AUDITORY COMPRESSION AND HEARING LOSS

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A truly remarkable aspect of human hearing is the vast range of levels over which we are able to process sound. Those with normal hearing can hear the rustling of leaves caused by a gentle breeze as well as tolerate (at least for brief periods) the roar caused by a low-flying jet. The range of human hearing is illustrated in Fig. 1. The bottom curve represents the absolute thresholds for a wide range of frequencies; these are the levels where the various pure tones can just be detected. The top curve, on the other hand, represents the levels where the pure tones are considered uncomfortably loud. The area in between these two curves is often referred to as the dynamic range of hearing. For a mid-frequency tone (about 1–4 kHz), this range is at least 120 dB, corresponding to a truly impressive range of 10^{12} in intensity units (watts/m^2). As we will see in this article, the enormous range of hearing is accomplished via a form of amplitude compression that exists in the cochlea of the inner ear. This compression allows the extremely large range of levels in the acoustic environment (inherent, for example, in speech and music) to be "squeezed" into a much smaller and physiologically manageable range of responses.

Cochlear compression

Sound waves in the atmosphere enter the external ear canal and impinge upon the tympanic membrane (ear drum), causing vibrations that are transmitted via three tiny bones in the middle ear to the cochlea of the inner ear. This vibration causes a displacement of the cochlear fluids which ultimately leads to a pattern of vibration along the basilar membrane of the cochlea. In particular, there is a wave of displacement that travels from the base of the cochlea to the apex. In response to a pure tone, the displacement increases in magnitude until it reaches a peak at some place on the basilar membrane and then it decreases rather precipitously. This is known as the traveling wave. The response to a high-frequency tone peaks near the base of the cochlea whereas the response to a low-frequency tone peaks near the apex. There is thus a frequency-to-place mapping along the basilar membrane; each place tends to respond best to one frequency (sometimes called the "best frequency" or "characteristic frequency"), although it will respond to other frequencies as well. Much of what is known about the traveling wave comes from the pioneering work of Nobel Laureate Georg von Békésy[1].

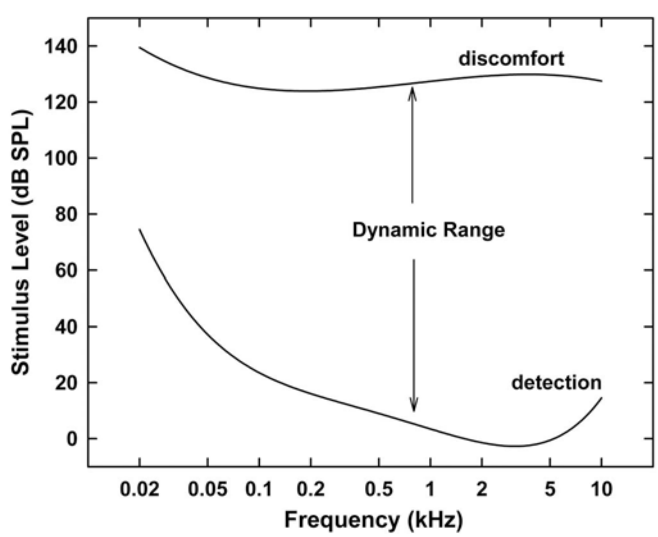

Fig. 1. The bottom curve represents the sound pressure levels where pure tones of various frequencies can be just detected. The upper curve represents the levels at which those tones become uncomfortably loud. The area in between the two curves represents the dynamic range of human hearing.

Lying directly above the basilar membrane are two distinct types of sensory cells, the inner hair cells (IHCs) and the outer hair cells (OHCs). Movement of the basilar membrane results in stimulation of these cells, and the greater the movement the greater the stimulation. Most auditory nerve fibers synapse directly with IHCs, and it is thought that neural activity in the auditory nerve *directly* reflects the response of these cells. If so, then what do the OHCs do? As we have learned over the last decade or so, the OHCs play a very important role in hearing. The emphasis in this article is on their role in the compressive response of the cochlea. To gain an understanding of that, let us consider how the magnitude of response at a given point along the basilar membrane changes as a function of the input stimulus level.

The movement of the basilar membrane in response to a stimulus is usually measured in terms of displacement or velocity. That metric is then plotted as a function of the stimulus level, to yield a so-called input-output (I-O) function. The solid line in the main part of Fig. 2 illustrates one such I-O function. In this case, the velocity of basilar membrane response has been converted to a response in dB (a 10-fold increase in velocity corresponds to a 20-dB increase in response). The input stimulus was a 10-kHz tone, and the measurements were taken from a place in the chinchilla cochlea that responds best to a frequency of 10 kHz[2]. The inset shows a cartoon of the traveling wave envelope to a 10-kHz tone at a given level. The arrow indicates the measurement site. Notice that the basilar membrane motion increases and reaches a peak at the measurement site.

As can be seen in Fig. 2, the magnitude of basilar membrane response increases with increasing stimulus level, but the growth is generally quite compressive. This is clear by comparing the I-O function with the linear function shown by the dashed line. Throughout its most compressive region (at moderate to high stimulus levels) the I-O function has a slope of about 0.2 dB/dB, corresponding to a compression ratio of about 5:1. In other words, over that range, a 50-dB increase in stimulus level (input) results in only a 10-dB increase in basilar membrane response (output). As a result of this type of compression, a given point along the basilar membrane is able to respond to an extremely large range of

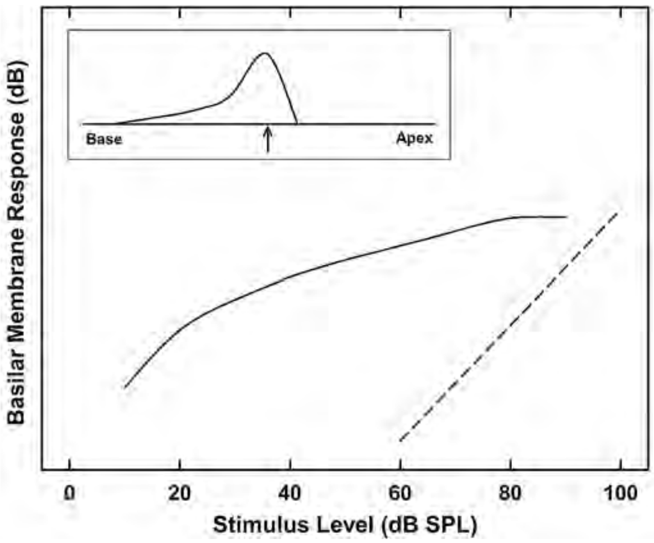

Fig. 2. The solid line in the main part of the figure represents the basilar membrane I-O function for a pure tone whose frequency (10 kHz) matched the best frequency of the recording site. The function is highly compressive. The dashed line represents linear growth (1 dB/dB). The inset is a cartoon of the traveling wave envelope in response to the 10-kHz tone at a given level. The arrow indicates the measurement site. The data are taken from Ruggero et al. (1997), with permission from the American Institute of Physics.

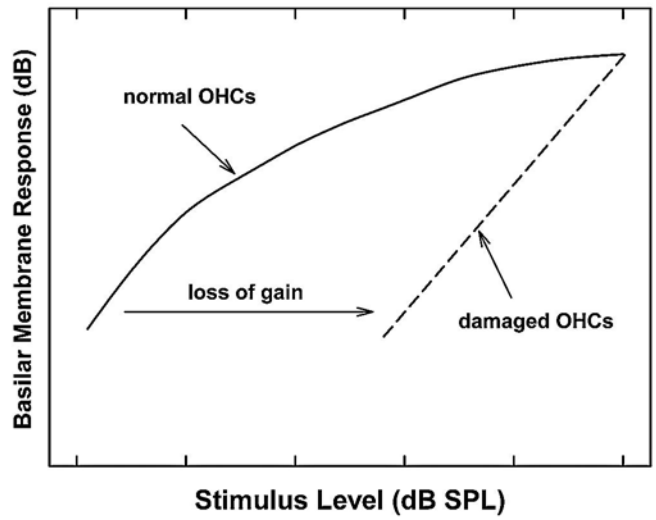

Fig. 3. This is a summary of the effects of OHC damage on the basilar membrane I-O function. The solid line shows an I-O function that might be expected from a cochlea with normally functioning OHCs. The dashed line shows a function that might be obtained from a cochlea with severely damaged OHCs. The horizontal distance between the two curves represents the amount of gain that was lost due to the hair cell damage.

stimulus levels. Because basilar membrane motion serves as the proximal stimulus for IHCs, and subsequently the auditory nerve fibers, the compression that is observed at the basilar membrane greatly extends the dynamic range of the peripheral auditory system.

Although compression can be measured at the basilar membrane, it is not due to the mechanics of the membrane *per se*. In other words, the basilar membrane by itself does not function compressively. Instead, basilar membrane compression is actually the consequence of normally functioning OHCs. Temporary or permanent damage to those cells results in a basilar membrane I-O function that is less compressive, and in fact significant amounts of damage result in a linear I-O function. This is shown schematically in Fig. 3. The solid line illustrates the compressive growth of response that is observed under normal conditions. The dashed line illustrates the linear growth of response observed when the OHCs are severely damaged or functioning abnormally. Although the precise way in which the OHCs affect the motion of the basilar membrane is unclear, it is likely the result of OHC electromotility. Indeed, an interesting finding from recent research is that OHCs have motor capability resulting in their being motile and, in isolation, being capable of changing shape at rates in the audio frequency range. The motor protein (prestin) responsible for this electromotility has recently been identified[3]. These shape changes are thought to alter the micromechanical properties of the cochlea so as to increase the response of the basilar membrane. This, in turn, will increase the response of the IHCs and the auditory nerve fibers that synapse with those hair cells. In other words, the OHCs provide local mechanical amplification in the form of feedback. For this reason they are often referred to as the "cochlear amplifier."[4] Damage to the OHCs results in a loss of that amplification, as shown in Fig. 3. The amount of gain that normally exists has been estimated to be as large as 50-80 dB for lower stimulus levels[2], but the gain decreases with increasing level and is negligible at high levels (as evidenced by the horizontal difference between the solid and dashed lines in Fig. 3). This level-dependent gain results in a compressive growth of response under normal conditions.

An interesting and important aspect of cochlear compression is that it is frequency-selective. In other words, the amplification or gain provided by the OHCs at a given place along the basilar membrane depends upon the frequency of stimulation. As we have described thus far, the basilar mem-

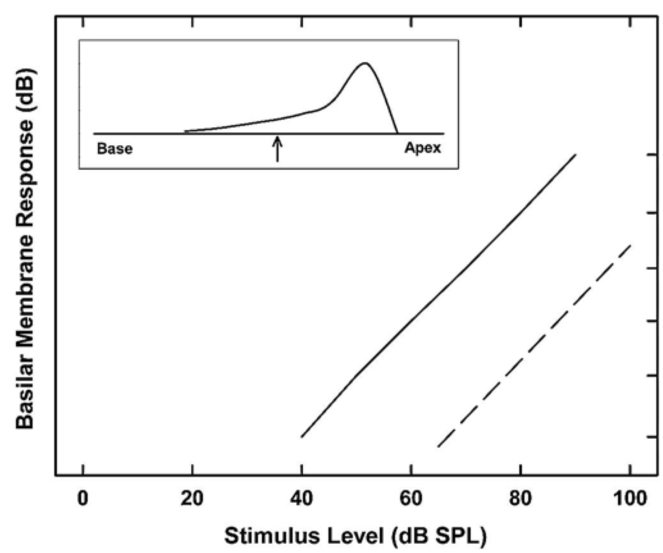

Fig. 4. The solid line in the main part of the figure represents the basilar membrane I-O function for a pure tone whose frequency (5 kHz) is one octave lower than the best frequency of the recording site (10 kHz). The function is linear, as can be seen by comparing it with the dashed line, which shows linear growth (1 dB/dB). The inset is a cartoon of the traveling wave envelope in response to the 5-kHz tone at a given level. The arrow indicates the measurement site. The data are taken from Ruggero et al. (1997), with permission from the American Institute of Physics.

brane response growth is normally highly compressive in response to a tone whose frequency is equal to the best frequency of the recording site (in Fig. 2, this was 10 kHz). However, in response to other input frequencies, the response growth *at that same site* may be less compressive or even linear. This is illustrated in Fig. 4, which shows the I-O function (solid line) at the 10-kHz place in response to a 5-kHz tone. The inset shows that the measurement site (indicated by the arrow) is basal to the peak of the traveling wave envelope. In this situation, the growth of response is linear (compare the I-O function with the linear reference shown by the dashed line). Had the measurements been taken at the 5-kHz place, where the traveling wave envelope peaks, the growth would have been compressive in response to the 5-kHz tone. Thus each place along the basilar membrane will exhibit a compressive growth of response, but only for tones with a frequency near the frequency of the measurement site.

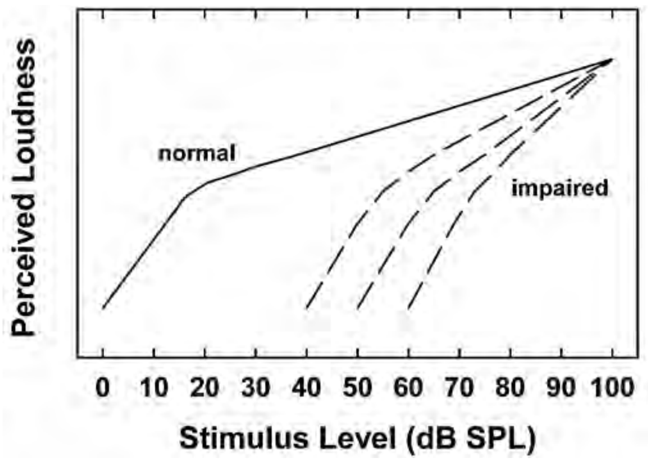

Fig. 5. The solid line shows how perceived loudness grows as a function of stimulus level in individuals with normal hearing. The dashed lines show loudness growth for individuals with different amounts of hearing loss.

Some perceptual consequences of normal and reduced cochlear compression

We began this article by describing the incredibly large dynamic range of human hearing, and indicated that it was due to a form of amplitude compression in the inner ear. It should now be clear that the cochlear compression described in the previous section is largely responsible for this dynamic range. We will now explore this further and consider some of the other perceptual consequences of cochlear compression. In addition, we will highlight the consequences of reduced (or absent) compression in individuals with a hearing loss involving damage to the OHCs. Although not all hearing losses result from such damage, most sensorineural losses involve at least some damage to those sensory cells.

When the OHCs are damaged in individuals with a sensorineural hearing loss, the dynamic range of hearing is reduced, sometimes severely. This is manifest as an elevated absolute threshold (this is typically what defines a hearing loss) and usually an *unchanged* uncomfortable loudness level. (For someone with a hearing loss, the bottom curve in Fig. 1 would shift up, whereas the top curve would not shift.) In individuals with a reduced dynamic range, the loudness of a sound goes from relatively soft to uncomfortably loud over a smaller range of sound pressure levels than it does in individuals with normal hearing. This is generally referred to as loudness recruitment, a relatively common phenomenon in individuals with sensorineural hearing loss. An example of this is shown schematically in Fig. 5. The solid line represents normal loudness growth, whereas the dashed lines represent loudness growth for different amounts of hearing loss. As the loss increases, the initial portion of the loudness growth function shifts to the right (to higher levels), but all functions meet at a high sound pressure level. Thus, the dynamic range decreases as hearing loss increases. The reduced dynamic range can be understood in terms of a loss of the level-dependent gain that normally exists in the cochlea (see Fig. 3). At low stimulus levels, the OHCs provide large amounts of gain, enabling sounds such as the rustling leaves to be heard by individuals with normal hearing. When the OHCs are significantly damaged, the subsequent loss of that gain will result in those sounds being inaudible. At high stimulus levels, on the other hand, the OHCs provide little or no gain anyway, and thus the response to those sounds will be largely unaffected by sensorineural hearing loss.

"An interesting and important aspect of cochlear compression is that it is frequency-selective."

As discussed in the preceding section, the gain provided by the OHCs is frequency-selective. An important consequence of this is a rather exquisite tuning that can be observed in both physiological and psychophysical measures. One such measure is a so-called tuning curve. These curves can be envisioned as filter functions: they are a plot of the stimulus level needed to achieve a given response as a function of the stimulus frequency. The solid line in Fig. 6 shows a tuning curve that might be expected from an auditory system with normal OHCs. The tuning is sharp. At the tip of the curve, only a small sound pressure level is needed to elicit the criterion response. As the stimulus frequency diverges from there, however, a greater and greater level is needed to elicit that same response. An unfortunate consequence of hearing loss is a degradation of tuning. This is illustrated by the dashed line in Fig. 6, which shows what might be expected from a system with damaged OHCs. The tuning curve from the impaired system is shifted upward, but only in the frequency region around the tip, resulting in broader tuning. This can be understood in terms of a loss of the frequency-selective gain provided by the OHCs. Without the cochlear amplification for frequencies near the best frequency, the sound pressure must be increased to elicit the criterion response. A perceptual consequence of this broader tuning is a greater difficulty processing sound in the presence of competing sounds—it is just more difficult to "filter out" the unwanted sounds with broad tuning. Thus, it may be especially difficult for someone with hearing loss to understand speech in a noisy environment. Indeed, and most unfortunately, this is typically the case for individuals with hearing loss.

Our exquisite sensitivity to sound, enormous dynamic range of hearing, and fine frequency resolution are all closely

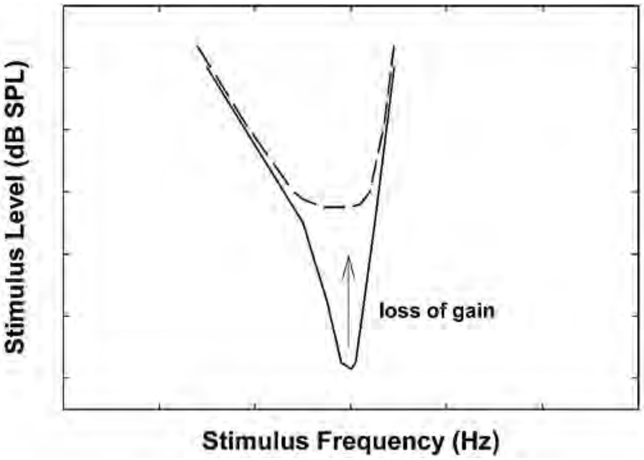

Fig. 6. These are tuning curves for an auditory system with normal OHCs (solid line) and damaged OHCs (dashed line). The upward displacement of the tip of the tuning curve in the impaired system represents a loss of the frequency-selective gain normally provided by OHCs.

associated with the level-dependent gain resulting from normally functioning OHCs in the cochlea. Damage to those cells results in elevated detection thresholds, a reduced dynamic range, and broader tuning. As discussed in several recent reviews[5–8], it is likely that cochlear compression plays an even more pervasive role in hearing than outlined here. It may, for example, play an important role in auditory temporal processing, thereby improving our ability to process the time-varying or dynamic aspects of sound.

Compression in hearing aids

In closing, we consider one form of aural rehabilitation for individuals with damaged OHCs, namely amplification via a hearing aid. The intent of hearing aids is to amplify sounds so that the individual with the hearing loss can hear them. The reduced dynamic range, however, provides a considerable challenge. This is illustrated in Fig. 7. In the top panel the growth of loudness is shown schematically for a normal (solid line) and an impaired (dashed line) ear. The goal of a hearing aid might be to amplify low-level sounds a great deal, but high-level sounds only a little, if at all. This would shift the response of the impaired ear to be more in line with the response of the normal ear (as indicated by the arrows). As noted previously, OHCs normally provide this type of level-dependent amplification: the amount by which they amplify the vibration of the basilar membrane decreases with increasing input level. The goal of level-dependent amplification will not be accomplished by simple linear amplification where all sounds are amplified by the same amount. Instead, compression amplification has become an increasingly more popular type of amplification for individuals with sensorineural hearing loss in order to deal successfully with their reduced dynamic range. An illustration of one type of compression amplification is shown as an I-O function in the bottom panel of Fig. 7. The output increases with increasing input, but the gain of the hearing aid (the difference between the output and the input) decreases with increasing input level. This type of amplification has accom-

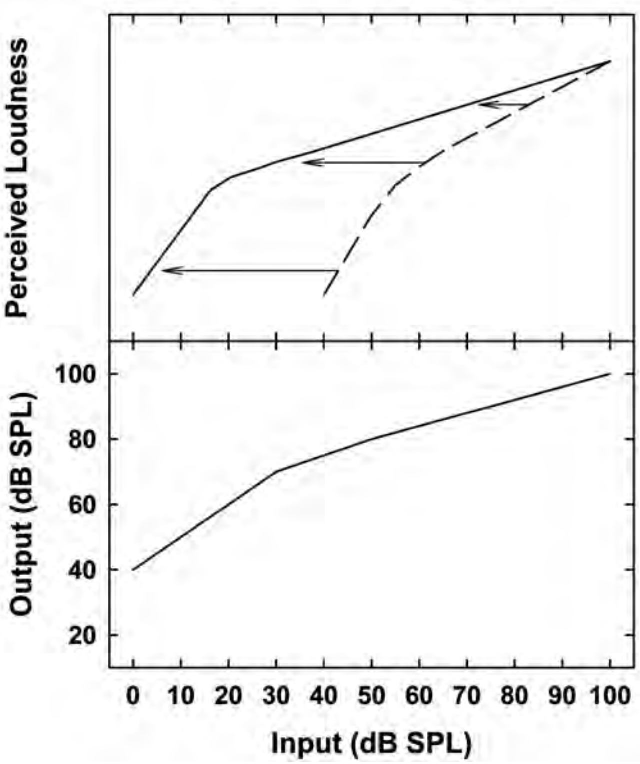

Fig. 7. The top panel shows the growth of loudness for a normal (solid line) and an impaired (dashed line) ear. The length of the arrows indicates the amount by which the sound would need to be amplified to shift the impaired ear to be equal to the normal ear. The bottom panel shows the I-O function for a hearing aid that employs compression. The amount of gain provided by the hearing aid is simply the difference between the output and the input.

plished the goal of providing considerable gain at low levels and increasingly smaller amounts of gain at higher levels. In a broad sense, compression hearing aids are attempting to restore the compression that is normally observed, and consequently extend the dynamic range of people with hearing loss. Although such aids may provide a more comfortable listening environment, they unfortunately do not restore hearing to normal. Indeed, a review[9] has shown that thus far they have had rather mixed success in terms of improving speech recognition in noisy environments. This may be at least partly related to the fact that the compression in hearing aids does not mimic the frequency selectivity that is observed in the compressive response of a normal cochlea. An important challenge, then, is to determine the best way to map the large range of acoustic levels in the environment to an auditory system that does not benefit from the compression that normally exists at the basilar membrane in the cochlea.**AT**

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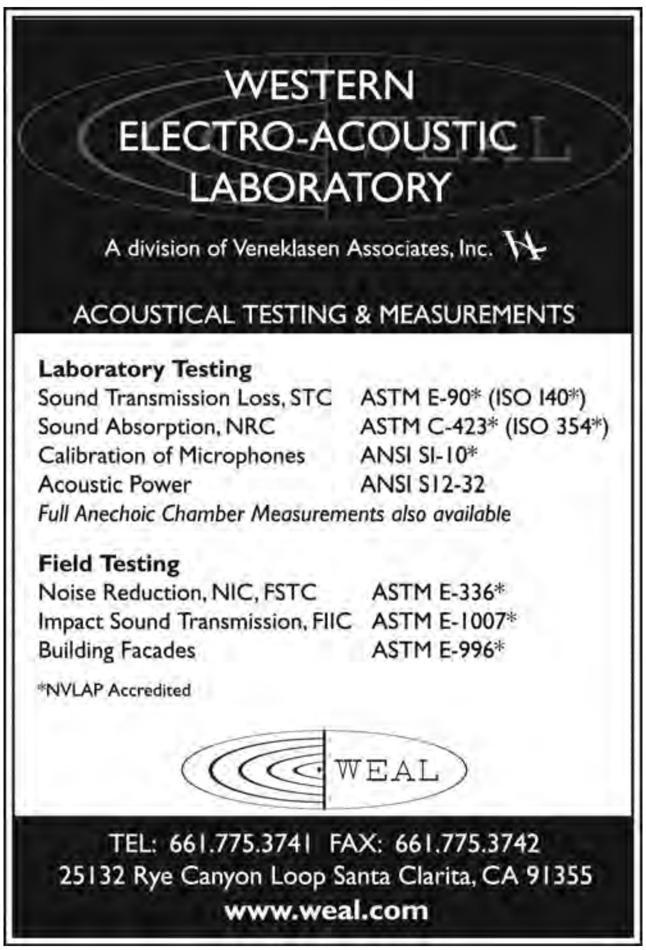

References for further reading:

1. G. von Békésy, *Experiments In Hearing*. (McGraw-Hill, New York, 1960).
2. M.A. Ruggero, N.C. Rich, A. Recio, S.S. Narayan, and L. Robles, "Basilar-membrane responses to tones at the base of the chinchilla cochlea," J. Acoust. Soc. Am. **101**, 2151–2163 (1997).
3. J. Zheng, W. Shen, D.Z. He, K.B. Long, L.D. Madison, and P. Dallos, "Prestin is the motor protein of cochlear outer hair cells," Nature **405**, 149–155 (2000).
4. H. Davis, "An active process in cochlear mechanics," Hear. Res. **9**, 79–90 (1983).
5. B.C.J. Moore and A.J. Oxenham, "Psychoacoustic consequences of compression in the peripheral auditory system" Psychol. Rev. **105**, 108–124 (1998).
6. A.J. Oxenham and S.P. Bacon, "Cochlear compression: Perceptual measures and implications for normal and impaired hearing," Ear and Hearing **24**, 352–366 (2003).
7. A.J. Oxenham and S.P. Bacon, "Psychophysical manifestations of cochlear compression: Normal-hearing listeners," in *Compression: From Cochlea to Cochlear Implants* edited by S. P. Bacon, R. Fay, and A. N. Popper, pp. 62-106. (Springer Verlag, New York 2004).
8. S.P. Bacon and A.J. Oxenham, "Psychophysical manifestations of cochlear compression: Hearing-impaired listeners," in *Compression: From Cochlea to Cochlear Implants* edited by S. P. Bacon, R. Fay, and A. N. Popper, pp. 107–152. (Springer Verlag, New York 2004).
9. H. Levitt, "Compression amplification," in *Compression: From Cochlea to Cochlear Implants* edited by S. P. Bacon, R. Fay, and A. N. Popper, pp. 153–183. (Springer Verlag, New York 2003).

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ASA–INCE/USA SYNERGY

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The roles and interests of the Acoustical Society of America (ASA) and the Institute of Noise Control Engineering of the USA (INCE/USA) have much in common. The very successful recent joint meeting of the two societies in Minneapolis demonstrates the mutual benefits of coordinated activities. This article reviews the history of the ASA–INCE/USA relationship and proposes several areas in which closer collaboration between them might provide greater benefit to their members, the global acoustics community, and society in general. The ASA was formed in 1929 with the purpose to increase and diffuse the knowledge of acoustics and promote its practical application.[1] The present membership, in excess of 7000, works in many diverse fields including physics, engineering, oceanography, biology, physiology, psychology, architecture, speech, and music. The ASA was one of the founding Member Societies of the American Institute of Physics (AIP) in 1931. The ASA promotes the use of technical groups and committees for intra-Society communication, holds regular professional meetings, publishes *The Journal of the Acoustical Society of America (JASA)*, supports the development of acoustics-related standards, offers awards for distinguished achievement in acoustics, re-prints out-of-print classic works, and keeps members apprised of acoustics news through its periodicals.

Likewise, the INCE/USA strives to advance the frontiers of knowledge, elevate the standards of professional excellence, stimulate technical progress, inform the public of technical developments, and apply technical progress to the satisfaction of the needs of mankind for a quieter environment in which to work and live.[2] At present, the Institute is organized similarly to ASA in that it is served by a group of volunteer officers, including five Vice Presidents, a Board of Directors, committees, and a paid staff. It publishes the bimonthly refereed journal *Noise Control Engineering Journal* (*NCEJ*) and the quarterly magazine *Noise/News International* (NNI), as well as the proceedings from its NOISE-CON and INCE/USA-hosted INTER-NOISE meetings. An important function of INCE/USA is the recognition of noise control professionals through its rigorous board certification program; approximately 17% of the 1000-plus members are board certified. International INCE (I-INCE) was fostered by INCE/USA and founded in 1974.

> *"Our organizations have contributed substantially to the International Commission on Acoustics, to the International Congresses on Acoustics, and to International INCE—these are organizations that facilitate international cooperation."*

Background[3]

In the 1950s and 60s, some acousticians were doing work in the area of acoustic noise and its control that led to the emerging discipline called noise control engineering. Unfortunately, the small group of noise control practitioners found that it was difficult to get their papers published in the research-oriented *JASA*. Through the leadership of then President Leo Beranek, the Society began publishing the magazine *NOISE Control* to provide a forum for noise and noise control papers. Nevertheless, there were members of the Executive Council who believed that the magazine should cease to exist because of the small percentage (~ 9%) of the membership interested in noise. A compromise was reached that led to the re-naming of the magazine to *Sound, Its Uses and Control*, within which practical papers in all areas of acoustics were published. For various reasons the production of *Sound, Its Uses and Control* ended in 1963, and in 1972, ASA and INCE/USA cooperated in the publication of *Noise/News*, a bimonthly newsletter.

Even though the ASA Technical Council was formed to serve as a channel of communication between the technical committees and the Executive Council, the Technical Committee on Noise (TCN) during the 1960s was unable to meet the needs of the increasing number of noise control engineers. A major reason for this growth was the National Environmental Policy Act of 1968, which led to the establishment of the Office of Noise Abatement and Control within the Environmental Protection Agency. Many members of TCN realized that there would be significant emphasis on noise in the future, and that an organization was needed to promote professionalism in the field of noise control engineering.

In January 1971, a workshop on noise control engineering was held at Arden House in Harriman, NY with Leo Beranek as Chairman and William Lang as Co-Chairman. These individuals kept the ASA and other related societies fully informed of the goal of this workshop to form a new professional organization devoted to the practice of noise control engineering. The majority of the participants of the workshop were members of the ASA; it was easily agreed that a close relationship between ASA and the new organization would be fostered. The Institute of Noise Control Engineering of the USA was incorporated in Washington, DC in June 1971. Leo Beranek became the first President, while John Johnson, the President of ASA at that time, fully endorsed this incorporation. Dr. Johnson later served as President of INCE/USA in 1980.

The relationship between ASA and INCE/USA continues to be a strong one. In fact, an ASA-INCE/USA Agreement presently exists.[4] The purpose of the Agreement, "…is to provide for cooperation in the holding of certain meetings and in the publication of certain educational periodicals." Because the Agreement will expire in June 2006, it is important to highlight some of the details of the present Agreement and also to suggest some areas that might be included in its next iteration.

Standards

The ASA is secretariat for American National Standards Institute (ANSI) Committee S12 Noise. INCE/USA is an S12 organizational member with a representative appointed by the INCE/USA Board of Directors.[4] A recent example of ASA-INCE/USA collaboration in the area of standards is ANSI S12.60-2002 on classroom acoustics.[5,6] This standard includes acoustical criteria and design requirements for control of noise and reverberation in classrooms and other learning spaces. There were 54 participants in the working group for this standard; 15 were members of both ASA and INCE/USA, 21 were members of ASA only, and 2 were members of INCE/USA only.

Participation of our organizations in the development of international standards in acoustics and noise control (through the International Electrotechnical Commission and the International Organization for Standardization) is less obvious. There is little participation of our acoustics experts in reviewing documents as they are being developed. Perhaps a reason for this is the financial commitment for experts to attend international meetings. The present author is not in a position to earmark ASA or INCE/USA funds for such travel, but the topic is one that needs discussion and resolution by the standards leaders from the our two organizations. This is important because it will benefit USA manufacturers, workers, and consumers.

The federal and state governments are expected to increase the funding for development of alternative sources of electrical power. An important candidate is the use of multiple wind turbines on wind farms. There have, however, been some significant violations of community and recreational land-use noise ordinances due to some of these wind farms now in operation. Several areas need input from acoustical experts.[7] Acoustical standards must be developed for wind turbine noise measurement and for the instrumentation used to measure this noise. The microphones on most sound level meters are only useful down to 20 or 30 Hz, but wind turbines generate emissions at frequencies lower than 20 Hz. The proposed new standard will address this issue. The human and animal response to these very-low frequency sounds also needs careful study. Although not part of standards development *per se*, acoustical experts from INCE/USA, ASA, and the National Council of Acoustical Consultants (NCAC) should be available to assist local authorities in the development noise ordinances that are applicable to wind farms.

Meetings

The first collaborative meeting held by ASA and INCE/USA occurred on the occasion of the United States' bicentennial celebration in Washington, DC. The semi-annual ASA meeting and INTER-NOISE 76 were held back-to-back in different hotels. Unfortunately, different fees were charged for registration that made it impossible to have reciprocity of badges between the two meetings. Those conferees interested in attending both meetings were not happy because of the additional fees required; thus, there was little cooperation or interaction during these meetings. Fortunately, those early problems have been corrected and ASA and INCE/USA have had three fruitful joint meetings within the last decade: 1997 in State College; 2000 in Newport Beach; and 2005 in Minneapolis. In 2006, the 152nd Meeting of the ASA will be held back-to-back with INTER-NOISE 06 in Honolulu; both meetings are co-sponsored with the Acoustical Society of Japan and INCE/Japan, respectively.

Clearly, there are on-going efforts to continue holding joint meetings. We should strive to have two joint meetings per decade. A joint meeting is one of the best ways to bring our members together for professional collaboration and social interactions. Joint meetings strengthen the ties between the Technical Council of ASA and the Technical Activities Board of INCE/USA because it is the members of these groups that suggest and organize the technical sessions of the meetings. The executive branches of ASA and INCE/USA must develop and refine the policy for holding joint meetings, including a master "memorandum of understanding" that can be used (with appropriate modifications) for each succeeding meeting. Key elements of the policy would include the selection of venues, dates, and chairs, hotel negotiations, financial management, short courses, seminars, manufacturer's exposition, social events, and management of printed materials including programs, proceedings, and CDs.

USA Noise Policy

The National Academy of Engineering (NAE) has initiated a project to collect and analyze data from government and private-sector sources on the impact of noise on the quality of life, on the current state of noise control technology, the role of noise control technology in international competitiveness, and the implications of all of the above on noise policy. The study is expected to develop recommendations for public- and private-sector action to reduce the adverse effects of noise. The development and execution of the NAE noise initiative is being undertaken in two distinct steps: (1) a project initiation (planning) workshop was convened on 13-15 September 2005; a prospectus for a consensus study has since been prepared and approved. (2) The consensus study will be conducted over a 30-month period of time by the NAE staff and an appointed committee made up of experts from several areas of acoustics and noise control. It will involve a variety of fact-finding activities such as additional workshops, background research, commissioned papers, and informal interviews. All of this will lead to the issuing of a consensus report with specific findings and recommendations for a follow-on implementation effort. This important project will involve many individuals from ASA, INCE/USA, and other professional societies, e.g., the Society of Automotive Engineers (SAE), the American Institute of Aeronautics and Astronautics (AIAA), the American Industrial Hygiene Association (AIHA), and others. The teaming will surely be an opportunity for strong collaboration between ASA and INCE/USA, but it will also provide an opportunity for *outreach* to other professional organizations that deal with some aspect of acoustics or noise. The important end result of this teaming will be a possible new National noise policy that will replace the presently ineffective Noise Control Act of 1972.

Following this NAE consensus study, additional policies may need to be developed at the state and municipal levels because there are different needs. Again, ASA and INCE/USA acoustical experts should participate in these policy developments.

International activities

Over the years, the ASA and INCE/USA have encouraged growth internationally in both acoustics and noise control engineering. Our organizations have contributed substantially to the International Commission on Acoustics, to International Congresses on Acoustics, and to International INCE; these are organizations that facilitate international cooperation. Most of the world's leading acoustical and noise control organizations are now members of I-INCE that promotes the annual INTER-NOISE series of conferences.

Over the past few years there has been an initiative within I-INCE to define, and promote the implementation of, a global noise control policy.[8] The policy concentrates on three major areas: (1) occupational noise, (2) community and environmental noise, and (3) consumer product noise. It suggests that individual professional organizations help their respective governments establish local noise policies and regulations, while the international bodies should provide standards and criteria by which to evaluate the noises of concern. Many members of the ASA and INCE/USA have contributed significantly to this effort, and it is clear that their cooperative leadership role in this crucial area will continue. More and more of our members will likely become involved in these types of activities as both the USA and global noise policies evolve and become legally enforceable. It is important that the Executive Council of ASA and the Board of Directors of INCE/USA continue to support this involvement by creating new, or maintaining existing, working groups and committees to work with the international community.

Publications

The present Agreement[4] notes that INCE/USA and International INCE (I-INCE) jointly publish *NNI*, the magazine that replaced *Noise/News* in 1993. Although ASA has no financial obligation to *NNI*, it has agreed to provide information that may be published in it. Such information might include the list of the titles of recent *JASA* articles related to noise, news on standards, occasional publication of noise-related articles from *JASA*, meeting information, and other noise-related news of the ASA. As a member benefit, *NNI* is distributed (at a nominal cost to ASA) to those ASA members whose first interest is in noise but who are not members of INCE/USA.

As the two organizations prepare a new agreement of cooperation, it is important that the respective Editors of *JASA*, *NCEJ*, *NNI*, and *Acoustics Today* (*AT*) collaborate in preparing statements of mutual concern in the publications arena. It is very likely that *JASA* and *NCEJ* will remain independent of each other because their respective charters and readership. On the other hand, *NNI* and *AT* may share several areas of common interest. As noted in the previous paragraph, there is specific information that is to be provided by ASA for publication in *NNI*. It is recommended that such directives become reciprocal in the next iteration of the Agreement, e.g., *AT* could publish certain INCE/USA news items that would be of interest to ASA readers.

Hearing conservation

A final area of collaboration between ASA and INCE/USA is in the general area of hearing conservation. Some of the ASA members whose primary interests are in noise, physiology, psychology, and speech are deeply concerned about hearing loss due to acoustic phenomena. There are likewise many INCE/USA members who share this concern. One forum where collaboration might be enhanced is by way of representation on the Council for Accreditation in Occupational Hearing Conservation (CAOHC). This Council was organized to elevate and maintain the quality of occupational hearing conservation, to establish and implement standards, and to certify those who meet those standards. Although INCE/USA is one of the nine component professional organizations that make up CAOHC, the ASA is not. Because the two current CAOHC representatives from INCE/USA are also members of ASA, a degree of collaboration is presumably in place. Another forum for collaboration is during future joint meetings of the ASA and INCE/USA. It would be desirable to have the Technical Committees on Noise, Speech Communication, and Psychological and Physiological Acoustics sponsor joint sessions with any of several INCE/USA Technical Committees that are concerned with the effects of noise on mankind.

Summary

Since its founding, the ASA has experienced on three different occasions a migration of some of its membership to form new professional organizations. In the 1950s, the IEEE Signal Processing Society and the Audio Engineering Society started as spin-offs from the ASA. In 1971, INCE/USA was formed by a group of ASA members seeking professionalism in the new field of noise control engineering. Of these three new organizations, it has only been INCE/USA that has maintained a close working relationship with ASA. The two organizations work together in supporting the development of acoustics and noise standards, in international and national noise policy development, in the holding of joint meetings, and in the sharing of information in their publications. These and other areas of synergy exist because of the common goals of both organizations to increase and advance the knowledge of, attain professional excellence in, and meet the needs and concerns of the general public and governmental bodies in a multitude of issues related to acoustics and noise control. This cooperation will surely continue into the distant future.**AT**

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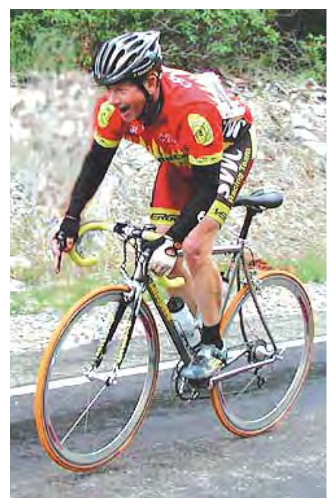
References for further reading

1. "Bylaws of the Acoustical Society of America, Inc.," 2002 Membership Directory and Handbook, A22-A24.
2. "Articles of Incorporation and Bylaws of the Institute of Noise Control Engineering of the USA, Inc.," INCE Policy, Procedures, and Informational Manual **9**, 28-31 (2004).
3. William W. Lang, "An informal account of the early years of the Institute of Noise Control Engineering of the USA, Inc.," INCE Policy, Procedures, and Informational Manual **9**, 710-747 (2004).
4. INCE/ASA Agreement drafted 8 December 2000; signed 7 June 2001 by ASA President Katherine Harris, and 9 June 2001 by INCE/USA President Paul Donavan.
5. Peggy B. Nelson, "The ASA classroom acoustics effort," Acoustics Today **1**, 28–32 (October 2005).
6. David Lubman, "The classroom amplification challenge to ANSI S12.60-2002," Acoustics Today **1**, 33-34 (October 2005).
7. Alan H. Marsh (private communication, 2006).
8. "Publication 05-1 of the International Institute of Noise Control Engineering Draft Report from I-INCE Technical Study Group 5: Global Noise Control Policy," Noise Control Eng. J. **52**(6), 250-298 (2004).



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