Hearing loss in the elderly and its compensation with hearing aids

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B.C.J.Moore, Hearing loss in the elderly and its compensation with hearing aids. Gerontechnology 2002; 1(3): 140-152. Hearing loss is common in the elderly, and the degree of loss tends to increase with increasing age. By 70 years of age, the majority of people have a hearing loss sufficient to cause communication problems in everyday life. The loss is typically greatest at high frequencies. The major cause of hearing loss in the elderly is loss of function of the hair cells within the cochlea. Reduced function of the outer hair cells (OHCs) results in loss of sensitivity (elevated absolute thresholds), reduced frequency selectivity, and loudness recruitment. Reduced function of the inner hair cells (IHCs) causes basilar-membrane (BM) vibrations to be transduced less efficiently and may lead to "noisy" transmission of information in the auditory nerve. In extreme cases, the IHCs may be completely non-functioning over a certain region of the BM, leading to a "dead region" in which there is no transduction. Current hearing aids can partially compensate for loss of sensitivity, by providing frequency-selective amplification, and for the effects of loudness recruitment by using compression amplification. This reduces the need to adjust the volume control to deal with different listening situations. The deleterious effects of reduced frequency selectivity on speech intelligibility in noise can be alleviated by various methods for improving the speech-to-noise ratio, although so far only directional microphones have given clear benefits. Hearing aids are usually of limited benefit for people with extensive dead regions, but for those with profound or total hearing loss cochlear implants may be of benefit. Improving the acoustics of meeting places and reducing background sounds in broadcasts could be of considerable benefit to all elderly people, regardless of whether or not they use hearing aids.

Key words: Hearing loss, presbycusis, hearing aids, speech comprehension

THE PREVALENCE OF HEARING LOSS IN THE ELDERLY

Hearing loss is usually quantified by the pure-tone audiogram. This is based on the measurement of absolute thresholds for the detection of pure tones (sinusoids) of various frequencies; the thresholds are plotted relative to the average "normal" thresholds obtained from young persons without any history of hearing disorders, and have the units dB HL (hearing level). Hearing loss measured in this way tends to increase with increasing age. One measure of overall hearing loss is the threshold in dB HL averaged for the frequencies 0.5, 1, 2 and 4 kHz. The data of Davis[1], based on a large scale survey in the UK, indicate that for listeners in the age range 61-71 years, 51% had a hearing loss greater than 20 dB, and 11% had a hearing loss greater than 40 dB. For listeners in the age range 71-80 years, 74% had a hearing loss greater than 20 dB, and 30% had a hearing loss greater than 40 dB. If the average threshold at high frequencies (4, 6 and 8 kHz) is used as a measure, the proportions are even greater. For example, for listeners in the age range 71-80 years, 98% had a hearing loss greater than 20 dB, and 81% had a hearing loss greater than 40 dB.

Hearing loss is not inevitable in the elderly; some elderly people have nearly normal hearing. Hearing loss in the elderly can have both environmental and genetic causes. It is not clear what proportion of hearing loss might be prevented by avoiding intense sounds (as encountered in rock concerts and discotheques, in some work places, and when using guns), by the use of ear plugs or ear defenders, by changes in lifestyle, or by avoiding ototoxic substances such as certain antibiotics.

PHYSIOLOGICAL BASES OF HEARING LOSS IN THE ELDERLY

Physiology of the peripheral auditory system

To understand the nature of hearing loss in the elderly, it is helpful to have a basic knowledge of the anatomy and physiology of the peripheral auditory system. Figure 1 shows the structure of the human peripheral auditory system. It is traditionally considered as composed of three parts, the outer, middle, and inner ear; the latter is also called the cochlea. The outer ear is composed of the pinna and the auditory canal or meatus. Sound travels down the meatus and causes the eardrum, or tympanic membrane, to vibrate. The eardrum forms the outer boundary of the middle ear. These vibrations are transmitted through the middle ear by three small bones, the ossicles, to a membrane-covered opening in the bony wall of the cochlea. This opening is called the oval window and it forms the inner boundary of the middle ear. The ossicle lying over the oval window is called the stapes. The major function of the middle ear is to ensure the efficient transfer of sound energy from the air to the fluids in the cochlea.

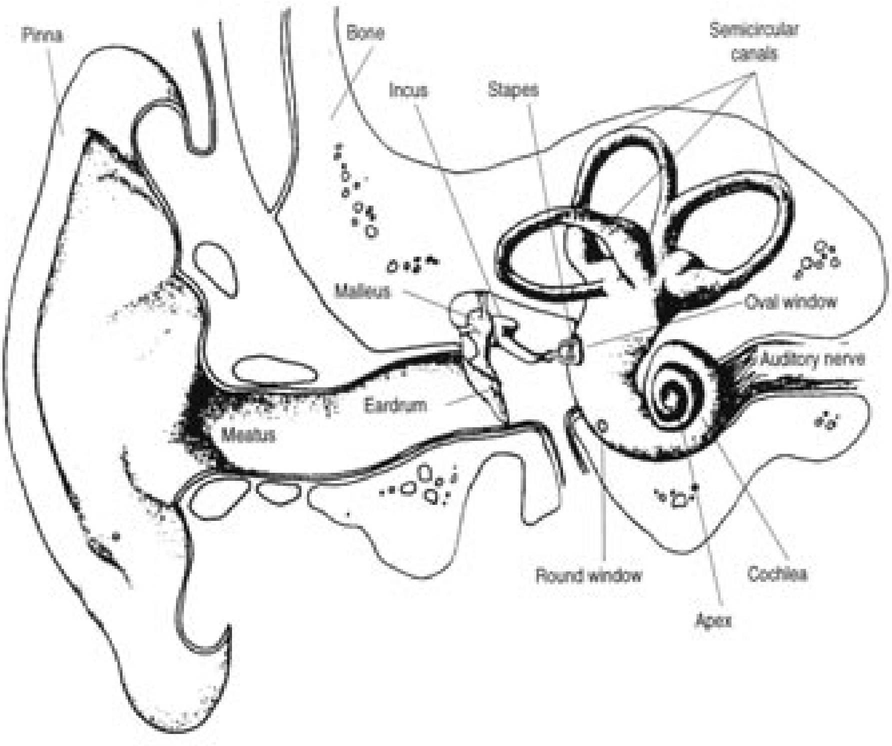

Figure 1. Illustration of the structure of the peripheral auditory system showing the outer, middle and inner ear. Redrawn from Lindsay and Norman[62].

The cochlea is shaped like the spiral shell of a snail. However, the spiral shape does not appear to have any functional significance (except for saving space), and the cochlea is often described as if the spiral had been "unwound". The cochlea is divided along its length by two membranes, Reissner's membrane and the basilar membrane (BM). The start of the spiral, where the oval window is situated, is known as the base; the other end, the inner tip, is known as the apex. It is also common to talk about the basal end and the apical end. Inward movement of the oval window results in a corresponding outward movement in a membrane covering a second opening in the cochlea - the round window. Such movements result in pressure differences between one side of the BM and the other (i.e. the pressure is applied in a direction perpendicular to the BM) and this results in movement of the BM.

A third membrane, called the tectorial membrane, lies close to and above the BM, and also runs along the length of the cochlea. Between the BM and the tectorial membrane are *hair cells*, which form part of a structure called the organ of Corti (Figure 2). They are called hair cells because they appear to have tufts of hairs, called stereocilia, at their apexes. The hair cells are divided into two groups by an arch known as the tunnel of Corti. Those on the side of the arch closest to the outside of the spiral shape are known as outer hair cells (OHCs), and they are arranged in three to five rows. The hair cells on the other side of the arch form a single row, and are known as inner hair cells (IHCs). It appears that the stereocilia of the OHCs actually make contact with the tectorial membrane, but this may not be true for the IHCs. The tectorial membrane appears to be effectively hinged at one side (the left in Figure 2). When the BM moves up and down, a shearing motion is created; the tectorial membrane moves sideways (in the left-right direction in Figure 2) relative to the tops of the hair cells. As a result the stereocilia at the tops of the hair cells are moved sideways. The movement of the stereocilia of the IHCs leads to a flow of electrical current through the IHCs which in turn leads to the generation of action potentials (nerve spikes) in the neurones of the auditory nerve. Thus the

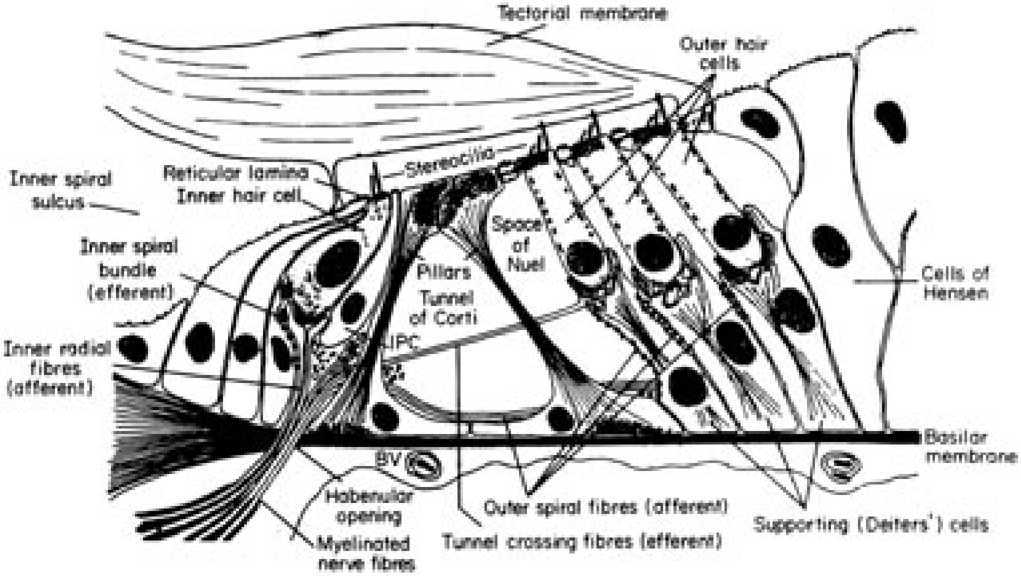

Figure 2. Cross section of the organ of Corti as it appears in the basal turn of the cochlea. Adapted from Ryan and Dallos[63].

IHCs act to transduce mechanical movements into neural activity.

The main role of the OHCs is probably actively to influence the mechanics of the cochlea. The OHCs have a motor function, changing their length, shape and stiffness in response to electrical stimulation[2,3], and they can therefore influence the response of the BM to sound. The OHCs are often described as being a key element in an active mechanism within the cochlea. The exact way in which the active mechanism works is complex, and is still not fully understood. The interested reader is referred to recent reviews[4-6].

The response of the BM to stimulation with a sinusoid takes the form of a travelling wave which moves along the BM from the base towards the apex[7]. The amplitude of the wave increases at first with increasing distance from the base and then decreases rather abruptly. The basic form of the wave is illustrated in Figure 3, which shows schematically the instantaneous displacement of the BM for four successive instants in time, in response to a low-frequency sinusoid. The four successive peaks in the wave are labelled 1, 2, 3 and 4. This figure also shows the line joining the amplitude peaks, which is called the envelope. The envelope shows a peak at a particular position on the BM.

The response of the BM to sounds of different frequencies is strongly affected by its mechanical properties, which vary progressively from base to apex. At the base the BM is relatively narrow and stiff. This causes the base to respond best to high frequencies. At the apex the BM is wider and much less stiff, which causes the apex to respond best to low frequencies. Each point on the BM is tuned; it responds best (with greatest displacement) to a certain frequency, called the characteristic frequency (CF) or best frequency, and responds progressively less as the frequency is moved away from the CF. The CF decreases monotonically with distance from the base. It is now believed that the tuning of the BM arises from two mechanisms. One is referred to as the passive system or passive mechanism. This depends on the mechanical properties of the BM and surrounding structures, and it operates in a roughly linear way. The other mechanism is the active mechanism. This depends on the operation of the OHCs, and it operates in a nonlinear way. The active mechanism depends on the cochlea being in good physiological condition, and it is easily damaged. When the OHCs operate normally, the BM shows sharp tuning, especially for low input sound levels. The travelling wave illustrated in Figure 3 is representative of what might be observed in a dead cochlea, when only the passive system is operating. In a living healthy cochlea, the envelope of the travelling wave would have a much sharper peak.

A second function of the active mechanism is to provide level-dependent amplification or

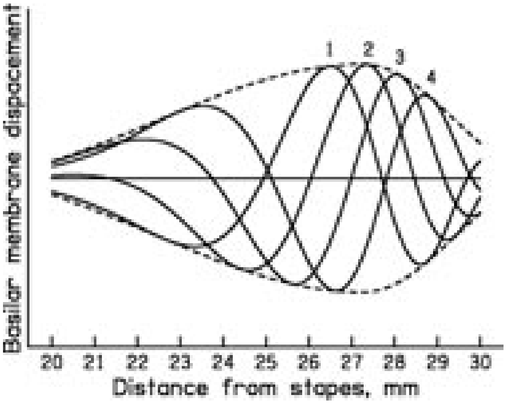

Figure 3. The solid lines show the instantaneous displacement of the BM at four successive instants in time (labelled 1 to 4), derived from a cochlear model. The pattern moves from left to right, building up gradually with distance, and decaying rapidly beyond the point of maximal displacement. The dashed line represents the envelope traced out by the amplitude peaks in the waveform. The envelope shown here is representative of what would be observed in a dead ear. In a healthy living ear, the envelope would have a much sharper peak. From Moore[51].

gain on the BM. The gain is greatest for low-level inputs (levels below about 30 dB SPL), and decreases progressively with increasing level for levels up to 90 – 100 dB SPL[8-10]. This level-dependent gain means that the response on the BM is compressive. For example, if the input level of a sinusoid is increased from 50 to 60 dB SPL, the response on the BM at the place tuned to the frequency of that sinusoid may increase by only about 2.5 dB.

Types of hearing loss

Hearing loss is typically divided into two broad categories. A conductive hearing loss occurs when the conduction of sound to the cochlea is impeded in some way, for example by cerumen (wax) in the ear canal or by growth of a bony substance around the stapes (otosclerosis). A sensorineural loss occurs when the functioning of the cochlea is impaired or when there is dysfunction of the auditory nerve or higher centres in the auditory pathway. When the loss of function is mainly attributed to cochlear damage, the loss is described as "cochlear", although the auditory nerve and higher centres in the auditory pathway may degenerate following cochlear damage.

Causes of hearing loss in the elderly

Hearing loss in the elderly can have a variety of causes, but by far the most common is dysfunction of the cochlea[11]. A common problem is loss of hair cells in the cochlea[12], although metabolic disturbances (caused for example by reduced functioning of the stria vascularis, which acts as a kind of "battery" supplying the voltage essential for operation of the hair cells) can affect the operation of the hair cells without the hair cells actually being lost. Generally, the loss of outer hair cells (OHCs) is greater than the loss of inner hair cells (IHCs). There may also be degeneration of spiral ganglion cells (whose axons make up the auditory nerve)[13], often associated with damage to the IHCs. There may be changes in the central auditory system associated with ageing, and these can lead to a reduced ability to process rapid sequences of sounds[14,15]. However, in this paper I will focus on the more "peripheral" (i.e. cochlear) aspects of age-related hearing loss, as these are the aspects that can be treated most effectively with hearing aids.

CONSEQUENCES OF REDUCED HAIR CELL FUNCTION

When the OHCs are not functioning normally, the active mechanism is reduced in effectiveness or lost altogether. As a result, several perceptual changes occur[16]: (1) Low-level sounds need to be more intense than normal to produce a given magnitude of response on the BM. This is one cause of elevated absolute thresholds (usually the main cause for mild to moderate hearing loss). (2) The tuning on the BM becomes much broader than normal. As a result, frequency selectivity - the ability of the auditory system to resolve (to a limited extent) the components in a complex sound - is reduced. This contributes to the difficulties experienced by the hearing impaired when trying to understand speech, especially when background noise is present[17,18]. (3) Input-output functions on the BM become more nearly linear (i.e. steeper). This is probably the main cause of loudness recruitment[16,19] ; when a sound is increased in level above the (elevated) absolute threshold, the rate of growth of loudness level with increasing sound level is greater than normal. When the level is sufficiently high, usually around 90 to 100 dB SPL, the loudness reaches its "normal" value. With further increases in sound level above 90-100 dB SPL, the loudness grows in an almost normal manner.

The IHCs act as transducers to transform BM vibration into action potentials in the neurones of the auditory nerve. Reduced functioning of the IHCs results in reduced efficiency of transduction, so the amount of BM vibration needed to reach threshold is higher than normal. This is a second cause of elevated absolute thresholds. Reduced transduction efficiency may also lead to "noisy" transmission of information in the auditory nerve. When IHCs are completely non-functioning over a certain region of the cochlea, there is no transduction of BM vibration in that region. I refer to such a region as a “dead region”[20,21]. Frequency components of sounds that produce maximum vibration of the BM within a dead region, are not detected at their normal “place”. However, if the components are amplified sufficiently, they may be detected at a place on the BM where there are functioning IHCs. It should be noted that such “off place” detection results in a kind of distortion of the normal frequency-to-place mapping in the cochlea, and it may also interfere with the processing of frequency components that normally excite the place where detection occurs.

COMPENSATION FOR HEARING LOSS WITH HEARING AIDS

Compensation for loss of audibility

The higher frequency components in speech, associated with sounds such as “t”, “k”, “f” and “th”, tend to be rather weak, even though they carry important information. If an elderly person has a high-frequency hearing loss, as is typical, then some of the weak high-frequency components in speech will be completely inaudible. It is obvious that if some speech sounds are inaudible, then the ability to understand speech will be limited. Indeed, traditional methods for predicting the intelligibility of speech in quiet are largely based on the extent to which the speech spectrum lies above the absolute threshold[22,23]. The primary goal of most hearing aids is to restore audibility via frequency-selective amplification. Generally, the greater the hearing loss at a given frequency, the more the amplification that is provided at that frequency. However, most hearing aids provide little or no amplification for frequencies above about 6 kHz. Hearing aids can, to a limited extent, make speech more audible, and hence improve its intelligibility. They can also lead to a greater awareness of environmental sounds.

Compensation for loudness recruitment

It is not practical to use linear amplification to compensate fully for the loss of audibility caused by cochlear hearing loss. The major factor preventing this is loudness recruitment. Say, for example, a person had a cochlear hearing loss of 60 dB at all frequencies. The level at which sounds became uncomfortably loud (called the uncomfortable level, UCL) for such a person would typically be around 100 dB SPL. A hearing aid that fully compensated for the loss of audibility would apply a gain of 60 dB at all frequencies. However, that would mean that any sound with a level above about 40 dB SPL would be amplified to a level exceeding the UCL. In practice, many sounds encountered in everyday life would become unpleasantly loud. Hence, various fitting rules have been developed for linear hearing aids that prescribe a gain between one-third and one-half of the hearing loss[24].

It was suggested many years ago that problems associated with loudness recruitment could be alleviated by the use of automatic gain control (AGC)[25]. An AGC amplifier is an amplifier whose gain is determined by a control signal. The gain is defined as the output voltage divided by the input voltage, or, if both are expressed in decibels, as the output level minus the input level. The control signal is derived either from the input to the amplifier or from its output. The gain is reduced as the input level is increased. An AGC amplifier can be characterised by plotting the output level in decibels as a function of the input level in decibels. A typical example is shown in Figure 4. For inputs below a certain level, most AGC amplifiers act as linear amplifiers. Over the range where the amplifier is linear, the output is directly proportional to the input. If the output level in decibels is plotted as a function of the input level in decibels, the result is a straight line with a slope of one. Once the input level exceeds a certain value (40 dB in Figure 4), the gain is reduced, and the slope of the line becomes less than one. The compression threshold is defined as the input level at which the gain is reduced by 2 dB, relative to the gain applied in the region of linear amplification. For example, if the gain was 25 dB for input levels well below the compression threshold, the compression threshold would be the input level at which the gain was reduced to 23 dB.

The "amount" of compression is specified by the compression ratio, which is the change in input level (in decibels) required to achieve a 1-dB change in output level (for an input exceeding the compression threshold); the compression ratio is equal to the reciprocal of the slope of the input-output function in the range where the compression is applied. For example, a compression ratio of three, as illustrated in Figure 4, means that the output grows by 1 dB for each 3-dB increase in input level. When the input level is high, the gain of an AGC amplifier, expressed in decibels, may actually become negative, i.e. the signal is attenuated rather than being amplified. This is not necessarily a bad thing. Many people, including both normally hearing and hearing-impaired people, find that sounds with levels of 100 dB SPL and above are unpleasantly loud. Reducing the sound level can make the loudness more acceptable, and may even improve the ability to discriminate the sounds.

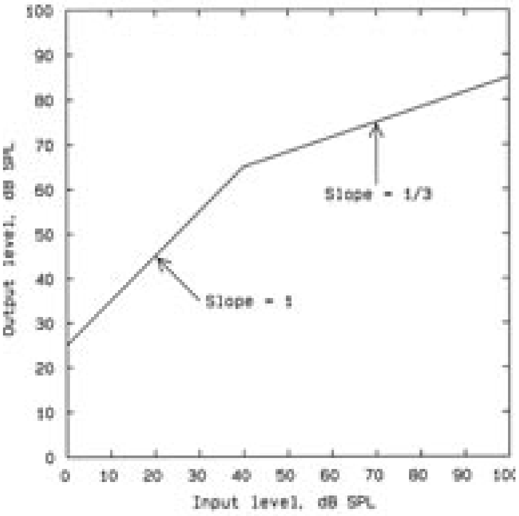

Figure 4. A schematic input-output function for an AGC system with a compression threshold of 43 dB SPL, and a compression ratio of 3. Notice that for input levels above about 78 dB SPL, the output level is lower than the input level, i.e. the system acts as an attenuator.

AGC amplifiers vary in how fast they react to changes in input sound level. Typically, the speed of response is measured by using as an input a sound whose level changes abruptly between two values, normally 55 dB SPL and 80 dB SPL. This is illustrated schematically in Figure 5. The envelope of the input is shown at the top, and the envelope of the output is shown at the bottom. When the sound level abruptly increases, the gain decreases, but this takes time to occur. Hence the output of the amplifier shows an initial "spike" or "overshoot", followed by a decline to a steady value. The time taken for the output to get within 2 dB of its steady value is called the attack time. When the sounds level abruptly decreases, the gain increases, but again this takes time to occur. Hence the output of the amplifier shows an initial dip, followed by an increase to a steady value. The time taken for the output to increase to within 2 dB of its steady value is called the recovery time or release time.

With AGC, it is possible to amplify weak sounds more than stronger ones, with the result that the wide dynamic range of the input signal is compressed into a smaller dynamic range at the output. Hence AGC systems are also called "compressors." Although this idea sounds simple, in practice there are many ways of implementing AGC, and there is still no clear consensus as to the "best" method, if there is such a thing[26]. Possibly, the best method for an individual depends on their lifestyle, for example, whether they are often exposed to rapid changes in sound level.

Some AGC systems are intended to adjust the gain automatically for different listening situations. The idea is to relieve the user of the need to adjust the volume control, which may be especially important for elderly people with poor dexterity. Usually, such systems change their gain slowly with changes in sound level; this is achieved by making the recovery time of the AGC circuit rather long (greater than a few hundred milliseconds). These systems are often referred to as "automatic volume control" (AVC). The compression ratio is often rather high (3 or more), so that sounds are maintained at a comfortable output level regardless of the input sound level. A problem with AVC systems is that, following a brief intense sound, such as a door slamming, the gain drops and stays low for some time; the aid effectively goes "dead." This problem can be alleviated by using an AGC circuit with dual attack times and dual release times[26-28]. Normally, the operation of the circuit is determined by long attack and release times. However if the sound level rapidly increases, a fast system takes over temporarily. This prevents the sound from becoming uncomfortably loud. Such systems are now widely used in hearing aids and cochlear implants (the latter are briefly described later).

An alternative type of compressor, with lower compression ratios and lower compression thresholds, has been used in hearing aids in attempts to make the hearing-

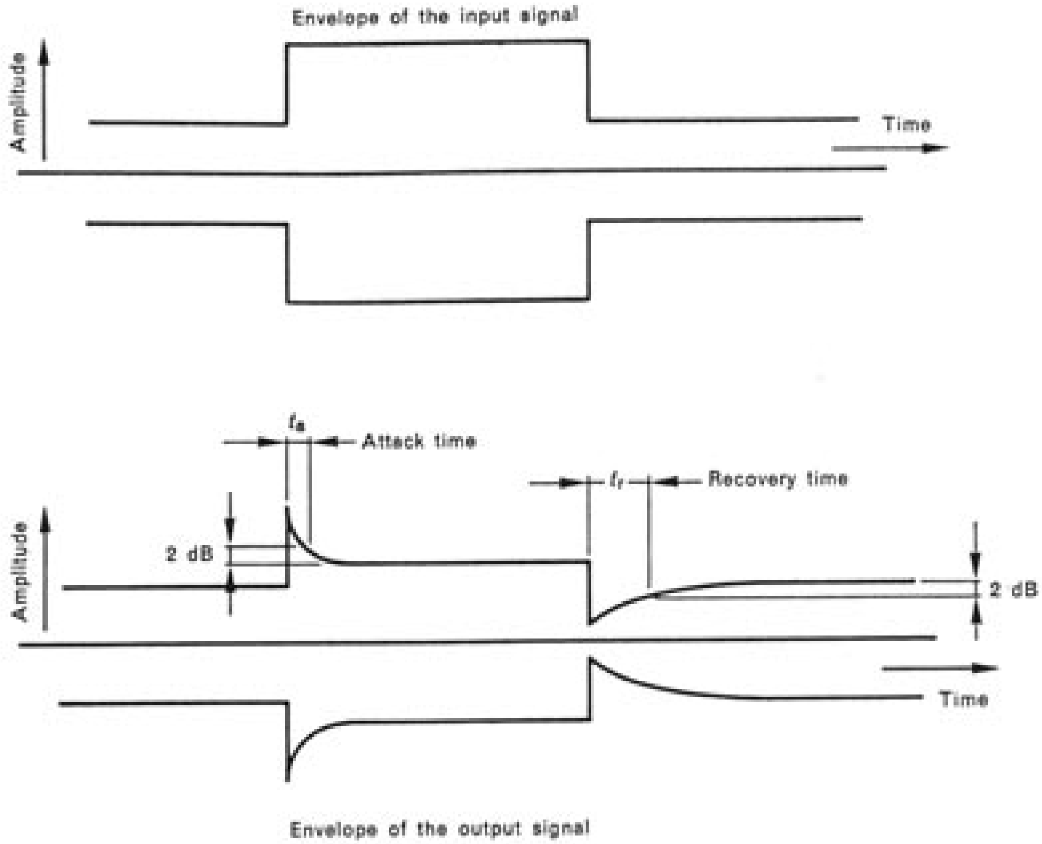

Figure 5. Illustration of the temporal response of an AGC system. The envelope of the input signal is shown at the top. The envelope of the response of the system is shown at the bottom.

impaired person's perception of loudness more like that of a normal listener and to ensure that the weaker consonant sounds of speech will be audible without the more intense sounds becoming uncomfortably loud. Such compressors usually have short attack times (typically 1-20 ms) and relatively short release times (typically 20-200 ms) and are often referred to as "syllabic compressors," since the gain changes over times comparable to the durations of individual syllables. Often, syllabic compression is applied separately in two or more frequency bands. Evaluations of such systems have given mixed results, but some studies have shown clear benefits[29]; the commercial success of multi-band syllabic compression is beyond doubt.

Compensation for reduced frequency selectivity

Multi-band compression does not compensate for the effects of reduced frequency selectivity, although high-frequency emphasis can partially alleviate masking of middle and high frequencies by low frequencies. Many researchers have attempted to improve speech intelligibility using digital signal processing (DSP) to enhance speech in background noise[30, 31]. Although these techniques have had only limited success, digital processing can be used to reduce interference from narrowband background sounds[32], and this is done in several commercial digital hearing aids. Current noise reduction systems in hearing aids can enhance listening comfort, but they have not been shown, so far, to improve speech intelligibility.

Substantial improvements in the intelligibility of speech in noise can be obtained using directional microphones[33-37], which enhance sounds from in front relative to sounds from the sides and back. This improves the speech-to-background ratio if the user faces the desired talker. Such systems have been used effectively in both analogue and digital aids[38]. Digital processing can be used to achieve larger improvements in speech-to-background ratio. The processing can be adaptive, so as to reduce the most prominent noise sources[39,40]. Directional microphones work best when the user is reasonably close to the talker they want to hear, so that room echoes (reverberation) are not dominant. For long distances, reverberation limits the benefit or directionality, as interfering reflected sounds come from more or less the same direction as the desired speech.

Compensation for dead regions

Hearing aids are often of limited benefit for people with extensive dead regions in the cochlea; for a review, see Moore[21]. For people with dead regions at the basal end of the cochlea (which normally responds to high frequencies), amplification of high frequencies often does not improve speech intelligibility, and sometimes impairs it[41-43]. Recently, we have developed a test for detecting dead regions and defining their limits[20]; the edge of a dead region is defined in terms of the characteristic frequencies of the IHC/neurones immediately adjacent to the dead region[21]. Our data[43] suggest that, for people with basal dead regions, there may be some benefit in amplifying frequencies up to 1.5 to 2 times the estimated edge frequency of the dead region. A possible signal processing strategy for people with dead regions at high frequencies but reasonable hearing at low frequencies is to use a hearing aid incorporating frequency transposition or frequency compression, although such systems have not been clearly demonstrated to be of benefit[44-46]. Alternatively, the combination of a hearing aid (for low frequencies) and a cochlear implant (for high frequencies) may be beneficial.

COCHLEAR IMPLANTS

Cochlear implants are devices that are used for the treatment of profound or total hearing loss. In a large proportion of people with such loss, the disorder is in the cochlea rather than in the central nervous system, and the auditory nerve is partially intact (but degenerated to some extent). Thus, it is possible to create a sensation of sound by electrical stimulation of the auditory nerve. This works because of the way in which the auditory nerve is connected to the central nervous system; nerve impulses in the auditory nerve lead to activity in those parts of the brain that are normally concerned with the analysis and perception of sounds, and are interpreted as having arisen from acoustic stimulation.

Most modern cochlear implant systems use several electrodes implanted within the cochlea. This makes it possible selectively to stimulate groups of neurones within the auditory nerve. It has been shown that different electrodes are associated with different sensations. For electrodes which stimulate neurones in the base of the cochlea, the sensation is described as "sharp", whereas stimulation of neurones close to the apex gives a "dull" sensation[47]. Thus, different places of stimulation are associated with different timbres. Unfortunately, it is difficult to isolate the current produced by stimulation of a given electrode to the neurones closest to the electrode; there is always a spread of current to adjacent neurones. This limits the effective number of separate "channels" for electrical stimulation.

The discrimination of electrical stimuli by a deaf person is generally much less acute than the discrimination of acoustical stimuli by a normally hearing person. Hence, much effort has been expended in exploring ways in which speech should be "coded" into electrical form, so as to convey as much information as possible. Modern coding systems have given impressive results[48,49]; many users can understand everyday speech without lipreading. However, the results with elderly people tend to be less good than with younger people or children. There are probably at least two factors that contribute to this. Firstly, the auditory nerve tends to degenerate following total deafness. The sooner after the onset of deafness that a cochlear implant is provided, the better are the results, as the implant appears to prevent further neural degeneration. Secondly, the brains of young people may be more "plastic" than those of elderly people, and better able to learn to make use of highly abnormal sensory input.

BINAURAL HEARING

Two ears are better than one, for several reasons. Firstly, differences in the intensity and time of arrival of sounds at the two ears provide cues that are used to localise sound sources[50,51]. Secondly, when a desired signal and a background noise come from different locations, comparison of the stimuli reaching the two ears improves the ability to detect and discriminate the signal in the noise[52]. Thirdly, when trying to hear a sound such as speech in the presence of background noise, the speech-to-noise ratio may be much higher at one ear than at the other ear. For example, if the speech comes from the left and the noise from the right, the speech-to-noise ratio will be higher at the left ear than at the right. Under these circumstances, people are able to make use of the ear receiving the higher speech-to-noise ratio[53]. Finally, even when the signals reaching the two ears are identical, the ability to discriminate or identify the signals is often slightly better than when the signals are delivered to one ear only[54].

Hearing loss in the elderly sometimes results in a reduced ability to exploit differences between the two ears to localise sounds and improve their discrimination[15,16]. Nevertheless, substantial benefits accrue from the effective use of two ears. In particular, the ability to select the ear receiving the better signal-to-noise ratio remains largely intact[53]. Fitting a person with a single hearing aid, when there is a hearing loss in both ears, results in a loss of many of the advantages of binaural processing. This is especially true of digital hearing aids, since such aids introduce a time delay which is larger than the largest time difference between the two ears that occurs naturally (when a sound source is located directly opposite one ear). Also, providing a hearing aid in one ear only can result in a kind of deprivation effect in the unaided ear, so that the unaided ear becomes less effectively used[55]. Hence, a person with bilateral hearing loss should almost always be fitted with two hearing aids.

CONSEQUENCES OF THE LIMITED FREQUENCY RANGE OF HEARING AIDS

As mentioned earlier, most hearing aids do not provide any useful amplification for frequencies above about 6 kHz, and some provide little amplification above 4 kHz. This has at least two adverse consequences. Firstly, the ability to understand speech, in quiet and in background noise is lower than it would be if amplification were provided over a wider frequency range[43, 56, 57] (this is not true for people with dead regions at high frequencies, as noted earlier). Secondly, the ability to judge the location of sounds is impaired. For normally hearing people, spectral changes produced by reflection of sounds from the pinna can be used to judge the location of a sound source[50, 58]. Pinnae cues are especially important in distinguishing whether a sound comes from in front or behind, and above or below. Since it is the spectral patterning of the sound which is important, the information provided by the pinna is most effective when the sound has spectral energy over a wide frequency range. High frequencies, above 6 kHz, are especially important, since it is only at high frequencies that the wavelength of sound is sufficiently short for it to interact strongly with the pinna.

Elderly people with high frequency hearing loss can usually make only limited use of pinna cues when listening unaided[59]. When they wear behind-the-ear hearing aids, cues provided by reflections from the pinnae are entirely lost, so the aids may even make the situation worse. Even when in-the-ear aids are worn, the lack of amplification at high frequencies largely prevents pinna cues from being used. Hence, people wearing hearing aids have difficulty in judging whether sounds are coming from in front or behind and above or below[60].

OTHER MEASURES FOR ALLEVIATION OF HEARING LOSS

Elderly people with hearing loss are very susceptible to the effects of background noise and reverberation. Hence, places where elderly people meet and communicate should be as quiet and reverberation free as possible[61]. Unfortunately, this is rarely the case in practice. The installation of sound-absorbing wall linings to reduce reverberation could be of considerable benefit. Also, broadcast speech sounds, and sounds in public places are often accompanied by background sounds which are regarded as adding "atmosphere" but which, for the elderly, are merely a cause of reduced comprehension. Reduced usage of such unnecessary background sounds could be of major benefit to elderly persons. "Loop" systems, in cinemas and theatres can also be of considerable help.

CONCLUSIONS

Hearing loss is very common in the elderly, and is a major source of communication difficulties. Hearing aids (or cochlear implants for profound or total hearing loss) can alleviate, but do not eliminate, these difficulties. The problems are made worse by poor acoustics in the buildings where elderly people meet, and by unnecessary background sounds in broadcasts.

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