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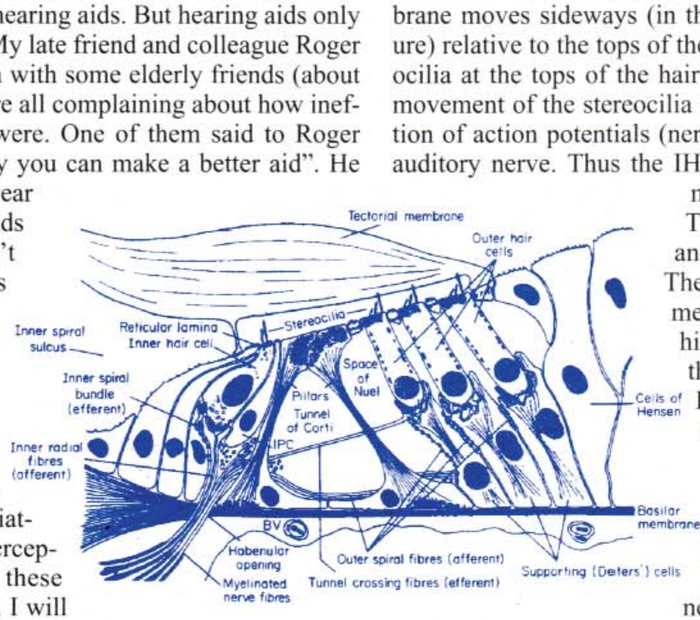
Cochlear Hearing Impairment and the Design of Hearing Aids

by Brian C.J. Moore

If you don't already have a hearing loss, the chances are high that you will develop one as you get older. Most cases of hearing loss cannot be "cured". The main form of treatment is to amplify sounds using hearing aids. But hearing aids only solve part of the problem. My late friend and colleague Roger Laurence was having lunch with some elderly friends (about 15 years ago), and they were all complaining about how ineffective their hearing aids were. One of them said to Roger "You're an engineer; surely you can make a better aid". He later ruefully told me "A year and fifteen thousand pounds later, I realized it wasn't going to be quite as easy as I anticipated".

Some reasons for the limited benefit of hearing aids are described in this article, starting with the major physiological changes in the inner ear (the cochlea) that are associated with hearing loss. The perceptual consequences of these changes are then discussed. I will explain why it is that hearing aids do not fully compensate for the effects of hearing loss and will point to some ways in which hearing aids may be improved in the future.



The great majority of cases of hearing loss in the developed countries are caused by damage to the cochlea. The cochlea divided along its length by the *basilar membrane* (BM). Sounds result in pressure differences between one side of the BM and the other and this results in movement of the BM. The mechanical properties of the BM vary progressively along its length. At one end it is relatively narrow and stiff, while at the other end it is wider and much less stiff. As a result, each point on the BM is *tuned*; it responds best to a certain frequency, called the characteristic frequency (CF), and responds progressively less as the frequency is moved away from the CF. Another membrane, called the *tectorial membrane*, lies above the BM, and also runs along the length of the cochlea. Between the BM and the tectorial membrane are hair cells (see the figure), which have tufts of "hairs", called *stereocilia*, at their tops. The hair cells are divided into two groups: the *outer hair cells* (OHCs) are arranged in three to five rows running along the length of the BM. The *inner hair cells* (IHCs) form a single row.

When the BM moves up and down, the tectorial membrane moves sideways (in the left-right direction in the figure) 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 the generation of action potentials (nerve spikes) in the neurons of the auditory nerve. Thus the IHCs act to transduce mechanical movements into neural activity.

The OHCs have a very different and remarkable motor function. They are the basis of an *active* mechanism which operates in a highly nonlinear way to influence the patterns of movement on the BM. The main functions of the OHCs are:

1. They enhance the response of the BM to weak sounds, for frequencies close to the CF.

2. They increase the sharpness of tuning on the BM.

3. They produce nonlinear (compressive) input-output functions on the BM for frequencies close to CF; for example, for mid-range sound levels an increase in sound level of 10 dB may produce only a 2.5-dB increase in response on the BM.

Most cases of cochlear hearing loss involve damage to IHCs and OHCs. Usually, the OHCs are more susceptible to damage than the IHCs, although impact noise such as gun shots can substantially affect the IHCs. In people, hair cells, once destroyed, do not regenerate (although in some animals, especially birds, hair cells do regenerate). Damage to the IHCs produces: less efficient transduction of mechanical vibration into neural activity; loss of sensitivity; reduced information flow in the auditory nerve; and (in extreme cases) no transduction of activity at some regions of the BM ("dead regions").

Damage to the OHCs produces: reduced amplitude of vibration on the BM in response to weak sounds; reduced sharpness of tuning on the BM; and more linear (i.e. steeper) input-output functions on the BM.

Loss of sensitivity for weak sounds is the most obvious

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We hear that...

Sir James Lighthill, noted acoustician and mathematician, died in July in a swimming mishap while attempting to recreate his record-making swim around the island of Sark. Lighthill retired from the office of Provost of University College, London in 1989. From 1969 to 1979 he was the Lucasian Professor of Mathematics at Cambridge, a chair that was passed to Stephen Hawking when Lighthill moved to London. His long and distinguished career also included service at the University of Manchester, the Royal Aircraft Establishment, and Imperial College. He received honorary doctorates from 24 academic establishments from Tallahassee to St. Petersburg, and was knighted in 1971.

In 1973 Lighthill became the first man to swim around Sark, after carefully studying the hazardous current and applying his knowledge of fluid dynamics to calculate the best route through strong tides. He modestly called the nine-mile swim a "pleasant way to see the scenery." He repeated the achievement half a dozen times before his fatal swim at age 74.

Clayton D. Mote, Jr. is the new President of the University of Maryland in College Park. Mote, a Fellow of the ASA, served as Chair of the Department of Mechanical Engineering at the University of California, Berkeley from 1987-1991, when he became Vice Chancellor at Berkeley. He has also held positions at Carnegie Institute of Technology, the University of Birmingham, the Norwegian Institute for Wood Science and Technology, and the technical University of Darmstadt.

Mote's technical expertise is in the areas of dynamic systems, instrumentation, vibration, and biomechanics. He is widely recognized for his research on gyroscopic systems, and his work on the biomechanics of skiing injury has resulted in 300 publications as well as patents in the U.S., Norway, Finland, and Sweden. He was elected to the National Academy of Engineering in 1988 and was chosen an Honorary Member of the American Society of Mechanical Engineers in 1997.

ECHOES

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Ilene Busch-Vishniac is the new dean of the Whiting School of Engineering at The Johns Hopkins University in Baltimore. Busch-Vishniac, a Fellow of the ASA, who has just completed a term as Vice-President, was formerly professor of mechanical engineering at the University of Texas. She will be the first woman dean of a Johns Hopkins division (other than the School of Nursing) and one of fewer than 10 women deans in an American university.

Busch-Vishniac, who received her PhD from MIT in 1981, has been interested in the design of cost-effective highway noise barriers. She has also researched electromechanical transduction for sensors and actuators. She gave a plenary lecture on "Trends in electromechanical transduction" at the ICA/ASA meeting in Seattle and published an article on this subject in *Physics Today* (July, 1998). In 1987 she received the R. Bruce Lindsay award from ASA.

A five-year grant to **James G. Miller** of the School of Medicine at Washington University School of Medicine in St. Louis has been awarded MERIT status by the National Heart, Lung, and Blood Institute, a part of the National Institutes of Health. Miller uses ultrasonic waves to image and obtain information about mechanical and elastic properties of normal and diseased hearts. A MERIT award, according to NIH, "is designed to provide long-term, stable support to investigators whose research competence and productivity are distinctly superior."

Alice Suter received the Alice Hamilton Award from the American Industrial Hygiene Association. This award is presented to "an outstanding woman who has made a definitive, lasting achievement in the field of occupational and environmental hygiene through public and community service, social reform, technological innovation or advancements in the scientific approach to the recognition evaluation and control of workplace hazards."

M. Mohan Sondhi has been awarded an Eric Sumner Award by the IEEE for "the conception and development of voice echo cancelers." Sondhi, who has published widely in the fields of acoustics and speech signal processing, was named a Bell Laboratories fellow in 1996.

Physicist **Rush Holt** is attempting to become the fourth PhD scientist in Congress, joining physicist Vernon Ehlers (R, Michigan), chemist John Oliver (D, Massachusetts) and physiologist Roscoe Bartlett (R, Maryland). Holt, former assistant director of the Princeton Plasma Physics Laboratory, who is running in New Jersey's twelfth district, plans to champion environmental issues such as global warming and biodiversity conservation in his bid to unseat incumbent Michael Pappas. "He has a good chance of winning," says Harry Sayen, a columnist for the *Trenton Times* who predicts that Democrats and moderate Republicans in the Princeton area will support Holt's ideas.

To Norfolk, by land, sea, or air

Although we hardly got our bags unpacked after Seattle, it's time to pack them again. The 136th meeting of ASA in Norfolk, only 3½ months after the 135th, is one that should not be missed!

In addition to a rich assortment of special sessions, there will be a tutorial on Sonoluminescence and two short courses, on Auralization and on Sonic Boom. The tutorial lecture will be presented by Seth Putterman, UCLA (see *Echoes*, Spring 1993, p. 4). The Auralization short course, which was very successful at the Honolulu meeting, will be taught by Mendel Kleiner and Peter Svensson, Chalmers University (Sweden), while the Sonic Boom short course will be taught by Kenneth Plotkin, Domenic Maglieri, and Louis Sutherland. The Sonic Boom short course will complement a Sonic Boom Symposium, a forum for government, industry, and university participants to present and discuss the present state of sonic boom technology and issues.

The Interdisciplinary Technical Group on Signal Processing in Acoustics will sponsor its third Gallery of Acoustics at the Norfolk meeting. The Gallery will consist of posters and video displays of images generated by acoustic processes or resulting from signal processing of acoustic data, and a $350 prize will be awarded to the winning entry. Further information about the Norfolk meeting, including abstracts of papers, is available on the ASA webpage: asa.aip.org.

"Take-Five" Goes International

When Tom Rossing and Uwe Hansen organized the first "Take-Five" session for the ASA Committee on Education in Acoustics at the Penn State meeting, they hoped it would become a tradition. It has. Similar sessions at the San Diego and Seattle meetings drew enthusiastic participants, and now a session is scheduled for the joint ASA/EAA meeting in Berlin next March.

A take-five session in sharing ideas for teaching acoustics, jointly sponsored by the ASA Committee on Education in Acoustics and the DEGA (German Acoustical Society) Fachausschuß Lehre der Akustik, will be organized by Uwe Hansen and Armin Kohlrausch. The procedure remains as before: no abstract is required; presenters sign up at the beginning of the session for 5-minute slots; presenters may sign up for multiple presentations but not consecutive slots.

Although past sessions have included a wide variety of presentations, some of the most memorable have been demonstration experiments (some new, some old, some borrowed). Realizing that presenters from the United States will not be able to transport heavy equipment to Berlin, Uwe Hansen suggests that demonstrations with simple equipment be emphasized or that presenters consider preparing a short video tape of their demonstration. While abstracts are not required, presenters are urged to prepare handouts, including sources for equipment and drawings of special apparatus.

Whether or not you currently teach a course in acoustics, you will enjoy participating in a take-five session, either as a presenter or a spectator. Some enthusiastic participants have shared as many as 4 different ideas on the same program (but not consecutively!). Others, coming to the session not intending to make a presentation, have gotten caught up in the enthusiasm of the moment and volunteered to share their ideas.

The Berlin take-five session is being publicized in *Sprachrohr* (DEGA's equivalent of *Echoes*) and other publications, and we hope to have lots of participation by European acousticians. Nevertheless, as Uwe points out, we need lots of participants from the United States. For additional information contact Uwe at phhanse@scifac.indstate.edu or by FAX at 812-237-4396.

From the Technical Council...

The Technical Council met June 21 and 26 on the first and last days of the Seattle ASA/ICA meeting. One of the major items was the approval of technical initiatives; items totaling around $50,000 have now been approved for 1998 and items totaling about $30,000 have thus far been approved for 1999. The largest award for 1999 was $5000 to Architectural Acoustics for a summer institute on concert hall acoustics. Technical committees have proposed a wide variety of technical initiatives, including receptions and awards for students, travel expenses for speakers, support for web pages, workshops for teachers, concerts and demonstrations, etc. Support for a Gallery of Acoustics under Signal Processing in Acoustics at the Norfolk meeting was approved.

Ideas for future meetings discussed by the Technical Council included sessions for late abstracts, sessions especially for exhibitors, and a session on "bad ideas in acoustics." Considerable discussion was devoted to special concerns about the joint ASA/EAA meeting in Berlin, which 2000 people are expected to attend. At this meeting a CD-ROM will contain papers usually given to the copying service, and the letter to authors requesting their papers will explain ASA policy on subsequent publication in JASA. Coffee and lunch breaks will be scheduled on a time-synchronous basis. Joint meetings of the technical committees of the ASA and EAA are planned.

ASA graduate fellowship for minorities

The Acoustical Society has announced the availability of a fellowship for minorities to support graduate study in scientific areas related to the field of acoustics. The stipend is $13,500 plus up to $1000 in travel to ASA meetings, and it can be renewed for a second year. The applicant must have citizenship or permanent residence in the United States or Canada at the time of application and must also be a member of an ethnic minority group that is underrepresented in the sciences (such as Hispanic, African-American, or Native American). Application deadline is *15 April 1999*.

(Cochlear Hearing..., continued from page 1

sign of a hearing problem. However, cochlear damage produces several other changes in the way that sounds are perceived. One such change is in frequency selectivity, which refers to the ability of the auditory system to separate or resolve (to a limited extent) the frequency components in a complex sound. Frequency selectivity probably depends largely on the filtering that takes place on the BM. Damage to the OHCs leads to reduced sharpness of tuning on the BM and hence to reduced frequency selectivity. Because of this, hearing-impaired people are very susceptible to masking produced by background sounds. Reduced frequency selectivity also has effects on the perception of timbre. For example, it can make it more difficult to distinguish different vowel sounds or different musical instruments. People with cochlear hearing loss often report that speech and other sounds appear "fuzzy" or "blurred", even when no background sounds are present. This blurring is almost certainly partly caused by reduced frequency selectivity.

Another consequence of cochlear hearing loss is loudness recruitment. 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; the sound appears as loud to the person with impaired hearing as it would to a normally hearing person. With further increases in sound level above 90-100 dB SPL, the loudness grows in an almost normal manner. Loudness recruitment probably results mainly from loss of the normal compression that occurs on the BM; input-output functions become steeper than normal when OHCs are damaged.

For sounds with inherent amplitude fluctuations, such as speech or music, recruitment results in an exaggeration of the perceived dynamic qualities. The sound appears to fluctuate more in loudness than it would for a normally hearing person. When listening to speech, the loudness differences between consonants and vowels are greater than normal. When listening to music, the *forte* passages may be perceived at almost normal loudness, but the *piano* passages may be inaudible.

One of the most common complaints of people with cochlear hearing loss is difficulty in understanding speech in background noise. The difficulty arises partly from reduced audibility (some parts of the speech spectrum are not heard at all) and partly from reduced frequency selectivity, loudness recruitment and other abnormalities of perception. In some listening situations, such as trying to listen to one person when another person is talking, people with cochlear hearing loss may require speech-to-background ratios 16 dB or more higher than normal to achieve reasonable intelligibility. This represents a very substantial problem.

The primary goal of most hearing aids is to restore audibility via frequency-selective amplification, and, in principle, they can do this reasonably effectively. However, many hearing aid users complain that their hearing aids are of limited benefit, especially when background noise is present. There are three main reasons for this:

1. Hearing aids often introduce harmonic and inter-modulation distortion, and they may have irregular frequency responses and a limited frequency range, giving poor sound quality. These undesirable properties are all unnecessary and can be largely eliminated.

2. Hearing aids produce undesirable side effects, such as feedback, the whistling produced when the sound generated by the aid leaks back to the aid microphone.

3. Hearing aids do not compensate effectively for loss of frequency selectivity and dead regions and they can compensate only partially for loudness recruitment.

Consider, first, compensation for recruitment. With linear amplification it is not possible to restore audibility of weak sounds without intense sounds being over-amplified and becoming uncomfortably loud. In principle, this problem can be alleviated by the use of *automatic gain control* (AGC). With AGC, weak sounds can be amplified more than stronger ones. Nowadays it is widely accepted that well-designed AGC systems can be very helpful in hearing aids; they can allow speech to be understood over a wide range of sound levels without adjustment of the "volume" control, and they can allow weak environmental sounds to be heard without intense sounds being uncomfortably loud. All AGC systems introduce some undesirable side effects, for example, distortions of the temporal envelope of sounds, and "pumping" or "breathing" sounds.

Compensation for the effects of reduced frequency selectivity is much more difficult. In my laboratory we have had some success with a digital signal processing method that we call "spectral enhancement". Subjectively, when this processing is applied to speech in noise, the speech seems to stand out more clearly from the background noise. Laboratory evaluations of this processing have shown modest improvements in the ability of hearing-impaired people to understand speech in noise.

Compensation for the effects of dead regions in the cochlea is also very difficult. Dead regions (or regions that are almost dead) may be quite common at the end of the cochlea which normally responds to high frequencies. Amplification of sounds with frequencies corresponding to a dead region does not seem to help, and sometimes actually impairs speech intelligibility. Some improvements may be produced by frequency compression ("squashing" the frequency range) or by transposition (moving frequencies from, say, 4-8 kHz, down to the range 0 to 4 kHz). However, the benefits of such signal processing are likely to be modest.

A very effective way of compensating for the overall effects of cochlear hearing loss on the ability to understand speech in noise is to increase the speech-to-noise ratio using directional microphones. It is assumed that the hearing aid user will normally face towards the desired sound source, so the microphones are designed to be more sensitive to sounds coming from the front than to sounds coming from the sides or back. Simple directional microphones have been used in hearing aids for many years, but recently, arrays with improved directionality have been found to give a give a high degree of user satisfaction. Two such arrays consist of five microphones which can be mounted either along the front of a pair of spectacles (broadside array) or along the side (endfire array).

An alternative approach is to apply digital signal processing to the outputs of two or more microphones to create the desired directional characteristic. These systems can adapt to the characteristics of the interfering sounds, so as to remove as much of the interference as possible. The microphones do not have to be widely spaced, so the microphone

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Echoes From Seattle

Organizers Charles Schmid, Nancy Penrose, Larry Crum & Pat Kuhl

Mariko Senju and Tom Rossing

Gold Medal to Floyd Dunn

Pacific Science Center

Music, Mountains and Merriment at ISMA98

Mountain scenery, good food and weather, and lots of music greeted participants from 24 countries at ISMA98, a conference on musical acoustics in Leavenworth, Washington following the ASA/ICA meeting in Seattle. ISMA98, which followed in the tradition of previous international musical acoustics conferences in Scotland, France, Sweden, Japan, Germany, and elsewhere, was sponsored by the ASA and the Catgut Acoustical Society with additional support from the Experience Music Project Foundation. The Organizing Committee consisted of Douglas Keefe, Maurits Hudig, and Charles Schmid. Carleen Hutchins was the Honorary Chair.

Invited papers were given by R. Dean Ayers (brass instruments), Chris Chafe (computer music), Joseph Curtin (innovation in violin making), Brian Moore (music perception), Bernard Richardson (guitars), William Strong (woodwind instruments), and Shigeru Yoshikawa (organs). Workshop leaders were Carleen Hutchins (violin octet), Martin Schleske (tonal copies of violins), Oliver Rodgers (adjusting modal frequencies of violins), Charles Besnainou ("best" violin materials), David Peterson (construction of hammered dulcimers), William Hartmann (practical electronics for instrument builders and performers), Uwe Hansen (modal analysis of musical instruments), and Karen Strom (handbell playing).

A highlight of the conference was the announcement of the Carleen Hutchins Medal, to be awarded by the Catgut Acoustical Society, and the presentation of the first medal to Carleen herself. The presentation was made, appropriately enough, preceding a concert by Ann Cole played on instruments of the Violin Octet, which Carleen has devoted much of her life to developing and building.

The Proceedings of ISMA98, including the 64 papers presented at the symposium and edited by Douglas Keefe, Thomas Rossing, and Charles Schmid, can be ordered (for $40+postage) from ASA.

The World's Oldest Musical Instrument

by Neville H. Fletcher

Organized sound, which we now call music, has been part of the culture of humans for a very long time. Log drums may well claim to be the oldest instruments of music, but the oldest non-percussion instrument is certainly the didjeridu (or didgeridoo) of the Australian aboriginal people, who have lived in isolation in this old land for more than 40,000 years.

The didjeridu is a gently flaring tube made from one of the many small trunks of the mallee tree that has been eaten hollow by termites. A suitable hollow trunk about 50 mm in diameter is selected and cut to a length of between 1 and 1.5 meters, according to tribal tradition, smoothed and decorated with totemic emblems, and with a rim of beeswax applied to the narrow end for comfort inblowing.

The passive acoustic behavior of the didjeridu is easily derived. The tube flares from about 30 mm to 50 mm in internal diameter, and, when closed by the player's lips, has an approximately odd-harmonic resonance series, but with the lowest modes appreciably sharpened by the tube flare. The fundamental is typically around 80 Hz for the longer instruments, which have a richer musical repertoire.

Basic playing technique resembles that for a tuba, with the lips buzzing at nearly the fundamental tube resonance to produce a drone sound, but that is only the beginning. Players have developed the technique of "circular breathing" in which the throat is sealed off at the soft palate and the supply of air held in the mouth is expelled to maintain the lip vibration, while a quick breath is taken. Because the instrument uses rather a high air flow, this exercise must be repeated every few seconds, and imparts a natural rhythm to the drone. This rhythm is often enhanced by pronouncing a nonsense word such as "ritoru" or "didjeridu" with the last syllable extended, and this probably accounts for the European name for the instrument, which is actually called a yiraki or yidaki in the native languages.

The upper modes of the didjeridu pipe can also be excited, using higher blowing pressure and lip tension, just as is done for higher notes on a brass instrument. Traditional technique uses these higher modes, particularly the second mode which is a rather flat musical twelfth above the fundamental depending upon the flare of the tube, as brief accents in the performance, rather than as tones in their own right.

The drone, however, provides only the basis of the didjeridu sound, which is typically embellished to provide a great repertoire of "program music". The first subtlety is possible because the input impedance of the didjeridu tube is comparable in magnitude with that of the human vocal tract, and is not isolated from it by a mouthpiece cup and constriction as in a modern brass instrument. This allows the formant resonances of the vocal tract to influence the spectral envelope of the basic didjeridu drone, which has a long series of harmonics produced by nonlinear flow through the player's vibrating lips. The second vocal formant, which is easily varied between about 1500 Hz and 2500 Hz by changing the mouth volume, is particularly important, and produces vowel-like embellishments "aaa-ooo-eee" on the tone.

The second major technique is a vocal one. If the player sings while playing, the human vocal folds modulate the air flow to the mouth in a periodic manner with a frequency f_1, say, while the lips may be vibrating at a frequency f_2. Because the two modulations of the flow are multiplicative, rather than additive, the flow into the instrument will contain frequencies $n f_1 \pm m f_2$, where n and m are small integers. This technique can be used to produce a deep growling sub-octave when, for example, $f_1 = 1.5 f_2$ and n=m=1, though other combinations are also used.

Finally, the player may produce vocal sounds with higher frequencies and shorter durations to imitate the cries of birds or other animals of the Australian bush in a quite realistic manner. These sounds, superimposed on the pulsating drone, and perhaps some clapping music sticks, can be made to tell a simple story related to the totem of the tribe.

This age-old instrument is now making its appearance in pop-music groups, particularly those with an Australian flavor, and creates a most characteristic musical background. Its history is the history of a rich and unusual cultural heritage.

Brief bibliography:

T.A. Jones "The yiraki (didjeridu) in North-Eastern Arnhem Land: Techniques and styles" in *The Australian Aboriginal Heritage* ed. R.M. Berndt and E.S. Phillips, (Sydney: Ure Smith, 1973) pp. 269-274.

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K. Neuenfeldt "The didjeridu: From Arnhem Land to the Internet" John Libbey (1997)

D. Schellberg "Didgeridoo: Ritual origins and playing techniques" (Amsterdam: Binkley Kok, 1997).

Neville Fletcher is professor emeritus of physics at the Australian National University in Canberra. Among his many publications are books on "Acoustics Systems in Biology," "Physics of Musical Instruments," and "Principles of Vibrations and Sound." He will receive the Silver Medal in Musical Acoustics at the ASA meeting in Norfolk.

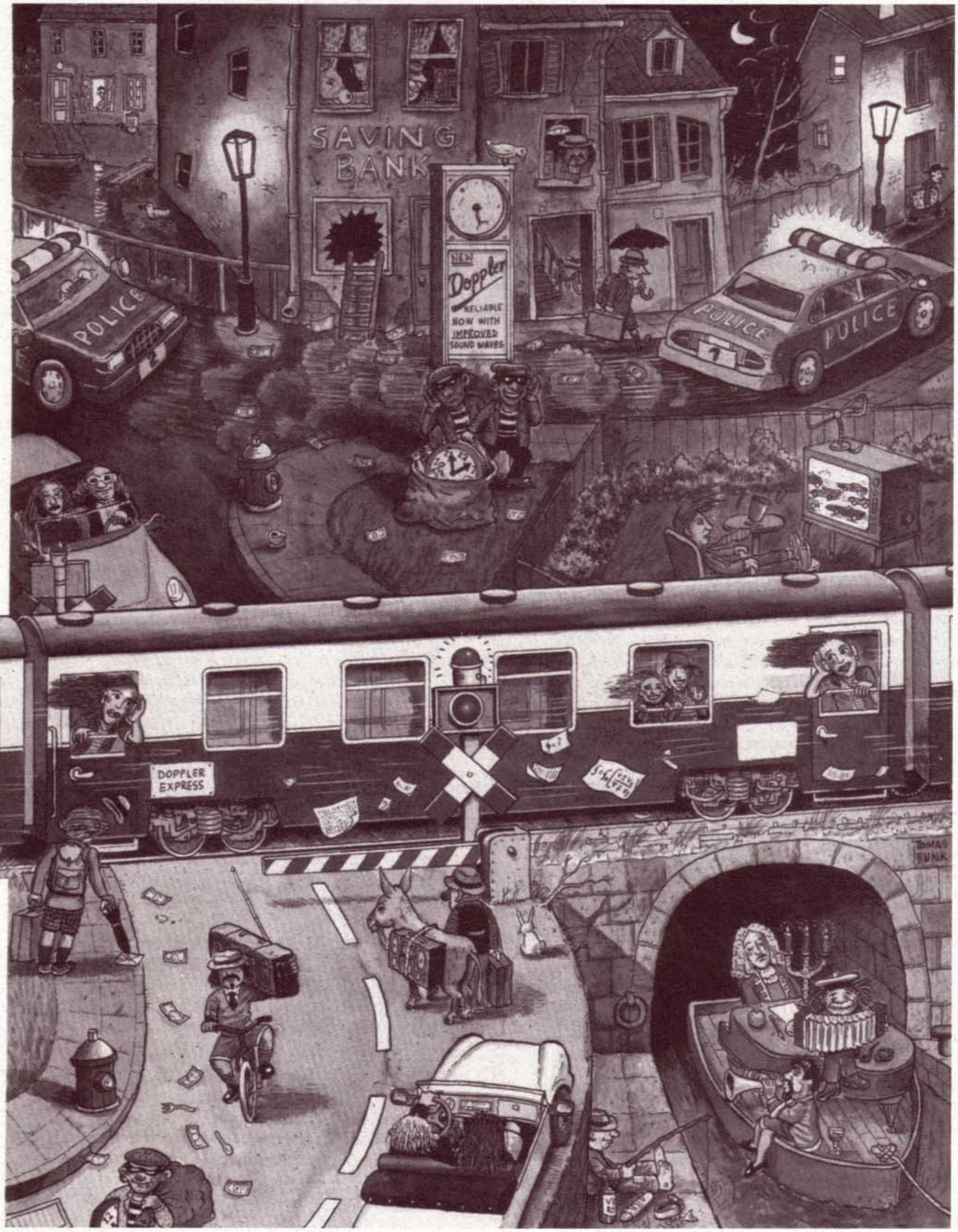
An artist's view of Doppler beats

Quantum magazine, aimed at literate high school science students but widely read by the general public as well, is published jointly by the National Science Teachers Association (NSTA) and the Quantum Bureau of the Russian Academy of Sciences (the Russian language edition is entitled *Kvant*). Not a small factor in its popularity are the creative cartoons by artist Tomas Bunk (whose work also appears in *MAD* magazine).

The cartoon on the facing page was drawn to enhance an article on "Doppler Beats" by Larry Kirkpatrick and Arthur Eisenkraft, a pair of extraordinary physics teachers who write regularly for *Quantum*. Larry, a professor at Montana State University, is vice-president of the American Association of Physics Teachers, while Arthur, who teaches at Fox Lane High School in Bedford, N.Y., is a well-known author of physics teaching material, including "Active Physics," a new course in applied physics for high schools.

Larry and Arthur, who have both coached the US Physics Olympics team, regularly write a "Physics Contest" column in *Quantum*, and the Doppler beats article in the July/August issue is a part of that series. Acousticians who enjoy contests should subscribe to *Quantum*. In the magazine, you will find Bunk's cartoons in *color!*

Doppler Beats



Acoustics in the News

- Astrophysicists may have found evidence of sound waves in spiral galaxies, according to a paper by B. G. Elmegreen et al. in the 20 August issue of *Astrophysical Journal Letters* (503, L119-L122, 1998). There is no sign of rapid star formation in the spiral galaxy NGC2207, and the conventional spiral-arm-making mechanisms in which correlated stellar orbits produce spiral density waves, doesn't work so near to the nucleus. Thus, the astrophysicists propose that spirals in the inner 3000 light years are amplified sound waves. Gentle acoustic waves are generated further out in the galaxy, perhaps by supernova explosions, and as they travel inwards they may be focused and amplified by the disk-like geometry to become strong disturbances. If so, they would constitute an impressively loud bass sound, about 56 octaves below middle C. "If a supernova explodes in a galaxy and nobody is there to hear it, is it a sound?" philosophers can now ask.
- A paper by Christo Pantev and colleagues at the University of Münster in the 23 April issue of *Nature* suggests that the degree of cortical reorganization and enhancement of the cortical response to musical notes depends on the age at which musicians first begin learning to play an instrument. Using magnetoencephalographic imaging, along with a single equivalent current dipole model to interpret the auditory evoked field, the researchers found that the younger the subjects were when they started to play, the larger was their cortical reorganization in recognition of piano tones.

A letter by Pat Monaghan et al. (Glasgow) in the 30 July issue of *Nature*, however, suggests alternative interpretations of the results of Pantev, et al. First, perhaps only children with a particular type of cortical response to musical sounds (which may be inherited) are capable of learning an instrument from a very early age. Second, it is possible that children brought up in musical families hear more music at a very young age, inducing more cortical reorganization. Neither explanation requires the children to have practiced an instrument. "Given our current state of knowledge, those wanting musical children might be well advised to examine carefully the musical abilities and compact-disc collections of potential mates, rather than investing in expensive music lessons for reluctant three-year-olds," advise Monaghan, et al.

- When Keith Lockhart conducted the Boston Pops Orchestra in a special concert for MIT alumni ("Tech Night at the Pops"), he wore an instrumented jacket designed by Teresa Marrin and Jocelyn Riseberg, doctoral students at the MIT Media Lab, according to an article in the August issue of *Computer Graphics World*. By connecting a "conductor's jacket" to a computer, the researchers were able to record data about his respiration, heart rate, temperature, muscle tension, and skin conductivity. These were interpreted and displayed as various shapes and colors that the audience could view on a TV screen above the orchestra. Marrin also captured the 3D position of Lockhart's wrists, elbows, shoulders, and torso, and plans were to display a stick figure that would mimic his movements in real time, but the computer driving this display crashed minutes before the performance.
- Our ability to localize sound on the basis of interaural time delays (ITDs) is generally assumed to require the combined activity of many neurons (40 thalamic neurons might be required for a resolution of 16 microseconds). According to a letter by Bernt Skottum in the 11 June issue of *Nature*, however, application of receiver operating characteristic analysis to previously published results suggests that only 6 neurons may be required.

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array can be quite compact. These systems are likely to become available in digital hearing aids within the next few years.

In conclusion, even the best current hearing aids do not restore hearing to normal. This situation may be improved in the future through the use of improved directional microphones and through the use of digital signal processing to improve speech-to-background ratios.

Simulations of some of the effects of cochlear hearing loss may be found on the compact disc "Audio demonstrations to accompany perceptual consequences of cochlear damage" which is available from the author (price US $20).

Brian Moore is Professor of Auditory Perception in the Department of Experimental Psychology, University of Cambridge. He is a Fellow of the ASA and is President of the Association of Independent Hearing Healthcare Professionals (UK). He is the author of Perceptual Consequences of Cochlear Damage *(Oxford University Press, Oxford, 1995), An Introduction to the Psychology of Hearing, 4th Ed. (Academic, San Diego, 1997) and* Cochlear Hearing Loss *(Whurr, London, in press).*

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