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Ear is the Excellent Acoustic Reader: The Effect of Acoustics on this Sophisticated Organ

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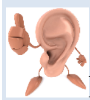
ABSTRACT



E.A.R. is Excellent Acoustic Reader and sound waves travel through the outer ear, are modulated by the middle ear and are transmitted to the vestibulocochlear nerve in the inner ear. This nerve transmits information to the temporal lobe of the brain, where it is registered as sound. A sound that travels through the outer ear impacts on the tympanic membrane (ear drum) and causes it to vibrate. The three ossicles transmit this sound to a second window (the oval window) which protects the fluid-filled inner ear. In detail, the pinna of the outer ear helps to focus a sound, which impacts on the tympanic membrane. The malleus rests on the membrane and receives the vibration. This vibration is transmitted along the incus and stapes to the oval window. Two small muscles, the tensor tympani and stapedius, also help modulate noise. The tensor tympani dampens noise and the stapedius decrease the receptivity to high-frequency noise. Vibration of the oval window causes vibration of the endolymph within the ventricles and cochlea. The hollow channels of the inner ear are filled with liquid and contain a sensory epithelium that is studded with hair cells. The microscopic "hairs" of these cells are structural protein filaments that project out into the fluid. The hair cells are mechanoreceptors that release a chemical neurotransmitter when stimulated. Sound waves moving through fluid flows against the receptor cells of the Organ of Corti. The fluid pushes the filaments of individual cells; movement of the filaments causes receptor cells to become open to the potassium-rich endolymph. This causes the cell to depolarize and creates an action potential that is transmitted along the spiral ganglion, which sends information through the auditory portion of the vestibulocochlear nerve to the temporal lobe of the brain. The human ear can generally hear sounds with frequencies between 20 Hz and 20 kHz. Although

hearing requires an intact and functioning auditory portion of the central nervous system as well as a working ear, human deafness (extreme insensitivity to sound) most commonly occur because of abnormalities of the inner ear, rather than in the nerves or tracts of the central auditory system. Sound below 20 Hz is considered infrasound, which the ear cannot process.
It has been proven that the use of mobile phones increases the risk of acquiring cancer. This is due to the emission of electromagnetic radiation, the electromagnetic radiation makes their way through the ear and cause thermal heating to the most parts of the brain by degradation of DNA strands at that particular region. These radiation waves cause various cancers such as glioma, meningioma and acoustic neuroma.

Keywords: Ear drum, Organ of Corti, Decibel, Incus, Stapes, Brain tumors.

INTRODUCTION

Anatomy of the ear

The ear is made up of three parts: the outer, middle and inner ear. All three parts of the ear are important for detecting sound by working together to move sound from the outer part through the middle and into the inner part of the ear. Ears also help to maintain balance.[1]

The outer ear

The outer ear includes

• Auricle (cartilage covered by skin placed on opposite sides of the head).
•auditory canal (also called the ear canal).
• Eardrum outer layer (also called the tympanic membrane).

The outer part of the ear collects sound. Sound travels through the auricle and the auditory canal, a short tube that ends at the eardrum.

The middle ear

The middle ear includes:

• Eardrum.
• Cavity (also called the tympanic cavity).
• Ossicles (3 tiny bones that are attached) .
• Malleus (or hammer) –long handle attached to the eardrum.
• Incus (or anvil) –the bridge bone between the malleus and the stapes.
• Stapes (or stirrup)–the footplate; the smallest bone in the body.

Sound entering the outer ear travels through the middle ear and causes the eardrum and ossicles in the middle ear to vibrate. As it travels, it amplifies (becomes louder) and changes from air to liquid.

The inner ear

The inner ear includes:

• Oval window–connects the middle ear to the inner ear
• Semicircular ducts–filled with fluid; attached to cochlea and nerves; send information on balance and head position to the brain
• Cochlea–spiral-shaped organ of hearing; transforms sound into signals that get sent to the brain
• Auditory tube–drains fluid from the middle ear into the throat behind the nose

When the stapes moves, it pushes the oval window, which then moves the cochlea.

The cochlea takes the fluid vibration of sounds from the surrounding semicircular ducts and translates them into signals that are sent to the brain by nerves like the vestibular nerve and cochlear nerve.[2]

Sound is a vibration that propagates as a typical audible mechanical wave of pressure and displacement, through a medium such as air or water. In physiology and psychology, sound is the reception of such waves and their perception by the brain. A distinct use of the term sound from its use in physics is that in physiology and psychology, where the term refers to the subject of perception by the brain. The field of psychoacoustics is dedicated to such studies. The physical reception of sound in any hearing organism is limited to a range of frequencies. Humans normally hear sound frequencies between approximately 20 Hz and 20,000 Hz (20 kHz), Both limits, especially the upper limit, decrease with age. Other species have a different range of hearing. For example, dogs can perceive vibrations higher than 20 kHz, but are deaf below 40 Hz. As a signal perceived by one of the major senses, sound is used by many species for detecting danger, navigation, predation and communication. Earth's atmosphere, water, and virtually any physical phenomenon, such as fire, rain, wind, surf, or earthquake, produces (and is characterized by) its unique sounds.

Many species, such as frogs, birds, marine and terrestrial mammals, have also developed special organs to produce sound. In some species, these produce songs and speech. Furthermore, humans have developed culture and technology (such as music, telephone and radio) that allows them to generate, record, transmit and broadcast sound. Sometimes sound refers to only those vibrations with frequencies that are within the hearing range for humans or for a particular animal.[3]

Decibels: dB, dB (A), dBA, dB (C), dBV, dBm and dBi? What are they all? How are they related to loudness, to phons and to sones? The decibel (dB) is used to measure sound level, but it is also widely used in electronics, signals and communication. The dB is a logarithmic way of describing a ratio. The ratio may be power, sound pressure, voltage or intensity or several other things. Later on we relate dB to the phon and the sone (related to loudness). But first, to get a taste for logarithmic expressions, let's look at some numbers. For instance, suppose we have two loudspeakers, the first playing a sound with power P1, and another playing a louder version of the same sound with power P2, but everything else (how far away, frequency) kept the same.[4]

The difference in decibels between the two is defined to be:

$10 \log (P_2/P_1)$ dB where the log is to base 10.

If the second produces twice as much powerful than the first, the difference in dB is

$10 \log (P_2/P_1) = 10 \log 2 = 3$ dB.

As is shown on the graph, which plots $10 \log (P_2/P_1)$ against P_2/P_1. To continue the example, if the second had 10 times the power of the first, the difference in dB would be.

$10 \log (P_2/P_1) = 10 \log 10 = 10$ dB.

If the second had a million times the power of the first, the difference in dB would be.

$10 \log (P_2/P_1) = 10 \log 1{,}000{,}000 = 60$ dB.

This example shows one feature of decibel scales that is useful in discussing sound: they can describe very big ratios using numbers of modest size. But note that the decibel describes a *ratio*: so far we have not said what power either of the speakers radiates, only the ratio of powers. (Note also the factor 10 in the definition, which puts the 'deci' in decibel).[5]

Sound pressure or acoustic pressure is the local pressure deviation from the ambient (average, or equilibrium) atmospheric pressure, caused by a sound wave. In air, sound pressure can be measured using a microphone, and in water with a hydrophone. The SI unit for sound pressure p is the pascal (symbol: Pa). Sound pressure level (SPL) or sound level is a logarithmic measure of the effective sound pressure of a sound relative to a reference value. It is measured in decibels (dB) above a standard reference level. The standard reference sound pressure in air or other gases are 20 µPa, which is usually considered the threshold of human hearing (at 1 kHz). Sound pressure is the difference, in a given medium, between average local pressure and the pressure in the sound wave. A square of this difference (i.e., a square of the deviation from the equilibrium pressure) is usually averaged over time and/or space, and a square root of this average provides a root mean square (RMS) value.

The human ear can detect sounds with a wide range of amplitudes, sound pressure is often measured as a level on a logarithmic decibel scale. The sound pressure level (SPL) or Lp is defined as:

$$L_p=10\ \log_{10}\ (p^2 \div p_{ref}^2)\ =\ 20\ \log_{10}\ (p \div p_{ref}) \times dB$$

Where p is the root-mean-square sound pressure and p_{ref} is a reference sound pressure. Commonly used reference sound pressures, defined in the standard ANSI S1.1-1994, are 20 µPa in air and 1 µPa in water. Without a specified reference sound pressure, a value expressed in decibels cannot represent a sound pressure level. Since the human ear does not have a flat spectral response, sound pressures are often frequently weighted so that the measured level matches perceived levels more closely. The International Electro technical Commission (IEC) has defined several weighting schemes. A-weighting attempts to match the response of the human ear to noise and A-weighted sound pressure levels are labeled dBA. C-weighting is used to measure peak levels.[6]

Cell phones and cancer risk

Cell phones emit radiofrequency energy, a form of non-ionizing electromagnetic radiation, which can be absorbed by tissues closest to where the phone is held. The amount of radio frequency energy a cell phone user is exposed to depends on the technology of the phone, the distance between the phone's antenna and the user, the extent and type of use, and the user's distance from cell phone towers. Studies thus far have not shown a consistent link between cell phone use and cancers of the brain, nerves, or other tissues of the head or neck. More research is needed because cell phone technology and how people use cell phones have been changing rapidly. There are three main reasons why people are concerned that cell phones (also known as "wireless" or "mobile" telephones) might have the potential to cause certain types of cancer or other health problems: Cell phones emit radiofrequency energy (radio waves), a form of non-ionizing radiation. Tissues nearest to where the phone is held can absorb this energy. The number of cell phone users has increased rapidly. As of 2010, there were more than 303 million subscribers to cell phone service in the United States, according to the Cellular Telecommunications and Internet Association.[7]

This is a nearly threefold increase from the 110 million users in 2000. Globally, the number of cell phone subscriptions is estimated by the International Telecommunications Union to be 5 billion. Over time, the number of cell phone calls per day, the length of each call and the amount of time people use cell phones has increased. Cell phone technology has also undergone substantial changes.

Radiofrequency energy is a form of electromagnetic radiation. Electromagnetic radiation can be categorized into two types: ionizing (e.g., x-rays, radon, and cosmic rays) and non-ionizing (e.g., radio frequency and extremely low-frequency or power frequency).

Exposure to ionizing radiation, such as from radiation therapy, is known to increase the risk of cancer. However, although many studies have examined the potential health effects of non-ionizing radiation from radar, microwave ovens, and other sources, there is currently no consistent evidence that non-ionizing radiation increases cancer risk.[8]

The only known biological effect of radiofrequency energy is heating. The ability of microwave ovens to heat food is one example of this effect of radiofrequency energy. Radiofrequency exposure from cell phone use does cause heating; however, it is not sufficient to measurably increase body temperature. It is generally accepted that damage to DNA is necessary for cancer to develop. However, radiofrequency energy, unlike ionizing radiation, does not cause DNA damage in cells, and it has not been found to cause cancer in animals or to enhance the cancer-causing effects of known chemical carcinogens in animals.

Researchers have carried out several types of epidemiologic studies to investigate the possibility of a relationship between cell phone use and the risk of malignant (cancerous) brain tumors, such as gliomas, as well as benign (noncancerous) tumors, such as acoustic neuromas (tumors in the cells of the nerve responsible for hearing), most meningiomas (tumors in the meninges, membranes that cover and protect the brain and spinal cord), and parotid gland tumors (tumors in the salivary glands).[9]

In one type of study, called a case-control study, cell phone use is compared between people with these types of tumors and people without them. In another type of study, called a cohort study, a large group of people is followed over time and the rate of these tumors in people who did and didn't use cell phones is compared. Older studies evaluated radiofrequency energy exposure from analog cell phones. However, most cell phones today use digital technology, which operates at a different frequency and a lower power level than analog phones. Digital cell phones have been in use for more than a decade in the United States, and cellular technology continues to change. Texting, for example, has become a popular way of using a cell phone to communicate that does not require bringing the phone close to the head. Furthermore, the use of hands-free technology, such as wired and wireless headsets, is increasing and may decrease radiofrequency energy exposure to the head and brain.[10]

Another study already under way is a case-control study called Mobi-Kids, which will include 2000 young people (aged 10-24 years) with newly diagnosed brain tumors and 4000 healthy young people. The goal of the study is to learn more about risk factors for childhood brain tumors. Results are expected in 2016.

Although recall bias is minimized in studies that link participants to their cell phone records, such studies face other problems. For example, it is impossible to know who is using the listed cell phone or whether that individual also places calls using other cell phones. To a lesser extent, it is not clear whether multiple users of a single phone will be represented on a single phone company account.

The NIEHS, which is part of the National Institutes of Health, is carrying out a study of risks related to exposure to radiofrequency energy (the type used in cell phones) in highly specialized labs that can specify and control sources of radiation and measure their effects on rodents. In theory, children have the potential to be at greater risk than adults of developing brain cancer from cell phones. Their nervous systems are still developing and therefore more vulnerable to factors that may cause cancer. Their heads are smaller than those of adults and therefore have a greater proportional exposure to the field of radiofrequency radiation that is emitted by cell phones. And children have the potential of accumulating more years of cell phone exposure than adults do.

Cordless phones (phones that have a base unit connected to the telephone wiring in a house) often operate at radio frequencies similar to those of cell phones; however, since cordless phones have a limited range and require a nearby base, their signals are generally much less powerful than those of cell phones.[11]

Ways to reduce the cancer risks caused by mobile phones (Ten commandments)[12-20]

1. Children should only use cell phones next to their heads for emergencies. Children's skulls are thinner than adults' and their brains are still developing. Hence, radiation from cell phones penetrates more deeply into their brains and is likely to cause more damage. Texting (while holding the phone away from their body) is still fine for kids![12]

2. While talking on your cell phone, try to keep the cell phone away from your body as much as possible. The amplitude of the electromagnetic field (radiation) is one fourth the strength at a distance of two inches and fifty times lower at three feet. Whenever possible, use the speakerphone mode or a wired headset (not a Bluetooth). [13]

3. Avoid using your cell phone when the signal is weak or when moving at high speed, such as in a car or train, as this automatically increases power to a maximum as the phone repeatedly attempts to connect to a new relay antenna.[14]

4. Avoid carrying your cell phone on your body at all times. Do not keep it near your body at night such as under the pillow or on a bedside table, particularly if pregnant. You can also put it on "flight" or "off-line" mode, which stops electromagnetic emissions.[15]

5. If you must carry your cell phone on you, make sure that the keypad is positioned toward your body and the back is positioned toward the outside so that the transmitted electromagnetic fields move away from you rather than through you.[16]

6. Only use your cell phone to establish contact or for conversations lasting a few minutes, as the biological effects are directly related to the duration of exposure. For longer conversations, use a land line with a corded phone, not a cordless phone, which also uses electromagnetic emitting technology similar to that of cell phones.[17]

7. Switch sides regularly while communicating on your cell phone to spread out your exposure. Before putting your cell phone to the ear, wait until your correspondent has picked up. This limits the power of the electromagnetic field emitted near your ear and the duration of your exposure.[18]

8. When possible, communicate via text messaging rather than making a call, to limit the duration of exposure and the proximity to the body.[19]

9. Choose a device with the lowest SAR possible (SAR = Specific Absorption Rate, which is a measure of the strength of the magnetic field absorbed by the body). Specific absorption rate (SAR) is a measure of the rate at which energy is absorbed by the human body when exposed to a radio frequency (RF) electromagnetic field; although, it can also refer to absorption of other forms of energy by tissue, including ultrasound. It is defined as the power absorbed per mass of tissue and has units of watts per kilogram (W/kg). SAR is usually averaged either over the whole body, or over a small sample volume (typically 1 g or 10 g of tissue). The value cited is then the maximum level measured in the body part studied over the stated volume or mass.

SAR ratings of contemporary phones by different manufacturers are available by searching for “SAR ratings cell phones” on the internet.[20]

10. Mobile must not be in vibration mode when it is in left pocket of shirt. Otherwise the electromagnetic outcome during vibration in decibel count will cause direct action in heart which is placed anatomically in left side of the body! It will create direct action on cardiac output and pumping rate.[20]

CONCLUSION

Noise is not just annoying; it is potentially dangerous, both physically and mentally. It has been described as “a slow agent of death.” A form of energy, sound or noise is caused by anything that vibrates, that moves back and forth. Our ears receive the effects of this vibrating motion from a distance, great or small, via sound waves. These waves are successive series of regions of compressed air and partial vacuums, or areas of high and low air pressure. Sound can also travel through liquids and solids. We hear sound because our eardrums are moved back and forth by the changes in air pressure. The eardrum, or tympanic membrane, may perceive a sound that moves it only one billionth of a centimetre-the threshold of hearing. If the intensity of sound pressure becomes too great, we experience pain, and the eardrum or the delicate structures inside the ear may be damaged.

The intensity of sounds is often measured in units called decibels, or db. These units are logarithmic, that is, 10 db is ten times as powerful as 1 db, 20 db is 100 times as powerful, 30 db is 1,000 times as powerful, and so on. On this scale, 0 db is at the threshold of hearing; rustling leaves, 20 db; a quiet office, about 50 db; conversation, 60 db; heavy traffic, 90 db; a pneumatic jackhammer six feet away, 100 db; a jet aircraft 500 feet overhead, 115 db; a Saturn rocket's takeoff, 180 db. For most people, the pain threshold is about 120 db; deafening ear damage can result at 150 db. But damage of various kinds can come from much lower exposures. Temporary hearing impairment can result from sounds over the 85 db now found in modern kitchens with all appliances going. If the ears do not get a chance to recover, the impairment will become permanent.

Damage to the inner ear

Although very loud noise can damage the eardrum, most physiological damage from noise occurs in the snail-shaped, liquid-filled cochlea, or inner ear. Sound transmitted to the cochlea produces waves in the liquid, which in turn move delicate and minute structures called hair cells or cilia in that part of the cochlea known as the *organ of Corti*. The motion of the cilia is transformed into electrical impulses that conduct the sensation of sound to the brain. The cilia can easily be fatigued by noise, causing a temporary loss of hearing, or a shift in the threshold of hearing. If they are not given a chance to recuperate, they will be permanently damaged, and irreversible hearing loss will result. There are some 23,000 cilia in the average cochlea; different sets of cilia respond to different frequency bands. The cilia responding to sound frequencies of 4,000 to 6,000 cps (cycles per second) are especially vulnerable to damage. The region of 85 to 95 db is generally regarded as the beginning of dangerous sound intensities. In general, the louder the noise, the longer it lasts, the higher it is, and the purer in frequency, the more dangerous it is. Thus, jet engines and powerful sirens are particularly hazardous.

Noise and stress

The EPA has estimated that some 20 million Americans live or work at noise levels that could cause hearing losses; about 18 million have experienced at least some hearing loss because of noise exposure. But sound, or noise, can lead to physical and psychological problems ranging from irritability to migraine headaches. Linked with many such problems is stress, which has been found to cause high blood pressure, insomnia, ulcers, digestive disorders, alcoholism, anxiety, and many other ills. Excessive noise has been implicated in such problems as adrenaline flow, elevated heart rates, and blood pressure. All are associated with heart disease. Noise can also affect children in special ways. For example, researchers believe it can retard language development and impair reading ability. Pregnant women exposed to excessive noise may show symptoms of stress and may pass on the harmful effects to their unborn babies. Studies in several countries have shown that the newborns of women living near airport runways experience a higher than normal incidence of birth defects. Noise-related stress has a definite effect on mental well-being. No one knows exactly how, but noise can produce irritability, tension, and nervous strain. More seriously, British medical authorities have reported a significantly higher incidence of mental illness among people exposed constantly to aircraft noise.

Workplace noise presents special problems. Persons working in such industries as construction, mining, steel, lumber, and textiles are almost universally exposed to loud noises. Certain operations in other industries expose workers to high decibel levels. Overexposure takes place when employees work eight hours a day at sites with noise levels exceeding 90 decibels. Such standards, established by the government's Occupational Safety and Health Administration (OSHA), provide also that overexposure occurs where workers are subjected to higher decibel levels for shorter periods. Workplace noise can lead to problems similar to those produced by-overexposure elsewhere. But many workers have little choice as regards the places where they work. For their parts, companies may have limited options insofar as noise control or abatement is concerned. Changing the gears of a machine or building an enclosure around it may not always be feasible. Some professional musicians find it difficult or impossible to avoid excessive noise on the job. Rock music artists, for example, spend hours at a stretch in enclosed places that magnify sound that is already greatly amplified. Such persons may be at serious risk of incurring hearing losses.

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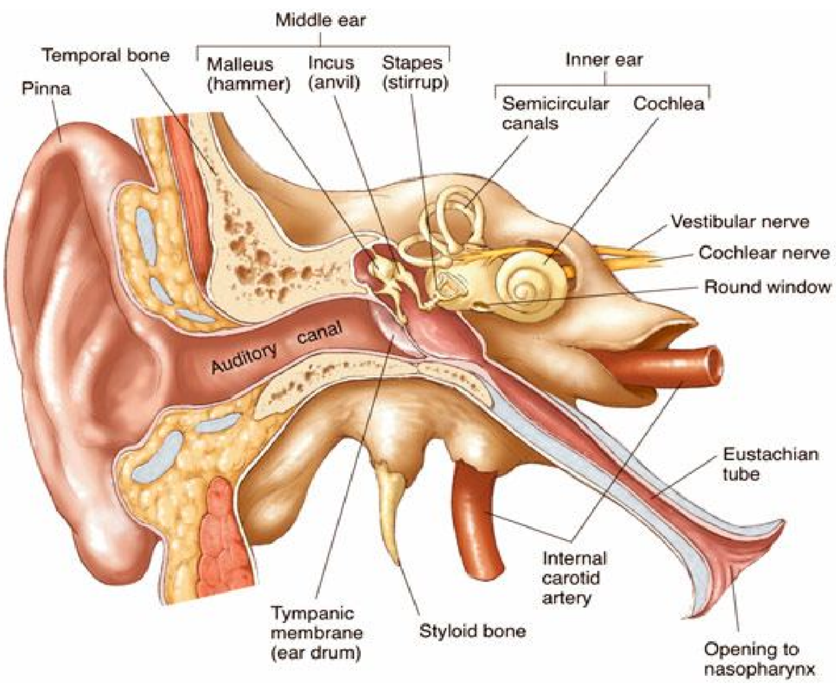

Figure 1. Anatomy of ear[1]

(Gerard J. Tortora, Bryan H. Derrickson (2008). *Principles of Anatomy and Physiology*, John Wiley & Sons, 11-Apr-2008.)

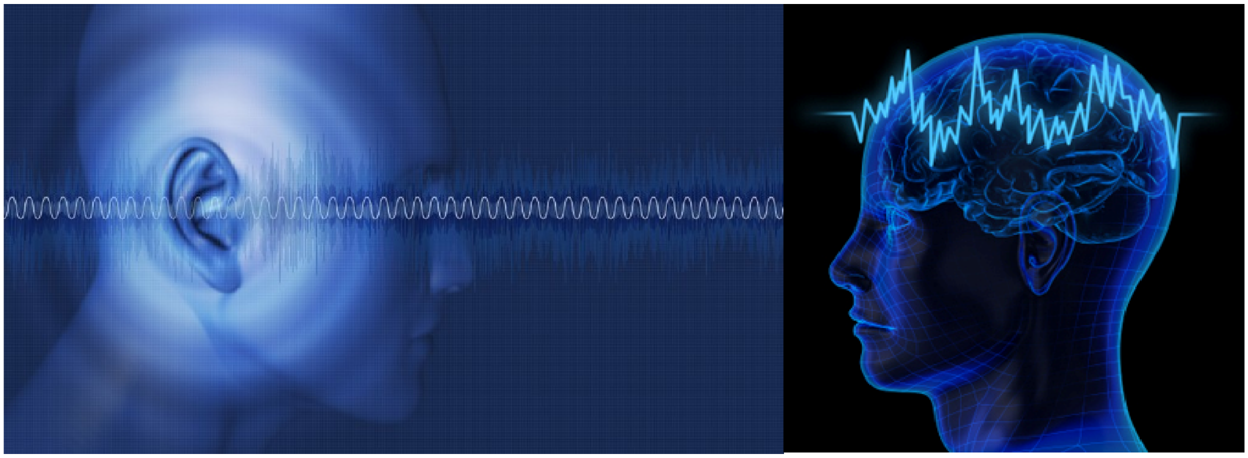

Figure 2. Ear and sound vibration[2]

(Hall Arthur C. Guyton, John E. (2005). *Textbook of medical physiology* (11th ed.). Philadelphia: W.B. Saunders.)

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Figure 3. Headphone and cell phones[3]

(Drake Richard L, Vogl Wayne, Tibbitts Adam W.M. Mitchell (2005). Illustrations by Richard; Richardson, Paul (2005). *Gray's anatomy for students*. Philadelphia: Elsevier / Churchill Livingstone.)

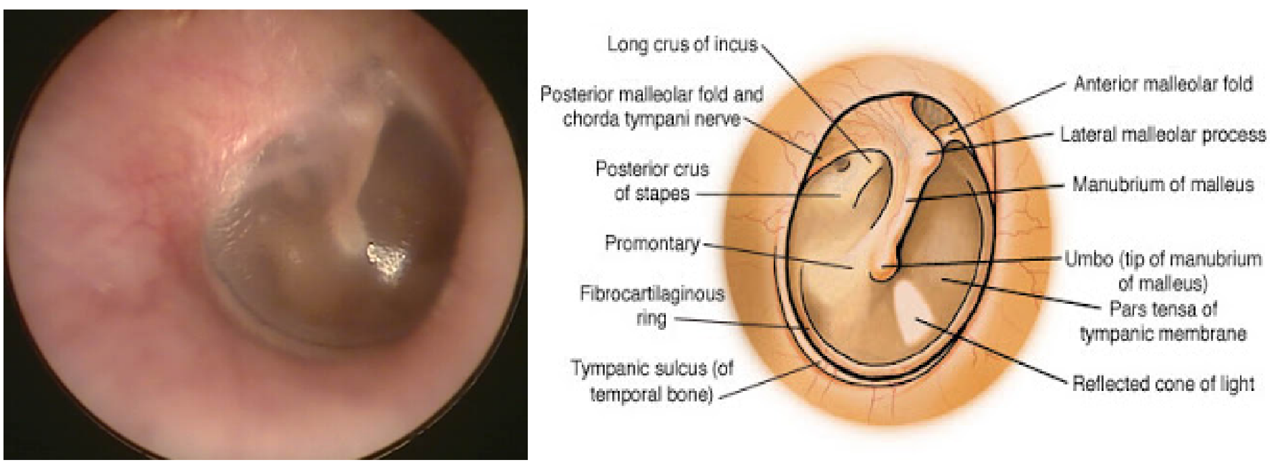


Figure 4. Anatomy of eardrum[4]

(Pompoli Roberto, Prodi Nicola (2000). Guidelines for Acoustical Measurements inside Historical Opera Houses: Procedures and Validation. *Journal of Sound and Vibration* 232(1), 281–301.)

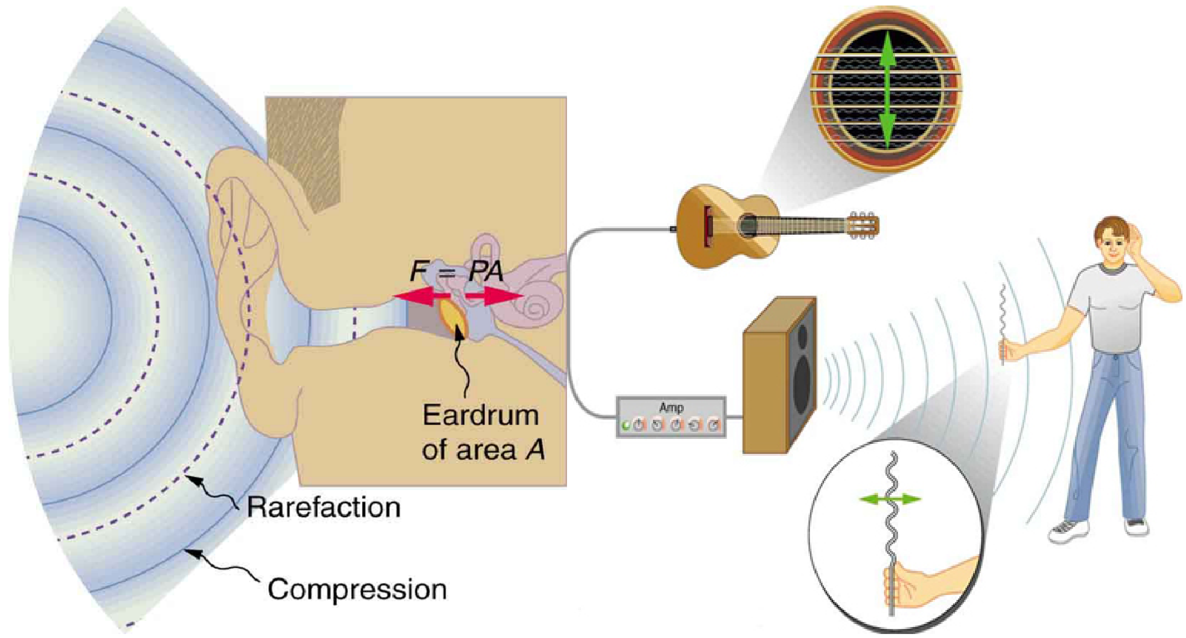


Figure 5. Ear & sound pressure[5]

(Farina Angelo, Tronchin Lamberto (2013). 3D Sound Characterisation in Theatres Employing Microphone Arrays. *Acta Acustica united with Acustica* 99(1), 118–125.)

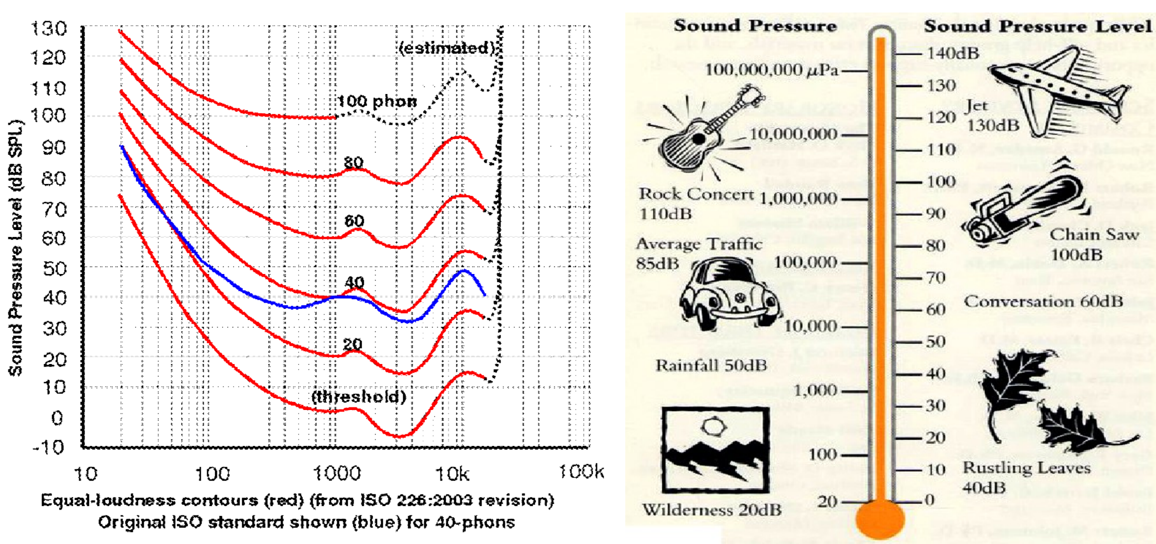


Figure 6. Decibel scale[6]

(Hartley R.V.L. (1928). TU' becomes 'Decibel'". *Bell Laboratories Record* (AT&T) **7**(4), 137–139.)

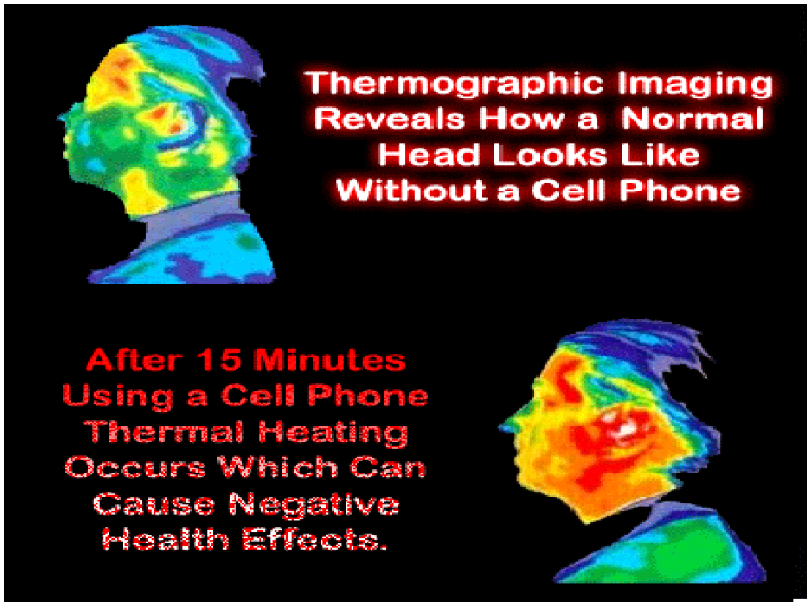


Figure 7. Thermal effects induced after or during use of mobile phones[7]

(Volkow ND, Tomasi D, Wang GJ, *et al*. (2011). Effects of cell phone radiofrequency signal exposure on brain glucose metabolism. *JAMA* 305(8), 808–813.)

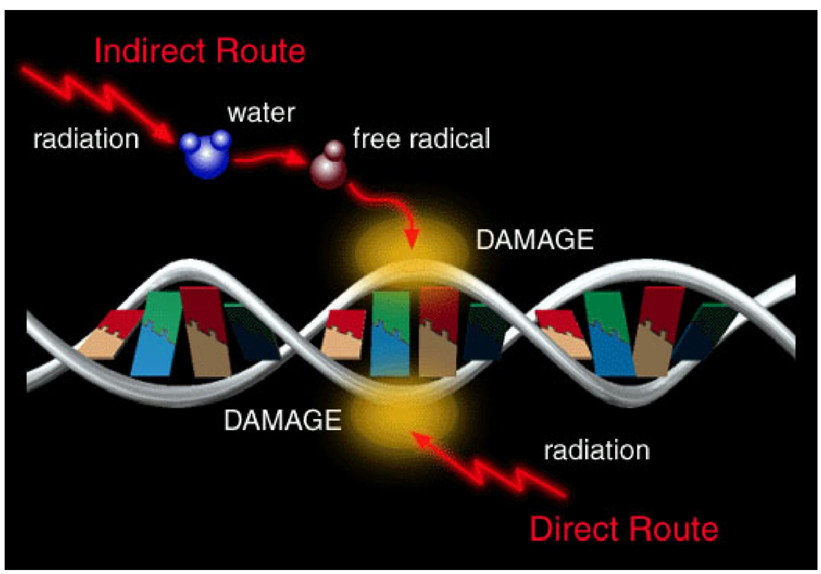


Figure 8. DNA damage by electromagnetic wave from cell phones[8]

(Hirose H, Suhara T, Kaji N, *et al*. (2008). Mobile phone base station radiation does not affect neoplastic transformation in BALB/3T3 cells. *Bioelectromagnetics* 29(1), 55–64.)

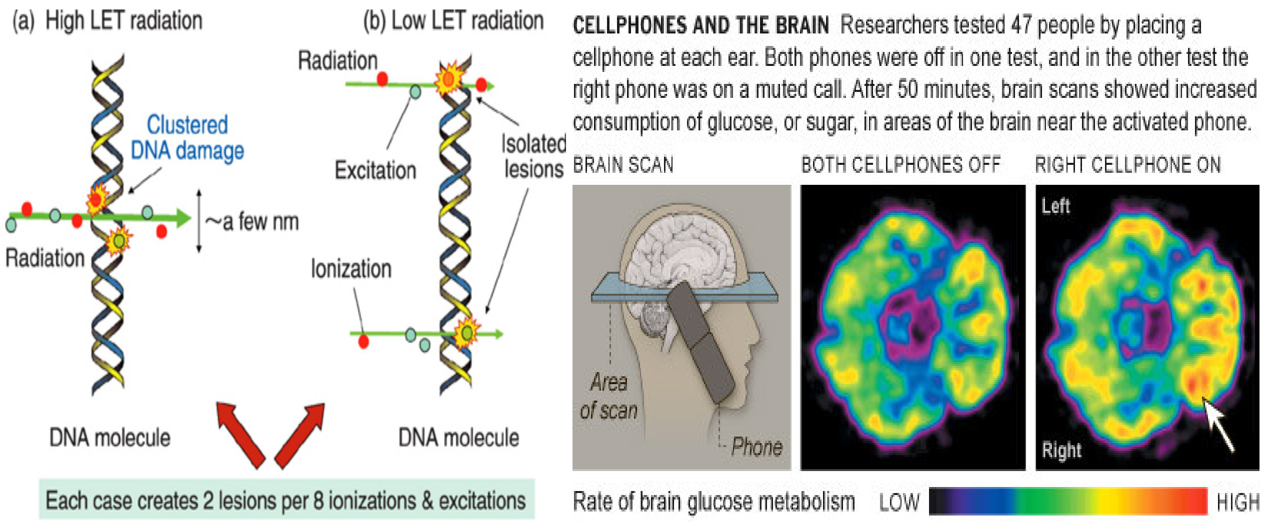
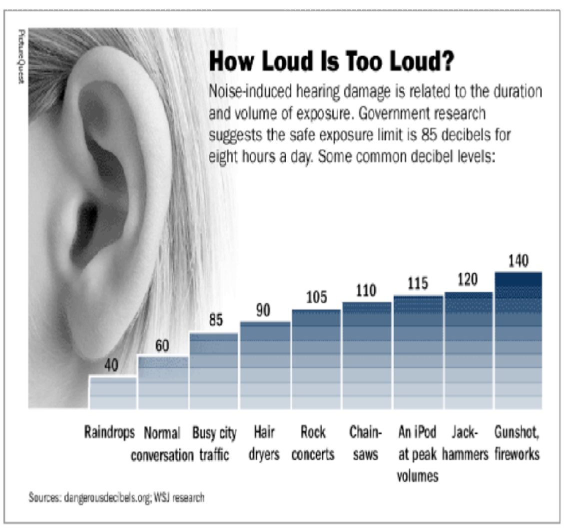


Figure 9. Electromagnetic radiation creating DNA damage of ear[9]

(Zook BC, Simmens SJ. (2006). The effects of pulsed 860 MHz radiofrequency radiation on the promotion of neurogenic tumors in rats. *Radiation Research* 165(5), 608–615.)



Source	Pressure rms (*Pa*)	Sound Intensity level SIL (*dB*)	Intensity (W/m^2)
Jet engine at 10 m		150	10^3
Jet engine	200	140	100
Jack hammer	60	130	10
Car horn	20	120 (pain threshold)	1
Rock band	6	110	0.1
Machine shop	2	100	0.01
Train	0.6	90	10^{-3}
Vacuum cleaner	0.2	80	10^{-4}
TV	0.06	70	10^{-5}
Conversation	0.02	60	10^{-6}
Office	0.006	50	10^{-7}
Library	0.002	40	10^{-8}
Hospital	0.0006	30	10^{-9}
Broadcast studio	0.0002	20	10^{-10}
Rustle of leaves	0.00006	10	10^{-11}
Threshold of hearing	0.00002	0	10^{-12}

Figure 10. Audio tolerance[10]

(Little MP, Rajaraman P, Curtis RE, *et al*. (2012). Mobile phone use and glioma risk: comparison of epidemiological study results with incidence trends in the United States. *British Medical Journal* 344, e1147.)