

Andrew J. Oxenham

*Postal:*

Department of Psychology  
University of Minnesota  
Twin Cities  
75 East River Parkway  
Minneapolis, Minnesota  
55455  
USA

*Email:*

oxenham@umn.edu

## Psychological and Physiological Acoustics

*Members of the Psychological and Physiological Acoustics Technical Committee have varied interests related to all aspects of hearing.*

The Technical Committee (TC) on Psychological and Physiological Acoustics (P&P) consists of scientists, clinicians, and engineers whose interests converge around the topic of hearing. Committee members in academia come from a wide variety of departments and disciplines, including biology, biomedical engineering, communication disorders, electrical engineering, neuroscience, otolaryngology, physics, psychology, and speech-language-hearing sciences. This broad range of departments highlights the multidisciplinary nature of the field. Of course, not all members work in academic settings, and we have strong industry representation, primarily from people working in the area of medical devices such as hearing aids and cochlear implants.

Progress in the field is being made on several fronts, and there remain many exciting mysteries to solve regarding how the workings of the ear and brain result in our perception of the acoustic environment around us. Since Cherry's (1953) famous paper on the "cocktail party problem," published over 60 years ago in *The Journal of the Acoustical Society of America* (JASA), much effort has been devoted to answering the question of how we are able to perceptually segregate and attend to one or more sounds in the presence of many other competing sounds, noise, and reverberation. In most cases, the problem is mathematically "ill posed": there is no unique solution to how the single pressure waveform reaching the eardrum should be decomposed into the multiple waveforms that were generated by the different sound sources in the environment. Instead, we must rely on previous information or "priors" to correctly parse the incoming signal into "auditory objects" or "streams." These priors may be learned from our previous exposure to sounds or they may be "hardwired" into our auditory system, representing information accumulated over evolutionary time and instantiated in the anatomy and physiology of the ear and auditory neural pathways.

Members of the P&P TC are studying every part of these auditory pathways from the eardrum and middle ear to the primary and secondary auditory cortex in the brain's temporal lobes and at every level of investigation from the mechanics and structure of single hair cells in the cochlea to the whole system approach required when studying perception through behavior in humans and other animals.

Starting with the ear canal, the tympanic membrane, and the middle ear (home to the smallest bones in the human body and the place where airborne sound is transduced into mechanical vibrations of those bones), new insights continue to be made into these first and crucial steps of the transduction process using ever-improving measurement techniques including laser interferometry and digital holographic techniques (e.g., Khaleghi et al., 2016). The cochlea of the inner ear is where the mechanical vibrations produced by sound are transduced into the neural spiking code of the brain. Here, too, new discoveries in physiology, molecular biol-

ogy, and genetics continue to solve puzzles and to raise new questions and controversies. One seemingly simple question is whether the sharpness of frequency tuning within the cochlea is similar across different species of mammals. Early work suggested that it was, and so researchers have generally been comfortable with extrapolating the results from invasive studies of cochlear mechanics in laboratory animals such as guinea pigs and chinchillas to explain human hearing. Over the past 15 years or so, suggestions that human cochlear tuning is considerably sharper than that in other mammals (Shera et al., 2002) has led to renewed interest and controversy in the topic of human cochlear mechanics (Ruggero and Temchin, 2005; Shera et al., 2010), a topic that was pioneered by P&P's own Georg von Békésy, who won the Nobel Prize for his work in the area in 1961.

The inner and outer hair cells, which line the cochlea and sense its vibrations, are an astounding feat of biology and continue to fascinate and confound researchers. While the inner hair cells transduce vibrations into a neural code that is sent along the auditory nerve, the outer hair cells form part of a complex process that amplifies the vibrations, sharpens tuning, and produces “otoacoustic emissions,” sounds that are generated in the ear. Since their discovery, published in a landmark *JASA* article by David Kemp (1978), otoacoustic emissions have been used to provide us with a window into the functioning of the human ear that is now employed as part of the health screening of every newborn infant in the United States.

Hearing loss affects a large number of people around the world and is particularly common among older individuals. Many forms of hearing loss involve damaged or dysfunctional inner or outer hair cells. However, a new form of hearing disorder was recently discovered in animals when it was found that a loud noise that produced only a temporary shift in thresholds resulted in a loss of up to 50% of the synapses that connect the inner hair cells to the auditory nerve (Kujawa and Liberman, 2009). A current hot topic of research is to discover the prevalence and perceptual consequences in humans of this “hidden hearing loss,” which remains undetected by traditional clinical screening tools (Schaette and McAlpine, 2011; Plack et al., 2014).

One of the great triumphs of auditory research has been the cochlear implant. This device is surgically implanted, with an electrode array inserted into the spiral turns of the cochlea to directly stimulate the auditory nerve with electrical pulses. The cochlear implant can restore some func-

tional hearing in people who were previously deaf to the extent that many cochlear-implant recipients can understand speech, even in the absence of lip-reading cues. Well over 300,000 devices have been implanted worldwide, and it is now common to provide deaf infants as young as 12 months with a cochlear implant. Despite its tremendous success, users of the cochlear implant still face numerous challenges, including understanding speech in noisy environments and perceiving pitch in music. Because of these remaining challenges, the push to better understand perception via a cochlear implant and to improve its performance continues; in 2015, a total of 15 articles on cochlear implants appeared in *JASA* alone. Exciting new work is being done in the area of alternative auditory implants, in the brainstem and even in the midbrain, for patients for whom a traditional cochlear implant is not an option, perhaps because of a tumor or the lack of an auditory nerve.

At a less invasive level, hearing aids still remain the best option for most people with a hearing loss that ranges from mild to severe. Although the technology itself goes back a long way, cutting-edge new signal-processing algorithms are constantly being updated in these devices to take advantage of the more rapid and powerful digital signal processing that can now be fitted within hearing aids. Here, too, researchers and companies are experimenting not only with the type of processing but also with the type of stimulation, be it via bone conduction or direct mechanical stimulation of the eardrum.

The auditory brain still remains something of a mystery for researchers despite the enormous strides that have been made over the past 50 years in understanding how signals are passed from the cochlea to the brainstem and midbrain structures and then on to the auditory cortex. Although perceptual attributes and features, such as pitch, loudness, brightness, and perceived location, have been identified and studied psychophysically, it is often challenging to find clear neural correlates of these features. The percept of pitch is one where neural correlates have been identified (e.g., Bendor and Wang, 2005), although considerable uncertainty regarding the location and underlying mechanisms remain. Neuroimaging techniques, such as EEG (electroencephalogram), MEG (magnetoencephalography), and fMRI (functional magnetic resonance imaging), are being recruited to solve some of these mysteries in the human brain. In addition, cutting-edge technologies, such as two-photon imaging and optogenetics, are being employed in other species to decipher how the brain processes sound and to discover

how deficits in human hearing can be treated beyond the ear itself. One area that is likely to grow in the coming years involves the study of the efferent or top-down pathways. Although most introductory accounts of auditory processing concentrate on the pathway from the ear to the brain, there are at least as many, and probably more, pathways extending from higher cortical levels down to brainstem structures and back to the ear itself. These pathways remain an under-explored but fascinating opportunity to understand how “higher level” processes, such as attention, expectation, and prior sound experiences, can shape how sound is processed as early as the ear itself.

Because of the clear health implications of hearing and its disorders, the National Institutes of Health, including the National Institute on Deafness and Other Communication Disorders (NIDCD), have been the primary sources of research funding for work in the P&P area in the United States. The basic scientific interest in communication has led to support from the National Science Foundation over the years, and the ubiquitous role of acoustics at many levels of communication has led to interest and support from many defense-related agencies. Support in other countries has also been primarily through national funding agencies in medicine, science, and technology.

Members of P&P are active at all levels of the Acoustical Society of America (ASA), forming a good proportion of the Society-wide award winners (including the 2014 Gold Medal winner, Brian C. J. Moore, and the R. Bruce Lindsay award winner, Matthew Goupell) as well as taking on leadership roles, with the 2014-2015 President Judy Dubno and Vice President Barbara Shinn-Cunningham, both active and long-standing members of the P&P TC.

There are obvious links between P&P and several other TCs as evidenced by the many joint and cosponsored sessions held at every ASA meeting. Most closely related are the TCs on speech, musical acoustics, animal bioacoustics, and noise. Understanding speech is, of course, a primary function of human hearing and it is the main target of efforts to restore hearing via hearing aids and cochlear implants. A love of music is what attracts many researchers to the field of auditory perception in the first place, and the study of music perception in both normal, impaired, and electric hearing remains a topic of great scientific interest in the P&P community. Of course, an interest in music is not something unique to P&P or even those in the committee on musical

acoustics; based on the talent on display at the regular jam sessions of the ASA, musical leanings are shared by members from all areas of the Society.

---

## Biosketch

---



**Andrew J. Oxenham** is a Distinguished McKnight University Professor in the Departments of Psychology and Otolaryngology at the University of Minnesota Twin Cities. After studying Music and Sound Recording (Tonmeister) at the University of Surrey, UK, he obtained

a PhD in experimental psychology from the University of Cambridge, UK. He worked at the Institute of Perception Research (IPO), Northeastern University, and MIT before going to Minnesota in 2006. He has authored over 150 articles and chapters and was the recipient of the Acoustical Society of America 2001 R. Bruce Lindsay Award and the National Academy of Sciences 2009 Troland Award. He currently serves on the ASA Executive Council.

---

## References

---

- Bendor, D., and Wang, X. (2005). The neuronal representation of pitch in primate auditory cortex. *Nature* 436, 1161-1165.
- Cherry, E. C. (1953). Some experiments on the recognition of speech, with one and two ears. *The Journal of the Acoustical Society of America* 25, 975-979.
- Kemp, D. T. (1978). Stimulated acoustic emissions from within the human auditory system. *The Journal of the Acoustical Society of America* 64, 1386-1391.
- Khaleghi, M., Cheng, J. T., Furlong, C., and Rosowski, J. J. (2016). In-plane and out-of-plane motions of the human tympanic membrane. *The Journal of the Acoustical Society of America* 139, 104.
- Kujawa, S. G., and Liberman, M. C. (2009). Adding insult to injury: Cochlear nerve degeneration after “temporary” noise-induced hearing loss. *Journal of Neuroscience* 29, 14077-14085.
- Plack, C. J., Barker, D., and Prendergast, G. (2014). Perceptual consequences of “hidden” hearing loss. *Trends in Hearing* 18, 1-11.
- Ruggero, M. A., and Temchin, A. N. (2005). Unexceptional sharpness of frequency tuning in the human cochlea. *Proceedings of the National Academy of Sciences of the United States of America* 102, 18614-18619.
- Schaette, R., and McAlpine, D. (2011). Tinnitus with a normal audiogram: physiological evidence for hidden hearing loss and computational model. *Journal of Neuroscience* 31, 13452-13457.
- Shera, C. A., Guinan, J. J., Jr., and Oxenham, A. J. (2002). Revised estimates of human cochlear tuning from otoacoustic and behavioral measurements. *Proceedings of the National Academy of Sciences of the United States of America* 99, 3318-3323.
- Shera, C. A., Guinan, J. J., Jr., and Oxenham, A. J. (2010). Otoacoustic estimation of cochlear tuning: Validation in the chinchilla. *Journal of the Association for Research in Otolaryngology* 11, 343-365.