Conversation with a Colleague: Karl Grosh

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Meet Karl Grosh

Karl Grosh is the next acoustician in our "Sound Perspectives" series "Conversation with a Colleague." He is a professor of mechanical engineering and biomedical engineering as well a member of the Kresge Hearing Research Institute, University of Michigan, Ann Arbor. He received his BS and MS degrees in engineering science from The Pennsylvania State University, State College, and his PhD in mechanical engineering from Stanford University, Stanford, California. From 1987 to 1990, he was a research scientist at the Naval Research Laboratory, Washington, DC. He is a Fellow of the American Society of Mechanical Engineering (ASME) and the Acoustical Society of America, and in 2019, he received the ASME Per Brüel Gold Medal for Noise Control and Acoustics. From 2007 to 2009 and 2017 to 2019, Karl acted as associate chair of mechanical engineering; his current service activities emphasize diversity, equity, and inclusion in engineering. He cofounded a piezoelectric microelectromechanical system (piezoMEMS) transducer company, Vesper Technologies. We asked Karl to give us his elevator pitch and then to elaborate on his inspirations, contributions, and hopes for the future.

Give your "elevator speech" about the thrust(s) of your scholarly work over your career.

A major focus of my work has been in the study of biological and engineered acoustic transduction. My work seeks to understand the fundamental structure-function relationships in the mammalian cochlea by building mechanistic mathematical models. We test hypotheses of active processes by comparing with and predicting experimental outcomes obtained by my amazing colleagues in cochlear electrophysiology. By understanding the cochlea well enough to model it, we hope to aid in the protection of hearing and in the development of noninvasive testing procedures, auditory prostheses, and sound-processing algorithms.

I started work in engineered electroacoustic transducers in 1985 during my master's thesis work at the Penn State Applied Research Lab's sonar research lab by designing and assembling piezoelectric actuators and sensors for a wave number-frequency measurement system. Fast-forward to the University of Michigan where we now leverage the tremendous dimensional control available by using microelectromechanical systems (MEMS) techniques to build miniature acoustic and vibrational sensors, first for consumer electronics and, more recently, for middle ear accelerometers for use in completely implantable auditory prostheses. Finally, our group has also been exploring the design of acoustic metamaterials using active, subwavelength electromechanical designs to achieve sound-quieting and nonreciprocal wave propagation. I thought I was a latecomer to the relatively new field of metamaterials; I recently realized I had been studying one of the world's oldest active acoustic metamaterial systems, the mammalian cochlea!

What inspired you to work in this area of scholarship?

Luck and amazing people! In the fall of 1983 while an undergraduate at Penn State, my advisor Sabih Hayek (2003 Trent-Crede Medal awardee and Professor Emeritus of Engineering Science) called to offer me a job to study the diffraction of sound by highway noise barriers. I remember fondly telling Sabih that I'd have to ask my parents first (they were delighted!). This position opened me up to the world of acoustics, including the beautiful geometric theory of diffraction, advanced mathematics,

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and the joy and frustration of comparing theory to experiment. Moreover, I was immersed in this world of research, where people were actually paid to do this fascinating work and learn new things. I was hooked.

I have been lucky to have supportive mentors throughout my career: Sabih, Jack Hughes, and Courtney Burroughs at Penn State, Earl Williams at the Naval Research Lab, and Peter Pinsky at Stanford (see profiles.stanford.edu/peter-pinsky). They always strongly challenged me during meetings and strongly supported me with advice and resources to achieve my goals. By far my best and strongest partner has and continues to be my wife Linda, whose support lets me focus when the page before me is empty and keeps me strong when times are the toughest. She was the first to realize that I really needed to obtain a PhD to attain my goals and has supported and encouraged me at each step of the way in my career.

Of all your contributions during your career, which are you most proud of and why?

When I was recruiting Bobby Littrell to my lab as a PhD student in mechanical engineering at the University of Michigan, he mentioned that he was very interested in research in acoustic transducers (microphones and loudspeakers in particular). I told him in no uncertain terms that I thought that microphone and loudspeaker research was not a fertile area, but I did have the great idea to build an active, engineered cochlea; he took that challenge. We worked toward that goal but quickly realized that integrating microscale piezoelectric bimorphs to act as sensing and amplifying outer hair cells (OHCs) in our microfluidic biomimetic cochlea was too big a challenge for a reasonable-length PhD project. So we pivoted to perfecting the design and manufacture of these tiny biomorphs first. Bobby convinced me to work on a microphone design as the model problem using the biomorphs (to provide some purpose to the design before returning to the biomimetic cochlea). For any number of reasons, I was sure this design would not be successful, but Bobby quickly disavowed me of this notion by inventing a better mousetrap, building a low-noise piezo-MEMS microphone for the first time. This became Bobby's thesis topic. I was never so glad to be so very wrong!

We went on to cofound a company that had over 50 employees worldwide and that was funded by Small Business Innovation Research (SBIR) grants, venture capital, and sales revenue. Our company, Vesper Technologies (see vespermems.com), was eventually acquired by Qualcomm. It is gratifying to have an outcome of academic research result in a practical device and even more so to see it successfully commercialized thanks to the hard work of many talented people. This project, our piezo-MEMS microphone, is a nice example of how research works, not always in the way originally intended, but it works. Sometimes we are fabulously successful. Often, we fail, but even when research fails, it succeeds because we teach others that a certain pathway is unproductive and an alternative should be sought. My philosophy is to let talented people follow their passion and seek to provide resources to make that happen.

The cochlear biomimicry research led to our interest in ultraminiature sensors. Now our transducer research has circled back to the cochlea, and we seeking to use these sensors as part of a totally implantable auditory prosthesis.

What are some of the other areas in which you feel you made substantive contributions over your career?

Since the discovery of OHC somatic electromotility in 1985 by Bill Brownell and colleagues (see bit.ly/AT-Bownell), a question that dogged cochlear biophysics was whether OHCs could overcome the filtering associated with the membrane's basolateral capacitance and conductance. Using mathematical models for the active and nonlinear response of the cochlea to acoustic input, we have demonstrated that OHC somatic motility is able to power the biologically vulnerable process known as cochlear amplification. There are still open scientific questions plaguing cochlear mechanics, for instance, the role of nonlinearity in processing complex sounds like speech, is still incompletely understood. To aid in developing mechanistic explanations for experimental results as well as to conceive of new theories, we have sought to develop a cochlear model that can be both challenged by new biophysical experimental data and enriched by the same data (to improve the model). In that way, it provides a platform for a mechanistic understanding of cochlear processing.

Another line of work that I was involved with and am proud of was focused on both theory and experiment for growth and remodeling of tendons and ligaments. This research focused not only on these tissues in their natural setting but also in a bioreactor setting as part of an effort to learn how to grow replacement tissues. Working with a team of researchers, including my mechanical engineering colleagues Ellen Arruda and Krishna Garikipati at the University of Michigan, we developed procedures for tissue engineering of tendons and ligaments using cells from the host as well as characterization of the constructs' mechanical behavior and phenotype. Furthermore, we developed a nonlinear model for growth and remodeling of biological tissues that is widely cited.

What do you think are the most pressing open questions that you would like to focus on over the next 5-10 years?

Hearing aids and cochlear implants represent amazing technology. I would like to see totally implantable hearing aids and cochlear implants become a reality, to improve the activities that auditory prostheses users can partake in, allow 24/7 use, and allow for a more naturalistic sound input (using the natural design of the pinna and ear canal). In this way, we may remove a barrier for adoption and allow for more patients to utilize these devices.

The nature of the cochlear amplifier is still in debate nearly 40 years after the discovery of the electromotility of OHCs by Bill Brownell. The structure of prestin and the components of the mechanoelectrotransducer (MET) channels are now tantalizingly close to being completely described at the molecular level. With these data in hand, I hope that we as a field can come to a complete structure-function relationship for OHC-mediated active processes.

Finally, both cochlear-inspired and engineered nonlocal active acoustic metamaterials hold the promise of unprecedented control of wave propagation in acoustic media (structures and fluids). I would like to see these materials studied in more detail because they hold great practical promise and scientific interest.

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