The Ear and Hearing Protection

By
Johan Liljencrants [1]

The ear is a wonderful feat of our Creator that without immediate damage can perceive sound pressure levels from 0 to 130 dB, an impressive power range of 10^{13} = 10000000000000 times. A central trick to achieve this big range is the Stapedius muscle that pulls and displaces the smallest bone in your body, Stapes, which then transfers the sound from the eardrum to the inner ear "microphone." When you hear a strong sound this muscle contracts by a reflex to pull Stapes such that the sound transmission to the inner ear is decreased; it acts as a protective "automatic volume control."

One problem is that this muscle contraction takes time, tens of milliseconds. That is why gunshots are so dangerous to the ear, because with such short sounds there is not enough time for this mechanism to act. Also, just because the gunshot sound is so short, you don't perceive it as loud as it really is and perhaps you neglect to protect yourself for that reason. With extended strong sounds Stapedius can do its work, but after a while it is fatigued and its protective action decreases. Correspondingly, the auditory nerve system is fatigued and you are mislead this sound is not as loud as it really is and again you may neglect protection.

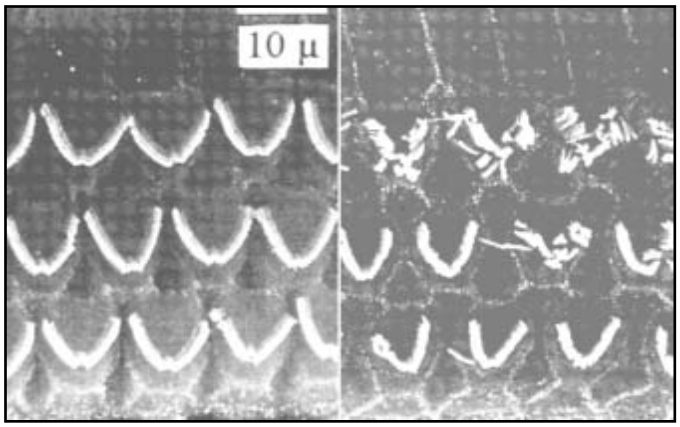

Figure. 1 Scanning electron micrographs showing about a dozen outer hair cells in rabbit. The three-row structure looks the same in all mammals. In the inner ear, the spiral shaped Cochlea, the sound induces vibrations in the thin Basilar membrane which by way of a complex wave motion makes a frequency to place conversion. This membrane carries some 30,000 hair cells, each with a characteristic V-shaped fence of tiny hairs like in these pictures. Adapted from: Borg, Conlon, Engström: Noise-induced Hearing Loss. Scandinavian Audiology, Vol. 24, suppl. 4, (1995).

The vibrations bend these hairs and this triggers the impulses to the auditory nerves. The basic mechanism in hearing damage from overexposure to sound is that you wear out and crush an increasing number of these hairs (Fig. 1, right). Once damaged they never recover and you suffer a permanent hearing loss. The hearing cells for high frequencies are adjacent to the sound input to the inner ear and these are the first ones to be decimated by over-exposure.

Another, and a worse, kind of damage is tinnitus, a virtual noise or beep that goes on forever, originating in your auditory nervous system. The cause can be infections or tumors in the inner ear, but also an over-exposure to sound. Tinnitus can drive people crazy.

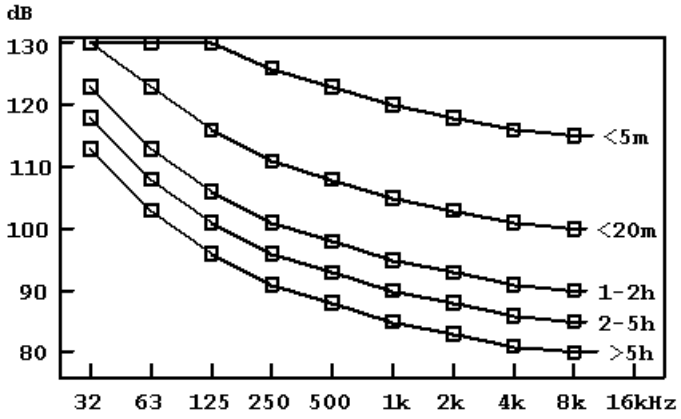

Figure 2 Hearing impairment induced by industrial noise.

Much research has been done on hearing impairment induced by industrial noise and there are consequent international recommendations for maximal noise dose to avoid such damage. Figure 2 shows a set of curves like this diagram of maximum permitted noise spectral level vs. frequency, sloping (very) roughly -3 dB per octave. At 500 Hz you allow 88 dB for more than 5 hours per day, 93 dB for 2-5 hours, 98 dB for 1-2 hours, 109 dB for less than 20 minutes per day, etc. If any of these conditions is exceeded you should wear a noise protector.

More recent investigations on symphony orchestra musicians have shown that they generally receive less hearing damage than predicted from the sound levels they are exposed to. The reason is believed to be psychological. Pop musicians using amplification, and their audience, are usually way up in the dangerous area and protectors are strongly recommended. Also, tinnitus cases among these people are much more frequent than you would like to know.

A typical mid-range organ flue pipe blown at 8 inches water column and 1 foot distance roughly matches the 1-2 hour per day curve, so you should be able to voice such pipes without fear. Calliope and reed pipes are considerably louder and clearly motivate protectors at close distance.

Figure 3 Plug protectors for musicians and other critical listeners designed for equal attenuation at all frequencies are exemplified in this figure showing a moderately priced standard type that attenuates about 20 dB. The protruding taps contain tubes forming an acoustic filter and the soft flanges ensure tightness to the ear canal. More elaborate special high equality types for 15 or 25 dB cost in the range of $200 and have to be individually tailored at a hearing clinic.

The simplest protectors are plugs made from cotton, special fibers, foam plastic, wax or molded plastic (Fig. 3). Using cotton, fold a flat pad in two and roll it hard into a cone with its tip at the fold, put it in your ear with the tip inward. These plugs attenuate high frequencies to the order of 20 dB but do very little toward low frequencies. They do a good protection job but distort the tonal balance. While doing my military service we used empty pistol cartridge shells as earplugs (hole inwards) while shooting. Slightly uncomfortable but quite efficient.

To reach more appreciable low frequency attenuation you will need the protector type with big cups covering the whole ears and soft cushioned brims resting against the head (Fig. 4). Lighter variants, perhaps with foam cushions stay in the 20-dB range. The better performance is with heavy cups and liquid filled or heavily encapsulated cushions to insure weight and tightness as shown here; this type attenuates in the 30-dB range.

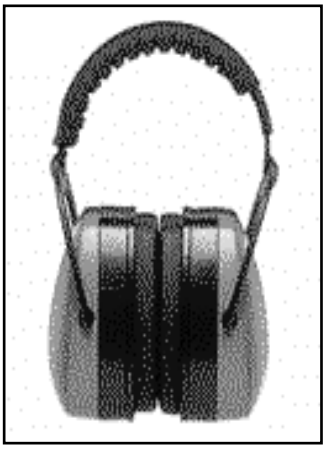

Figure 4 Cup-type protecto\rs which cover the entire ear.

You cannot get notably higher attenuation than this because of the bypass sound entering directly through your skull. For ultimate requirements like on an aircraft carrier you have to enclose your entire head in a helmet, like an astronaut.

There also exist fancy protector variants including electronics with active noise suppression. This involves a microphone at the ear driving a loudspeaker to counteract whatever external sound that penetrates into the cup. For reasons of cost and complexity this is marginally motivated for noise suppression alone, but is a logical add-on if you anyway want a speaker for distraction or communication purposes.

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Johan Liljencrants is a professor of speech communication and electroacoustics and teaches at the Royal Institue of Technology in Stockholm, Sweden. Besides publishing many scientific articles on topics from loudspeaker enclosures to sound production in the human throat he enjoys several hobbies including pipe organ building and is moderator of the MMD Pipes Forum, an e-mail technical discussion group concerned with the theory and design of small player pipe organs.

Book Review by Phil Jamison

On Display

The publication of the Fair Organ Preservation Society's 40th Anniversary book *On Display* is a welcome addition to the limited literature on our favorite subject. It's large (8 1/2 " X 12") glossy format is based on the Dutch organ society's superb “Draaiorgels” anniversary book, edited by the esteemed Romke deWaard. In fact, both books end at 128 pages (and, unfortunately, lack indexes). Both mix color and black and white photographs in abundance. DeWaard's text and photo captions are a bit more detailed, but *On Display* has the distinct advantage (from our perspective) of being entirely in English. Not only that, it contains several articles about fair/band organ history including “The Fairground Organ in Great Britain” (Philip Upchurch), “The Australian Mechanical Music Scene” (Richard Ellis and Bob Hunt), “Mechanical Music in the Netherlands” (Hans van Oost and Rein Schenk) and “The American Market” (Tim Trager and myself). John Page contributes a useful “Glossary of Terms” addendum which clearly defines organ terms from “accompaniment” to “zinc.” Numerous other writers familiar to all organ buffs add their own knowledge to the text. The entire project was supervised by “Key Frame” editor Phil Benson whose hard work must be heartily commended. Very little if any material is repeated in this book from the Dutch publication, so enthusiasts can confidently purchase both. Historic photos are always of interest to collectors, and David S. Smith of Cornwall and Tim Trager have contributed several interesting shots. Primarily, though, we see organs as they appear today. The full range of mechanical organ is displayed, from the huge Mortier, DeCap, and Gavioli to the petite portable models. The paper seems of good quality, so this book should amuse and inform for many years. Price: $35.00 (*On Display* may be ordered from Phil Jamison, 17 Sharon Alley, West Chester, PA 19382).