such as mowers and leaf blowers, as well as the recreational use of firearms. In relation to the latter, there is a voluminous literature on ballistic or "impact noise" much of it in relation to the military. Impact noise from a gun is of short duration but at a very high intensity, and poses a real danger to haircells. Any use of guns for skeet or target shooting, or hunting must be done with hearing protectors; responsible gun clubs and firing ranges understand this. There is a wide range of hearing protector types ranging from simple ear plugs, though earmuff (circum-aural) protectors, to fancy noise activated sound attenuators (mainly for military and industrial use). Good quality ear plugs made of expanding foam can provide a sound attenuation of 25-30 decibels. Ear muff hearing protectors also provide about 30dB of attenuation. If one considers that a gun-shot impulse noise (at close range) will be over 160dB, a 30dB reduction by ear plugs of muffs will still result in a sound exposure of 130dB. The cautious youth or guardian might consider a 60dB protection by wearing ***both*** earplugs and ear muff protectors.

I started this paper by describing the haircell destruction that can result from acoustic trauma, and the fact that there is no recovery of such haircells. In this sense there is really no treatment for noise induced hearing loss other than hearing aids; but these cannot fully restore normal hearing. This being the case, we should all pay considerable attention to hearing loss prevention.

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