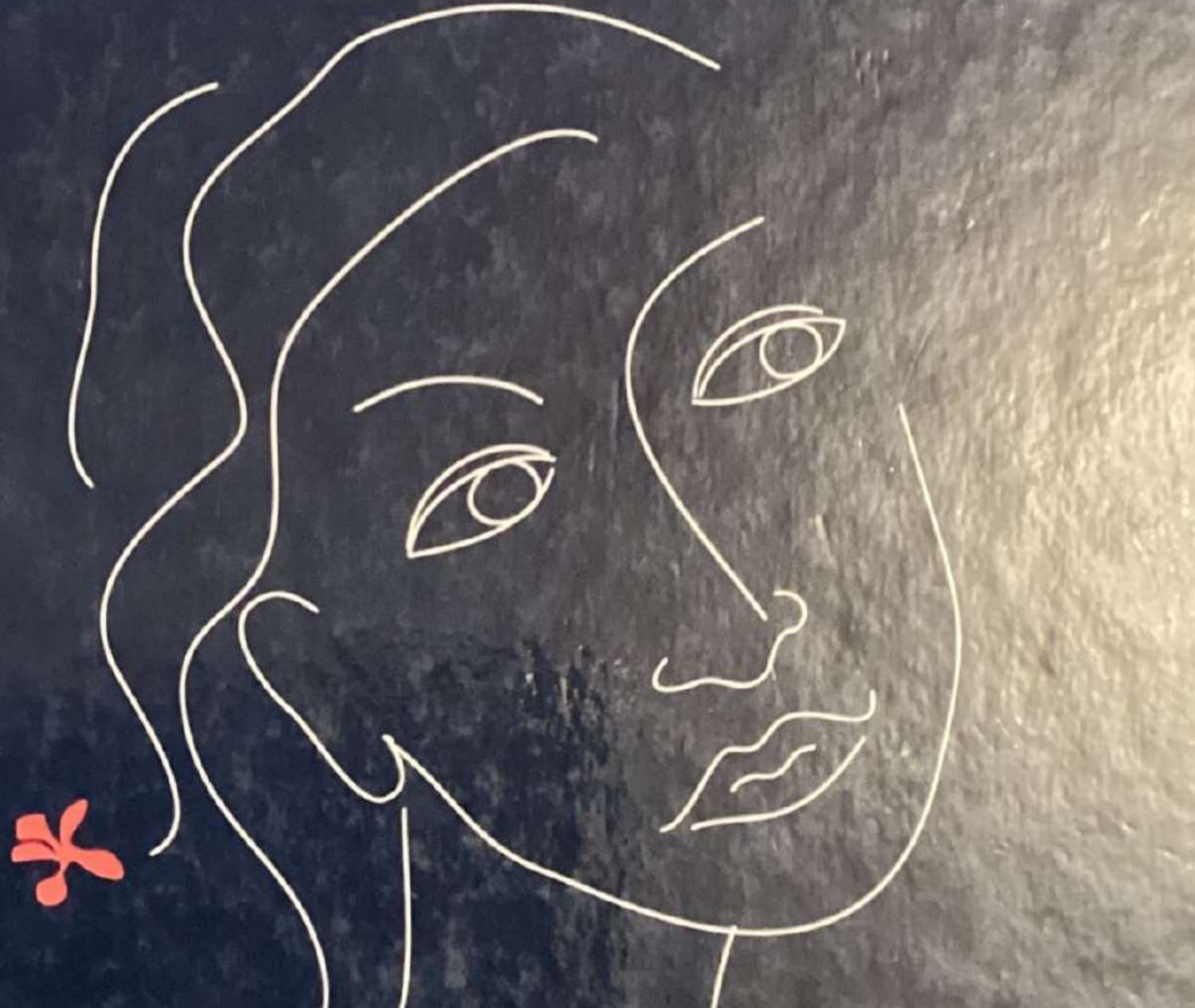
Claus Elberling & Kirsten Worsoe

Fading sounds

- about hearing and hearing aids



The Oticon Foundation

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Table of Contents

Preface

This book has been written for people looking for more information about hearing, hearing loss, and hearing aids than can be found in dictionaries or popular magazines. The book is particularly aimed at people with hearing loss and their families, friends and colleagues who are hereby given a chance to understand the implications of a hearing loss. With its style and format, the book will hopefully also be an inspiration for specialists in audiology and hearing professionals.

As far as possible, difficult concepts and technical terms have been avoided without rendering the text superficial. However, a certain professional foundation for understanding the fundamentals of hearing is provided in order to give meaningful assistance in the following areas: how the sense of hearing functions; how hearing ability is measured; the most common types of hearing loss; the parts of the hearing pathway most often affected; the limitations incurred by a hearing loss, and how these limitations arise; how hearing aids are constructed; and the benefits and limitations of using hearing aids.

The text is aimed at people without special knowledge about the sense of hearing or natural science. In places, explanatory boxes have been inserted in order to give additional information, but the book can be read without this supplementary text. The main text is supplied with many illustrations and figures prepared especially for the present publication. In the illustrations, a compromise has been attempted between detail and oversimplification. Therefore, only the most pertinent information is included.

In both text and figures, we have aimed at presenting the topics in such a way that people who are already using hearing aids, and therefore have had their hearing examined, hearing aids fitted, etc. should be able to recognize the procedures that are described and at the same time get answers to many questions that they either may not have asked or to which they may not have been given adequate explanations. For people who do not use hearing aids or have not yet had their hearing tested, the book will, hopefully, give answers to some of the questions that inevitably arise when one's hearing is failing or when one observes that this is happening to someone close or among one's acquaintances.

The book is made up of eight chapters which should provide a guide through the most common questions and problems:

1. How does sound reach the brain? A presentation of the sense of hearing and the most important anatomical and physiological components

2. How is hearing tested and a hearing loss determined?

3. Which types of hearing loss are the most common and where along the hearing pathway do the problems arise?

4. How is the individual person affected by a hearing loss? What is it one cannot do any longer?

5. What are the causes of this influence? A description of the many dimensions of hearing

6. How do hearing aids function? A description of the main components of hearing aids

7. What benefits can hearing aids be expected to provide? What are the limitations? And with a hearing loss, how does one handle various situations?

8. How does the hearing-impaired person cope with a hearing loss? A short introduction to hearing tactics

The book also contains a *glossary*, which can be used to look up words or terms that need to be explained. Finally, the book is equipped with a *subject index*.

The book contains much information that hopefully will prove useful for the reader. There are, however, four messages that we find to be of particular importance:

- In most types of hearing loss, the ability to hear soft sounds is reduced whereas the perception of loud sounds is usually not affected
- In most types of hearing loss, the ability to distinguish individual components of a complex sound, such as speech, is reduced
- In most types of hearing loss, the ability to determine the direction of a sound source is affected
- Hearing aids are not able to re-establish normal hearing

1. The hearing sense

In order to understand how the sense of hearing functions, it is useful to have a fairly accurate idea of the anatomical structures that are involved. Therefore, in this chapter we first describe those aspects of the human anatomy and physiology that enable us to hear everyday sounds, such as speech, music, sounds in nature, warning sounds, etc.

Most of the everyday sounds reach us through vibrations of air molecules. Young people with normal hearing are able to perceive the vibrations when these are faster than about 20 times per second, which corresponds to the lowest bass sounds that we can hear, but slower than approximately 20,000 vibrations per second, which corresponds to the highest treble sounds that we can hear.

The number of vibrations per second is called frequency and is usually given in the unit of Hertz (Hz). We say, therefore, that our hearing is located in the frequency range from 20 to 20,000 Hz. Ordinary speech is in the frequency range between 100 and 8,000 Hz.

However, even in the frequency range from 20 Hz to 20,000 Hz we are not able to perceive all sounds. This is due to the fact that our hearing is not without limitations. For instance, if the sound vibrations become too weak, we cannot hear them, and we say that the sound level is below the hearing threshold.

How soft the sounds may become and still be audible depend on their frequency – that is, whether they are bass or treble sounds. Generally, bass sounds must be louder than treble sounds in order for us to hear them. There are presumably two reasons for this: the middle ear has difficulties transmitting sounds at very low frequencies and the physical size of the inner ear puts a limit to how 'large' a given sound can be – as denoted by the so-called wave length, which becomes larger the lower the tone frequency

At the other end of the scale – that is, when the sounds become very loud – there is an upper limit to what is pleasant, or acceptable, to listen to. The relationship between the softest audible sound and the loudest acceptable sound is approximately 1,000,000 – i.e. one million times.

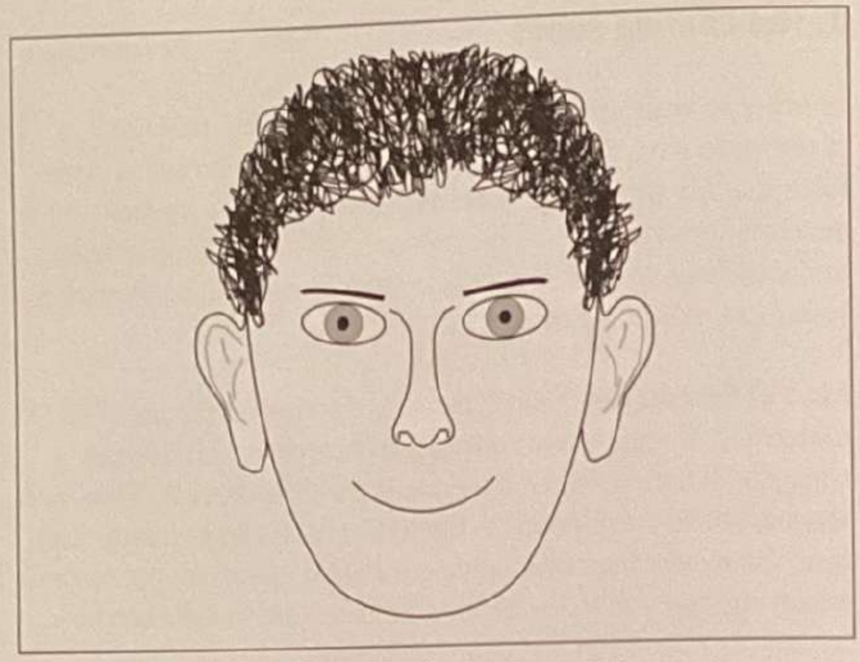

Figure 1.1. The two outer ears are placed symmetrically on the right and left side of the head

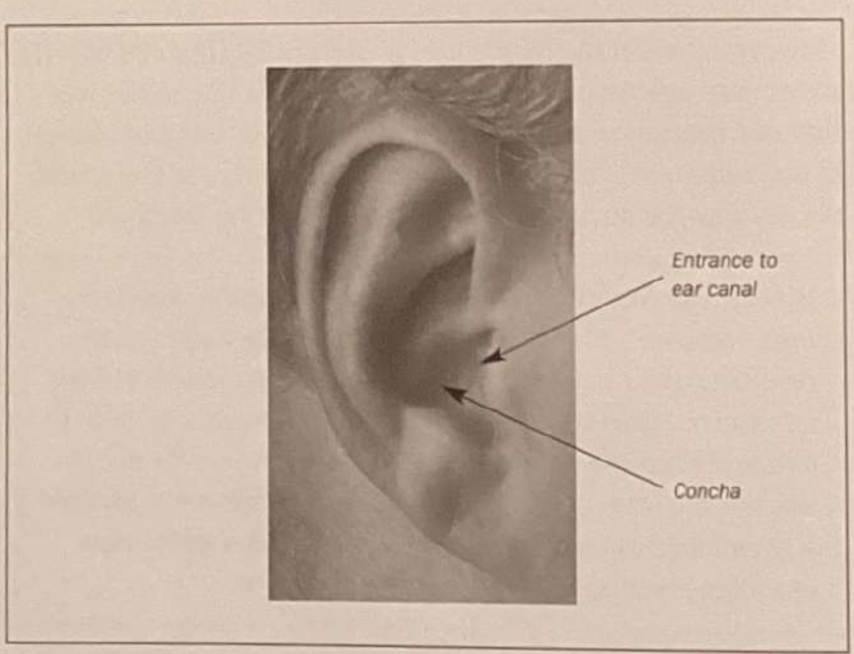

Figure 1.2. Outer ear with indication of the bowl-formed recess, the Concha, located immediately behind the entrance to the ear canal

Normally, our hearing sense is regarded to be a very sensitive and extensive instrument, but in reality its capacity is limited both with regard to frequency and level.

What makes it possible to transform vibrations in air molecules into sound perceptions in the brain – or, in other words, to create a sound impression that we can hear? This is facilitated by means of the hearing pathway, as described below.

1.1 The outer ear

The outer ear, or *auricula*, is placed on the side of the head (figures 1.1 & 1.2) and forms the visible part of the hearing pathway. With its form and many different folds, it has a certain impact on our ability to locate sound sources – that is, to determine where a given sound comes from. On its way to the *ear canal*, the sound is influenced by the physical shape of the outer ear, dependent on the location of the sound. The entrance to the ear canal is placed just in front of the center of the outer ear.

> *When the sound reaches the entrance to the ear canal, it has already been 'colored' by its direction of origin. The form of the auricula influences the ratio between the bass and treble sounds and the brain uses this frequency 'coloring' to determine the direction of the sound source. However, also for this purpose, the brain makes use of the difference between the sounds at the entrance to the two ear canals – on the right and left side, respectively. This difference is created both by the different arrival times and the different sound levels and derives from the fact that normally the sound has to travel different distances to reach the two ears and that the head has a certain shadow effect that is dependent on frequency*

1.2 The ear canal

The ear canal extends from the outer ear to the *ear drum* – a thin membrane (about 1/10 mm) forming an airtight seal at the end of the canal (figures 1.3 & 1.4). The ear canal consists of a soft outer part and a bony inner part extending as a tube-shaped cavity into the *temporal bone* (figure 1.4). The ear canal has a diameter of approximately 7 mm and a length of about 25 mm. Since it does not run in a straight line, but twists and bends, it is impossible from the outside to look directly into the ear drum at the end of the canal.

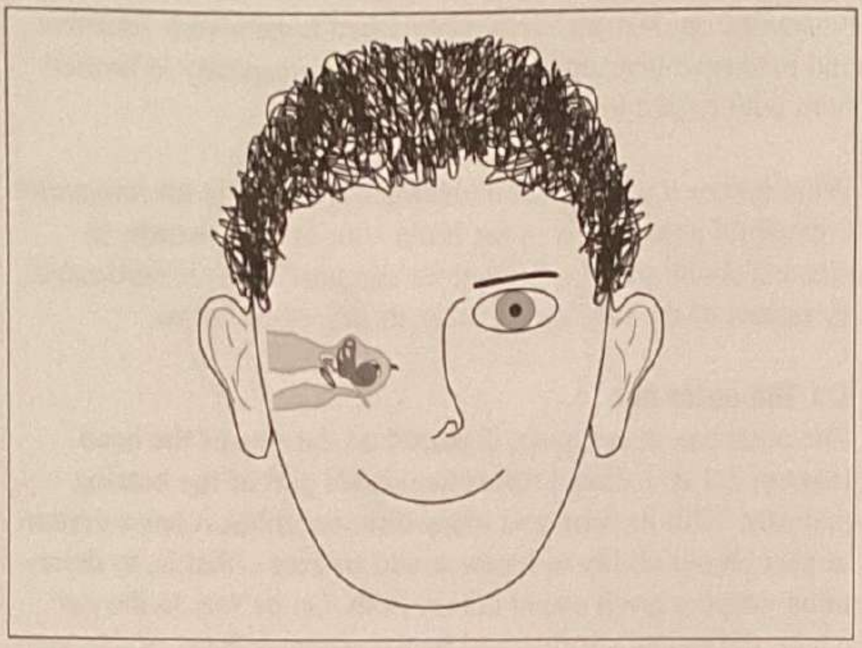

Figure 1.3. The temporal bone is located at a level with the outer ear – slightly below and behind the eye. The temporal bone houses the ear canal, the ear drum, the middle ear with the ossicular chain, the inner ear, the cochlea, as well as the first part of the hearing nerve

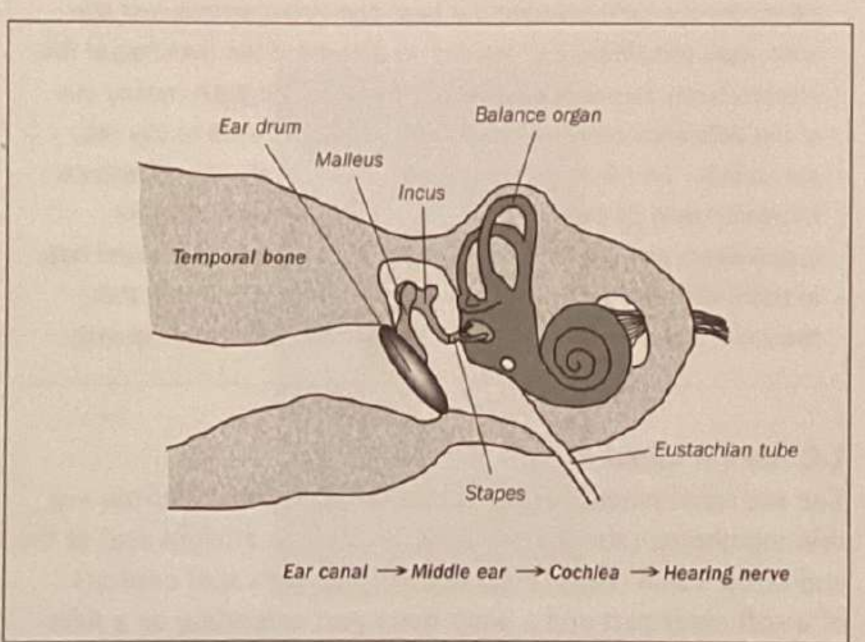

Figure 1.4. The most important parts of the hearing pathway in the temporal bone

In principle, the ear canal is a tube which is sealed at one end and therefore functions acoustically as a Pan flute with a so-called resonance frequency at about 3,000 Hz. This means that the length of the ear canal quite naturally enhances, or amplifies, the sounds that are most important for understanding speech. This enhancement corresponds to an amplification of 6-8 times (15-18 dB)

By means of a small speculum the ear canal can be straightened out so it becomes possible to inspect the ear drum and see whether or not it is normal (figure 1.5). This examination is called otoscopy. The skin of the outer part of the ear canal contains numerous wax producing glands, which form part of the normal physiology and have a protective and self-cleaning function.

When the sound vibrations in the air reach the end of the ear canal the ear drum is set in motion. This means that the sounds are no longer transmitted by vibrations of air molecules, but by vibrations of other structures of the hearing pathway.

The vibrations of the ear drum are very small. When we speak at a normal speaking level, the vibration of the ear drum is only about 1/1,000,000 mm – that is, just one millionth of a millimeter

1.3 The middle ear

The ear drum separates the ear canal from the *middle ear* (figure 1.4) – a cavity situated in the middle of the temporal bone. The middle ear has an exit via the *Eustachian tube* that opens into the nasal cavity. The Eustachian tube is normally closed, but is opened when we swallow. This allows air to flow in and out of the middle ear and helps to maintain the same air pressure on both sides of the ear drum, which is therefore 'slack' (flaccid) and in a neutral position.

In the middle ear, there is an *ossicular chain* consisting of the three smallest bones in the body: the *malleus* (hammer), the *incus* (anvil) and the *stapes* (stirrup) (figure 1.4). The malleus has a long process, which is attached to the ear drum (figures 1.4 & 1.5), whereas the stapes has a footplate, which is

Figure 1.5. A normal ear drum (right ear). Through the ear drum, the contours of the handle of the malleus can be glimpsed (here graphically enhanced by a thin, white line)

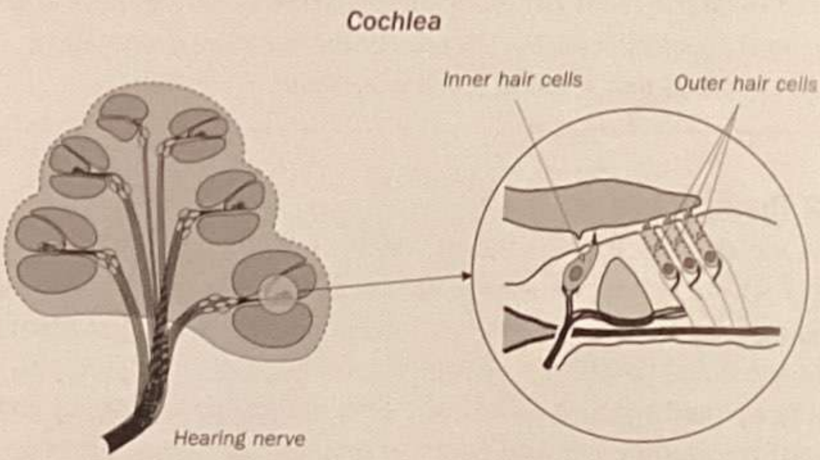

Figure 1.6. Left: a section through the cochlea formed like a snail-shell and with the three fluid-filled canals (of which the middle one contains the organ of Corti with the sensory cells) and the hearing nerve, tightly knitted together by individual nerve fibers. Right: a section of the organ of Corti. Note how the sensory cells form one row of inner hair cells and three rows of outer hair cells and how the nerve fibers connect to these

The transmission of sounds from the ear canal to the middle ear is most efficient when the ear drum is in its neutral position. When there is either a low or a high air pressure in the middle ear, or in certain other conditions, the ear drum cannot move freely and the sounds are therefore not transmitted optimally. This may change the characteristics of the sounds, as can be experienced when we have a common cold

implanted in the *oval window* in the inner ear (figure 1.4). The vibrations of the ear drum are thus transmitted via the ossicular chain (→ the malleus → the incus → the stapes) to the inner ear. The three middle-ear bones are kept together by a number of small ligaments and the entire ossicular chain can be influenced by two small muscles, of which the most important one is the *stapedius muscle* that connects to the top of the stapes.

The stapedius muscle is not shown in figure 1.4 because, from the top of the stapes, it bends backward and connects to the back wall of the middle ear. Therefore, the incus and the stapes would partly hide the muscle

1.4 The inner ear – the cochlea

The inner ear in the temporal bone consists of the snail-shell structure with the Latin name *cochlea*, which contains the sensory cells as well as a system of three semicircular canals that constitutes the *vestibular system* and contains the *balance organ* (figure 1.4). From the middle ear, there is access to the fluid-filled inner ear through two small windows: the *oval window*, in the niche of which the footplate of the stapes is attached, and the *round window*. Both windows are covered by thin membranes preventing the fluid in the inner ear from leaking back into the middle ear. The cochlea has the form of a snail-shell, which coils about 2¾ times and has an unfolded length of about 30 mm. Cross-sections of the snail-shell are shown in figure 1.6 and demonstrate how the individual coils are divided into three fluid-filled ducts – or canals – extending throughout the length of the cochlea.

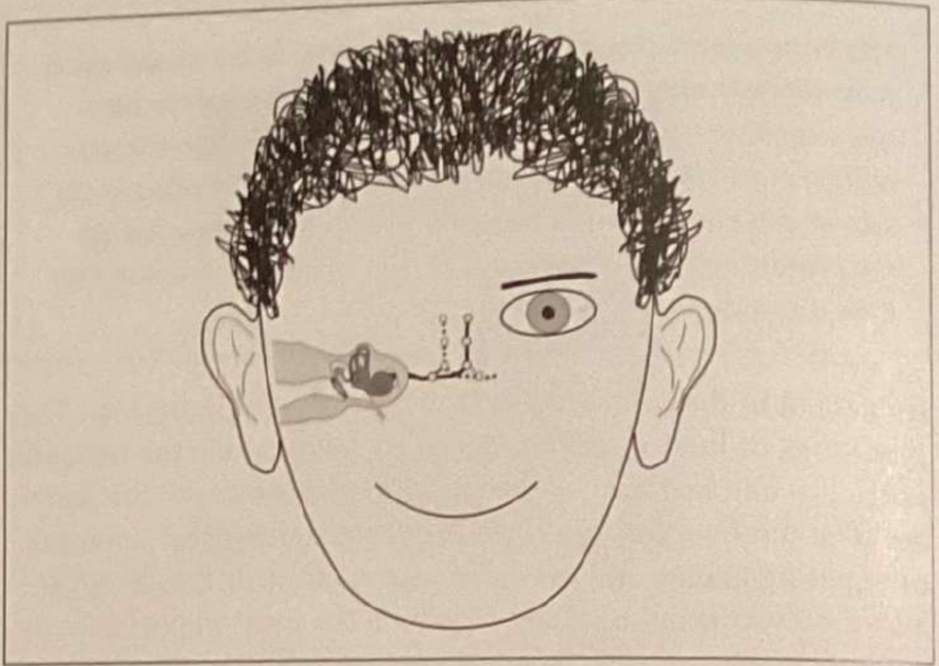

Figure 1.7. From the inner ear, the hearing nerve continues into the brain stem forming four distinct relay stations. After the first station, the hearing nerve crosses over to the opposite side – here the left – of the brain stem

> *The walls between the three ducts consist of thin membranes that serve to maintain the chemical balance, which is regulated by the metabolism of the cochlea*

In the middle duct is located the *organ of Corti*, which contains the sensory cells that connect to the tiny nerve fibers. In the middle of cochlea, all nerve fibers are interwoven into one nerve – the hearing nerve. The sensory cells consist of one row of 4,000 inner hair cells and three rows of a total of 12,000 outer hair cells (figure 1.6). The inner hair cells, in particular, are responsible for transmitting sound information to the hearing nerve. Thus, these cells connect to about 28,000 nerve fibers, while the outer hair cells have only about 1,500 nerve fibers at their disposal. When the outer hair cells are set in motion by sound vibrations, they perform a muscle-like contraction/expansion. These movements of the outer hair cells have the effect that the stimulation of the *inner* hair cells will be considerably greater than if the outer hair cells had not been present. The outer hair cells can thus be said to perform a 'mechanical' enhancement function.

When the outer hair cells are stimulated and thereby alternately contract and stretch, the mechanical energy is led back to the vibrating system – like a child in a swing who is able to increase and maintain the movements of the swing by rhythmical body movements

The sound vibrations transmitted from the ear drum to the footplate of the stapes now create movements of the fluid in the cochlea. The fluid movements stimulate the hair cells so that the sound information – mainly via the inner hair cells – is transmitted to the hearing nerve. The sounds have now been transformed into electric impulses in the nerve fibers and are transmitted quickly along the hearing nerve into the central nervous system.

Because of the special structure of the cochlea, the treble tones (high frequencies) mainly affect the hair cells at the bottom of the cochlea while the bass tones (low frequencies) mainly affect the hair cells at the top of the cochlea

The sounds that started out as airborne vibrations have now been transformed into mechanical vibrations in the ear drum and the middle-ear bones, then into vibrations in the fluid system of the inner ear and, finally, into electric impulses in the hearing nerve.

1.5 The hearing nerve and the brain stem

The hearing nerve (8th cranial nerve) leaves the cochlea and the temporal bone through a hole, or small duct, and together with the balance nerve it reaches the *brain stem*. On its way through the brain stem, and later on the middle brain, the hearing nerve, similarly to all other nerves, passes a number of *relay stations* that consist of clusterings of nerve fiber cell nuclei – called *neurons*. As shown in figure 1.7, there are four distinct relay stations on each side of the brain stem. After the first station, the major portion of the nerve fibers crosses over to the opposite side of the brain stem. This means that the major nerve representation for the right ear is in the left side of the brain stem – and vice versa. The patterns of nerve impulses are modified considerably at the individual relay stations,

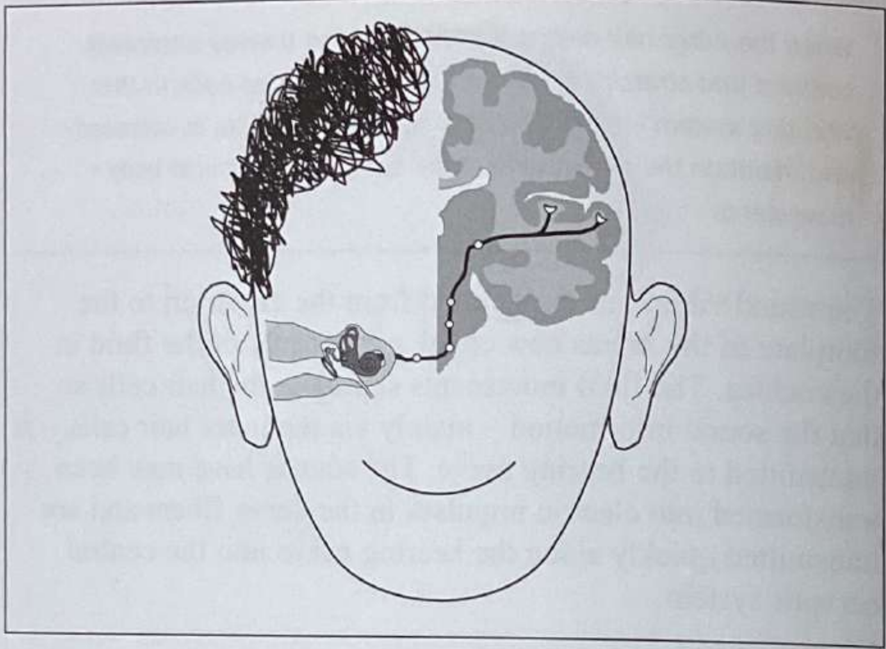

Figure 1.8. From the brain stem, the hearing nerve runs to the hearing cortex on the upper surface of the temporal lobe

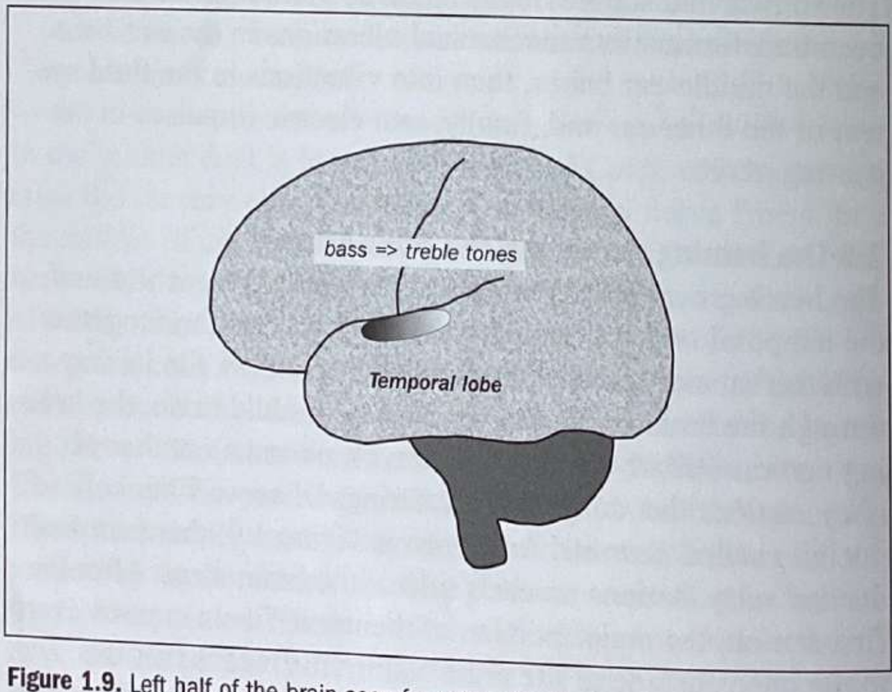

Figure 1.9. Left half of the brain seen from the side. The hearing cortex and primary hearing center of the brain are located on the upper surface of the temporal lobe. The figure indicates how the bass tones activate the hearing center towards the nose, whereas the treble tones activate the hearing center towards the back

dependent on specific characteristics of the incoming sounds. Special types of neurons generate nerve impulses when a sound begins, others when it stops; some signal the sound level, some the frequency content, while other types of neurons signal differences in sound patterns between the two ears, etc. Altogether, the different groups of neurons in the brain stem play a significant role in analyzing the incoming sound before it is sent off to the part of the brain that we hear with (the *cortical* center of the brain).

> *Groups of neurons in the brain stem take care of a specialized preprocessing of the incoming sound information before sending it on for further processing in the hearing center of the brain. The signal processing in the brain stem forms a very important part of the hearing process*

1.6 The brain and the hearing cortex

When the hearing nerve leaves the brain stem it proceeds through the middle brain before reaching the *hearing cortex*, which is located on the upper surface of the *temporal lobe* (figure 1.8). This is the end station of the hearing pathway and if we look at the brain from the side (figure 1.9) we can get an impression of where this end station is located – in the area constituting the *primary hearing center.*

> *As indicated in figure 1.9, the primary hearing center functions rather systematically in that the treble tones (high frequencies) primarily activate the nerve cells towards the back of the head, while the bass tones primarily activate the nerve cells towards the nose. This corresponds to the systematic frequency representation in the cochlea described above. Such a systematic grouping of the individual frequency areas is called a tonotopical organization*

Finally, figure 1.10 gives a survey of the complete hearing pathway. Only the most important components of the many structures of the central nervous system have been included in order to give a general view rather than focusing on details.

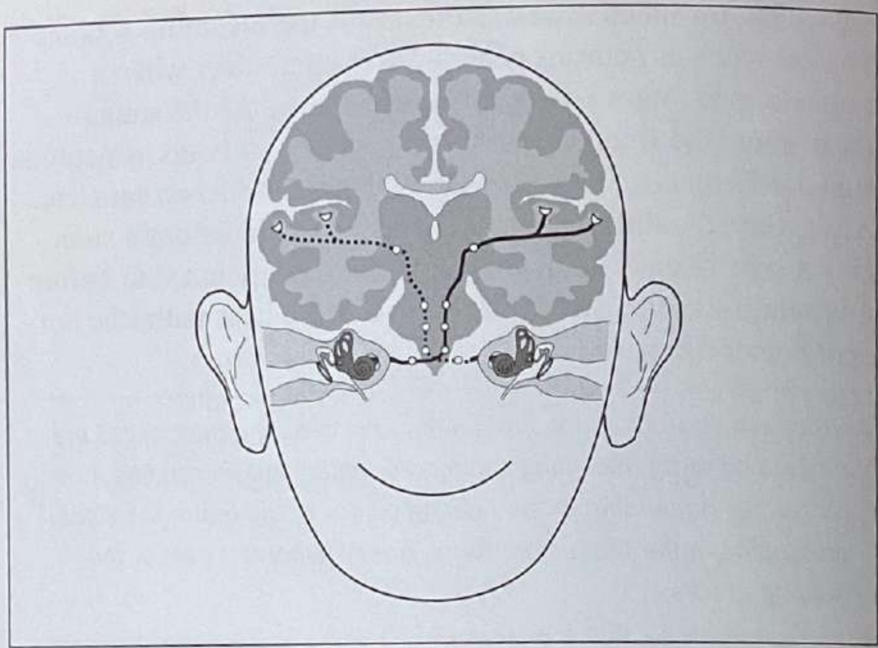

Figure 1.10. A survey of the left and right hearing pathways

2. Hearing tests - audiometry

Hearing ability is measured by a *hearing test* – also called *audiometry*. The first step is to determine the ability to hear soft bass and treble sounds. In this way, the *hearing threshold* is determined, which indicates the level of the softest sound that can be perceived. The test is made with pure tones of different frequencies and is carried out for the left and right ear separately. The result is plotted onto an audiogram (figure 2.1), also called a *pure-tone* audiogram or *hearing curve*. The deviation of the hearing threshold from what is considered normal hearing is called the *hearing loss* and is indicated in the audiogram for each frequency as the distance from the horizontal line indicated by 0 dB HL (normal hearing).

In the audiogram, the low frequencies (bass sounds) are shown to the left and the high frequencies (treble sounds) to the right. The sound level required to make the sounds just audible is shown with increasing intensity downwards and is indicated in dB HL.

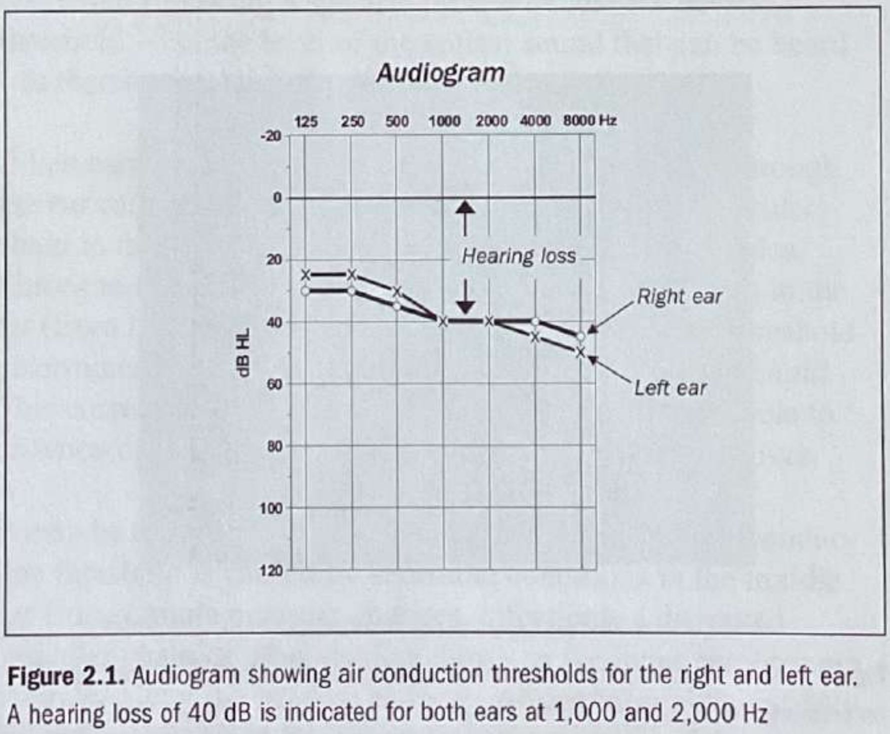

Figure 2.1. Audiogram showing air conduction thresholds for the right and left ear. A hearing loss of 40 dB is indicated for both ears at 1,000 and 2,000 Hz

Figure 2.2. External earphones used to determine the air conduction threshold at an ordinary hearing test

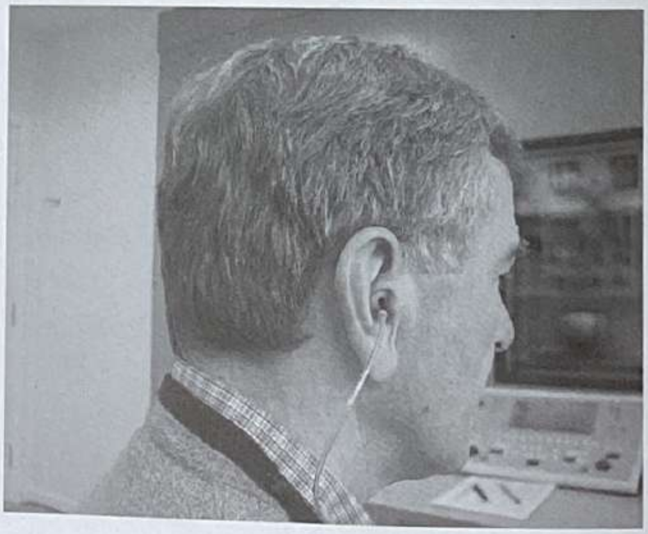

Figure 2.3. An 'insert' earphone used to determine the air conduction threshold at an ordinary hearing test

dB means decibel and is a term frequently used to indicate the level of acoustic sounds; when a sound is increased by 20 dB it becomes 10 times more intense. HL means Hearing Level

An ordinary hearing test is often performed in a *sound booth*, which is a special acoustically treated room built to exclude the most powerful sounds from the surroundings. In this way, the hearing test can be performed without excessive background noise and the measurements can therefore be considered to be fairly precise. The hearing test is carried out using an *audiometer*, which delivers tones of varying frequency and level.

An ordinary hearing test is carried out by placing *headphones* on the head (figure 2.2) or *'insert'* phones in the ear canal by means of rubber foam plugs (figure 2.3). Tones lasting one to two seconds are sent from the audiometer to the earphones and the person being tested indicates whether or not the sounds are heard. This is done either by pressing a button or raising a hand, so that the examiner is made aware of whether or not the tone has been perceived. The sound level is increased or decreased following a specific procedure and the hearing threshold – i.e. the level of the softest sound that can be heard – is thereby established.

When earphones are used, the sounds are transmitted through the ear canal to the ear drum which, by way of the ossicular chain in the middle ear, activates the inner ear, the cochlea. Since the sounds are transmitted to the ear as vibrations in the air (from the earphones to the ear drum), the hearing threshold determined in this way is called the *air conduction threshold*. This corresponds to the hearing sensitivity that is available to us when dealing with ordinary sounds in our everyday lives.

It may be difficult to determine whether a changed air conduction threshold is caused by abnormal conditions in the middle ear (for example pressure changes, infections, a disrupted ossicular chain or other dysfunctions), in the inner ear, or more centrally along the hearing pathway. Abnormal middle-ear conditions may result in an incomplete transmission of the sound vibrations from the ear canal to the inner ear. However, it is not always possible on the basis of the measured air conduction

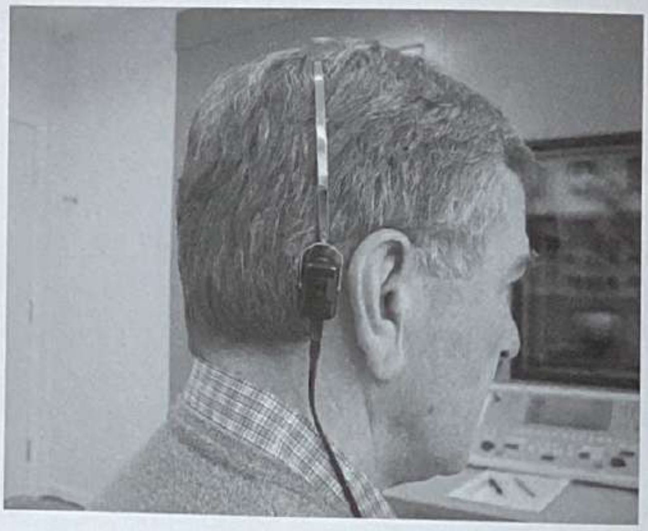

Figure 2.4. A bone conductor used to determine the bone conduction threshold at an ordinary hearing test. Here, the bone conductor is placed behind the right ear

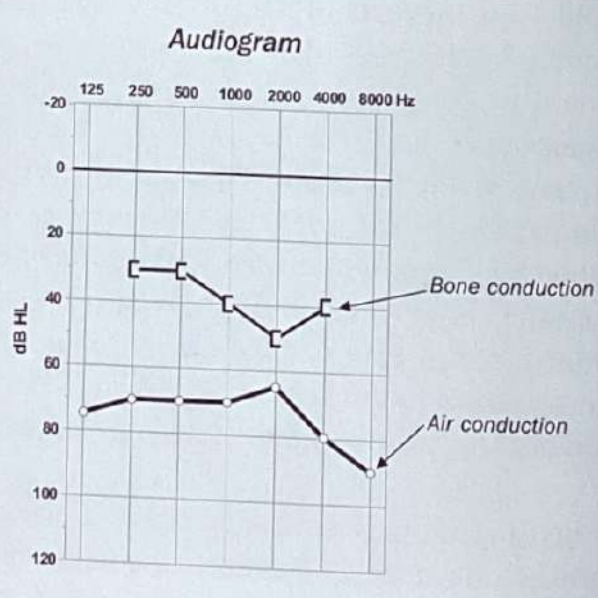

Figure 2.5. A right-sided audiogram showing a difference between the bone conduction threshold and the air conduction threshold

threshold to identify the possible causes of an abnormal hearing threshold.

Therefore, the ordinary hearing test may be supplemented by an examination carried out by means of a small vibrator, a so-called *bone conductor*, instead of the earphones. The bone conductor is placed in direct contact with the skull using a spring band, either behind the ear or on the forehead (figure 2.4). The sounds from the bone conductor are transmitted through the cranium and activate the cochlea directly, thereby by-passing the middle ear. This allows the hearing threshold to be determined independently of how the middle-ear functions. The tones from the bone conductor become sound vibrations in the skull and are transmitted equally to the two inner ears (left and right). It may therefore be necessary to transmit a noise sound into the ear that is not being investigated. This technique is called *masking* – which means that one ear receives a noise sound from the earphone and therefore cannot at the same time perceive the tone from the bone conductor. As can be seen, hearing testing may become a rather complicated affair. A hearing threshold obtained by means of the bone conductor is called the *bone conduction threshold* and is marked in a special way in the audiogram (see figure 2.5).

Sometimes it is necessary to perform additional testing of the middle-ear function. This is done by means of an *impedance audiometer*. A small probe is placed in the ear canal and the impedance audiometer can measure the *air pressure* in the middle ear and the *mobility* of the ossicular chain. The latter is done by measuring the *compliance* of the ear drum and the so-called stapedius reflex.

The stapedius reflex is a muscle reflex elicited by relatively loud sounds. 'Stapedius' is the name of the small muscle fastening to the head of the stapes – the innermost of the middle-ear bones (see figure 1.4). When the stapedius muscle is activated the ossicular chain tightens and the result is a reduced transmission of the sounds from the ear drum to the inner ear. In this way, the stapedius reflex serves to protect the inner ear against loud sounds

As we have seen, the audiogram reveals the function of the middle and inner ear by showing either normal hearing or reduced hearing. The degree of hearing loss is given in dB. Compared to normal hearing, a hearing loss of 40 dB means that sounds must be 100 times more intense in order to be heard.

> *Each time a hearing loss is increased by 20 dB, the sounds must be 10 times more intense to be heard – 40 dB thus corresponds to 20 dB + 20 dB ~ 10 x 10 = 100 times*

It should be remembered, however, that the audiogram shows only the level at which pure tones can be heard, or, in other words, how different soft tones are perceived, whereas it reveals nothing about the ability to communicate with other people – that is, how well speech is understood. This is not just a question of understanding speech in quiet surroundings, but, more importantly, of perceiving and understanding speech in noisy surroundings. It may, therefore, be necessary to supplement the hearing test by yet another examination called *speech audiometry*.

In addition to pure tones and noise sounds, the audiometer can also deliver speech sounds – either alone or mixed with various types of background noise. The speech sounds consist of combinations of numbers – for example 'three-nine-two' – or monosyllabic words, such as 'cat', 'door' or 'ball', which are sent in series via the earphones from the audiometer to the ear. The test person then repeats the series of numbers or words that have been heard. By changing the level of the speech sounds and the accompanying background noise, the ability to understand speech in quiet and noise backgrounds is evaluated. When monosyllabic words are used, the result is recorded either as the number of correctly understood words, which is called *speech intelligibility* (SI) or *discrimination score* (DS), or as the number of words that were *not* correctly repeated, which is called the *discrimination loss* (DL).

> *The result of speech audiometry can also be given as the sound level at which 50 % of the speech sounds were correctly perceived, or as the level ratio (given in dB) between the speech sounds and the background noise when 50 % of the speech sounds were correctly perceived*

In this chapter, we have looked at the hearing tests usually carried out in order to get a general impression of the hearing ability, for instance in connection with fitting of hearing aids in adults. There are, however, a number of situations where there is a need for a more detailed diagnosis or clarification of both the extent and cause of the hearing loss. Additional testing may be required in the following instances: before deciding to perform a *cochlear implantation*; before performing middle-ear surgery; to evaluate patients with symptoms or diseases related to hearing (dizziness, tinnitus, etc.); or to examine children who cannot participate actively in an ordinary hearing test. In these instances, the hearing tests may comprise a number of other tests than those mentioned here.

3. What goes wrong and where?

To describe the degree of a hearing loss and its consequences for the hearing impaired, various simple expressions are used. We say that the hearing loss is *mild*, *moderate* or *severe*, or use other similar, descriptive phrases. If a more detailed classification of the hearing loss is needed, the first crude distinction is made between a *conductive* and a *perceptive* hearing loss. In addition to these two main types, there are other, relatively frequent types of hearing losses that are either associated with certain complications or present special hearing problems. This chapter focuses on what goes wrong, and where, in the most frequently occurring types of damage to the hearing system.

3.1 The degree of hearing loss

The extent, or size, of a hearing loss is often described as *mild*, *moderate*, *severe* or *profound* and this description is used as a first – very crude – indication of the hearing problem. When a hearing test has been performed, the tested person will often have a need to discuss the result in ordinary words – 'how bad is it?' There are no exact definitions, but a mild hearing loss typically ranges from 10 to 35 dB, a moderate hearing loss from 35 to 70 dB, a severe hearing loss from 70 dB to 100 dB, and a profound hearing loss greater than 90-100 dB.

Occasionally, the lost hearing ability is indicated as a percentage, with a mild hearing loss corresponding to a loss of 10-35 %, a moderate hearing loss 35-70 % and a severe hearing loss 70-100 %. It should be emphasized, however, that such a classification is almost meaningless because it does not indicate what specific ability is affected, how much of this ability is actually lost, the type of hearing loss, and to which degree the loss can be alleviated

3.2 Conductive hearing losses

A conductive hearing loss – an *air conduction loss* – indicates that the hearing has been affected in such a way that the sounds no longer reach the inner ear in a normal fashion. This means that somewhere along the way through the ear canal, the ear drum, the middle ear and the ossicular chain, obstacles have arisen that prevent the sounds from reaching the inner ear in a normal way. Therefore, the incoming sound must be made louder in order to achieve a normal stimulation of the inner ear – this condition is called a conductive hearing loss.

Conditions in the ear canal

Some people, especially the elderly, produce a lot of wax in the ear canal. If the production of wax becomes excessive, firm wax plugs may completely block the passage of sounds to the ear drum. For hearing aid users, wax may cause recurrent problems because the hearing aid partly blocks the free passage of air to the ear canal, thereby increasing the humidity and temperature in the ear canal. This may in turn affect the production of wax and the way in which the wax builds up.

> *Regardless of whether or not a hearing aid is used, one should never attempt to remove wax from the ear canal by using objects such as cotton sticks, matches, or other unsuitable tools. Usually, this merely causes the wax to get packed deep in the ear canal. If one experiences problems with ear wax, an otologist should be consulted*

In rare cases, inflammation may occur in the ear canal caused by either eczema or skin infection and this condition may become so severe that the entire ear canal is obstructed.

In both instances, the sounds are prevented from reaching the ear drum and the result may be a considerable conductive hearing loss.

Conditions relating to the middle ear

The most common problem encountered in relation to the middle ear is caused by infections, which may be induced by either general infections or common colds. Small children, in particular, are at risk and approximately 65 % of all children have had a middle-ear infection at some stage. Middle-ear infections may cause creation of pus and fluid, or give rise to changes in the middle-ear pressure resulting in a decreased mobility of the ear drum. When the ear drum is prevented from moving freely, the sound vibrations are no longer transmitted to the inner ear in the normal way. Changes in the middle-ear pressure may be caused by middle-ear infections, but may also arise from external pressure changes, for instance in connection with flying or diving.

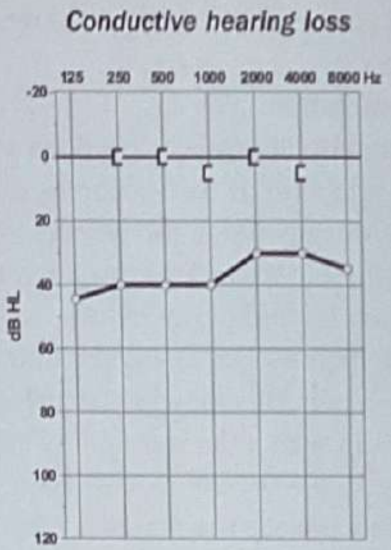

Figure 3.1. The audiogram shows a conductive hearing loss in the right ear. The bone conduction threshold is normal, whereas the air conduction threshold shows that there is a hearing loss for air-borne sounds

Other mechanical problems may arise in the middle ear, such as perforations of the ear drum and disruptions of the middle-ear ossicular chain. A particular middle-ear disease, *otosclerosis*, may cause the footplate of the stapes to be fixed to the niche of the oval window (see chapter 1.3). Such conditions in the middle ear may affect, to varying degrees, the transmission of sound vibrations from the ear canal to the inner ear.

The hearing loss caused by a conductive disorder may reach a maximum of about 50 dB, but is usually considerably smaller. In most cases, this type of hearing loss is *reversible*, which means that it disappears almost completely when the cause is removed (removal of wax plugs, infection cured, surgical closure of ear drum perforations, etc.)

Figure 3.1 shows the audiogram of a purely conductive hearing loss. The bone conduction threshold indicates that the condition of the inner ear is normal, whereas the air conduction threshold shows that there is a considerable hearing loss of air-conducted sounds. The difference between the two threshold curves indicates the size of the conductive hearing loss for each frequency.

A conductive hearing loss leads to generally poor hearing, and if the hearing loss reaches maximum it will severely affect one's everyday life, especially the ability to participate in ordinary conversations. Another obvious effect is that even a slight conductive hearing loss affects the ability to localize sounds.

In the small child, one often first suspects a beginning middle-ear infection by noting that the child speaks more loudly than usual or has difficulty localizing sounds – this means that the child has problems determining the location from where mom or dad is speaking. A conductive hearing loss caused by frequent and long episodes of middle-ear infection may have serious implications for the child's language development.

3.3 Perceptive hearing losses

A *perceptive hearing loss* – also called a *sensori-neural hearing loss* – is caused by changes in the inner ear and the first part of the hearing nerve. This means that on their way through the cochlea, with its fluid system and hair cells, the sounds do not stimulate the hearing nerve in the normal way.

Usually, the hair cells themselves have been damaged. If the hearing loss is small, the damage mostly, or exclusively, affects the outer hair cells, while larger hearing losses also involve the inner hair cells.

The contribution to our sense of hearing from the mechanical function of the outer hair cells, namely their muscle-like contractions, is greatest at the normal hearing threshold and gradually diminishes at increasing sound levels. Therefore, a complete or partial loss of outer hair cells will not result in an equivalent, or 'one-to-one', loss of hearing, but will result in reduced hearing for soft sounds in particular. A small hearing loss thus affects the hearing at low sound levels while larger hearing losses result in difficulties hearing both soft and loud sounds.

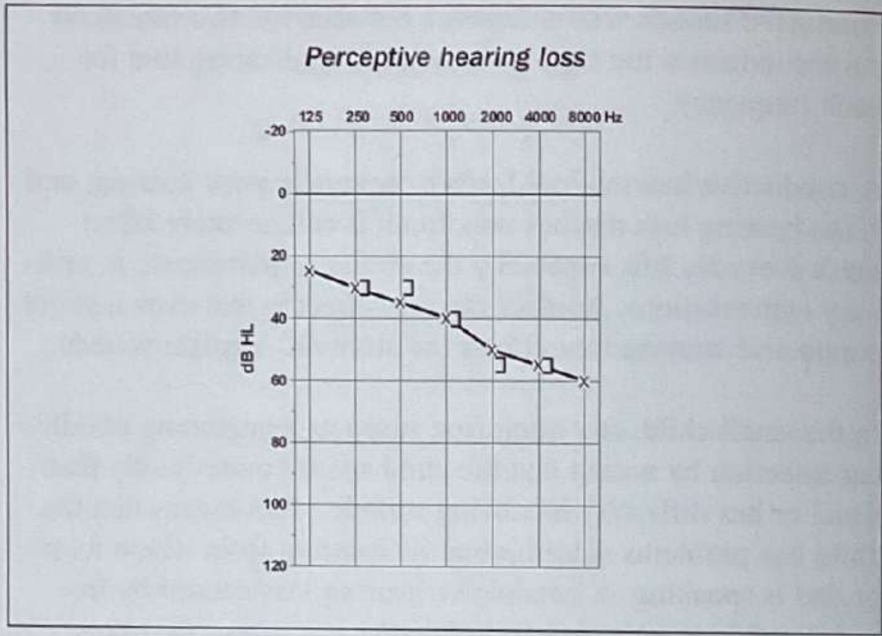

Figure 3.2. The audiogram shows a perceptive hearing loss in the left ear. The air conduction and bone conduction thresholds are very similar

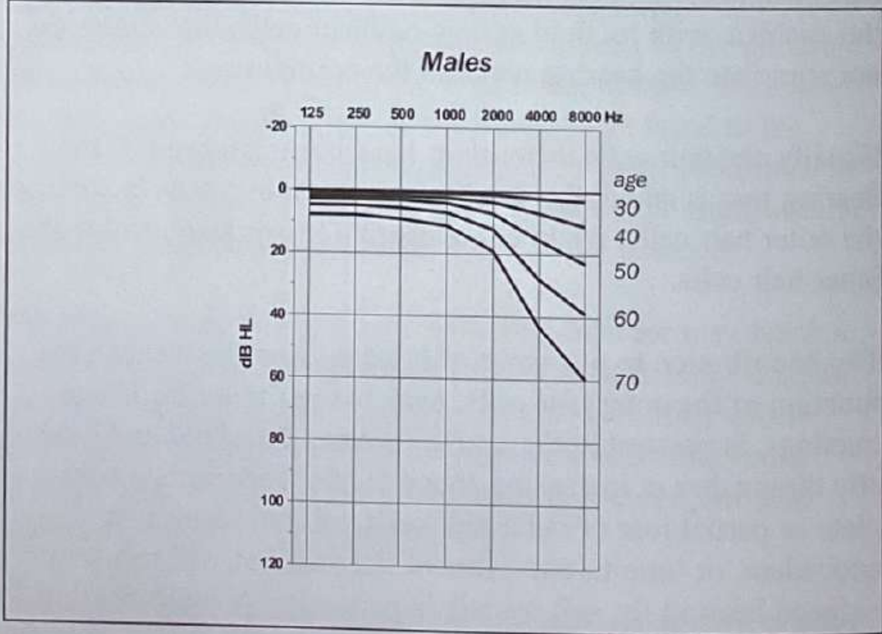

Figure 3.3 a. The development of the average, age-dependent hearing loss in men

The hair cells and other important structures in the cochlea are extremely sensitive to a number of conditions, such as age, environmental noise, medication, etc. Other changes may be hereditary and cause either a congenital hearing loss or a hearing loss that does not appear until later on in life. Congenital hearing losses that require treatment occur in approximately 3 out of every 1,000 newborns (0.3 %).

Figure 3.2 shows an audiogram of a typical perceptive hearing loss. The air and bone conduction thresholds are almost identical, indicating that the conduction loss is insignificant. The damage is therefore most probably caused by loss of hair cells in the inner ear.

A rule of thumb says that hearing losses smaller than 60 dB are caused by loss of outer hair cells, while larger hearing losses also involve a loss of inner hair cells. In practice, there are many deviations from this rule, just as it is probably not just the sensory cells that are damaged or have stopped functioning, but also other structures in the cochlea that may be affected

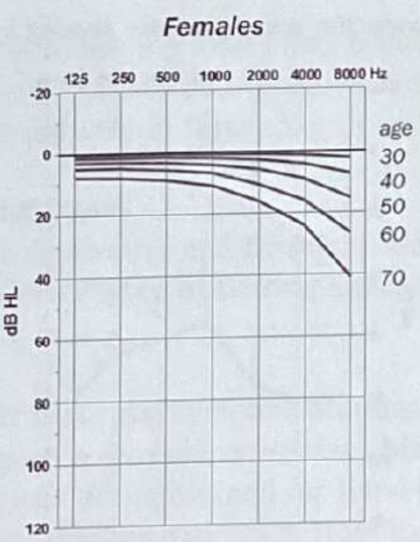

Figure 3.3 b. The development of the average, age-dependent hearing loss in women

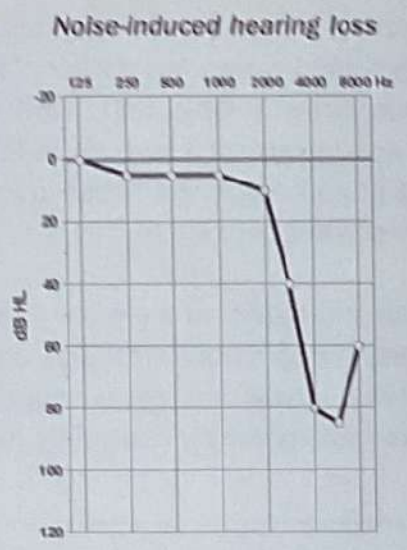

Figure 3.4. The audiogram shows a right-sided, noise-induced hearing loss, which is particularly pronounced in the frequency range from 3,000 to 6,000 Hz

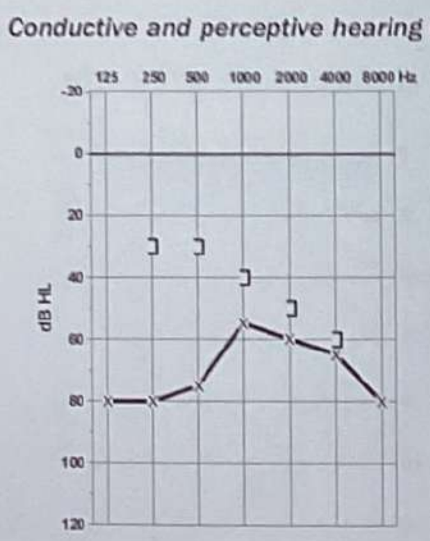

Figure 3.5. The audiogram shows a mixed, conductive/perceptive hearing loss in the left ear (a similar example is shown in figure 2.5)

The age-related hearing loss develops systematically with age, but differently in women and men. The average hearing thresholds for this systematic, age-related change in hearing are shown in figures 3.3 a and 3.3 b.

An audiogram of a typical noise-induced hearing loss due to long-lasting exposure to loud noises, for instance heavy machinery, is shown in figure 3.4.

3.4 Mixed hearing losses

The previous paragraph dealt with purely conductive or purely perceptive hearing losses. The two types of hearing losses may, however, occur at the same time, as so-called *mixed* hearing losses. Figure 3.5 shows an example of such a mixed hearing loss, where the air conduction threshold shows the size of the total hearing loss, the bone conduction threshold shows the size of the perceptive hearing loss (in the cochlea), while the difference between the two thresholds indicates the conductive component of the hearing loss. There are a number of pitfalls when testing mixed hearing losses and these may be difficult to diagnose correctly – especially when there are substantial differences between the hearing ability of the two ears.

Other types of mixed hearing losses may occur as a result of combinations of noise exposure and age – an example is shown in the audiogram depicted in figure 3.6.

3.5 Other hearing losses

In addition to the conductive and perceptive hearing losses described above, other types of hearing losses and symptoms may occur.

A very frequently occurring symptom accompanying hearing disorders is 'ringing in the ear', or *tinnitus*. Many people suffer from various degrees of tinnitus and for some it is a very distressing condition. Tinnitus may result from damage to various parts of the hearing pathway. It may synchronize with the pulse, which implies that it is caused by a regular sound created in or surrounding the many tiny blood vessels running close to the cochlea. Or it may arise spontaneously from non-sound provoked contractions of muscles and other structures in the

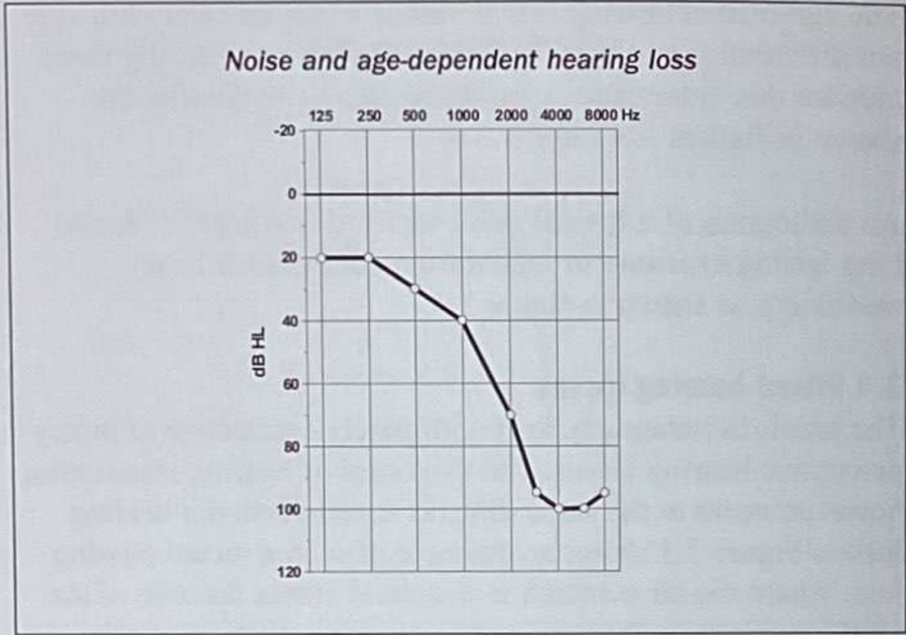

Figure 3.6. The audiogram shows a mixed, noise-induced/age-dependent hearing loss in the right ear

middle ear. Such sounds that do not come to the ear from the outside are called *body sounds*.

Most often, however, tinnitus presents as a *phantom sound*, which means that the perception of sounds is not related to any external physical event or to any of the body sounds mentioned above. This form of tinnitus is usually a symptom that accompanies a perceptive (cochlear) hearing loss. Such hearing losses are usually related to noise trauma inflicted by prolonged exposure to noise from heavy machinery, loud music or loud impulse sounds from fireworks, gunshots, etc. Tinnitus may also arise from medication or other chemical substances and, finally, it may be associated with common, age-related hearing loss.

The way in which the brain tries to adapt to the changes occurring in the cochlea as a result of a hearing loss (*cortical plasticity*, see chapters 5.6 and 7.3) presumably plays an important role in the occurrence of tinnitus.

Many people experience shorter or longer episodes of tinnitus in connection to exposure to loud noise from rock music, fireworks, firearms, machinery, etc. It should be stressed that this form of tinnitus is nature's warning sign that the hearing system has been exposed to acoustical events which, over time, may lead to permanent damage to the sense of hearing

A particularly complicated type of hearing loss is caused by a condition called *Ménière's* disease. It usually affects people aged 40 to 60 years and involves both the cochlea and the vestibulum (balance organ). The symptoms may occur alone or in combination, but typically in attacks, and include *hearing loss* (especially at low frequencies, that is, bass sounds), *dizziness*, *tinnitus* and a sensation of *fullness* in the ear. There are great variations in the way in which Ménière's disease affects people. Some have attacks at rare intervals, while others have them frequently; some have very weak episodes, while others experience very severe attacks; some have only a few of the symptoms while others have them all. The hearing loss may be associated with sound distortion, violent dizziness and severe tinnitus, making Ménière's disease very incapacitating for the individual patient.

The cochlea and the semicircular canals are situated closely together in the temporal bone (see chapter 1.4) and the two sense organs for *hearing* and *balance*, respectively, share a common fluid system. Ménière's attacks are probably caused by sudden changes in the chemical composition of this fluid system, known as *endolymphatic hydrops*.

The fluid system consists of two liquid substances: the perilymph and the endolymph, which have very different chemical compositions. The perilymph has a relatively high content of sodium ions while the endolymph has a relatively high content of potassium ions. Endolymphatic hydrops are presumably associated with a pressure increase of the endolymph which then leaks into the perilymph, thereby changing its ion balance

It is a small comfort for the patient with Ménière's disease that the attacks tend to weaken in strength and frequency over the years and that the disease finally 'burns out', often leaving, regrettably, a considerable permanent hearing loss. Because of the fluctuating hearing loss and the accompanying sound distortion during the active phase of the disease, the benefit of using hearing aids is often limited. With regard to other medical treatments, the readers are referred to special literature on this topic.

Finally, there are a number of relatively rare types of hearing losses that can be attributed to damages to the part of the hearing pathway that is located after the cochlea. These types are called *retro-cochlear* or *central* hearing losses and include benign tumors on the hearing nerve (acoustic neuroma) and injuries to the central nervous system caused by various malignancies involving the brain stem, mid-brain, and cortex.

4. How is your daily life affected?

A person who has acquired a hearing loss seldom knows where in the hearing system the problem is located, but will, in most cases, feel that the hearing no longer functions the way it used to. Everyday situations may become difficult to cope with: things said are misunderstood more frequently than before; other people's speech becomes indistinct; it is increasingly difficult to understand what the grandchildren say; door bells and telephones are frequently ignored; and sounds in nature have almost disappeared. In many different ways, speech communication is an important element in our everyday lives. The hearing impaired will start noticing that it becomes more and more difficult to follow a conversation when many people are present or in noisy surroundings and that it becomes increasingly more difficult to localize sounds. Furthermore, the hearing impaired may be surprised by no longer noticing warning sounds in the traffic or signals from electric household appliances. Finally, the hearing-impaired person often finds that a number of everyday sounds have gradually disappeared.

4.1 Speech communication

Speech communication implies that we alternately speak and listen to what others are saying. When we speak, we unconsciously hear our own voice – not in order to understand what is being said, but for the brain to use the hearing feedback to control the strength of one's own voice. This applies especially to difficult situations, for instance outdoor conversation, or when speaking in a large room or having a conversation in surroundings with background noise. In such situations, the speaker will unconsciously use both vision and hearing to evaluate how loud it is necessary to speak in order to achieve optimal communication in the given physical environments. For a person with a hearing loss, it is more difficult to control the level of one's own voice. Therefore, when you meet someone who speaks unusually loud in various situations, it may be a first indication that the person's hearing is beginning to fail.

Speech communication is important throughout one's entire life. It starts in infancy, when the newborn baby from the very beginning must be 'bombarded' with sounds – especially speech sounds and continuous speech – partly in order for the

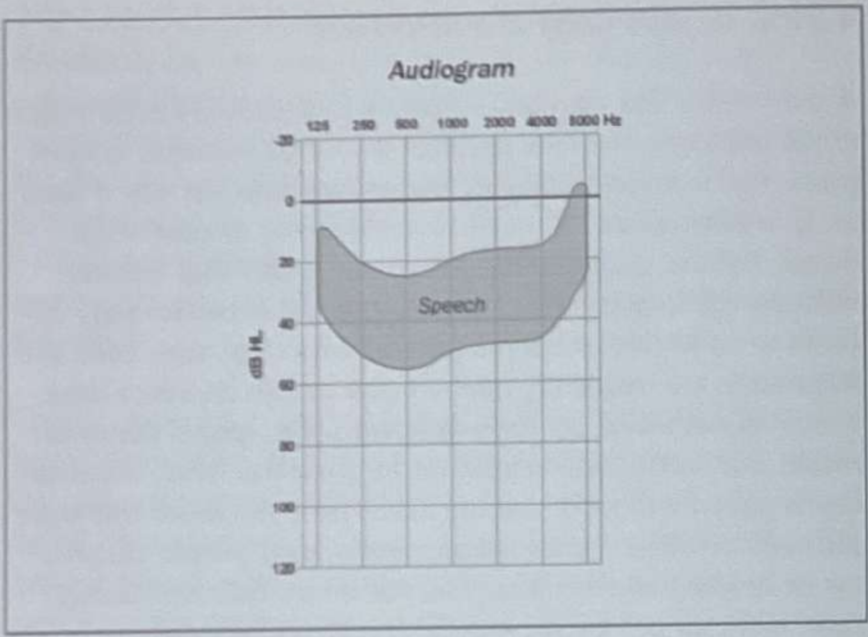

Figure 4.1. The audiogram shows the area usually covered by speech at normal speaking level. The speech covers a range of 30 dB

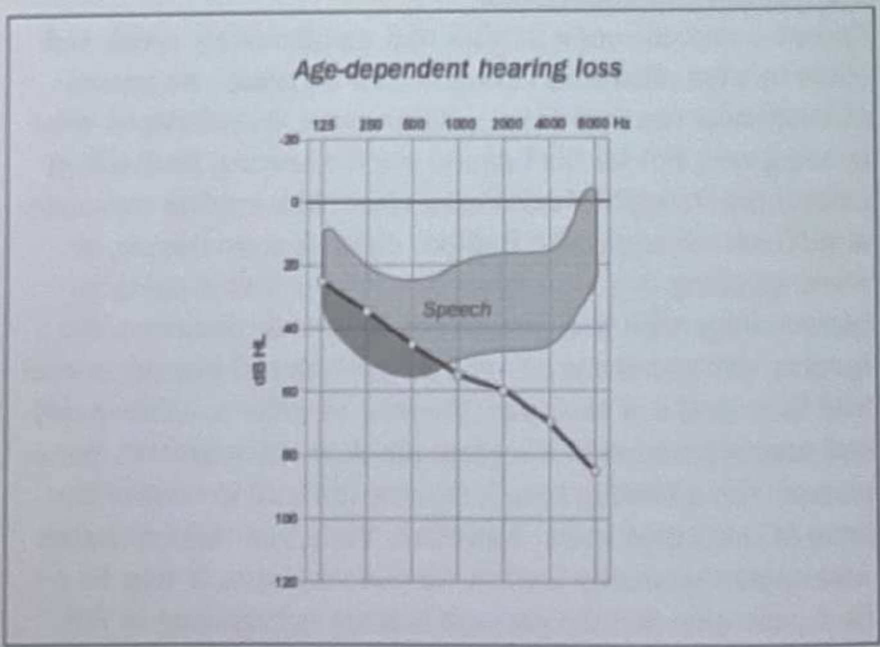

Figure 4.2. The audiogram shows a right-sided hearing loss. Only a small portion of normal speech is above the hearing threshold and thereby available for speech perception (here shown as the dark grey area)

neural connections in the hearing system to mature and partly for the linguistic competence and perception of language to develop in a normal way. For the infant, there is only a limited period of time to acquire the foundations of language. From the first year in the child's life and up to the age of seven, the possibilities gradually decline for the hearing system to develop and for acquiring effective language skills and a varied perception of language.

Later on in life, speech communication plays an important role in our everyday lives. Speech is an essential part of our communication with other people and it is important for the development of social skills as well as for the education of children and young people. Furthermore, a good perception of language is a prerequisite for acquiring knowledge through reading of books and other texts, for instance via the computer, and, of course, for acquiring foreign languages. For most people, a hearing loss will therefore greatly affect their everyday lives, especially their social interactions, and for young people the hearing loss may influence their possibilities for effective learning in school and of getting a higher education.

Regardless of the cause of the hearing loss, an impaired sense of hearing means that there are parts of the normal speech signal that are no longer made available to the brain. Figure 4.1 shows, in an ordinary audiogram, the area covered by speech information at normal speaking level. This speech area can be illustrated in many ways: in an audiogram, as shown here, it is often referred to as the *"speech banana"*. The figure indicates that the speech signal is most intense around 500 Hz and then declines for both the lower and higher frequencies, and that normal speech sounds cover an area of about 30 dB. For a normally hearing ear, indicated in the audiogram by the horizontal 0 dB HL line, almost all speech information will be available because it is louder than the normal hearing threshold. Similar conditions for an ear with a considerable hearing loss are shown in figure 4.2. The hearing loss means that only a small part of the speech information (dark grey area) is made available to the brain and therefore for speech intelligibility. The hearing impaired will therefore have great problems with conversation and other forms of communication that are carried out at a normal speech level. If, however, the level of the

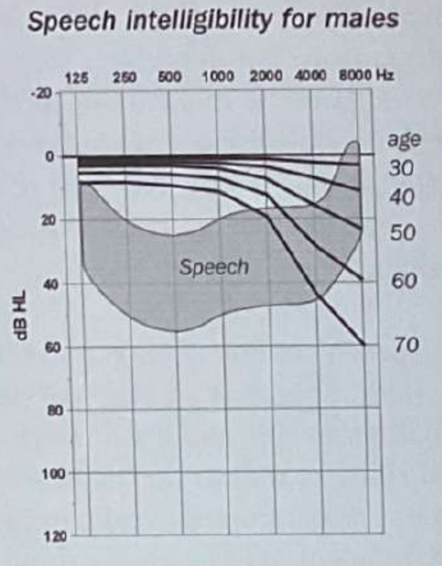

Figure 4.3. The audiogram shows how the age-dependent hearing loss (men) gradually influences the audibility of normal speech. At age 70, most of the speech information above 3,000 Hz will be lost

speech signal is increased, either by the speaker raising his voice (without yelling) or by means of electronic amplification (a loudspeaker system or a hearing aid), a greater part of the speech information will be available and the hearing impaired will have a better chance of understanding what is being said.

Finally, figure 4.3 shows how the development of an age-dependent hearing loss in men influences the audibility of normal speech. On an average, men aged 70 years have lost most of the speech information above 3,000 Hz, that is, the treble sounds of speech, music and in nature, while hearing in most cases will remain normal at the lower frequencies. Especially the high frequency consonants, such as /s/ and /th/, will be affected, and, if not heard, these language elements will typically give rise to misunderstanding and confusion.

If speech communication takes place in quiet surroundings and with only one or two other people, most persons with a minor hearing loss will manage fairly well. In noisy surroundings, however, the hearing-impaired person will often have great difficulties. A hearing loss and background noise make an unpleasant cocktail. Therefore, most hearing-impaired persons find that communication in larger groups of people is extremely difficult. Another difficulty is that the ability to determine the direction of a sound source may be affected – this is called the ability to localize. When listening to others in noisy surroundings, most people make use of lip reading. When larger groups of people are gathered, the conversation jumps from speaker to speaker and if the hearing-impaired person cannot localize where the sound is coming from, it becomes difficult quickly to direct oneself towards a new speaker and thereby make use of lip reading. A person with a hearing loss is therefore severely affected in situations with disturbing background noise.

4.2 Warning sounds

First and foremost, warning sounds consist of the various sounds in the traffic that we use more or less consciously to guide us around safely. These sounds may come from horns, bicycle bells, emergency vehicles, noise from tires, etc. But also in our homes and at work, there are countless alarm or other warning sounds associated with safe handling of machinery, tools, domestic utensils and to assist us in our everyday lives. In our homes, this would typically be such signals as door bells, telephones, stoves, microwave ovens, washing machines, etc, but also alerting sounds from the people we live with, when they call us or shout, "Watch out!". Depending on the severity of the hearing loss, the hearing impaired will not be able to hear all of these warning sounds, which means that they run greater risks than others when moving around in the traffic and when handling machinery, tools and instruments. The inability to hear these warning sounds may add to the feeling of uncertainty and isolation and, furthermore, give rise to a growing irritation on the part of the people associating with the hearing-impaired individual.

Both in the traffic and at home, a reduced ability to localize sounds may add to the feeling of insecurity, frustration and confusion over perhaps being able to hear that something is going on, but being unable to determine what is happening and where. In the traffic, it may prove fatal for the hearing impaired not to be able to react appropriately to the acoustic signals, which for normal-hearing people create the basis for navigating safely in an apparently chaotic world.

4.3 Music and natural sounds

If we turn to music and natural sounds, which to a greater extent affect our quality of life rather than intelligibility and safety, other factors come into play. For the music lover, it may be a great loss not to be able to enjoy music as before, because the hearing loss often reduces or destroys the ability to hear or perceive the finer details of music. When listening to electronic music, for instance from CD players, the hearing-impaired person can control the play-back level and thereby to some degree compensate for the hearing loss. This possibility does not exist when attending a concert. For the professional musician, a hearing loss may negatively affect the ability to work, and for both professionals and amateur musicians this may have an enormous impact on their quality of life.

When we enjoy nature, we use several of our senses, typically vision, smell and hearing. For many people, a trip to the ocean is a wonderful experience, not least because of the roar of the waves. It is enjoyable to walk in the woods and listen to the wind blowing in the trees, the singing of the birds and other sounds in nature. Many of these, often weak, sounds disappear completely for the person with a hearing loss and in combination with the reduced ability to localize, this may have a dramatic effect on ones enjoyment of nature. This, too, affects the quality of life, especially when the hearing-impaired person is made aware of such sounds by others and realizes his/her loss. Figure 4.3 (and figures 3.3 a & b) shows that it is the treble sounds (in the frequency area above 3,000 Hz) that first disappear for a person with an age-dependent hearing loss. This is the reason why most people when getting older lose the ability to hear grasshoppers, cicadas, and, to some extent, bird song. For many people with reduced hearing, this is deterioration in their quality of life.

5. The five dimensions of hearing

Most people imagine that a hearing loss only affects the hearing-impaired person's sensitivity to sounds and if all sounds were made louder, hearing would be normal.

It is not so simple, however – several things go wrong when you get a hearing loss.

An ordinary hearing loss (a perceptive hearing loss) has implications for at least five important dimensions of the sense of hearing. In this chapter, these dimensions will be examined on the basis of the audiogram and several characteristics of hearing will be taken into consideration in addition to those related to the level of sound. The importance of these characteristics will be related to the listening and communicative situations that give rise to the greatest problems for the hearing-impaired person. The focus will be on the problems associated with a purely perceptive hearing loss, but the five dimensions, either alone or together, are affected also by other types of hearing loss.

5.1 Sensitivity

As mentioned earlier (see chapter 2), the hearing threshold indicates the sensitivity of the ear to sound intensity or sound level. The hearing threshold is determined by a hearing test and corresponds to the softest sound that can be heard; the result is shown in an audiogram. In this chapter, two audiograms are used: one indicating normal hearing and the other a considerable age-dependent hearing loss (figures 5.1 a & b). The air conduction thresholds are labeled hearing threshold level (HTL). The audiogram for the normal-hearing ear (figure 5.1 a), shows naturally, a very small deviation from the horizontal line indicating the average, normal threshold at 0 dB HL. In contrast, the audiogram for the severe age-dependent hearing loss (figure 5.1 b) shows a significant hearing loss for all frequencies. Note, however, that the hearing loss is more pronounced for the high frequencies than for the low frequencies. The hearing loss ranges from 25 dB to 85 dB.

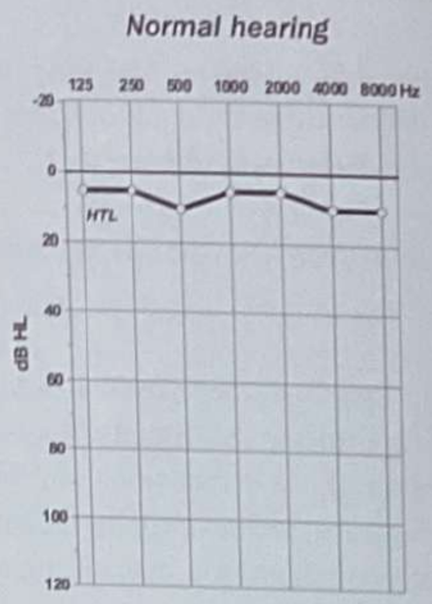

Figure 5.1 a. The audiogram shows the hearing threshold, HTL, for normal hearing (right ear)

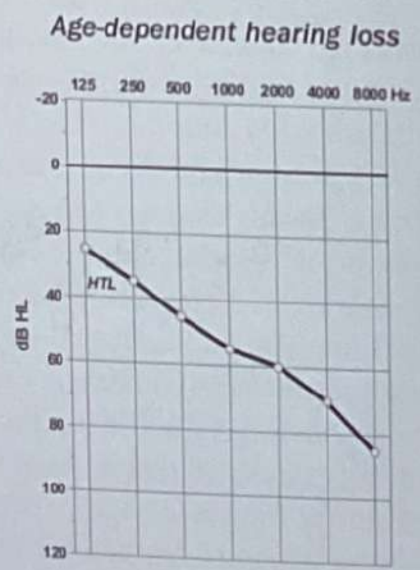

Figure 5.1 b. The audiogram shows the hearing threshold, HTL, for a considerable, age-dependent hearing loss in the right ear. The hearing loss ranges from 25 dB (at 125 Hz) to 85 dB (at 8,000 Hz)

5.2 Dynamic range

While one end of the sound level scale is limited by the hearing threshold, the other end of the scale is limited by the so-called *uncomfortable loudness level* (UCL), which indicates the loudest sound that can be tolerated for a short moment. The uncomfortable loudness level is indicated in the audiograms in figures 5.2 a & b. In the case of the age-dependent hearing loss, the uncomfortable loudness levels are only modestly affected – in fact considerably less than the corresponding hearing thresholds. For most types of hearing losses (perceptive hearing losses), the uncomfortable loudness levels are changed only slightly. In fact, the uncomfortable loudness level is not seriously affected before the hearing loss reaches about 60 dB. The conclusion is, therefore, that the uncomfortable loudness level changes less than the hearing threshold, which means that:

a hearing loss affects the perception of soft sounds rather than loud sounds!

The difference between the softest sound that we can hear and the loudest sound that we will accept to listen to, i.e. the distance between the hearing threshold and the uncomfortable loudness level is called the *dynamic range* of hearing and indicates the range of sound levels that our hearing is able to utilize.

A (perceptive) hearing loss reduces the dynamic range!

Some examples: figure 5.2 a shows that the normally hearing person at 1,000 Hz has a dynamic range of 105 dB (HTL = 5 dB HL and UCL = 110 dB HL), while figure 5.2 b shows that the person with the age-dependent hearing loss at 500 Hz has a dynamic range of 65 dB and at 4,000 Hz a dynamic range of 45 dB

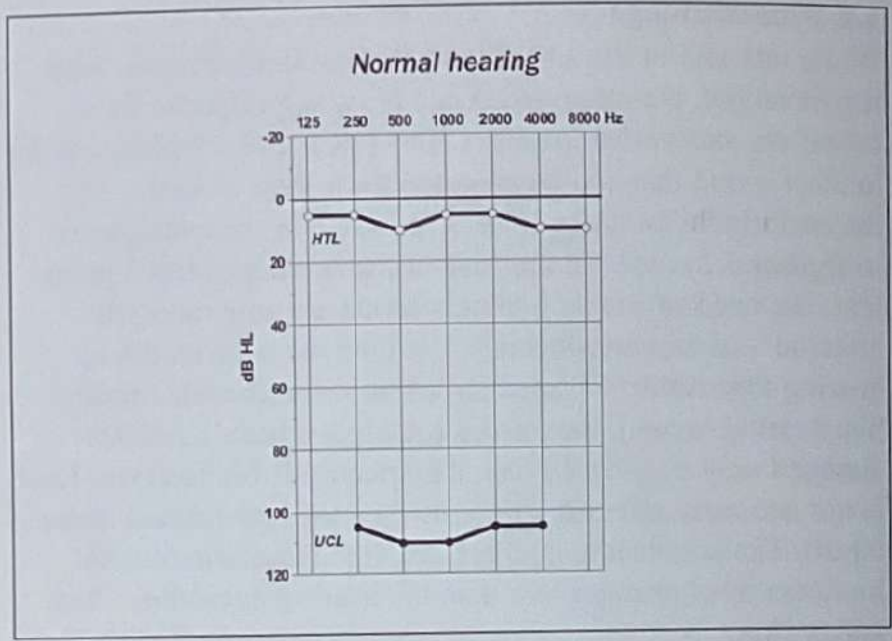

Figure 5.2 a. The audiogram shows the normal hearing threshold, HTL, as in figure 5.1 a, with the addition of the uncomfortable loudness level, UCL. The distance between HTL and UCL indicates the dynamic range – here approximately 100 dB

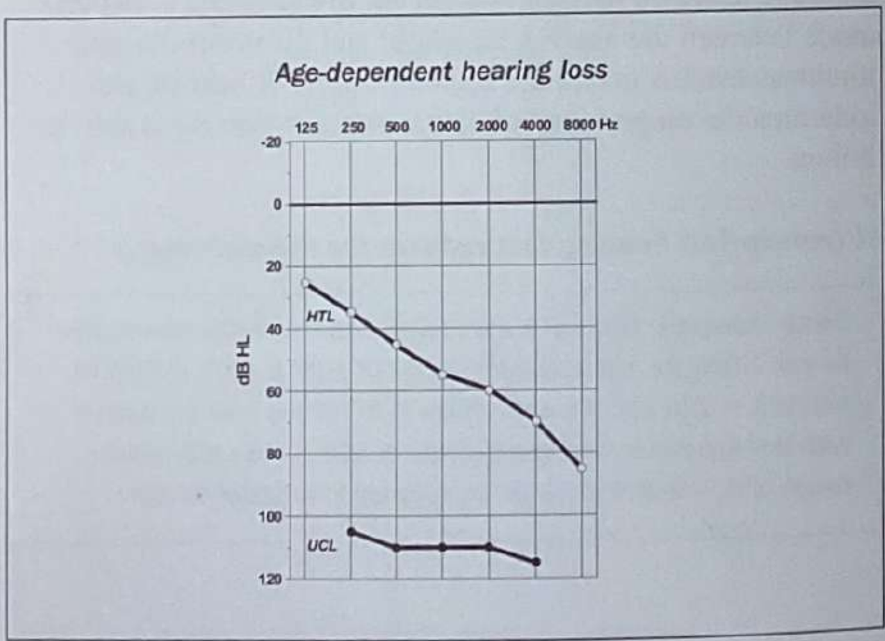

Figure 5.2 b. The audiogram shows the age-dependent hearing loss, HTL, as in figure 5.1 b, with the addition of the uncomfortable loudness level, UCL. The distance between HTL and UCL indicates the dynamic range – here varying with the sound frequency from 70 dB (250 Hz) to 45 dB (4,000 Hz)

When the dynamic range is reduced, there is less capacity to cover all the natural level variations of everyday sounds. This, of course, has important implications for how hearing aids should be constructed.

The hearing threshold and the uncomfortable loudness level are determined by listening to a single tone at a time. However, when we need to describe the sense of hearing for more than one tone at a time, for example for complex sounds like speech, noise and music, the situation becomes much more complicated. Such sounds constantly change in frequency and level and contain sound elements of different frequencies that may come simultaneously or soft and loud sounds that may come in close succession. It is therefore important to look at those aspects of hearing that are important for our ability to separate the individual elements of complex sounds in our everyday lives.

5.3 Frequency resolution

Normal-hearing persons are not always able to distinguish between two simultaneous sounds of relatively close frequencies. The low-frequency tone (bass) throws a shadow over the high-frequency tone (treble). This is due to the vibration patterns created in the cochlea by these sounds. The vibrations spread out in both directions, but mostly in the direction from the top towards the bottom of the cochlea – that is, from the place where the tone most strongly affects the cochlea and towards the place where the vibration patterns from a more treble tone are present. These vibration patterns are sketched in figure 5.3 a and show how the bass tone 'disturbs' the treble tone. One way of reducing this disturbance is to separate the two tones – that is, to increase the frequency difference between them – or by making the treble tone more intense. The ability to distinguish and perceive two simultaneous tones is called *frequency resolution*.

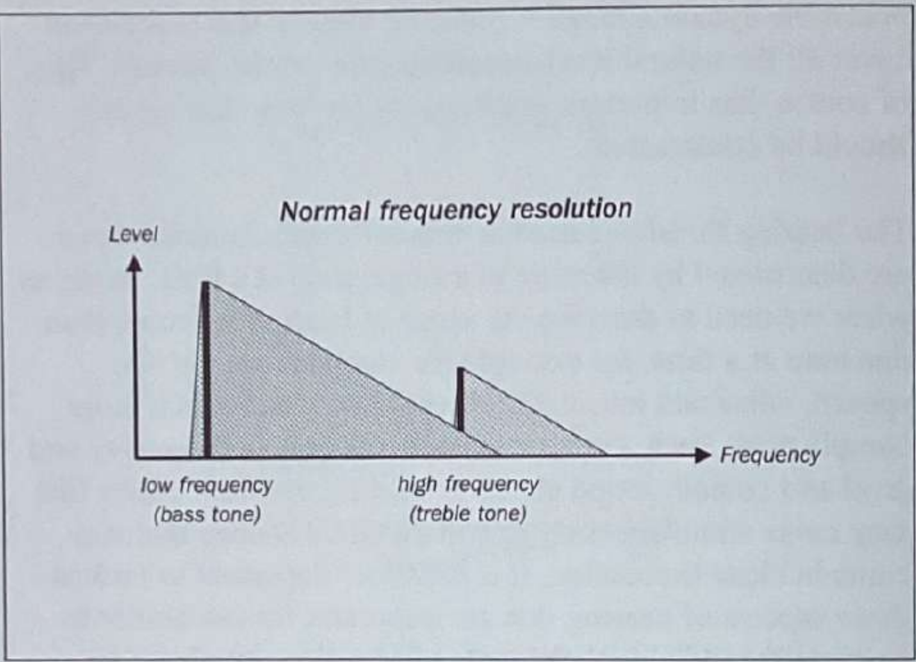

Figure 5.3 a. Frequency resolution. The figure shows, in an ear with normal hearing, the frequency activity patterns in the cochlea in response to two different, but simultaneous, pure tones: a loud bass tone (low frequency) and a soft treble tone (high frequency). The bass tone 'disturbs' the treble tone

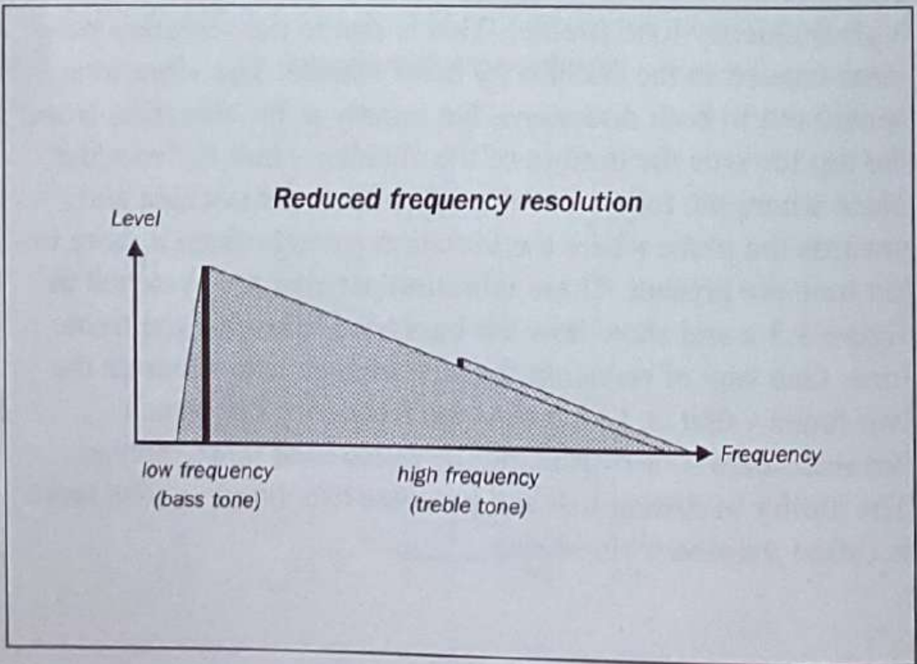

Figure 5.3 b. Frequency resolution. The figure shows, in an ear with a perceptive hearing loss, the frequency activity patterns in the cochlea corresponding to two different, simultaneous, pure tones: a loud bass tone (low frequency) and a soft treble tone (high frequency). The bass tone greatly 'disturbs' the treble tone, resulting in a reduced frequency resolution

There are, as mentioned, two types of frequency resolution – also called frequency masking: an 'upward' type (towards the higher frequencies) where a loud tone influences a tone with a higher frequency, also called upward-spread-of-masking, and a 'downward' type (towards the lower frequencies) where a loud tone influences a tone with a lower frequency, also called downward-spread-of-masking

The upward-spread-of-masking is the most important of the two and to indicate its size in normally hearing ears, and what it means, the concept of 'the critical band' is used. The critical band corresponds to a frequency range within which two simultaneous tones cannot be separated or perceived individually

The critical band is frequency-dependent and corresponds to a frequency band of about 20 %. For example at 1,000 Hz, the critical band, and thereby the frequency resolution, is about 200 Hz and at 4,000 Hz about 800 Hz

For the hearing-impaired person, the ability to perform such frequency resolution is reduced. One of the reasons is that the vibration pattern for the individual tone is now broader, which means that it takes up more space in the cochlea – dependent on the number of outer hair cells available and the extent of their muscle-like contractions. With a hearing loss exceeding 60 dB, most of the outer hair cells are lost and the ability to distinguish between two or more simultaneous tones is therefore strongly reduced, corresponding to the reduced frequency resolution. This situation is illustrated in figure 5.3 b.

The consequence of reduced frequency resolution is that it becomes more difficult for the hearing-impaired person to understand speech – especially in background noise. Speech consists, among other things, of many simultaneous frequency elements that all contribute to speech intelligibility and the perception of such speech elements therefore requires a good frequency resolution.

5.4 Temporal resolution

Normal-hearing people are not always able to distinguish between two sounds that come in close succession. The first

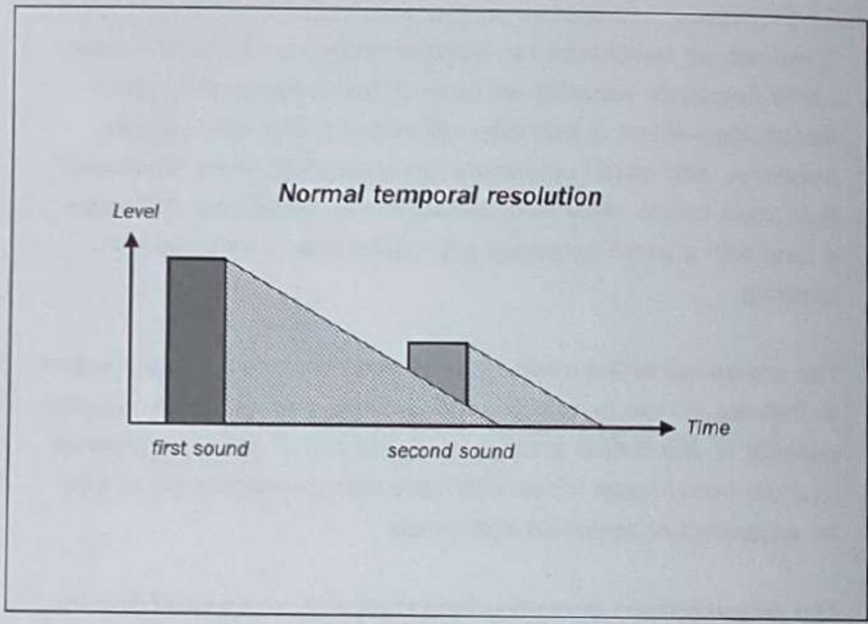

Figure 5.4 a. Temporal resolution. The figure shows, in a normal hearing ear, the temporal activity patterns in the cochlea for two consecutive tones: a loud tone (first sound) followed by a soft tone (second sound). The first sound 'disturbs' the second one

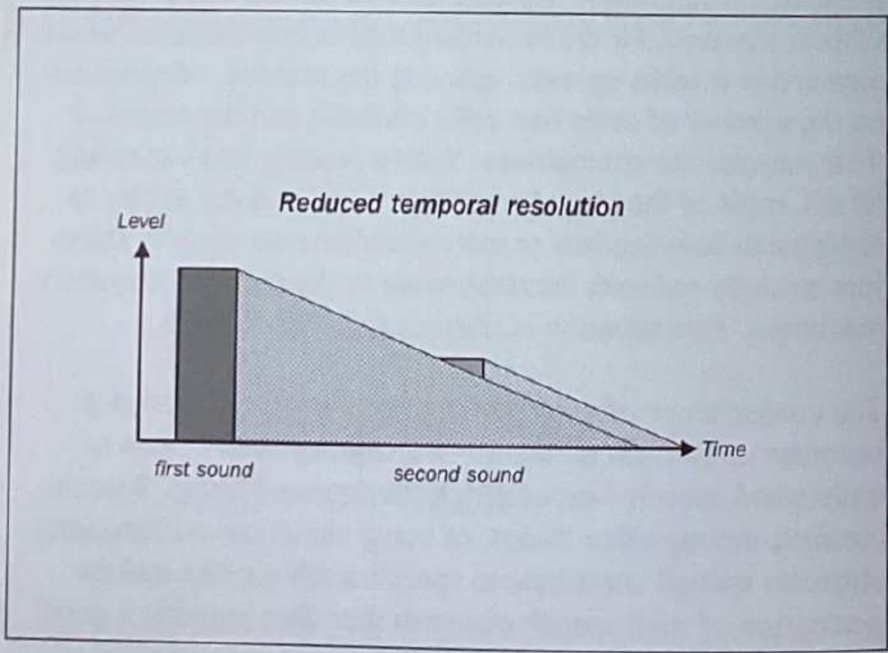

Figure 5.4 b. Temporal resolution. The figure shows, in an ear with a perceptive hearing loss, the temporal activity patterns in the cochlea for two consecutive tones: a loud tone (first sound) followed by a soft tone (second sound). The first sound greatly 'disturbs' the second one, resulting in a reduced temporal resolution

sound tends to 'disturb' the second sound. This is presumably due to the way in which the first tone *excites* the hearing nerve. When the first sound has sent its information to the central nervous system, it takes some time for the system to recover before it is ready to handle the next sound correctly. The result of this course of events is illustrated in figure 5.4 a, which shows how the first sound 'disturbs' the following sound. One way to reduce this disturbance is to separate the two sounds from each other – that is, to increase the time delay between them or to make the second sound louder. The ability to distinguish between two successive sounds is called *time*, or *temporal resolution*.

There are two types of temporal resolution, also called temporal masking: A 'forward' type, where a loud sound influences a sound that appears immediately after, also called forward masking, and a 'backward' type, where a loud tone influences a tone that already has occurred, also called backward masking. Forward masking is probably the most important of the two and for normal-hearing persons it is effective for about 0.2 second (= 200 ms) after the loud sound

The underlying mechanisms controlling the temporal masking are not known in detail. One explanation often put forward is that the nerve impulses created by the loudest sound arrive in the central nervous system before the nerve impulses for the softest sound

For the hearing-impaired person, the ability to carry out temporal resolution is reduced, as sketched in figure 5.4 b.

The consequence of reduced time resolution is that it becomes more difficult for the hearing-impaired person to understand speech – especially in background noise. Speech consists of many different elements, for instance strong vowels alternating with soft consonants. The ability to perceive the soft consonants of speech, therefore, requires a good time resolution, especially in noisy surroundings.

5.5 Hearing with two ears

Hearing with both ears is called *binaural hearing* and allows the brain to constantly compare the sounds that reach the left and right ear, respectively. This comparison makes it possible for the brain to determine the location and movement of sounds in the environment. This may apply when several people are speaking at the same time at parties, when moving around in the traffic or hearing sounds from machinery. When many people are assembled, for example at a party, there is often a lot of background noise. In such situations, it is important, especially for hearing-impaired persons, to be able to locate, and turn towards, the person with whom they want to communicate. When you can watch the person you are speaking with, lip reading can be very helpful in situations when speech intelligibility is made difficult by poor acoustic conditions.

The comparison in the brain between the sounds received from the two ears makes it possible to suppress unwanted sounds among different sound sources in the surroundings, for example, noise.

> *Many studies show that we communicate much better in noisy surroundings when both ears are used instead of just one ear – this applies to both normal-hearing persons and most of the hearing impaired*

Most forms of hearing losses are not caused by alterations in the brain, but rather in the *peripheral* part of the hearing pathway – and in particular in the inner ear (perceptive hearing loss). Therefore, when hearing is impaired, the brain does not receive the complete sound information from the two ears and, therefore, will not be able to carry out its tasks as well as if hearing had been normal. The result may be the following:

- ***reduced ability to locate sound sources***
- ***poor speech intelligibility in situations with disturbing background noise***

5.6 Reduced hearing

In the previous section, the following five dimensions of hearing have been reviewed:

1. Sensitivity
2. Dynamic range
3. Frequency resolution
4. Time resolution
5. Hearing with two ears

A hearing loss (perceptive) changes all of the above-mentioned five dimensions and not just the sensitivity. This means that a hearing aid, in addition to amplifying sounds, should also be able to compensate in the best possible way for the other changes that have occurred.

It should be emphasized that most people with a hearing loss are not conscious of the five dimensions, but rather have the feeling that the hearing no longer functions the way it used to: certain situations have become difficult to participate in; what others are talking about is not always correctly understood; or there are sounds in nature that are no longer heard. The five dimensions are *objective* measures, whereas the person with a hearing loss has a *subjective* experience which may not be measurable, but nevertheless is of the utmost relevance to the person involved.

When our sense of hearing is impaired, the sound information that reaches the brain is composed in a different way than previously. The result may be that over time the hearing cortex starts to reorganize itself and change some of the nerve cells that are particularly sensitive to those sounds that no longer reach the brain. If the cochlea no longer transmits information about the highest frequencies (the treble tones), the nerve cells in the hearing cortex that are particularly sensitive to high frequency sounds (see the tonotopical organization, chapter 1.6) will no longer receive any information to work with. Therefore, the brain starts to reorganize itself in such a way that the nerve cells in question change their sensitivity to the neighboring frequencies that are still being sent to the brain. Such a reorganization of the hearing center forms part of the cortical plasticity of the brain.

Figures 5.5 a & b are attempts to illustrate this phenomenon. In normal hearing (figure 5.5 a), the peripheral nerve activity (the activity in the hearing nerve when it leaves the cochlea) and the cortical resources (the nerve cells in the hearing cortex) are presumably equally distributed across the frequency range – from bass towards treble tones. In the case of a large high-frequency hearing loss (hearing loss for treble sounds, figure 5.5 b) that has developed over a long period of time, the composition of the peripheral activity will change considerably,

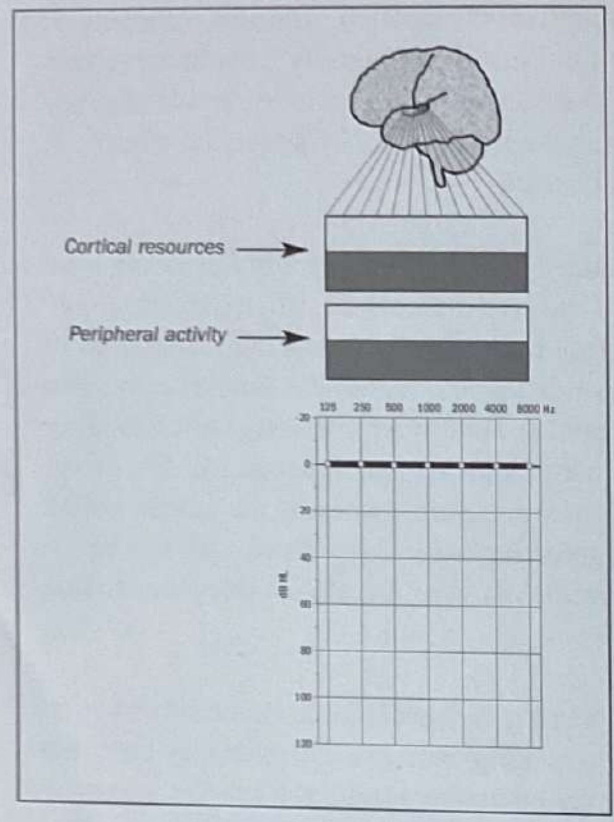

Figure 5.5 a. The figure shows the conditions in a normal-hearing ear (normal audiogram) where the peripheral neural activity (the activity in the hearing nerve when it leaves the cochlea) and the corresponding cortical resources (neurones in the hearing cortex) are equally distributed across the frequency range, from the low frequencies (bass tones) to the high frequencies (treble tones)

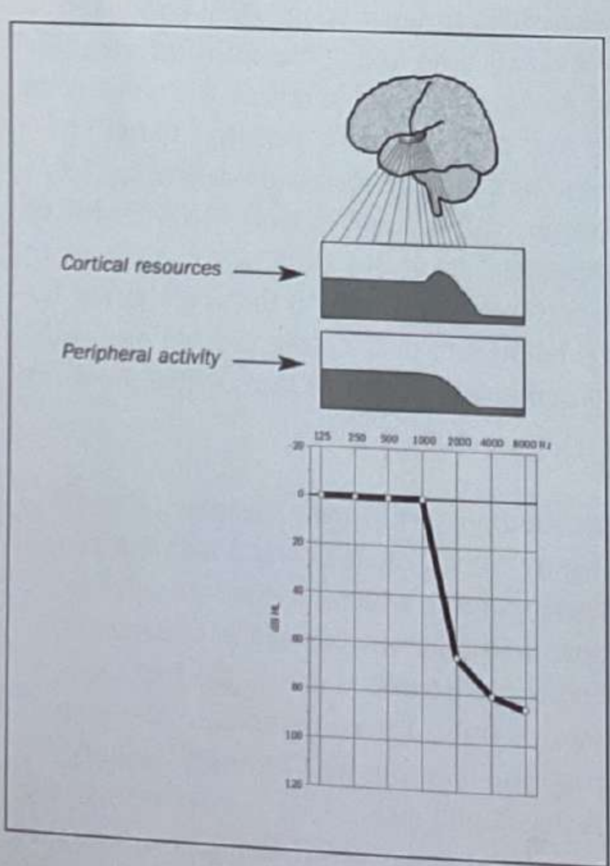

Figure 5.5 b. Cortical plasticity. The figure shows the same conditions as in figure 5.5 a, but now for a large high-frequency hearing loss that has been developing over a long period of time. There is no, or almost no, neural activity in the area where the hearing loss is most pronounced (the highest frequencies). Reorganization has taken place in the cortex by some of the nerve cells having changed their sensitivity to those frequency areas from where information still is coming from the cochlea

and thereby also the cortical resources – because of the cortical reorganization.

This may be the explanation why many first-time users of hearing aids have problems with perceiving the 'new sounds' and that it takes some time to get used to wearing the hearing aids. In the beginning, many first-time users find that the sounds are too sharp, and that rustling from newspapers or clattering from plates and cutlery – all high-frequency sounds – are unpleasant noises. The hearing-impaired person may not have heard these sounds for many years and in the cortical center there are no longer any nerve cells available to receive and handle these sounds, which therefore are experienced as disturbing noise. Studies have shown that a first-time hearing aid user whose hearing loss has developed over a long period of time may need many months before achieving the full advantage of one or two hearing aids. A certain period of time is needed for getting used to the hearing aids – a period of *acclimatization*. This is probably due to the fact that the brain needs some time to reorganize its cortical resources again.

6. What are hearing aids?

This chapter describes the most common features and characteristics of hearing aids. This includes a description of the various types available, their main construction, what they contain, what their functions are, how they are adapted to the individual user and how they are maintained. Since modern hearing aids vary greatly, this chapter will describe only the most common features of the many different hearing aids that are available.

6.1 Various types of hearing aids

The hearing aid has existed for many years in various types and designs, but the technological development has favored certain types, while other types – such as body-worn hearing aids and hearing glasses (a combination of hearing aids and glasses) – are rarely used today.

Today, the following types are available:

a. *Behind-The-Ear*, BTE (see figure 6.1 a). This type of hearing aid is placed behind the outer ear and the sound is led from the hearing aid to the ear canal by means of a small plastic tube, which is kept in place in the ear canal by an ear mold (see figure 6.1 a). The BTE aid is manufactured as a ready-made industrial product and the physical fitting to the ear is made by means of an individually designed ear mold.

b. *In-The-Ear*, ITE (see figure 6.1 b). The ITE hearing aids are either relatively large hearing aids that fill out a part of the outer ear (the concha – see figure 1.2), or smaller hearing aids that take up only a limited space.

c. *In-The-Canal*, ITC (see figure 6.1 c). Only a small part of this type of hearing aid is visible in the outer ear whereas the main part is placed in the outer part of the ear canal.

d. *Completely-In-Canal*, CIC (see figure 6.1 d). This type of hearing aid is placed deep inside the ear canal.

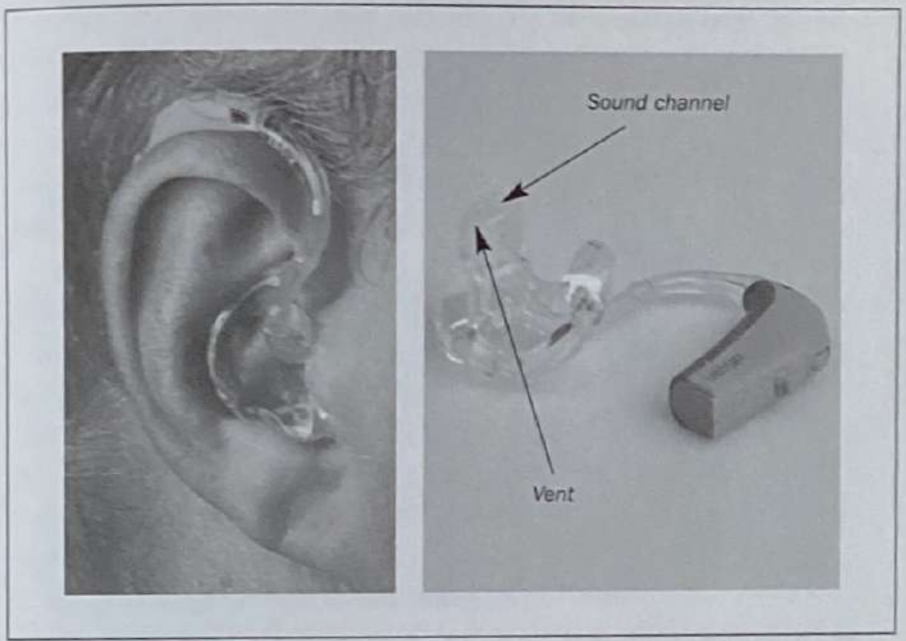

Figure 6.1 a. BTE hearing aid: to the left, placed in the ear; to the right, placed on a table so that all the outer parts of the hearing aid are visible, including the ear mold

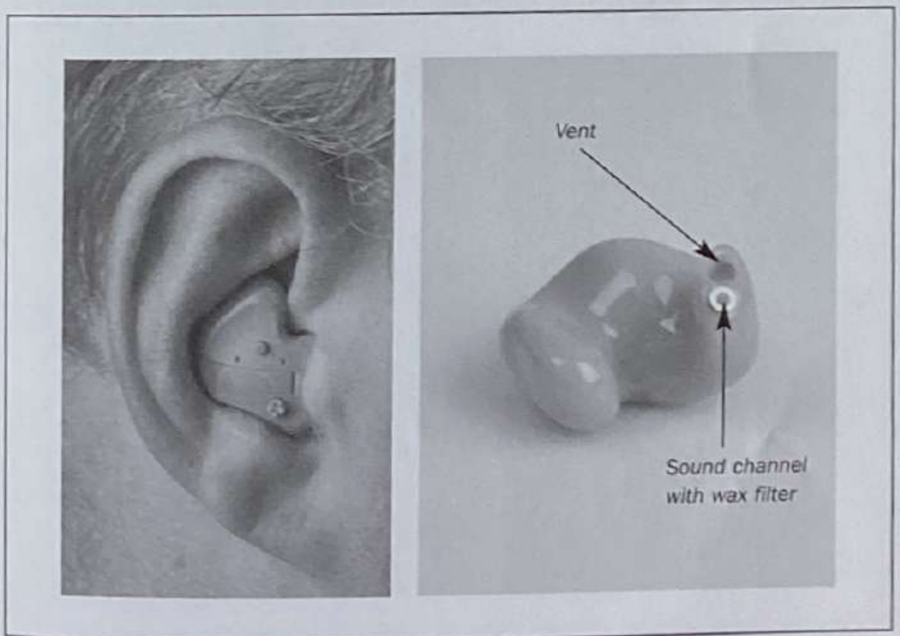

Figure 6.1 b. ITE hearing aid: to the left, placed in the ear; to the right, placed on a table

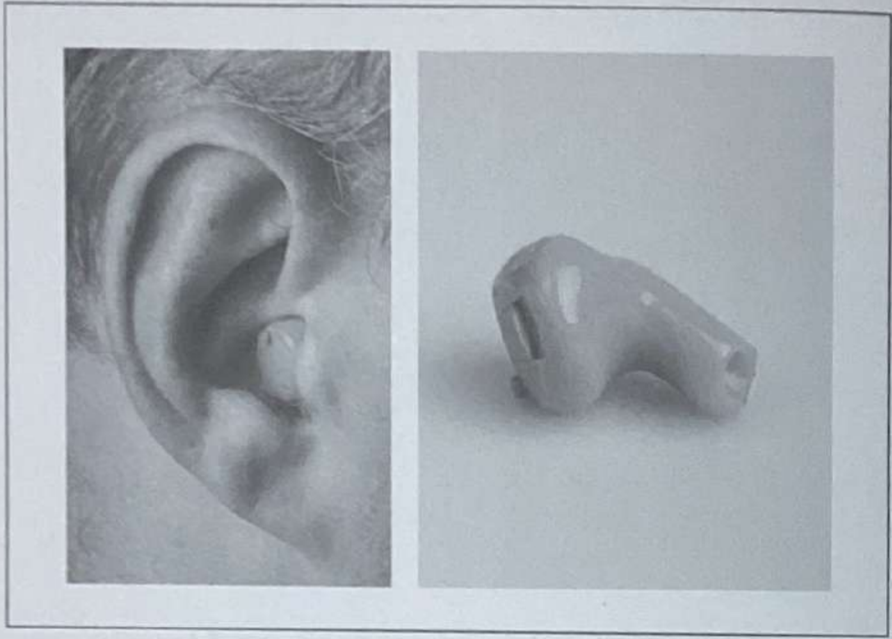

Figure 6.1 c. ITC hearing aid: to the left, placed in the ear; to the right, placed on a table

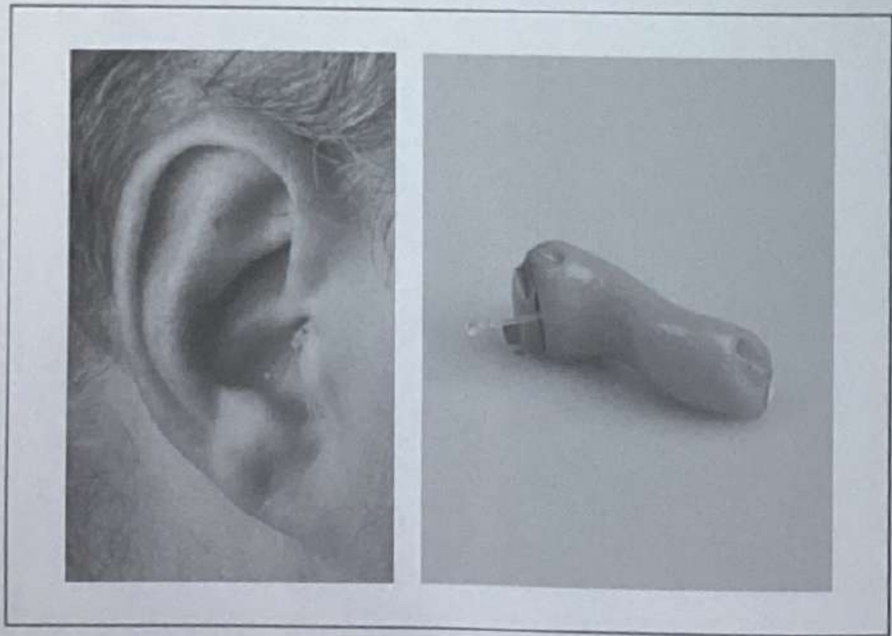

Figure 6.1 d. CIC hearing aid: to the left, placed in the ear; to the right, placed on a table

In contrast to the BTE, the other types of hearing aids (ITE, ITC and CIC) do not have a separate ear mold, because the mold forms an integrated part of the hearing aid itself and is referred to as the *shell* of the hearing aid. This means that only the electronic insides of the hearing aids are ready-made products, while the finished hearing aids are custom made.

6.2 The composition of a hearing aid

A hearing aid (see figure 6.2) has the following features: (a) an *input*, usually a microphone picking up the surrounding sounds; (b) an electronic *amplifier*, which both amplifies and in other ways adapts the signal from the microphone; (c) an *output*, which is a small loudspeaker sending the final sound signal into the ear canal, and (d) a *battery*, supplying the energy required to run the hearing aid.

a. The input

The microphone picks up sounds from the surroundings and creates the necessary input signal to the hearing aid. Usually, the microphone has equal sensitivity for sounds coming from different directions, but it may also be *directional* (or back-

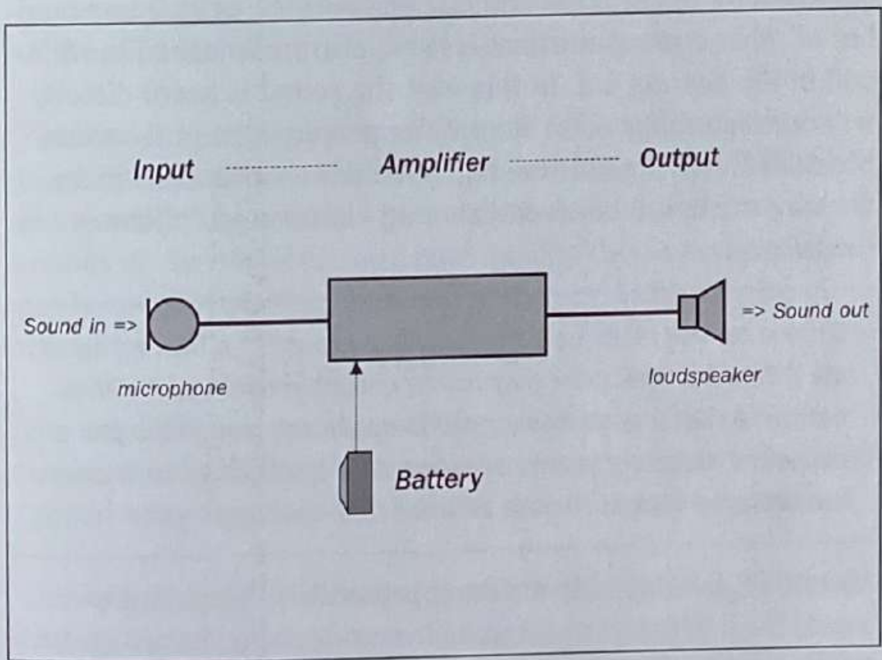

Figure 6.2. A diagram showing the principal parts of a hearing aid. The main components are the microphone, the amplifier, the loudspeaker, and the battery

ground-suppressing), so that it gives preference to sounds coming from, say, in front, while sounds coming from all other directions are given less amplification. The hearing aid user will get the feeling that sounds coming from the side or from the back are suppressed and that those sounds therefore interfere less with the speech signal normally coming from the front. A directional, or background-suppressing, microphone usually consists of two microphones – or a pair of microphones.

> *By treating the signals from the two microphones in a special way, the amplifier can create the directional effect automatically. This means, for instance, that the hearing aid automatically becomes directional if there is a dominating sound source*

The hearing aid can also be equipped with a telecoil, which picks up the signals from a teleloop system, for example in cinemas, theatres, auditoriums, lecture halls and churches. By means of the teleloop, the sound from film projectors or microphone systems creates a magnetic field that affects the telecoil in the hearing aid. Assistive devices for telephones and for listening to TV, radio and CD players etc., as well as a number of other communication devices, also make use of the telecoil in the hearing aid. In this way, the sound is heard directly without disturbing noise from other people or from the room. Most BTE hearing aids are equipped with a switch enabling the user to choose between listening via the microphone or via the telecoil.

> *Since a telecoil takes up a relatively large space in a hearing aid of the ITC or CIC type, there may not be enough room in ears with a narrow ear canal for a hearing aid to be placed deep in the ear canal and at the same time accommodate a telecoil. In such cases, the user may have to choose between size and functionality*

Most BTE hearing aids are equipped with a Direct-Audio-Input, DAI. The electric signals from other sound sources, such as telephones, CD players, conference microphones and teaching equipment, can be connected directly to the hearing aid by means of a small 'shoe' on the bottom of the hearing aid.

b. Amplifier

The electronic amplifier of the hearing aid is usually based on *digital* technology, which by and large has taken over from the *analog* technology that controlled the market up to the mid 1990's. For the user, there are in principle no differences between the two technologies. The digital technology, however, is associated with much greater flexibility, including programming facilities and other features that make it possible to adapt modern hearing aids to the user's needs and wishes as well as allowing for a more individual fitting.

The main function of the amplifier is to amplify the incoming sounds so that these become meaningful to the hearing impaired. But the amplified sound must be adapted to the individual's hearing – the dynamic range – so that all important sounds can be heard without any of them becoming uncomfortably loud. This must be achieved for all frequencies, for both bass and treble sounds.

Hearing aids can either be equipped with a *volume control*, allowing manual adjustment of the amplification, or the amplifier can be designed to adjust automatically to the actual level of the sounds that surround the user at any time.

The modern hearing aid amplifies the different frequency bands individually, just as loud and soft sounds are adjusted individually. The way in which the amplification adjusts for sounds of varying level, and how quickly this is done, can partly compensate for a reduced frequency and temporal resolution.

The amplification may require the use of special signal processing methods, known as *noise reduction*, whereby the background noise is reduced and/or the speech signal emphasized.

Similarly, the amplification may involve a special signal processing that suppresses the tendency of the hearing aids to 'whistle'. This may happen if an object with a relatively hard surface is placed near the hearing aid (for example a hand, a hat, or a door frame), if the hearing aid is not correctly placed in the ear, if the volume control is turned up too high, or if there is excessive wax in the ear canal.

> *When the hearing aid whistles it is called acoustic feedback. This phenomenon is caused by a part of the amplified sound in the ear canal being picked up by the hearing aid's microphone so that the sound is further amplified, etc. The signal processing methods that can suppress this acoustic feedback are called anti-feedback methods*

Hearing aids may be equipped with several 'programs' – that is, different sets of amplification adjustments covering the various listening needs that the hearing impaired may have. Besides the volume control, the hearing aids may be equipped with a program switch so that the user may choose between two or more fixed settings. Instead of having the volume control and the switches placed on the hearing aid itself, some hearing aids have a remote control so that sound intensity, listening program, microphone or telecoil, etc. can be selected without touching the hearing aid.

c. Output

The output from the hearing aid consists of a small loudspeaker that transmits the amplified and signal-processed sounds into the ear canal.

In the BTE hearing aid, the sound is first fed from the loudspeaker through a *hook* – a hard, curved plastic tube that is an integral part of the hearing aid – and thereafter via a soft plastic tube, the *sound tube*, to the *sound channel* of the ear mold (see figure 6.1 a). From the loudspeaker to the ear canal, the sound has to travel a distance of about 70 mm.

NB: the loudspeaker in a hearing aid is confusingly called the hearing aid receiver!

For the other types of hearing aids (ITE, ITC and CIC), the ear mold, as mentioned above, forms an integral part of the hearing aid and the loudspeaker is placed directly in connection with the sound channel. Because the loudspeaker is now placed much closer to the ear canal, there is a greater risk that ear wax – which easily is pressed into the sound channel of the hearing aid when this is placed in the ear – may reach the sound outlet, thereby blocking the sound from the loudspeaker. If the ear wax has advanced far into the sound channel it may be difficult to remove without damaging the fine mechanical parts of the loudspeaker. 'In-The-Ear' hearing aids can be equipped with various forms of wax protectors – or wax filters, which prevent the ear wax from reaching the loudspeaker and ease the cleaning and maintenance of the hearing aid.

In addition to the sound channel, the ear mold or the hearing aid contains another channel, called a *vent*, which connects the enclosed ear canal to the outside and thereby prevents the formation of static air pressure as well as too much moisture to build up in the ear canal. In addition, the vent serves to minimize *occlusion*.

Occlusion means that the sounds are getting trapped. This applies especially to sounds produced by the hearing-impaired person himself, e.g. when speaking, humming, singing, eating, swallowing, etc. When these sounds are confined to the ear canal - because the ear mold prevents their escape - they can be experienced as uncomfortably loud and booming. For the hearing-impaired person with a considerable hearing loss for bass tones (low frequencies) a small vent may suffice. With a large vent, with a diameter up to 3-4 mm, very few hearing aid users will be really bothered by occlusion problems. However, a large vent may have the effect that the hearing aid whistles more easily and there is therefore a limit to how much amplification the hearing aid can provide when a large vent is implemented. In the case of the smaller ITC and CIC hearing aids, there is often not enough room to accommodate a large vent, and the hearing aid user again has to accept a compromise between size and functionality (occlusion)

Some BTE hearing aids are designed to function with an *open fitting* (called *open ear acoustics* by one manufacturer), which means that the only task of the ear mold more or less is to hold the sound tube in place in the ear canal.

A new generation of 'Thin-Tube Open Fitting'-BTE hearing aids has recently been introduced. In these hearing aids the sound tube is extremely thin and the open ear mold just keeps the thin tube in place, see figure 6.3. Therefore, these hearing aids are both cosmetically attractive and for the user very comfortable to wear. However, as explained above, these solutions

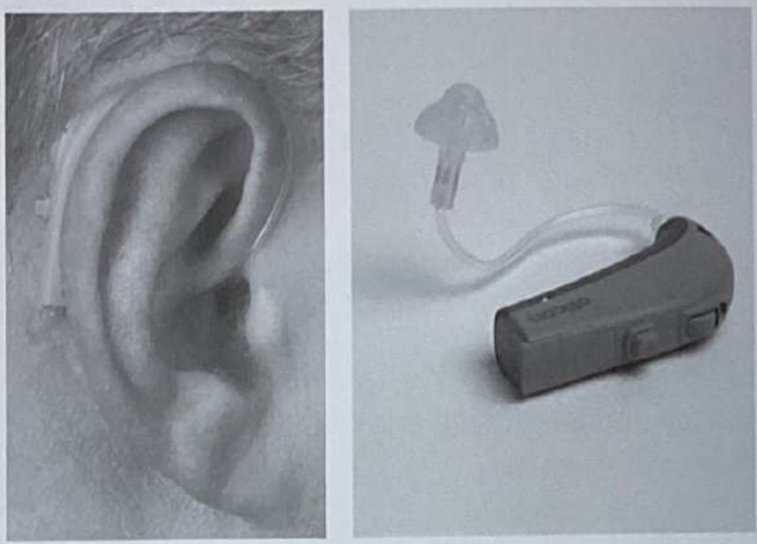

Figure 6.3. 'Thin-Tube Open Fitting' hearing aid: to the left, placed in the ear; to the right, placed on a table so that all the outer parts of the hearing aid are visible, including the thin tubing and the open ear mold

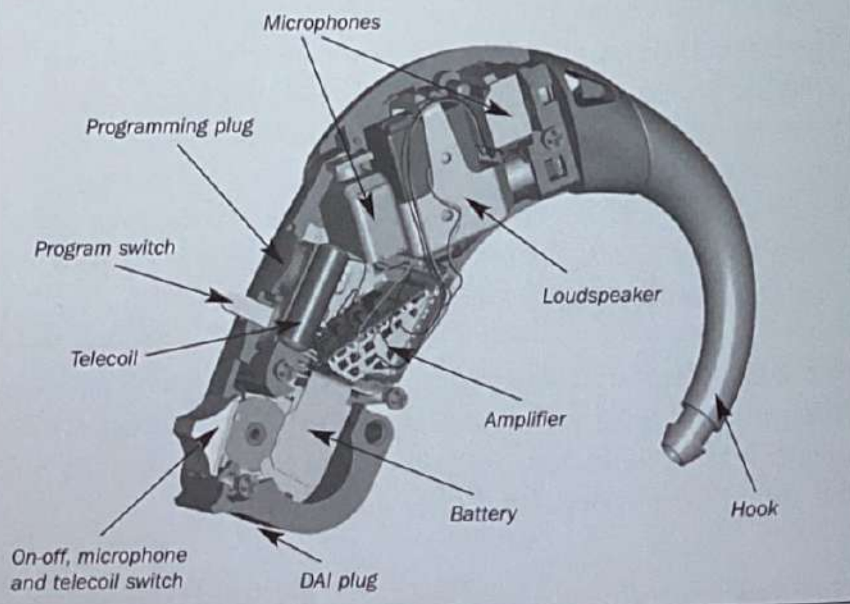

Figure 6.4. An example of how a hearing aid may be constructed. Here, a BTE hearing aid is shown. The hearing aid is automatic, which means that it has no volume control, and it has two microphones for directional purposes. A cross section of the hearing aid is shown, revealing the internal components and their placements

allow only limited amplification, especially for treble sounds (the high frequencies).

d. The battery

The battery supplies the energy necessary for the hearing aid to function and is placed in a battery compartment that may be opened by a fingernail. In some hearing aids, the battery compartment serves also as an on-off switch, which means that the hearing aid is shut down when the battery compartment is opened. In other hearing aids, the on-off switch may be built into the microphone-telecoil switch, or into the volume control.

Hearing aid batteries are available in different standard sizes and they deliver electric energy in varying amounts. The larger the battery, the more energy it can deliver, and the longer the hearing aid will function before a change of battery is required. There are great variations in the battery consumption required by individual hearing aids and it is therefore difficult to give an exact estimation of how long a hearing aid will function on one battery. Hearing aid manufacturers are constantly striving to make hearing aids that require as little energy as possible so that smaller battery types can be used. At the same time, the batteries are constantly being improved. If, however, a very small hearing aid is requested, the battery also has to be small, so here too the user needs to accept a compromise between size and functionality (battery consumption).

e. The complete hearing aid

As an illustration of the above, figure 6.4 shows the most important components of a BTE hearing aid. The hearing aid is automatic and there is, therefore, no volume control. The individual parts and their positions are shown in the figure. In principle, the components are the same as those used in other types of hearing aids. In the smallest 'In-The-Ear' hearing aids, however, components are often chosen for their small size and their suitability, but they may have limited functionality.

6.3 Functionality

The modern hearing aid has many different functions besides its most basic one: to amplify the surrounding sounds. Traditionally, when hearing aids are described, all of their functions are often listed at random making it very difficult for the average user to understand the background for the individual function and the way in which it may help the hearing impaired.

It may, therefore, be useful to divide the hearing aid's functions into the following four categories:

a. Alleviation of problems arising when a hearing aid is inserted into the ear

The hearing aid blocks the entrance to the ear canal and this affects the ear canal resonance (see chapter 1.2). Thus, the presence of a hearing aid will to a certain degree abolish the ear canal's natural amplification of 6-8 times in the frequency range around 3,000 Hz. Therefore, the hearing aid must first compensate for this lost amplification before it can effectively assist the hearing impaired.

Hearing aids may give rise to occlusion problems (see above under c: Output). If this is the case, the ear mold or the 'In-The-Ear' hearing aid must be equipped with a relatively large vent, or, if possible, a BTE hearing aid with *open ear acoustics* can be chosen. Also, it is possible to alleviate some of the problems arising from occlusion by means of the hearing aid's signal processing facilities and the way in which these are adjusted.

When the hearing aid is placed in the ear, it may begin to whistle (see under b: Amplification). When this happens, the hearing aid is not of much assistance to its user and may be a great annoyance to other people. Most hearing aids can be fitted in such a way that the risk of whistling is reduced and several types of hearing aids are equipped with an active anti-feedback mechanism, which effectively diminishes the tendency of the hearing aid to whistle. In general, it is important that the amplification and the size of the vent are finely balanced.

b. Alleviation of the hearing loss

The primary function of the hearing aid is to compensate, to the greatest possible extent, for a given hearing loss. This compensation consists primarily of alleviating the changes that have occurred to the five dimensions of hearing: reduced sensitivity, changed dynamic range, impaired frequency and temporal resolution, and reduced binaural capabilities. These compensation strategies are necessary for overcoming the hearing loss. This means that the amplification of the hearing aid is *non-linear* (different amplification of soft and loud sounds); it is divided into several *frequency channels*; it works at different speeds (called *time constants*); it is adjusted taking both ears into consideration, etc. The option of two or more program settings, which allow optimal compensation for the hearing loss in different sound environments, for example speech and music, is also possible.

The hearing aids may be equipped with a number of tools, which during the fitting session can be used to optimize the adjustment to a specific hearing loss. Among these are tools to measure specific characteristics of the hearing loss through the hearing aid.

c. Additional functions

For the hearing impaired with a perceptive hearing loss, the hearing aid cannot recreate normal hearing, but a number of other functions may be of great assistance to the hearing impaired. These include directional (background-suppressing) microphones, which may be of assistance in noisy surroundings, or noise reduction methods that will make it more comfortable – or less strenuous – for the user to cope in noisy surroundings.

d. Practical functions

This final category includes functions that are not directly related to the user's hearing loss, but may ease the daily use and operation of the hearing aid. These include warning signals indicating that the hearing aid is switched on or that the battery is getting low, or the possibility of coupling a cell phone directly to the hearing aid, etc.

6.4 Fitting of hearing aids

Most hearing aids are adjusted electronically to fit the individual user – the expression used is that the hearing aid is *programmed*. This is usually done by means of a PC and a special software program suited for the particular hearing aid being fitted. Through a small electronic box, the PC is connected to the hearing aid – either to a programming plug or through the battery compartment. Several general principles for the programming of hearing aids exist, but most manufacturers have developed their own strategies. In this way, the specific functions of the individual hearing aids are optimized. This helps to ensure that the hearing aids are adjusted according to their designed functionality and that they function optimally for the individual user.

Regardless of whether general or specific programming methods are used, the fitting of a hearing aid is done in two stages: the first *fitting* and a follow-up *fine tuning*. The first fitting is made according to a special prescription – a kind of formula called a *fitting rationale*, which takes into account the user's specific data: audiogram (hearing threshold, uncomfortable loudness level, etc), age, lifestyle, and other important information – and proposes one setting among the many thousand combinations available. When the hearing aid is programmed with this setting, the user can experience how it sounds and the extent to which it is able to compensate for the hearing loss.

The fine tuning may take place immediately after the first fitting, or after some days or weeks – or it may be necessary to make several fine tunings over an extended period of time. Most of the fitting programs include a large selection of tools for the expert who is fitting the hearing aids. These include a catalog of proposals for changes dependent on how the user evaluates the fitted hearing aids: it may be suggestions on how to solve problems with unacceptable sound levels or 'whistling'; or sounds may be presented to find out how the hearing aid functions in specific acoustic environments. If the person fitting the hearing aid has great experience with the specific hearing aid model and if the hearing loss is not too complicated, the fine tuning is relatively unproblematic in most cases.

6.5 Basic maintenance – why?

All types of hearing aids must be checked, kept dry, and cleaned every day in order to function optimally. It is important to treat the hearing aid with the same care and consideration as glasses or high-tech equipment. The hearing aid must be removed from the ear in situations where it may be damaged.

It is not a good idea to handle the hearing aids in the bathroom, since they may easily break if they fall on a hard surface. Also, it may be difficult to find tiny parts of a broken hearing aid in these surroundings. It is therefore a good idea to get a working routine so that the daily care of the hearing aids is performed on an even, clean surface which is well lit – for instance on a table.

Normally, hearing aids cannot tolerate water so they must be removed before a shower is taken or the hair is washed. Also, they cannot tolerate ultrasound (at physiotherapy), hairspray, perfume, moisture, or heat from a hairdryer. A hearing aid should never be placed on a radiator as it simply cannot endure being exposed to high temperatures over an extended period of time. It is, furthermore, important to remember that hearing aids cannot function as intended if they are blocked by ear wax.

For the hearing aid to function at all, two basic requirements must be fulfilled: there must be a charged/fresh battery and free passage through the sound outlet. If these two requirements are not fulfilled, the hearing aid will not function.

a. Battery supply

In order to ensure that the hearing aid receives the necessary electric energy, the battery must be in a good working condition and the battery compartment kept shut as long as the hearing aid is being used. Some hearing aids have a battery switch built into the battery compartment, in which case the compartment must be opened just slightly if the hearing aid is to be turned off. The battery compartment must be kept dry and free of dust, dirt and ear wax. The battery must be changed regularly dependent on how much energy is required by that particular type of hearing aid and on the lifetime of the battery. For some hearing aid users, it may be a good idea to put a mark in the calendar when the battery is changed so that the battery can be changed in time before the hearing aid suddenly does not function any longer. It is, in all cases, a good idea always to have extra batteries available. The seal on the battery should not be removed until immediately before the battery is placed in the hearing aid.

b. Free passage of sounds

If the output channel of the hearing aid is blocked – most often by ear wax – the hindrance must be removed before the hearing aid can function. This can be done in different ways dependent on the type of hearing aid.

A BTE consists of a hearing aid with a hook, a plastic tube and an ear mold and should be cleaned daily in the following way:

1. All parts of the hearing aid must be wiped using a soft cloth or paper tissue.
2. Wax and dirt in the sound channel (hook and ear mold tubing) and in the vent must be removed by a soft toothbrush acquired for that specific purpose, or by the tool that is supplied with the hearing aid.

If the BTE has become very dirty it can be cleaned in the following way:

1. Separate the ear mold from the plastic tube.
2. Place the ear mold in a bowl with lukewarm water and a denture-cleaning tablet for about 30 minutes.
3. Rinse the ear mold in running, lukewarm water.
4. Let the ear mold dry over night so that it is completely free of moisture, or blow the mold free of damp by means of a small blowing pump (do not blow with your mouth as this will only add more moisture). It is important to ensure that the ear mold is completely dry before the plastic tube is put back on again.
5. The plastic tube must be replaced if it is cracked, hard and yellow or if there is moisture in the tube. When the tube has become hard, it can be very difficult to change.

ITE, ITC or CIC aids are maintained in the following way:

1. The hearing aid is wiped using a soft cloth or paper tissue.
2. The filter covering the sound outlet is changed when it is blocked using the tools provided. Some hearing aids have a filter which is cleaned by being drawn over a small plate covered with fabric while others have a permanent filter which is cleaned using the special tool that comes with the hearing aid.

NB: only the short cleaning tool with a small metal sling at the end must be carefully used to clean in and around the sound output. The hearing aid can be damaged if this is not observed. Also, here a toothbrush may be well suited for removal of wax or other dirt in the outer end of the sound channel.

3. The vent which runs through the hearing aid must be cleaned using a specially suited cleansing tool or for instance a piece of nylon thread (hair pins, needles or other pointed objects must never be used as these may easily damage the hearing aid's plastic shell).
4. The microphone opening (a small, round or oblong hole in the surface of the hearing aid, typically close to the battery compartment) may occasionally be blocked by dirt. This opening must be cleaned using the small cleaning brush that is usually supplied with the hearing aid. Use this brush very carefully and avoid putting the hair of the brush directly into the microphone opening.

7. The hearing aid – what it can do and what it cannot do!

For the most common types of hearing loss, hearing aids greatly improve the perception of the surrounding sounds as well as communication with other people. In many cases, hearing aids make it possible for their users to have almost normal communication with other people in most everyday situations. Despite the hearing loss, many hearing aid users are also able to take part in most of the activities they wish to. It is, however, important to realize that:
- a hearing aid cannot restore normal hearing!

A fundamental problem is that even though the hearing aid is capable of changing many important characteristics of the sounds that are picked up by the microphone, the processed sound signal must still pass the damaged part of the hearing pathway on its way from the output of the hearing aid to the brain. The damaged hearing can be said to impose a number of restrictions on sound perception and the hearing aid must attempt to present the surrounding sounds in such a way that the most important ones are perceived without being uncomfortable to listen to. At the same time, the hearing aid makes available a number of assisting functions, including directionality and noise suppression, which are helpful in particularly difficult situations – although they cannot normalize the sense of hearing

7.1 The hearing aid and the five dimensions

In chapter 5, the five dimensions of hearing were reviewed and a description was given of how they are changed by a common hearing loss – either individually or in various combinations. When a hearing loss is to be alleviated by hearing aids it is therefore natural to look at how and to what degree they are capable of compensating for the changes of the five dimensions. In the following, a few short and general comments are made regarding this topic without attempting to give a detailed account of the complex signal processing in modern hearing aids:

a. Reduced sensitivity

In order for the hearing impaired to hear the sounds that the hearing loss has made inaudible, the hearing aids must amplify the sounds in such a way that compensates for the hearing loss. Most often the amplification needs to be frequency dependent – that is, different for bass and treble sounds – and in this way it indirectly mirrors the audiogram: the greater the hearing loss, the more amplification is needed.

b. Reduced dynamic range

With increasing sound level, less amplification is generally needed. Therefore, the hearing aids are designed to amplify soft sounds more than loud sounds, which are given little or no amplification at all. At the same time, the hearing aids are adjusted in such a way that the user is not too often exposed to uncomfortably loud sounds.

c. Reduced frequency resolution

In order to counteract reduced frequency resolution, which means that it is difficult to distinguish individual frequency components in complex sounds, the hearing aid is divided into a number of frequency bands or channels (typically 2, 3, 4, or more) the amplification of which may vary independently. This means that the way the amplification varies in one frequency channel is independent of what happens in the other channels. In some listening conditions, this independent amplification scheme makes it easier for the hearing-impaired person to distinguish the individual elements of complex sounds.

d. Reduced temporal resolution

In order to counteract reduced temporal resolution, which means that it is difficult to distinguish sound components presented in rapid succession, the hearing aid must vary its amplification in a special way. The amplification may vary for each of the frequency channels and at different speeds according to whether the sound changes from being soft to being loud or vice versa. A hearing aid's time constants describe how fast the amplification varies relative to changes in the sound level. It is important that the time constants are adjusted in such a way that the user can keep the focus on the surrounding sounds and not on how the hearing aid changes its amplification.

e. Reduced binaural capabilities

A hearing loss often gives rise to problems with localizing sounds as well as with communicating in noisy surroundings. Part of the reason is that the brain no longer has the full sound information at its disposal. By using two hearing aids – binaural fitting – the user will experience improved hearing in such surroundings. However, not all hearing-impaired people can make use of two hearing aids, as described in more detail in section 7.2

As described above, hearing aids are able to compensate for at least part of the changes occurring to the five dimensions of hearing. It is, however, not possible to compensate for one dimension independently of the other dimensions. This means that it is necessary to make compromises, for instance between the best possible speech intelligibility and the most comfortable sound quality – a weighing between two or more requirements that only can be decided by the hearing-impaired person.

It is important that the user understands and accepts the following:

- ***the final setting of the hearing aid is often a compromise between two or more contradictory requirements!***

7.2 One or two hearing aids?

It has been mentioned a few times that hearing with both ears is important both for localizing sounds and for communicating in noisy environments. One would think, therefore, that a binaural fitting – the use of two hearing aids – would always be optimal. This would be similar to claiming that most people using glasses need to have their eyesight corrected for both eyes! When the expert responsible for the fitting of the hearing aids suggests that two hearing aids might be the best solution, it often happens that the hearing impaired says: "I am not that deaf", thereby indicating a certain reservation towards testing the possibilities offered by modern hearing aids.

In addition to improving the ability to localize sounds and to communicate in difficult listening situations, the fitting of two hearing aids also makes it possible to create the correct sound balance, so that the hearing impaired will have a feeling of balance between the sounds coming from the right and left side.

There are, however, a number of circumstances that may contribute to the fact that not all hearing-impaired people – including those with considerable hearing losses on both ears – will benefit from using two hearing aids. It is not always possible to make a binaural fitting because some hearing losses develop in such a way that one of the ears no longer contributes effectively to the understanding of speech. Before a binaural fitting is attempted, it is therefore important to test whether both ears are in fact able to transmit speech information to the brain, and thereby avoid making a decision to fit two hearing aids on the basis of the audiogram alone. To attempt a binaural fitting in cases where one of the ears does not function may ruin the possibility of a good result, because the hearing aid on the bad ear will often contribute with distorted sounds and noise instead of additional information. In some cases, however, it is possible to create a good sound balance despite the fact that one of the ears contributes very little to the understanding of speech.

The final decision to fit one or two hearing aids depends, therefore, on whether or not the user can benefit. If a binaural fitting is not selected, the hearing expert must concentrate on finding the optimal adjustment of the hearing aid for the better ear.

In case of a long-lasting, asymmetrical hearing impairment, the brain may have become accustomed to utilizing the information coming from the better ear, in which case the worst ear is 'forgotten'. If the worst ear is not used, its ability to transmit speech information to the brain may deteriorate and, finally, it may no longer be brought to function again, even after long-lasting training with a hearing aid – and in spite of the fact that the audiogram may tell a different story. In contrast, in the event that the worst ear is still functioning, it is important to keep it stimulated, and in such cases the worst ear should also be fitted with a hearing aid. This all depends on the cortical plasticity of the brain

Even though a hearing-impaired person might benefit from two hearing aids, there may be various reasons for not choosing this solution. One of these might be that the person finds it difficult to learn to handle two hearing aids, as it is of course more difficult to operate and take care of two hearing aids than one; it may be a question of cost if the hearing aids are to be purchased; or there may be other reasons. However, it should be stressed that one hearing aid is better than none!

7.3 Getting used to wearing hearing aids

The hearing cortex plays an important role for the higher cognitive functions, including the way in which we perceive speech, music and sounds in our acoustic environment. Learning and training, for instance early exposure to speech and music, determines the organization of the cortex. Exposure to speech and language early in a child's life is crucial for the normal speech and language development. We know that when the cochlea is damaged, as is ordinarily the case with a common hearing loss, the cortical plasticity ensures that the nerve cells in the cortex are reorganized in such a way that they are utilized to their fullest capacity. This is nature's attempt to counteract the damaging effect of the injury to the hearing pathway.

As in all other learning situations, it takes some time to learn to utilize the new sound elements that the hearing aid makes available to the brain. Several studies have shown that this learning process takes about three to four months – presumably the longer the brain has had to cope without the assistance provided by a hearing aid, the longer and slower the adjustment process will be.

It has also been shown that cortical plasticity plays a part in permanent ringing in the ear – called *tinnitus* – which often occurs following damage to the cochlea (see chapter 3.5). Recent research in this area seem to indicate, that when a hearing loss has occurred, for instance following a noise trauma, early use of hearing aids to a certain degree would be able to limit the hearing loss, the cortical reorganization, and the development of tinnitus.

It is therefore important not to wait too long before acquiring a hearing aid – the shorter you wait, the less cortical reorganization will probably take place, and the smaller the risk of developing tinnitus. You will also learn faster to handle and use the hearing aids.

For many hearing-impaired people with tinnitus, the hearing aids have the positive effect that the surrounding sounds are now amplified to such a degree that these may drown the tinnitus and thereby make it less audible and disturbing.

7.4 To hear and to understand

There is a basic difference between being able to hear whether a certain sound is present, which is called *detection*, and being able to understand the meaning of the information carried by the sound, which is called *intelligibility*. In the case of speech sounds, one might be able to hear that someone is talking without necessarily understanding what is being said. We therefore distinguish between being able to *hear* (i.e. that something is audible) and to *understand* (i.e. that what is being heard is meaningful).

The term *audibility* is used in relation to the audiogram or the hearing threshold, and signifies that all sounds louder than the hearing threshold are by definition audible. An audible sound means that it is fully available for the signal processing in the brain. In chapter 4, the relationship between the audiogram and the ordinary, standardized speech signal was described for the different types of hearing loss, with focus on those parts of the acoustic elements of the speech signal that are louder than the hearing threshold.

When evaluating how a speech signal is understood or how we transform what we hear into *speech intelligibility* – the audibility of the speech signal is of critical importance. The degree of audibility is given as a percentage and corresponds to the part of the speech signal that is louder than the hearing threshold and therefore audible.

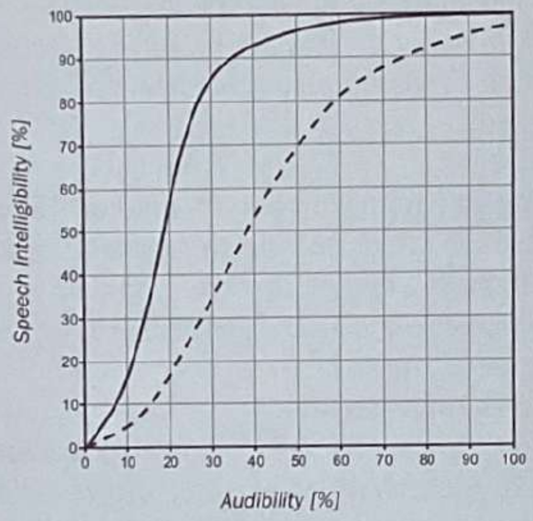

Figure 7.1. The relationship between audibility (in percent) and speech intelligibility (in percent). The full-drawn curve indicates ordinary speech. Already at an audibility of 40 %, a speech intelligibility of more than 90 % is achieved. The dotted curve indicates speech in a foreign language, in an unfamiliar dialect, about an unknown topic, or deviates in other ways from what the listener is accustomed to listening to. At an audibility of 40 %, the speech intelligibility has now dropped to about 50 %

An audibility of 100 % indicates that all elements of the speech are louder than the hearing threshold and an audibility of 20 % means that only one fifth of the speech sounds are audible. For most people – both those with normal and those with reduced hearing – there is usually a relatively simple relationship between audibility and speech intelligibility. This relationship is shown in figure 7.1. The curve indicates the relationship for normal, continuous speech consisting of ordinary, well-known words pronounced in the language and dialect that the listener has grown up with. As shown, it is not necessary to be able to hear all the elements of speech because already with an audibility of about 40 %, the intelligibility reaches almost 100 %. The speech signal is said to be *redundant* – that is, it contains more information than is needed. The figure also shows a curve below the first one. This curve corresponds to situations where a foreign language is being spoken; a dialect is used that is not completely familiar to the listener; a conversation is being carried out using terminology unknown to the listener; or the speaker is using a sentence structure, a tone of voice, or expressions that are surprising or new to the listener.

> *Not all frequencies contribute equally to speech intelligibility. A certain weighting is being carried out and especially the mid-frequency area is important. For a normal conversation in quiet surroundings, the frequency areas below 500 Hz and above 4,000 Hz contribute only a little to the speech intelligibility*

Audibility is not determined exclusively by the hearing threshold shown in the audiogram. In noisy surroundings, the noise may – when it is louder than the threshold – have the effect that the real hearing threshold is determined by the noise and not by the hearing loss. The hearing threshold is *masked*. If you listen to speech in noisy surroundings, audibility will normally be worse than when listening to the same sounds in quiet surroundings. In this way, speech intelligibility is reduced, which corresponds well with the experience most people have in noisy surroundings. If the audibility in quiet surroundings is 40 %, most listeners will manage quite well, whereas for a hearing-impaired person at a party, for instance, audibility may easily fall below 15-20 %, both because of the background noise and of the hearing loss. In this way, speech intelligibility may fall to below 50 % and the hearing impaired must either guess what is being said or give up on being involved in the conversation.

Even though audibility – and thereby the hearing loss as it appears from the audiogram – is an important factor for predicting speech intelligibility, there are great differences in the speech intelligibility that different people actually achieve, especially in background noise. This applies to both normal-hearing and hearing-impaired persons – with or without hearing aids. Therefore, apart from the hearing threshold, there must be individual differences that are not directly accounted for by the audiogram or by the other dimensions of hearing. We know that great variations exist in the way the brain is capable of deducing and processing the information it receives from the senses: sight, smell, taste, feeling, balance and hearing, and the ability to combine this information with learning, experience, and previous impressions that may be stored in the

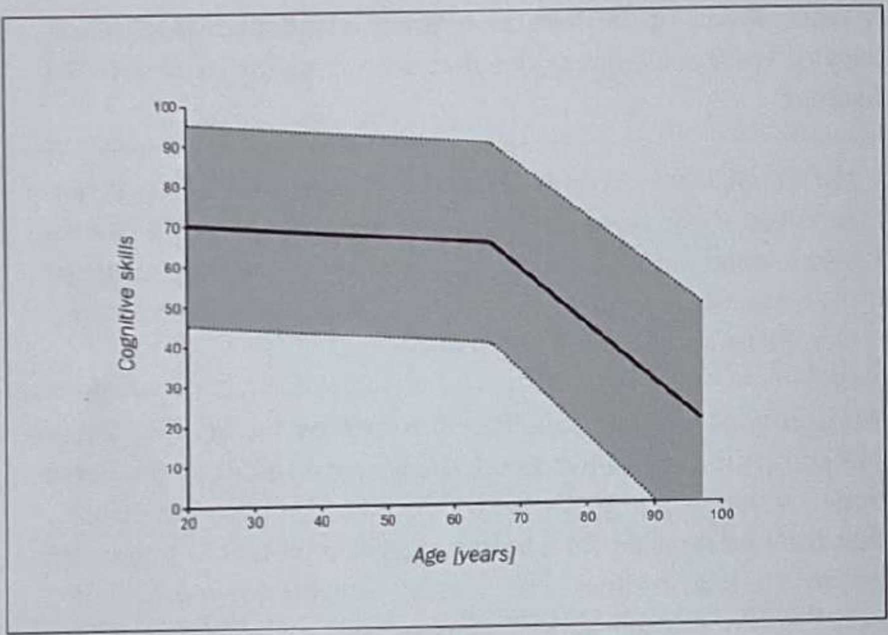

Figure 7.2. Cognition. Cognitive abilities change with increasing age: on an average (fully drawn line), the cognitive abilities are more or less constant until the age of 65 years, after which they decrease with increasing age. The grey area indicates the considerable variations in cognitive abilities that may be found in both young and elderly, normally functioning people

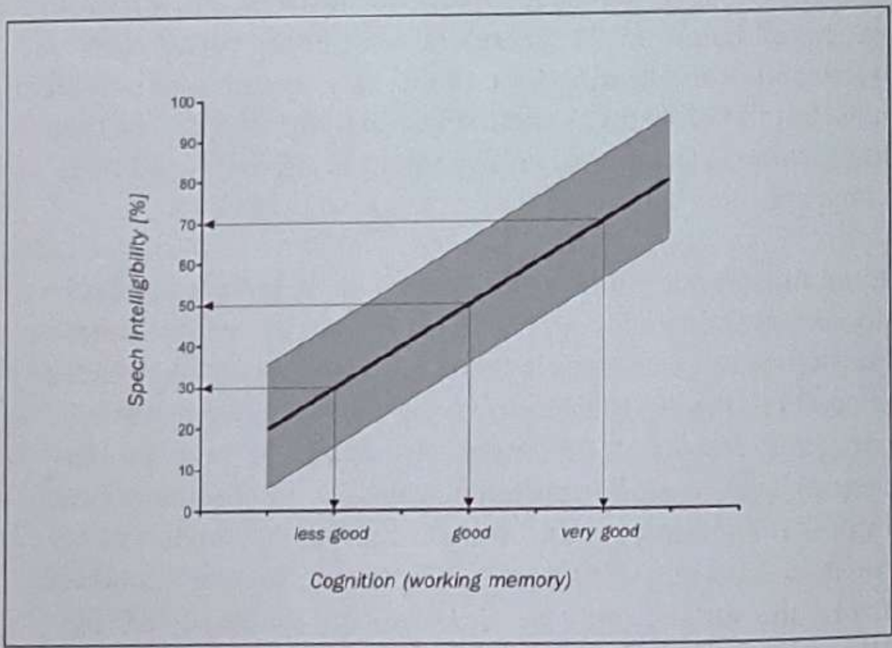

Figure 7.3. The relationship between cognition and speech intelligibility (in percent). The figure shows that the better the cognition, the better the speech intelligibility. The grey area indicates the considerable variations that exist for this relationship.

long-term or *short-term* memory. The short-term memory is also called the *working memory* and can be described as the ability to maintain new information over a short period of time. Usually, the working memory participates in problem solving and in controlling our attention. Taken together, this is generally known as *cognition* or *cognitive skills*, which comprise the brain functions that help us understand, store and use information.

If cognition is analyzed in a large group of ordinary people, there is considerable variation from person to person. Also, it appears that the cognitive skills are usually independent of age up to around 65 years, and then they slowly decline with increasing age. This is shown in figure 7.2.

A large number of studies have pointed to a connection between speech intelligibility and cognition. It appears that speech intelligibility – especially in background noise – is strongly related to cognition, expressed as the ability to utilize the working memory: the better the cognitive skills, the better speech intelligibility. This is illustrated in figure 7.3, which shows a difficult communication situation where people with average cognition have a speech intelligibility of 50 %. In the same situation, persons with less good cognition will have an intelligibility of 30 %, whereas persons with a very good cognition will achieve a speech intelligibility of 70 %.

Similarly, other studies have shown that there is also a relationship between cognition (working memory) and both speech intelligibility and the benefit the user gets from the hearing aids, dependent on the specific signal processing in the hearing aid. These results show that the setting of the hearing aid giving the best result for the hearing-impaired person with less good cognitive skills may be very different from the setting that is optimal for hearing impaired with very good cognitive skills. It appears, furthermore, that hearing-impaired people with very good cognitive skills have a brain that is better at utilizing the sound information made available through the hearing aid than hearing impaired with less well-developed cognitive skills.

People are very different with regard to what they are good at and with regard to the opportunities they have. Some people are good at reading, others are good at using tools and others excel in sports or at playing or composing music, etc. In the same way, people differ with regard to their cognitive skills. It is, therefore, not surprising that two hearing-impaired people – with similar audiograms – will presumably need to have their hearing aids adjusted in completely different ways in order for each of them to achieve the best possible result. The amount of benefit they get from their hearing aids is very likely different, too.

7.5 A person with hearing loss and hearing aids

In the above, we have discussed a number of important issues regarding hearing loss and the use of hearing aids. First and foremost, there is the hearing loss itself, which may affect the frequency areas in the cochlea in different ways and be caused by lesions at different locations along the hearing pathway. Secondly, there is the damage to the five dimensions of hearing by means of which we have attempted to describe the sense of hearing in this book. With focus on improved speech communication by means of hearing aids, attempts have been made for many years to normalize in the best possible way the changes occurring in these five dimensions. However, it has become clear that hearing aids are not able to restore normal hearing. Furthermore, it is not possible to normalize the individual dimensions of hearing simultaneously. It is also clear that there are other characteristics apart from the purely audiological – that is, the five dimensions – that determine how a given hearing loss will affect an individual. In addition to the cognitive skills, other factors such as the personality, lifestyle and listening preferences are decisive for how much the hearing impaired will benefit from the hearing aids and for how the hearing aid should be adjusted to function in the best possible way.

For the practical, everyday use of the hearing aids, there are other characteristics that are important, for instance the hearing-impaired person's sense of touch, dexterity and eyesight. Such abilities are important for placing the hearing aid in the ear correctly, for the daily maintenance and cleaning of the hearing aids and for changing the battery and wax filter.

It can be concluded that it is essential to perceive the hearing-impaired individual as a whole person and to be aware of this *holistic* viewpoint. This applies to everyone who is associated with hearing-impaired people and hearing aids – whether this is in connection with teaching, treatment, training, research, development, or care.

8. How to cope with a hearing loss

Just as personality and lifestyle are decisive in determining the benefit the hearing-impaired person may get from using hearing aids, the same factors are decisive for how well a hearing loss is handled at the personal level.

8.1 Strategies for coping with a hearing loss

The word *coping* is used to describe how we handle the mental and behavioral reactions that arise when we are challenged with a hearing loss.

The hearing-impaired person may react positively to the changed life situation by being conscious of it and by planning strategies for difficult listening situations in advance. This means, for example, being well rested before an important meeting or large parties. Such situations are often demanding and require great concentration and may therefore be strenuous for the hearing-impaired person.

In the pro-active coping process, the hearing-impaired person may attempt to involve other people. This can be done by drawing attention to the hearing loss, by speaking distinctly, and by obtaining good visual contact as well as using good communication strategies. In this way, there is hope that other people may also feel responsible for creating a good communication situation.

If, on the other hand, the hearing impaired tries to avoid situations that make demands on the hearing sense, or situations where one may run the risk of being misunderstood or even being 'disclosed' as a person with a hearing loss, the hearing impaired will have no control when such situations appear anyway. In more 'passive' coping situations, there is no mutual responsibility and the ultimate consequence is that the hearing-impaired person will withdraw and avoid social contacts.

It is not always easy to cope with a hearing loss in the most optimal way. There are certain days and situations that are easier to handle than others. Now and then, there will be a need for the hearing impaired to retreat and recover and it is therefore completely normal to use different strategies. It is important, however, that the hearing impaired is conscious of which of the two coping strategies is being used in the different situations.

In general, being pro-active about social situations is the most constructive but also most demanding approach. The passive approach may be less demanding in the situation, but in the long run may have serious implications and lead to loneliness.

8.2 Coping strategies and hearing tactics

a. General strategies

Strategies for how the hearing loss can be handled and for choosing the optimal tactics in the given situation can be listed as follows:

- inform other people about the hearing problem
- participate in activities required by family and job
- do not isolate yourself
- remember to be well rested before participating in difficult listening situations
- seek eye contact and look at other people's mouth, face and hands
- speak clearly and distinctly yourself – good habits are contagious!
- ask control questions and point out if something has not been heard
- draw attention to the fact that background noise may prevent you from hearing everything that is said
- be aware of situations that are annoying and try to change the situation so that stress can be avoided
- ask that consideration be shown to you, within reason

b. Hearing tactics – on the job

The hearing impaired should consider the following advice:

- inform your colleagues that it is difficult to carry out a conversation or phone call in noisy surroundings
- draw attention to the fact that there may be problems hearing on the telephone
- use e-mails or cellphone messages (sms)
- use assistive listening devices for telephoning and at meetings
- make it clear that good acoustic environments are fundamental for optimal communication
- suggest that a chairman is chosen at meetings and that there is only one speaker at a time
- volunteer to write the minutes of the meeting and write a summary of the resolutions so that it becomes clear what has been decided
- if you cannot take the minutes yourself, ask a colleague to give an account of the most important decisions taken at the meeting
- at breaks – or in the corridors – notify the others if it is impossible for you to follow the conversation and thereby contribute to the decisions made

c. Hearing tactics – for coping in large gatherings

The hearing impaired should attempt to:

- be well rested
- be placed at the end of the table or close by, if it is at all possible to choose ones own seating
- be placed as far away from a noise source as possible; this applies whether the noise source is a loudspeaker system, orchestra, kitchen, exit doors, etc.
- accept that it may not always be possible to hear everything, but enjoy the food, look at the others and be content that you are not sitting at home in isolation
- tell a dance partner that it is not possible to have a conversation while dancing

The hearing impaired should try to take an active attitude towards the changed life situation in relation to family and friends. It is important to have a continuous dialog with both family and friends about the hearing loss and its consequences (isolation, communication difficulties, participation in club work and meetings with authorities, in the bank etc.). Furthermore, it is important that the hearing-impaired person does not blame the hearing loss for ordinary problems in the family.

It may be difficult for relatives to see and feel that the person they know well has changed and that effortless communication is no longer possible. In order to succeed it is important that both parties make an effort. The relatives must articulate distinctly and not change the subject at short intervals. The hearing impaired must participate actively, ask control questions and in general accept and handle the difficulties that arise in connection with everyday communication.

Glossary

A **Acoustic neuroma**
Benign tumor on the hearing nerve, at the location where it leaves the inner ear, and together with the balance nerve, runs in a small canal in the temporal bone towards the brain stem

Acoustics
A common term for the physical conditions of sounds and sound waves, including the way in which these are created, transmitted and reflected from surfaces, how they behave in different materials and create resonance in tubes, etc.

Air conduction
Refers to air-borne sounds which, in contrast to bone-conducted sounds, reach the ear drum (and thereby the middle ear and inner ear) via sound vibrations in the air. When a hearing test is performed using an earphone, the air conduction threshold is measured

Amplifier
The electronic unit that amplifies the sound on its way through the hearing aid – i.e. the sound that comes out of the hearing aid is louder than the sound entering the hearing aid

Analog
In connection with hearing aids, 'analog' technology is used in opposition to 'digital' technology. In an analog hearing aid, the incoming sound waves are picked up by the microphone and transformed into a continuous electric signal, which is processed without disruptions by the analog, electronic amplifier of the hearing aid

Asymmetric hearing loss
A hearing loss that is significantly different in the right and left ear. The difference between the two ears must exceed 15-20 dB. Both the bone and air conduction thresholds can be asymmetrical

Audiometry
Means 'measurement of hearing' and is the professional term used for a hearing test

B **Binaural**
Means 'both ears'. Hearing aids fitted to both ears is called a binaural fitting

Bone conduction
Refers to bone-conducted sounds, which, in contrast to air-conducted sounds, reach the inner ear through the bones of the skull. When a hearing test is performed by means of a bone conductor that transmits sound vibrations to the skull, the bone conduction threshold is determined

Brain stem
Consists of the extension of the spinal cord (medulla oblongata), the bridge-like structure called the pons, and the mid-brain. The brain stem is located under the fore-brain in front of the cerebellum

BTE
A hearing aid that is placed behind the ear (Behind-The-Ear)

C **Central nervous system, CNS**
Consists of the brain and the spinal cord. The brain consists of the fore-brain, the hind-brain, the mid-brain and the brain stem

CIC
A hearing aid that is placed deep in the ear canal (Completely-In-Canal)

Cochlea
The Latin term for the snail-shell structure of the inner ear that contains the sensory organ of hearing

Cochlear implant, CI
A hearing prosthesis that stimulates the hearing nerve by means of electrodes inserted into the cochlea. CI is used in people with severe to profound hearing losses that cannot be adequately compensated for by hearing aids. In children, for instance, who are born with a considerable hearing loss, early treatment with a cochlear implant may often ensure normal language acquisition and development

Cognitive skills
Comprise the brain functions that assist us in understanding, storing and using information

Conductive
In a conductive hearing loss, air-borne sounds are not able to reach the inner ear in a normal way. The obstacles may be located either in the ear canal, near the ear drum, or in the middle ear. The conductive hearing loss corresponds to the difference between air conduction and bone conduction thresholds (the air-bone gap)

Concha
The bowl-formed recess in the outer ear directly behind the entrance to the ear canal

Cortex
The outer layer of the fore-brain, comprising the primary sensory centers for feeling, vision, smell, taste and hearing. The hearing cortex is located at the upper surface of the temporal lobe

Cortical plasticity
Related to hearing, this means the brain's ability to adapt to long-term changes in the sound information from the two ears; for instance as a result of a hearing loss

Cortical resources
The number of nerve cells available in the hearing cortex

Corti, Organ of
Denotes the sensory organ in the inner ear, the cochlea, and comprises the inner and outer hair cells, the supporting cells, and the membranes enclosing these structures as well as the peripheral parts of the nerve fibers

Critical band
A narrow frequency band within which two simultaneous tones cannot be distinguished. Is a measure of the normal frequency resolution

D **dB, decibel**
A unit of measurement indicating, in this context, the physical sound level. Each time the sound level is increased by 20 dB, it means that the sound becomes 10 times more intense. NB: dB is a general unit of measurement and is not used exclusively within the field of acoustics

dB HL
Denotes the sound level in relation to the normal hearing threshold – also called the hearing level

Detection
The ability to hear that a sound is present without necessarily being able to understand, or utilize, the information that is provided

Digital
In connection with hearing aids, the term 'digital technology' is used as opposed to 'analog technology'. In a digital hearing aid, the microphone signal is transformed into a digital signal. In the hearing aid's digital, electronic amplifier (computer), the digital signal can be manipulated, as a series of numbers, in the same way as in an ordinary PC

Direct Audio Input (DAI)
An input to the hearing aid to which other components than the hearing aid microphone or telecoil can be connected. Most BTE hearing aids have a small plug for connection of a conference microphone, a CD player etc

Directional microphone
A microphone capable of picking up sounds from a specific direction

Dynamic range
The range of sound levels between the hearing threshold (HTL) and the uncomfortable loudness level (UCL) – that is, the difference between the softest sound that can be perceived and the loudest sound that will be tolerated. The dynamic range thus denotes the range of physical sound levels that can be utilized by the sense of hearing

E **Endolymphatic hydrops**
Sudden changes in the chemical composition of the fluids in the inner ear. The term is used in connection with Ménière's disease

F **Frequency**
Denotes the number of sound vibrations per second and is indicated in Hertz, Hz

Frequency range
The range between a low and a high frequency; for instance, the range of frequencies that can be heard or the range of frequencies that can be reproduced by the hearing aid

Frequency resolution
The ability to separate two simultaneous tones of relatively close frequencies

H **Hair cells**
The sensory cells in the inner ear, the cochlea. Consist of outer and inner hair cells

Hearing cortex
The primary hearing center of the brain situated in the outer layer of the fore-brain called the cortex. The hearing cortex is located on the upper surface of the temporal lobe

Hearing threshold
Sound level corresponding to the softest sound that can be perceived. The hearing threshold is indicated in dB HL and is shown in the audiogram for the individual frequencies (bass and treble sounds)

HTL
The Hearing Threshold Level, i.e. the sound level that corresponds to the hearing threshold

I **Interaction**
The way – and extent – of socializing with other people as well as the benefit derived from such relationships – social interaction

ITC
A hearing aid that is placed in the ear canal (In-The-Canal)

ITE
A hearing aid that is placed in the ear – partly in the ear canal and partly in the concha (In-The-Ear).

L **Linear**
A characteristic feature of a hearing aid. The amplification can either be linear or non-linear. A linear hearing aid amplifies soft and loud sounds equally

Localization
The ability to determine the direction of a given sound source

Loudspeaker
A small sound source, which is the output of the hearing aid that sends the sound from the hearing aid into the user's ear canal. Within the field of hearing aid technology, this loudspeaker is referred to as the receiver

M **Masked hearing threshold**
In background noise that is louder than the hearing threshold, softer sounds cannot be heard. The noise masks the soft sounds and the effective hearing threshold is then determined by the noise. This is called a masked hearing threshold

Microphone
The normal input to a hearing aid. The microphone receives sounds from the surroundings and transforms them into electric signals

N **Neurons**
The cell nuclei of the nerve fibers. The collection of the individual nerve fibers' cell nuclei constitutes the relay stations of the hearing nerve

Non-linear
A characteristic feature of the hearing aid. The amplification can be either linear or non-linear. A non-linear hearing aid gives greater amplification for soft sounds than for loud sounds

O **Occlusion**
Indicates that sounds are captured in the ear canal. Many body sounds that are produced when the user is speaking, humming, singing, eating, or swallowing, are therefore experienced as unnaturally loud and unpleasant

Open fitting
A hearing aid equipped with a very large vent, or just an ear mold device keeping the tube in place in the ear canal. This is an effective way of preventing occlusion, but yields only limited amplification for the high frequencies, in particular

Output
A hearing aid's output consists of a small loudspeaker which sends the amplified sound into the user's ear canal

P **Perceptive/sensorineural**
A perceptive or sensorineural hearing loss is caused by changes in or damages to the inner ear. Such damage may occur in or around the Organ of Corti and involve the sensory cells, the hair cells, and the peripheral parts of the hearing nerve. Corresponds to the bone conduction threshold

Periphery
Outside of the central nervous system: (1) the peripheral part of the hearing pathway refers to the outer ear, the ear canal, the middle ear, the inner ear and the first part of the hearing nerve. (2) peripheral neural activity is activity in the first part of the hearing nerve between the nerve fibers' contact with the hair cells and the brain stem. (3) peripheral resources indicate the available number of hair cells and nerve fibers

Primary hearing center
The terminus of the hearing pathway on the surface of the brain, the cortex. The primary hearing center is also called hearing cortex and is located on the upper surface of the temporal lobe

Pulse synchrony
An internal sound elicited from and arriving at the same time as the beat of the heart

R **Redundancy**
Redundant information is superfluous information. Ordinary speech generally consists of more information than is necessary for understanding what is being said

Retro-cochlear/central hearing loss
Damages to the hearing pathway occurring after the hearing nerve has left the inner ear, the cochlea. Often, the central nervous system or the brain structures associated with the sense of hearing are affected

Reversible
Can be changed or made undone. A reversible hearing loss is a hearing loss that disappears if the damaged hearing can be restored. Many conductive hearing losses are reversible, or partly reversible

S **Speech banana**
An often used expression for the area in the audiogram indicating the range covered by normal speech

Speech intelligibility
Corresponds to the amount of information in a speech signal that has been perceived; is often indicated in per cent. A speech intelligibility of 100 % indicates that all information has been perceived, whereas an intelligibility of 25 % indicates that only one fourth of the information has been perceived

Speech signal
Acoustic speech signals denote the sounds emitted during speaking. An electric speech signal is the corresponding electric activity, for instance from the output of a microphone recording the speech sounds

T **Teleloop (-system)**
A technical installation often employed in cinemas, theatres, auditoriums, churches, and lecture halls, where the sounds from movies or microphones are transformed into a magnetic field which can be received by the telecoil in the hearing aid

Temporal resolution
The ability of the hearing sense to distinguish between two different sounds delivered in close succession

Tinnitus
The experience of 'ringing' in the ears. Often a phantom sound, that is, a sound perceived without any physical sound source in the environment

Tonotopical organization
A systematic grouping of the individual frequency bands, for instance in the cochlea or the hearing cortex

U **UCL**
UnComfortable loudness Level, indicates the sound level of the loudest sound that will be tolerated

V **Vent**
A channel in the ear mold or in the hearing aid which ventilates the otherwise closed ear canal. This is to ensure that a normal air pressure can be maintained in the ear canal and to avoid that the user is troubled by occlusion

Subject index

D

E

F

H

P

Q

R

S

About the authors

Dr. Claus Elberling is a Danish scientist. During almost 40 years, he has done research within the fields of psycho-acoustics, hearing physiology, hearing testing, and hearing aids. At present, he works as a senior scientist in the hearing aid company, Oticon A/S in Denmark, and for 15 years he was heading the company's research center, Eriksholm. Over the years, dr. Elberling has published more than 100 international papers on hearing-related topics.

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