Restoring the Soundscape with Hearing Aids

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Our sense of hearing provides a fundamental connection between an individual, the natural world and society. Recognition of sound allows us to be comforted, enlightened, surprised, warned, frightened, reminded, pleasured and intrigued. When sound recognition is diminished by hearing loss, the connections between individuals, nature and society are broken or distorted.

Impact of Hearing Loss

It may appear self-evident that hearing loss can have significant effects on an individual. The ability to detect sound, to decipher the nuances, to comprehend meaning, to fully appreciate music and to respond appropriately becomes an ongoing challenge. It takes listening endurance to compensate for hearing loss on even the most basic level. It is common for individuals with hearing loss to gradually withdraw from social situations and remove themselves from activities that require accurate hearing skills. They mourn the loss of their favorite sounds.

Wayner and Abrahamson, (2001) describe the hearing circle of communication comprised of the emotional, social, psychological, occupational, environmental and educational aspects of hearing. Within each of these facets are the unique reactions of each person to hearing loss and the ramifications for different types of auditory communication. For example an individual who is a socially active extrovert may experience more impact than an individual who spends time in solitary activities. If the individual with hearing loss works as a waiter/waitress, then the acoustics and noise of the workplace restaurant could be an issue. Possibly an audio engineer with a hearing loss finds his/her ability to perform adequately on the job jeopardized. For each person the effects of hearing loss are variable and the demands for hearing unique.

What are not as obvious to the person with the hearing-impairment are its effects on others. Personal relationships are impacted by hearing loss. Spouses frequently report negative consequences of their partner's hearing impairment, including a loss of communication during intimacy. Family members and friends are often left compensating for the person with hearing loss, by repeating menu choices in restaurants, answering phone calls, handling business transactions etc. In essence, significant others become the "hearing aide."

Hetu, Getty and Quoc (1995) evaluated the communication impact of noise-induced hearing loss (NIHL) between spouses. These authors list a larger number of communication difficulties reported by the hard-of-hearing spouse than the number of items reported by the non-impaired spouse. For the hearing-impaired partner, complaints included, 1) effort and fatigue from having to ask the partner to repeat things and to pay close attention, 2) frustration with not communicating, not understanding, being left out of conversations, disagreements over television volume settings and 3) stress, anger and resentment due to an intolerance of the hearing loss by others and their listening difficulties not being understood. For the unimpaired partner, complaints included 1) stress, tension and irritation at having to tolerate loud speech and television, compensating for the social dependence of the impaired spouse and worrying because of unreliable hearing of warning signals, responsibility for the telephone and taking messages, 2) effort and fatigue at having to repeat things, bearing the burden of interpreter and disguising the severity of the hearing loss and 3) frustration, anger and guilt at being isolated from groups, restriction of social activities and limitations on communication. Ultimately, the challenge of hearing impairment is faced by both partners and their family and friends.

Aside from these impacts on human speech communication, there are also effects on the joy and necessity of hearing sound in natural environments. For one person, it was an experience with his young granddaughter that was most disturbing to him. While sitting on the porch one summer evening, she asked him "What's making that sound Grandpa?"—he listened; she asked again—"What's making that sound?"—he strained and listened as closely as possible and heard nothing but a ringing in his ears. "I don't know" he reluctantly replied. Ultimately, his wife joined them on the porch and when the granddaughter directed the question to her, she was able to immediately identify the high-frequency chirp of a cricket coming from under the wooden slats. The grandfather felt inadequate and sad at missing that acoustic experience with his family. Later he related, "What if the cricket where a rattle snake?" He wondered if he might have missed the subtle rattle and perhaps been unaware of the need to protect his young granddaughter. These concerns were enough to motivate him to pursue hearing-aid fittings.

Hearing Aid Technology

Hopefully through the encouragement of friends and family members, the person with a hearing loss can be motivated to seek help in re-establishing their connections to nature and society. This re-connection can be through the use of hearing aids which are sophisticated miniature amplification systems.

Technological advances in hearing aids have progressed to the point where hearing aids are worn ear level (Fig. 1) and may be virtually undetectable in the ear canal. They commonly contain sophisticated computer processing strategies that can be customized to each wearer and their selected acoustic environments. Today, digital hearing aids dominate the market and have significant advantages in terms of fitting flexibility. There are other signal processing strategies and features used in hearing aids; however it is beyond the scope of this article to review them in detail.

A simplified digital hearing aid design is illustrated in Fig. 2. A microphone picks up sound from the environment and provides the input to the amplifier and the computer processing chip. The digital signal processor (DSP) is the heart of the hearing aid, controlling the signal manipulations necessary to improve speech intelligibility. Once the sound source has been electronically manipulated, it is converted back to an analog signal for the hearing aid receiver (speaker) and delivered to the ear canal.

An audiologist will connect a desktop or laptop computer directly to the hearing aid to "program" the settings for the DSP. Several models of hearing aids have multiple memories, which is analogous to multiple hearing aids in one case. If a hearing aid has three memories as illustrated in Fig. 2, then one memory might be used to program the hearing aid for speech understanding in a quiet listening environment, another memory for speech understanding in noisy listening environments and the third memory can be reserved for music listening. This is ideal since the listening and acoustic characteristics of music are very different than those necessary for speech. Memory parameters can be set for any unique listening demands a wearer might have. The wearer simply pushes a button on the hearing aid or uses a remote control to select the preferred memory, or in some instances the hearing aid may automatically sample the acoustic environment and self-determine the settings. If the hearing aid does not have multiple memories, then the programming has to be compromised in order to meet diverse listening demands.

The sophistication of the DSP capabilities and the style of hearing-aid shell are the primary price determinates. Smaller is more expensive. Enhanced signal processing parameters are more expensive. There is an inverse trade-off between space and circuit capacity. The smaller the hearing aid, the less physical space there is to incorporate multiple microphones, larger DSP chips, add-on features and larger batteries necessary for increased power demands.

Hearing aids are primarily dispensed in a private-pay system in the U.S., however socialized medical programs and third-party pay sources are more common in many other parts of the world. In some locales, the government-delivered healthcare system limits the kind of hearing aid technology that can be dispensed (often to a less-than-state-of-the-art level) and may even limit amplification to just one ear rather than two. One might expect to spend between $800 and $3500 per hearing aid in the U.S.; twice that much if both ears are fit. The local economy and the distribution system drives the pricing in other parts of the world, with the amount being comparable to the U.S. or somewhat less expensive. The average price of a hearing aid sold in 2004 was approximately $1400 (Kochkin, 2005b). The average life of a hearing aid is approximately five years. This extrapolates to approximately $1.50 per day for an average pair of aids worn over their lifespan. During this five-year period one should expect to have two to three repairs performed by the manufacturer. Repair is necessary because the hearing aid is worn in a hostile environment for electronics. The ear canal is moist and waxy and the hearing aid is subjected to daily handling. This creates problems for the hearing-aid microphones and receivers that must remain "open" and clean in order to process sound. Extended warranties are available to cover this inevitability. Routine cleaning and maintenance will also prolong the life of a hearing aid beyond its typical five-year lifespan.

Aside from purchasing and maintaining the hearing aid, a wearer should receive regular hearing evaluations and hearing aid checks. Hearing loss is not always a static situation. Hearing levels may fluctuate and/or the listening demands change. It is common for hearing to decrease as one ages and new ear diseases might develop. Due to these situations, the hearing aids may require reprogramming to maintain the optimal level of performance and benefit. It is not uncommon for a hearing loss to have progressed significantly between the time a person first becomes aware of their hearing loss and the decision to rehabilitate with hearing aids. If years have passed, then hearing aid dispensing should be supplemented with a rehabilitation program to help re-learn to recognize the auditory subtleties and distinctions that have faded away over time. Physiologically, our auditory systems must stay active to perform optimally.

Figure 1—Hearing aid styles are described by the way the shell fits into the ear. From left to right; CIC: completely-in-the-canal; Canal: fills canal; HS: half shell; ITE: in-the-ear; BTE: behind-the-ear. It is not possible to differentiate the specific features and circuit technology used within a hearing by visual inspection alone.

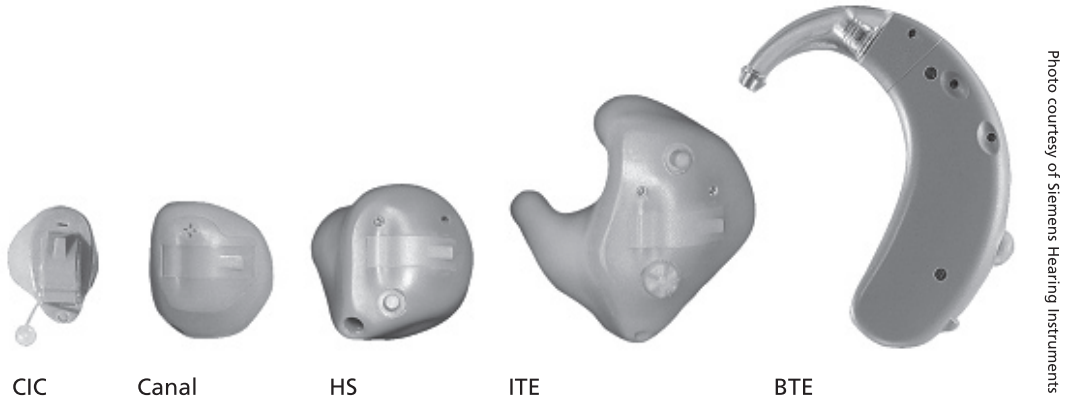


Photo courtesy of Siemens Hearing Instruments

Sensing the soundscape with hearing aids may take special consideration. Since the microphone's sensitivity and directional characteristics cannot exactly match those of the human ear, the reproduced experience can never exactly match the unaided normal-hearing ear. Furthermore the characteristics of the soundscape itself may also dictate particular programming considerations. For individuals using hearing aids outdoors for natural sound appreciation, omni directional microphone settings, wind-noise reduction and increased volume (gain) demands for all frequencies may be desirable. For a birdwatcher, there may be a desire to have a dedicated program tuned for increased gain for avian sounds that typically contain more high-frequency information than human speech.

It is important to recognize that the sound delivered to the ear canal by a hearing aid may have pristine acoustic characteristics; however the amplified sound must still be processed through the physiologically damaged auditory system of the wearer. In spite of this, the overall customer satisfaction with new hearing instruments is 77% and ranks within the top-third of all products and services sold in the United States (Kochkin, 2005b). Additional hearing aid tips are provided in the sidebar to this article and global audiology resources may be identified by visiting the International Society of Audiology at www.isa-audiology.org/links/lk.html.

What Hearing Aids Can and Cannot Do

Fortunately, hearing aids do improve hearing for mild-to-severe hearing losses. There is ample evidence in the research literature to support this statement, especially when discussing speech perception ability. As mentioned in the companion article by Arehart, hearing loss creates hearing deficits in terms of detection, decreased dynamic range, diminished frequency resolution, decreased spatial resolution and decreased temporal resolution that combine to make speech less intelligible. Technology provides for an electroacoustic compensation for some of these hearing deficits, but not all.

Detection

A hearing aid restores the audibility of human speech by amplifying the sounds picked up by the hearing-aid microphone. For severe hearing losses, this means amplifying all of the various speech sounds or phonemes to a level that can be detected. In the case of mild-to-moderate degrees of hearing loss, the frequencies of the softer or missing speech sounds are selectively amplified. For hearing losses due to noise or aging, the missing speech sounds are usually the high-frequency consonants as opposed to the stronger vowel sounds. Speech becomes unclear and words may be mis-interpreted. If the phrase "take the fast car" is misheard as "rake the back yard," then the higher pitched phonemes of /t/, /f/, /s/ and /k/ must be amplified. The discrepancy between hearing low- and high-frequency speech sounds accounts for the typical complaints such as "if only people wouldn't mumble and would speak clearly" or "your voice is loud enough, I just can't understand what you are saying." Persons with hearing loss often hear only a portion of the speech message. With hearing aids, familiar voices may not be immediately recognizable due to the additional frequency characteristics that become audible with the benefits of the amplification they provide.

Decreased dynamic range

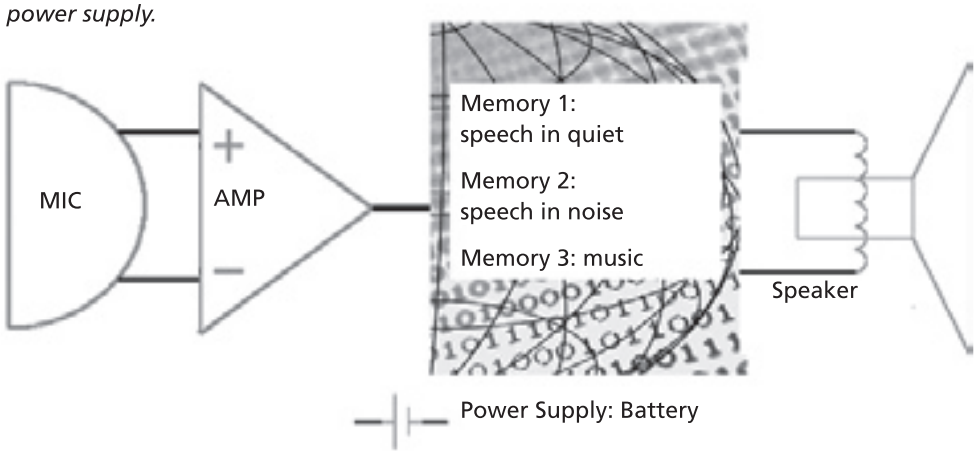
For sensorineural hearing losses, the range of sound levels that are comfortable becomes drastically reduced. Louder sounds (e.g. cars accelerating at a stoplight) encountered in routine life may become physically uncomfortable for a person with a hearing loss. This then becomes an issue with hearing aids, since it is inappropriate to amplify all sounds with the same amount of gain as needed for soft constant sounds. If all sounds are amplified equally, then mid- to high-level sounds will exceed the wearer's comfort level and the hearing aid will not be well tolerated. This was often the case with the older linear type of hearing aids, which were commonly dispensed prior to the advent of compression circuitry that automatically reduces the amount of volume as the input sound gets louder. Hence, most modern hearing aids "compress" the broad dynamic sound levels of the environment into a narrower range that can be heard comfortably.

Hearing in Noisy Environments

A healthy ear can detect fine differences in frequencies (frequency resolution) and discriminate speech from background noise. As hearing loss progresses, the ear becomes "mushy" in the frequency domain; the greater the degree of hearing loss, the poorer the ability to differentiate speech sounds. An analogy might be a listening to music on a piano with only 60 keys instead of the usual 88 keys, because some are "stuck together." This becomes a major disadvantage when it comes to understanding speech in a background noise.

Hearing aids can only partially compensate for decreased frequency resolution. It is difficult for a hearing aid itself to differentiate the target sound from other sounds when they are similar in frequency. This is especially true when a listener is focused on one conversation embedded in a background of other voices. The hearing aid cannot recognize which voice should be the amplification priority. Perhaps in the future hearing aids will incorporate some form of familiar voice-recognition intelligence.

Figure 2—Simplified hearing-aid diagram. Sound is processed through a hearing aid from left to right. The *microphone* detects sound, the *amplifier* increases the sound levels, the *digital signal processor* shapes the sound for specific purposes and the *speaker* or *receiver* delivers the amplified sound to the ear canal. All of these processes require a *power supply.*



Currently, there are several strategies incorporated into hearing aids to promote better hearing in the presence of background noise. First, the hearing aid microphone(s) can be designed and oriented so as to be more sensitive to the target sound source. This is called a "directional" microphone; typically this involves a microphone or multiple microphones being most sensitive to sound originating from one direction (typically the front) and suppressing sounds from the side and back. A microphone that is equally sensitive in all directions is termed "omni-directional." Second, a remote microphone placed at the target speaker location can transmit sound via FM (frequency modulation) to a hearing aid. Finally, a hearing aid can be designed and programmed to differentially amplify low-frequency sounds from higher-frequency sounds.

For listeners who appreciate "silence," amplification of weak signals may be undesirable. If the "silence" contains weak distant sounds in the ambiance, the hearing aid may over-emphasize these subtleties that usually are undetected by normal hearing listeners. In addition, hearing aids themselves generate electronic noise. This may become audible to the wearer in extremely quiet environments if normal hearing exists in some frequency regions. It may be more advantageous for the hearing-impaired person to go without hearing aids when the desire is to appreciate quiet.

Strategies to improve the signal-to-noise ratio (SNR) are essential for the hearing-impaired listener. Positioning a hearing-aid microphone in close proximity to the sound source and distancing it from competing noise improves the SNR. Frequently, SNR is improved by using practical communication tips such as moving closer to the speaker, dining at restaurants with quieter ambient

noise levels, turning off competing noise sources (e.g. dishwashers, radios etc.), selecting quieter places in a room to converse and facing away from the noise source. It is not advisable to shout or raise the voice in order to help a hearing-impaired listener understand while wearing a hearing aid. This tends to push the limits of their dynamic range and distort the amplification process.

Localization

Accurate localization of a sound source requires that all of the frequency components of a complex signal are audible since the brain uses subtle differences in the timing and sound level between the ears to accomplish the process. If hearing is asymmetrical between the two ears, then localization becomes a greater problem. Binaural hearing aids are necessary to compensate for this limitation and also facilitate listening in an environment with background noise.

Temporal Resolution

Speech sounds are strung together in rapid succession and weaker sounds can become lost in the louder speech sounds that immediately precede or follow the softer sounds. This can make speech unintelligible for a hearing-impaired listener. Hearing aids must operate quickly to provide increased volume for the soft sounds and decrease gain or "compress" the louder sounds. This will help restore some of the intelligibility of speech.

Quality of Life

Hearing-aid use provides for more than just auditory benefit. Several quality of life indicators demonstrate a positive relationship with hearing aid use. Kochkin (2005a) provides a succinct review in his article posted at www.betterhearing.org/hearing_solutions/qualityOfLifeDetail.cfm. Beyond the obvious repair of communication problems, hearing-aid use was shown to correlate with physical health, earning power, family relationships and emotional stability. It has also been shown to mitigate many of the psychological and emotional consequences by reducing frustration, anger, anxiety and depression.

Ultimately, the success of hearing-aid fittings is dependent upon the ability of a hearing-impaired individual to effectively describe and interpret their own listening experiences to the audiologist. It requires combining the technology, science, and art of audiology, in order to optimally sculpt the hearing-aid performance for each individual. Perception of an acoustic "space" will be altered for persons wearing hearing aids; a familiar soundscape will be partially restored, and an environment will be created that is more conducive to communications, and more protective and pleasurable as well.

References

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Hearing Aid Tips and Internet Resources

- Prevent further hearing loss; seek prompt medical and audiological care for your hearing loss.
- Maintain your hearing abilities; utilize hearing aids when first advised to do so. Delaying amplification only contributes to greater communication problems and poorer long-term benefit.
- Work with a licensed audiologist who is willing to spend time understanding your individual communication demands and listening needs, when programming your hearing aid.
- Be patient and use the hearing aid consistently; sounds may have gradually disappeared from your soundscape and it takes time to relearn to recognize and integrate the sounds again.
- Make your own decisions; what works for a friend or relative may not be ideal for your personal needs. Brands are not as important as the technology and programming used to solve the hearing problems.
- Maximize the trial period; all hearing aids are dispensed with a 30-day trial period. Use this time to assure your satisfaction with the fitting or ask for an extension to make additional modifications.
- Educate yourself; the more you can learn about your hearing loss and hearing aids, the better able you will be to participate in your hearing care. Consider some of these internet sites as beginning resources;

  American Academy of Audiology: Consumer Resources www.audiology.org/consumer/guides/howtopurchase.php/

  American Speech-Language-Hearing Association: Treatment and Rehabilitation www.asha.org/public/hearing/treatment/

  Expectations: A consumer checklist www.hearingresearch.org/Dr.Ross/expectations.htm

  Hearing aids: reasonable expectations for the consumer www.audiologyonline.com/articles/arc_disp.asp?id=347