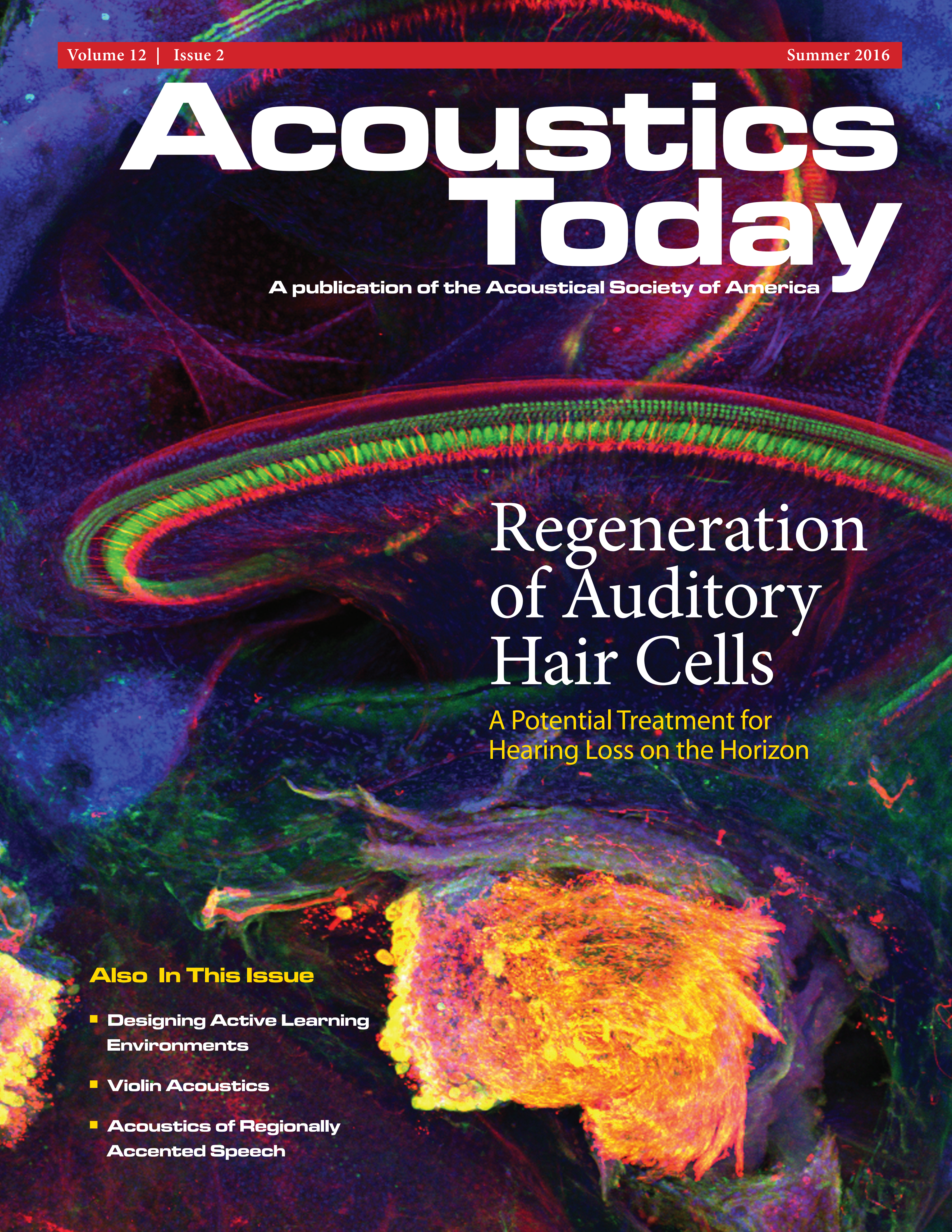
Volume 12 | Issue 2 Summer 2016

Acoustics Today

A publication of the Acoustical Society of America



Regeneration of Auditory Hair Cells

A Potential Treatment for Hearing Loss on the Horizon

Also In This Issue

- Designing Active Learning Environments
- Violin Acoustics
- Acoustics of Regionally Accented Speech

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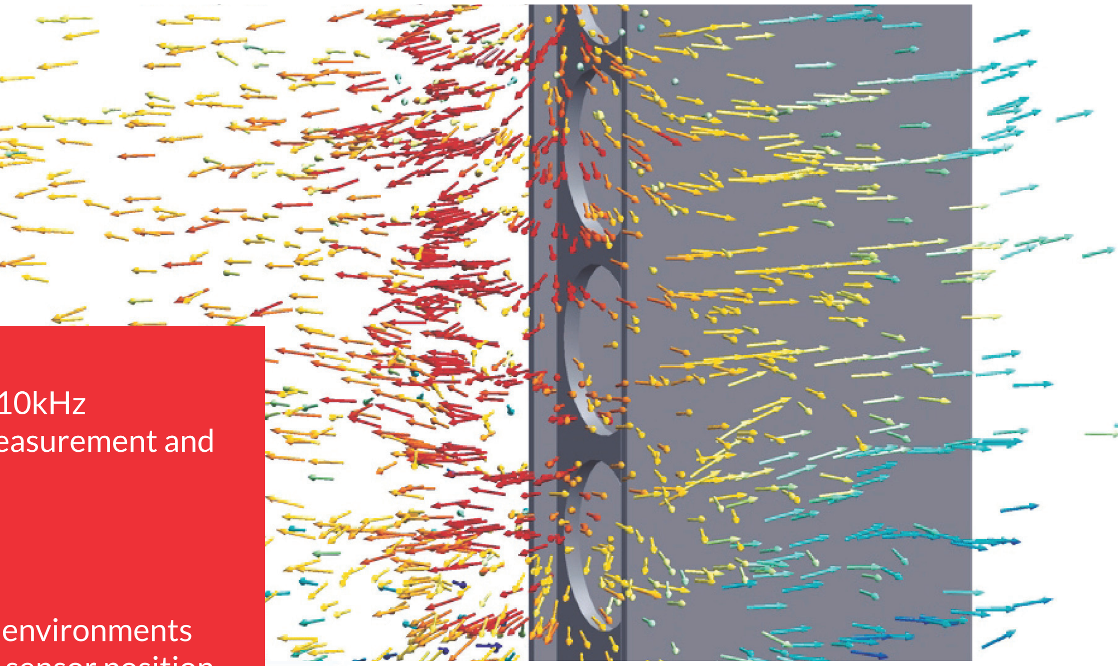
3D Sound Vectors on a 3D model



KEY FEATURES

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  · Particle velocity vectors
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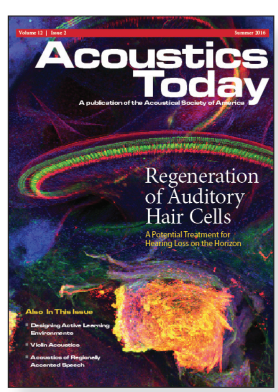

The cover image is from the article, Regeneration of Auditory Hair Cells: A Potential Treatment for Hearing Loss on the Horizon, by Rebecca Lewis, Edwin Rubel, and Jennifer Stone, located on pages 40-48 of this issue (see Figure 2a). It is a photomicrograph of a side view the mammalian cochlea stained by fluorescent antibodies. The apex, encoding low frequencies, is toward the top and it spirals toward the base (high frequencies). The rows of hair cells (green) and adjacent nerve fibers (red) are seen along with the spiral ganglion neurons (yellow mass at the bottom). Image provided by Glen MacDonald and Edwin Rubel.

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508-362-1211

Acoustical Society of America

The Acoustical Society of America was founded in 1929 "to increase and diffuse the knowledge of acoustics and to promote its practical applications." Information about the Society can be found on the Internet site: **www.acousticalsociety.org.**

The Society has approximately 7,000 members, distributed worldwide, with over 30% living outside the United States.

Membership includes a variety of benefits, a list of which can be found at the website:
www.acousticalsociety.org/membership/membership_and_benefits.

All members receive online access to the entire contents of the *Journal of Acoustical Society of America* from 1929 to the present. New members are welcome, and several grades of membership, including low rates for students and for persons living in developing countries, are possible. Instructions for applying can be found at the Internet site above.

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From the Editor | Arthur N. Popper

This is an eclectic issue with topics ranging from regeneration of sensory hair cells of the ear to the acoustics of my favorite instrument, the violin. But before discussing the articles in the issue, I do want to mention that we are looking for a new *Acoustics Today (AT)* intern to join us for a year of being part of the print and Web presence of *AT*.

You may recall that our first *AT* intern, Laura Kloepper, worked on helping *AT* (and ASA) move into social media in a big way. Our current intern, Andrew (Pi) Pyzdek, is doing a series of articles for the *AT* Web page on various interesting areas of acoustics that are very much aimed at a lay audience (http://goo.gl/Fg0bDJ). You can find out more about being an *AT* intern at http://goo.gl/tiKPp0. The specific responsibility for each *AT* intern varies and depends on the interests of the individual and the needs of the magazine. I'm very glad to explore ideas that anyone might want to propose.

One of the real contributions of ASA is in the education of future acousticians and the public about our disciplines. The fall 2015 issue of *AT* had an article about overall education projects of the society (http://goo.gl/IEUthG). This issue has an article on new and very interesting approaches to overall education, with specific examples using acoustics but which are applicable to most any discipline. Thus, this article written by John Buck, Kathleen Wage, and Jill Nelson might be shared with a far broader audience than just ASA members.

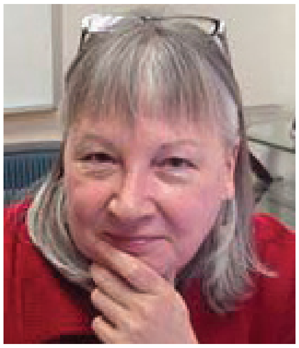
In the next article, Colin Gough shares his abiding interest, and hobby, on the acoustics of violins. Colin points out that even experts sometimes cannot differentiate between the sounds of some of the oldest and rarest instruments and new instruments. Colin takes advantage of multimedia, available on the *AT* Web site, to illustrate acoustics and the sounds produced by violins.

Ewa Jacewicz and Robert Fox explore the variation in sounds in a very different way in a discussion of regionally accented speech. This paper came out of a wonderful presentation that Ewa and Robert made at a recent ASA meeting. It provides substantial insight into the variation in speech around the United States and, again, takes advantage of multimedia to illustrate how speech varies.

The final article moves from sound production to sound reception. One of the major health issues in the United States and around the world is hearing loss, and much of this loss results from damage to the sensory hair cells of the inner ear. Becky Lewis, Jenny Stone, and Edwin Rubel provide great insight into recent studies that are trying to figure out methods to regenerate hair cells in the mammalian ear.

The issue also has a number of other articles of interest. Regretfully, ASA has lost several distinguished members in the past months and this issue thus includes four obituaries. However, unlike "standard" obituaries, the goal of *AT* is to include material that gives insight into the scholarly contributions of very interesting people. Thus, although most people tend to skip obituaries, I encourage you to look at those published here for interesting information about various areas of acoustics.

As always, I am pleased to hear about ideas for future articles for *Acoustics Today*. Please drop me an email with ideas (apopper@umd.edu) and I'll get back to you quickly.



I am writing this column on a crisp, bright blue spring day. There is just a hint of red and green in the trees and purple and yellow early bloomers line our paths. Although T. S. Eliot may claim April as the cruelest month, it's my favorite for all the promises it holds. It is the perfect backdrop for this latest update on what we have achieved so far in these early days of our Strategic Leadership for the Future Plan.

One of the Acoustical Society of America (ASA) signal strengths is the energy, enthusiasm, and commitment of our members and the grassroots nature of our work together. In the spring column, President Christy K. Holland and I reported on the four goals in the plan and an initial set of achievements. These very early achievements demonstrated how effective a focused and coordinated set of actions can be in situating ASA to build on our strengths and, importantly, use them to rise to the challenge of thinking and acting strategically.

In just the past few months, through the collective hard work of four task forces assigned to move the goals forward, there is now even more to report. The successes to date, in addition to those iterated in the spring issue, are impressive.

Along with those successes, there are additional, important transitions taking place within ASA. One significant one is the retirement of our Standards Manager Susan Blaeser following the Salt Lake City meeting and after 16 years of excellent dedication to the Society. A Search Committee consisting of Susan Blaeser, myself, Robert Hellweg, William Murphy and Standards Director Christopher Struck conducted a search for Susan's replacement. The position attracted close to 20 applicants in a highly competitive field. The committee selected Neil Stremmel, who is now working full time with Christopher and Susan in transitioning duties. He brings a wealth of experience from the United States Bowling Congress (USBC) where he served for 16 years as Technical Director, Director of Research, and Managing Director.

What follows is a report on initiatives and accomplishments in each of the four goal areas of the Strategic Leadership for the Future Plan.

Goal 1: Awareness of Acoustics
(Michael Stinson, Chief Champion)
In a project that crosses the scope of three goals (Awareness of Acoustics, Member Engagement and Diversity, and Dissemination of Knowledge), the ASA Standards Program is also embarking on a project with ASA Web Office Manager Dan Farrell to make the S1.1 and S3.20 Terminology Standards available on the ASA Standards Web site as a searchable index. This tool will enable users to search terminology standards for individual terms and will be available to all ASA members. It is expected to be launched on the ASA Web site by July 1, 2016.

A long-time aspiration for the Society is fulfilling the need for an Education and Outreach Coordinator. A search for a full-time coordinator is currently underway under the auspices of a Search Committee consisting of Fredericka Bell-Bertie, David T. Bradley, Tracianne Nielsen, Victor Sparrow, and myself. The position announcement drew more than 40 responses. The committee is currently in the process of vetting resumes and scheduling the first round of interviews. We hope to have someone on board in the very near future.

Last fall, the ASA Web Office migrated the entirety of the ExploreSound.org site, from the Optical Society of America to ASA servers. Recently, the ASA launched a contest (http://exploresound.org/explore-sound-logo-competition/) to develop a new logo for the site, a vehicle that initially focused strictly on K-12 outreach activities but will now evolve into an outreach mechanism for the entire field of acoustics. The new logo will be used to brand not just the ExploreSound site but other ASA outreach activities as well.

Goal 2: Member Engagement and Diversity
(Lily Wang, Chief Champion)
Because not all ASA members have the capacity to attend Society meetings, ASA initiated an effort to broadcast over the Web seven special sessions and one Technical Committee meeting at the Fall 2015 meeting. This initial effort was such a success that ASA expanded broadcasts at the spring meeting to 19 sessions. All Hot Topic sessions were recorded or broadcast live.

This year, we offered for the first time an Early Career Acousticians Retreat (EAR) (http://acousticalsociety.org/early-career-acousticians-retreat-2016) in Salt Lake City on Friday

Continued on next page

and Saturday, May 27-28, 2016. The goal of the workshop was to help develop leadership and networking skills for early career professionals in the field of acoustics. The workshop provided an opportunity for attendees to connect and socialize with fellow early career acousticians, expand leadership and networking skills, learn more about the Society, and contribute to the future of ASA. It featured a keynote speech by Gregory B. Northcraft, Harry J. Gray Professor of Executive Leadership in the Department of Business Administration at the University of Illinois. The response rate for the retreat exceeded expectations and as of this writing more than 40 people are expected to attend.

To properly engage members, it is important that we first better understand the makeup of the current membership. Another initiative of the Goal 2 Task Force is to analyze ASA membership data to determine what information is currently available and what information ASA needs in order to best position the Society toward understanding future trends, challenges, and opportunities within our demographic.

Goal 3: Dissemination of Information and Knowledge
(James Lynch, Chief Champion)
Last fall, the ASA Executive Council approved funds to hire a full-time Managing Editor for the Publications Program. Mary Guillemette, Publications Manager, James Lynch, Editor in Chief, and Helen Murray, *POMA* Manuscript Manager and *AT* Coordinator, conducted a search, with the successful conclusion in the hire of Elizabeth Bury. Ms. Bury comes to the position with over eight years of experience in a scientific journal editing office, the last four of which she served as Associate Managing Editor.

This position will oversee the entire submission, review, and transmittal workflow for *JASA*, including guiding implementation of new features and helping to resolve process and technical issues. Ms. Bury has had much experience working with the Editorial Manager system and will help train the publications staff in its use and capabilities as well as assist authors, handling editors, and reviewers in negotiating the system. The hiring of additional full-time staff for the Publications Office is a significant step forward in our journal operations and we look forward to benefitting from Ms. Bury's expertise.

The Publications Program also successfully transitioned all three journals' (*JASA, JASA EL* and *POMA*) peer review system from PeerXpress (PXP) to Editorial Manager (EM), resulting in better control of the submission system and allowed for the development of new options in the process. Further, the Publications Program instituted important initiatives such as "Gold" open access, Publish-Ahead-of-Print (PAP), video and sound multimedia files, and supplementary material file archiving for the *Journal*.

Goal 4: Financial Stewardship
(David Feit, Chief Champion)
The Task Force for Goal 4 is in the process of addressing two actions: one, creating a clear charge to establish a Finance Committee and two, analyzing ASA operations and finances to assess the need for a new business model to guide the Society into the strongest position in terms of income, subsidies, reserves, and fiscal transparency. Once these issues are addressed, plans are in place to hire a full-time Finance Manager to help ASA achieve its fiscal goals as guided by the Treasurer and the Executive Council.

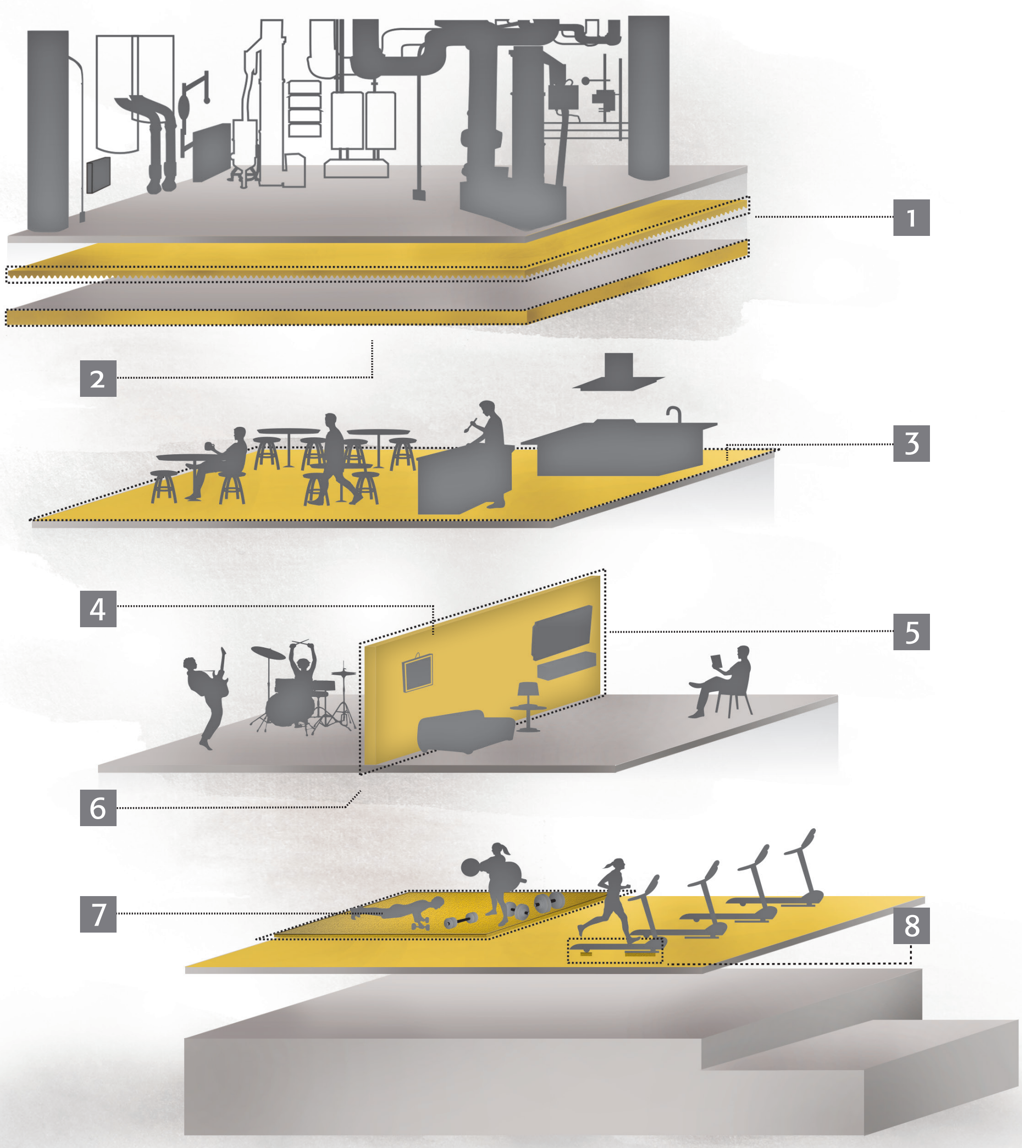
Conclusion
These, of course, are not the only activities to be generated in each of the four goal areas. Nonetheless, these are indicative of the amount of energy, focus, and commitment that exists among members and leadership to work collaboratively toward our core purpose to increase and diffuse the knowledge of acoustics and its practical applications.

This is both a five- and ten-year plan. The fact that so much energy released in just the early months of the plan demonstrates that this will not be one to sit on the shelf and that this, in fact, will be a plan with a number of demonstrable outcomes, resulting in an even stronger, more resilient, and nimble ASA.

Membership in any of the four goal task force groups is open, and we welcome your ideas and especially your participation. I encourage your involvement. There's great enthusiasm behind the Strategic Leadership for the Future Plan and much ambitious, creative thinking about how to bring these goals to fruition. Your voice is important and valued as we move forward.

Other opportunities exist for participation. Between meetings, the task force groups meet via conference calls. Let me or any of the Chief Champions know of your interest and we will add you to the task force. We also welcome suggestions, thoughts, and ideas related to the goals that you can relay in more informal ways. What's most important is that moving ASA forward is a collective enterprise, and there are many ways to let a 1,000 flowers bloom.

I hope that you will join us.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From the Editors of *JASA-EL* and *POMA*

Charles C. Church and Kent L. Gee

The Acoustical Society of America (ASA) has a number of ways of disseminating the scholarship of the acoustics community. Although *The Journal of the Acoustical Society of America (JASA)* is very well-known to members and you are reading *Acoustics Today*, ASA has two other important journals that members should be aware of and consider as outlets for their scholarly works.

The Journal of the Acoustical Society of America-Express Letters

The Journal of the Acoustical Society of America-Express Letters (JASA-EL) is dedicated to providing rapid and open dissemination of important new research results and technical discussion in all fields of acoustics. Access to *JASA-EL* is free online to all readers. The ASA also strives to make publication in *JASA-EL* as affordable as possible for everyone regardless of financial circumstances. Thus the Society subsidizes each paper by an amount equal to approximately two-thirds of the total cost of publication. And with a maximum length of 6 pages, *JASA-EL* papers are short enough to allow several to be read at a sitting, permitting the reader to become familiar with all aspects of our wide-ranging Society.

Another significant advantage offered by *JASA-EL* is that contributions are permanently archived in their entirety, including all audiovisual files and any other multimedia. Furthermore, letters are published online as soon as possible after the authors have reviewed the proofs. Letters also appear monthly as a section in *JASA* with links to color figures and multimedia files. And, of course, the contents are fully indexed by all of the major abstracting and indexing services.

How can you become part of this important and exciting function of our Society? In many ways! Do you have an interesting new result? Then submit an article! Are you good at critiquing the writing of others? Then consider joining us as an Associate Editor in your area of technical expertise! Do you have an idea for a collection of papers on a particular topic? Then consider joining us as a Guest Editor and make it happen! Have you developed a new way to demonstrate an important acoustical principle? Then record it and submit it as a video-paper! Send your name and your ideas to Charlie Church (cchurch@olemiss.edu) and join the fun today!!

Proceedings of Meetings on Acoustics

Proceedings of Meetings on Acoustics (POMA) publishes articles from our semiannual meetings and also serves a critical role in expanding the ASA's global reach by publishing the proceedings of workshops and meetings cosponsored by the Society. *POMA* also serves as an important archival bridge between ASA meetings and its fully refereed journals. Moreover, publication in *POMA* does not preclude submission to the peer-reviewed *JASA* or *JASA-EL*. To date, over 2,500 articles from ASA and other cosponsored meetings have been published in 25 volumes, with four new volumes planned for 2016.

Publication of a proceedings paper should be rapid and cost effective. Archival-ready manuscripts are reviewed by *POMA* associate editors for correctness and clarity. A newly designed cover page and manuscript template, coupled with on-going efforts to streamline processing, make *POMA* an attractive choice for disseminating new research findings, case studies, and historical perspectives. Additionally, publication in *POMA* remains free of charge in nearly all cases; only non-ASA members submitting to a cosponsored meeting must pay a nominal publication fee.

The visibility and utility of *POMA* are increasing. In addition to ensuring *POMA* indexing in Google Scholar, Compendex, and other technical document search engines, we have rolled out two new opportunities for ASA special session organizers. First, organizers can write an article to describe the session – its scope, participants, discussion, and outlook. Second, with a sufficient number of papers, articles from one or more special sessions can be grouped as a collection on the *POMA* hosting site Scitation.

Why submit to *POMA*? A 200-word abstract typically contains insufficient detail to be useful to future researchers, yet relatively little of the outstanding technical content from our meetings is ever published. We encourage researchers and practitioners, students and professionals alike, to turn their abstracts and presentations into an archival proceedings paper and submit to *POMA* today!

Kent Gee, kentgee@byu.edu

Designing Active Learning Environments

John R. Buck

Postal:
Electrical and Computer Engineering (ECE) Department
University of Massachusetts Dartmouth
285 Old Westport Road
Dartmouth, Massachusetts 02747-2300
USA

Email:
johnbuck@ieee.org

Kathleen E. Wage

Postal:
Electrical and Computer Engineering (ECE) Department
George Mason University
4400 University Drive
Fairfax, Virginia 22030
USA

Email:
k.e.wage@ieee.org

Jill K. Nelson

Postal:
Electrical and Computer Engineering (ECE) Department
George Mason University
4400 University Drive
Fairfax, Virginia 22030
USA

Email:
jnelson@gmu.edu

Switching from lecture to active learning is an act of courage, but the growing consensus of research on the benefits of active learning is difficult to ignore.

"...teachers possess the power to create conditions that can help students learn a great deal -- or keep them from learning much at all. Teaching is the intentional act of creating those conditions..." - Parker Palmer (1998)

Introduction

What conditions help students learn? How do we design a course environment to foster those conditions? How can we tell if students are learning what we teach? The advent of massive open online courses (MOOCs) and flipped classrooms has reinvigorated discussion of these questions in higher education. At the same time, research by Kuhl and her colleagues (2003, 2010) demonstrates that even infants learn better from engagement with a live person than they do from watching recordings. Kuhl et al.'s research resonated with our own experience that university students also learn better from interactive engagement than from passive viewing of lectures. Recent neuroscience and education research on learning and memory confirms the benefits of active learning, which includes techniques such as collaborative in-class problem solving (Ambrose et al., 2010; Brown et al., 2014). This article highlights research on active learning and describes our implementation of it in engineering courses.

DJ Prof versus Popstar Prof

Blending active learning with some lecture and external resources such as textbooks and videos creates the conditions needed for a student-centered learning environment. In a musical analogy, the professor in a student-centered course becomes the DJ, mixing together multiple modes of instruction for the students' benefit (**Figure 1**). In contrast, the professor in a traditional lecture course is the soloist or pop star, delivering content with minimal feedback from students. Although many faculty worry that changing from lecture to student-centered learning means that they will not have time to cover as much material, the data indicate that students master more material despite the professor covering less. Switching from lecture to active learning is an act of courage, but the growing consensus of research on the benefits of active learning is difficult to ignore.

Research on Learning

Two recent books provide guidance on creating effective conditions for student learning in university-level courses. *How Learning Works* (Ambrose et al., 2010) presents seven principles for teaching derived from the literature on psychology, anthropology, and organizational behavior. Ambrose et al.'s first principle is "Students' prior knowledge can help or hinder learning." The book's discussion of this principle (p.4) highlights the importance of addressing students' prior misconceptions to help them learn new material. Simply informing students of their miscon-

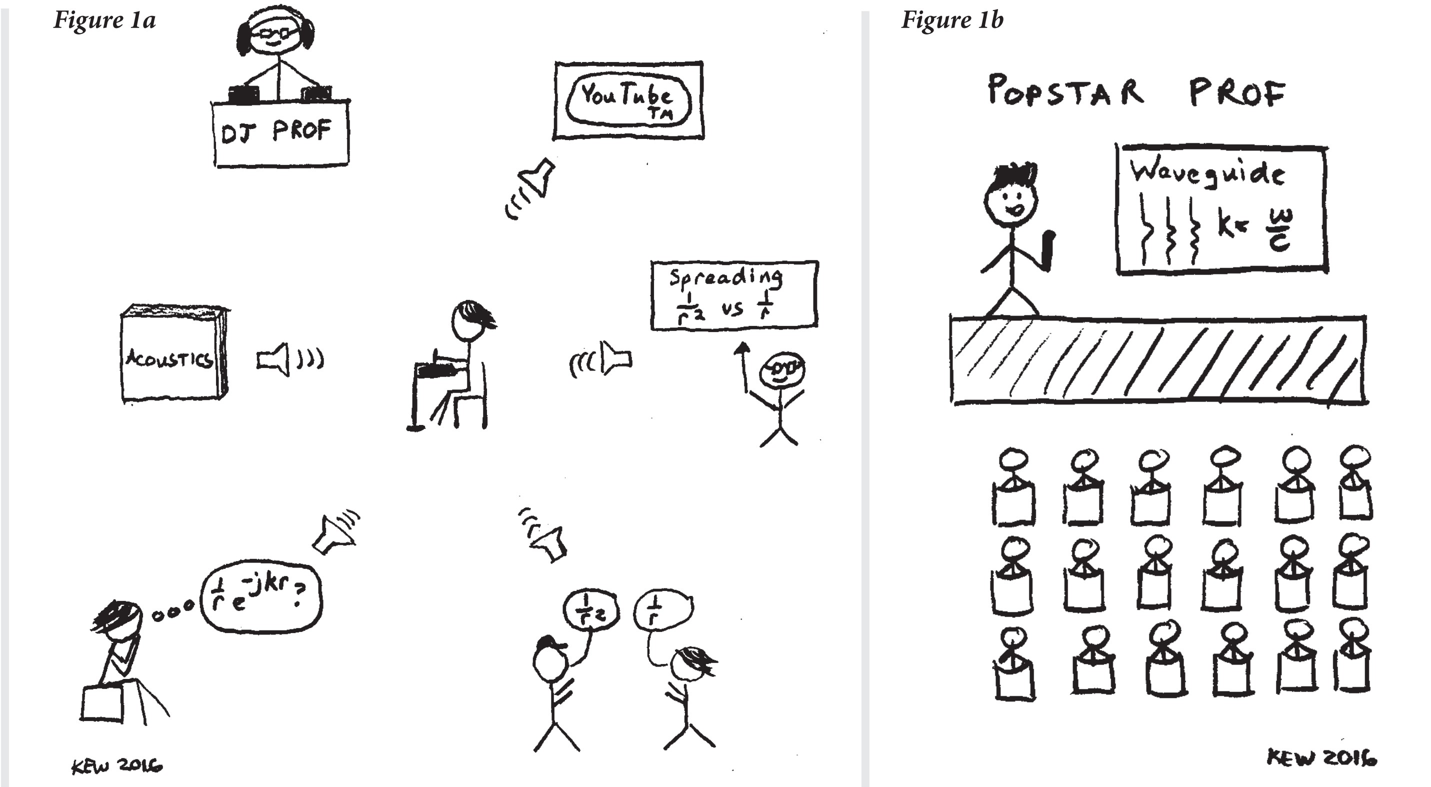

Figure 1. *a: In a student-centered course, DJ Prof mixes multiple modes of instruction: Think-Pair-Share exercises, lecture, video examples, and reading assignments. b: In an instructor-centered course, Popstar Prof presents a lecture with little or no feedback from the students.*

ception is rarely sufficient to dislodge that misunderstanding. A better approach is to have students confront their misconceptions through exercises that ask them to predict the outcome of an experiment and then carry out that experiment and analyze the results. *Make it Stick* (Brown et al., 2014) grew out of a 10-year project to apply cognitive science research to improve education. Brown et al. assert that many people use suboptimal learning strategies that are not supported by research, and that "the most effective learning strategies are not intuitive" (p. ix). For example, Brown et al. observe that "trying to solve a problem *before being taught the solution* leads to better learning," (p. 4, emphasis original). Neither of these books provides step-by-step instructions for designing and implementing courses. Rather, they present a set of general principles, derived from research, to create conditions for effective learning.

Many university courses are still taught in the standard lecture format. The lecture is an ancient form of instruction, dating back to at least medieval times in western European universities (see **Figure 2**). As Professor Joe Redish of the University of Maryland points out, lecture predates the printing press (Hanford, 2011). An instructor would read a manuscript to students so that the students could make copies for themselves. In a world without printed books, this makes perfect sense. In a world with not only books but also an Internet full of articles, podcasts, TED talks (www.ted.com), and YouTube videos (www.youtube.com), is lecture the best way to educate students? To answer this question, consider several analyses of student learning in science, technology, engineering, and math (STEM) courses.

Benefits of Active Learning

Hake (1998) compared student learning in traditional lecture-based physics courses with learning in *interactive engagement* (IE) courses. He defines IE courses as those that are designed to "promote conceptual understanding through interactive engagement of students in heads-on (always) and hands-on (usually) activities which yield immediate feedback through discussion with peers and/or instructors" (Hake, 1998, p. 65). For our purposes, we consider IE to be synonymous with active learning. Hake focused on Newtonian mechanics courses and used data from the force concept inventory (FCI) (Hestenes et al., 1992) in the analysis. A concept inventory (CI) is a multiple-choice exam designed to test student understanding of the core concepts in a subject area. CI questions require few, if any, computations, and the wrong answers (distractors) elicit common student misconceptions. In Hake's (1998) study, students took the FCI twice: before the start of the course and then at its conclusion. Hake used the pretest and posttest averages to define the average gain in conceptual understanding due to instruction: gain = (Post-Pre)/(100-Pre). The gain represents

Figure 2. *Painting by Laurentius de Voltolina dating from the second half of the 14th century. Judging from this illustration, student distraction and dozing during lecture are not modern problems. Photo from commons.wikimedia.org.*

the fraction of the available improvement that was attained during the course. Hake's survey of over 6,000 students in mechanics courses showed that the average gain for traditional lecture courses was 0.23. That is, students learned less than 25% of what they didn't know (**Figure 3**). In contrast, active-learning courses had an average gain of 0.48.

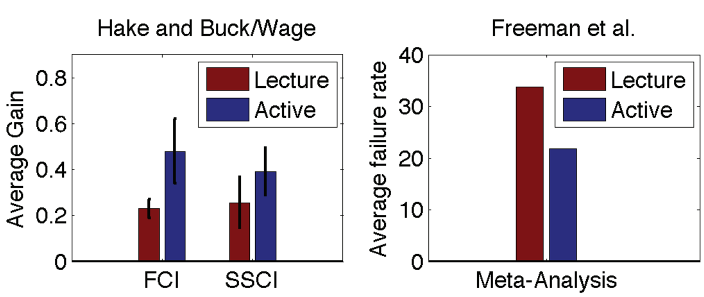

Figure 3. *Active learning increases how much students gain and reduces failure rates. Left: Gains (means ± SD) for lecture and active courses as measured by two concept inventories, the force concept inventory (FCI) and the signals and systems concept inventory (SSCI). The FCI results are from Hake's analysis (1998) of 14 lecture courses and 48 active courses. The SSCI results are from our own analysis of 28 lecture courses and 34 active courses. Right: Freeman et al.'s (2014) results from a meta-analysis of the failure rates in lecture and active learning courses in science, technology, engineering, and math (STEM).*

Are Hake's results applicable to courses other than Newtonian mechanics? Two of us (JRB and KEW) developed the signals and systems concept inventory (SSCI), which is designed to measure conceptual understanding in undergraduate linear systems courses (Wage et al., 2005). The SSCI assesses students' understanding of Fourier analysis, convolution, filtering, and sampling. **Figure 3** shows the results of our analysis of gain for the SSCI. Similar to Hake's (1998) results, the SSCI analysis shows a significant increase in gain for active learning courses.

Recently, Freeman et al. (2014) prepared a meta-analysis comparing traditional lecture and active learning for STEM disciplines. Based on data from 225 studies, they showed that student performance on examinations in active-learning courses increased by 0.47 standard deviations over examinations in traditional lecture courses. Using CI data from 22 studies, including those for the FCI and SSCI, the authors concluded that active learning improves the final CI score by 0.88 standard deviations, indicating that students in active-learning courses demonstrated greater improvement in conceptual understanding. Finally, as **Figure 3** illustrates, Freeman et al. showed that the failure rate for students in traditional lecture courses was 33.8%, whereas the failure rate in active-learning courses was 21.8%. Based on this meta-analysis, Freeman et al. concluded that active learning is the "preferred empirically validated teaching practice" and suggested that the traditional lecture should no longer be used as the control in research studies.

Why Is the Traditional Lecture So Ineffective?

A skilled lecturer can present material in such a gloriously smooth fashion that everything seems clear to even the most naive listener. But is this clarity real? Or is it an illusion? Watching an expert perform in any domain, be it technical, musical, or athletic, can mislead us into thinking we can easily duplicate their performance. This "illusion of knowing" (Brown et al., 2014, pp. 102-130) is typically dispelled the moment we attempt the same feat. The typical college classroom has more illusions floating around than Hogwarts School of Witchcraft and Wizardry (Rowling, 1999). The students are under the illusion that they understand what the instructor is saying. The students often don't realize that their understanding is a mere mirage until they get home and start the homework. At that point, there is no one around to answer his or her questions. The instructor is under the illusion that the lecture is clear and that all students understand everything perfectly. Instructors often don't realize this was an illusion until they grade the midterms and sometimes not even then. If most of the exam questions are taken from the homework, students will be able to answer them by rote memorization. However, many students will lack the understanding to apply the concepts correctly in new contexts.

Why Does Active Learning Work Better Than Lecture?

Active learning seeks to minimize the illusion of knowing and spark questions when there are instructors available to answer. Guided by research, active learning also acknowledges that students' prior knowledge affects their ability to learn and tries to bring misconceptions to the fore to correct them. In the analysis leading to the development of the FCI, Halloun and Hestenes (1985) concluded that conventional lecture courses do not force students to confront their misconceptions. This conclusion motivated significant research in physics education and the development of active methods of instruction, including Mazur (1997). These active methods are consistent with the principles summarized in *How Learning Works and Make It Stick*.

The authors of this article teach signal processing and linear systems theory courses. Students in these courses encounter fundamental acoustical concepts like impulse response, frequency response, filtering, and Fourier analysis for the first time. Examples drawn from music, speech processing, psychoacoustics, and bioacoustics make the mathematics come alive for students. For instance, one of the authors begins the semester by drawing a block diagram of an MP3 encoding system and then identifies which chapters in the textbook address each block. These courses can open doors to a life in acoustics research for students as similar courses did for the authors. We believe that the pedagogical lessons learned teaching these courses transfer naturally to other acoustics courses.

In the remainder of this article, we describe a variety of active learning techniques that are supported by research, and we illustrate these techniques using examples from our own courses. We hope the rest of the article will motivate the reader to try some of these techniques. The final section provides ideas and a list of resources for getting started.

Elements of Active Learning

Although a variety of definitions for active learning exist, we choose to define the term broadly for the purposes of this article. Active learning, as the name implies, refers to classroom activities in which students are engaged in the learning process (Prince, 2004). This is in contrast to the traditional lecture, where it is assumed that students are listening passively to material and that engagement does not move beyond copying notes. Active learning brings engagement with the material into the classroom, where instructors can provide immediate feedback rather than relegating hands-on practice to homework that is often completed alone. Collaborative learning is a subset of active learning, requiring students to work together to understand concepts, solve problems, and master material. Active-learning implementations often vary across disciplines. Common forms of active learning in STEM courses include group problem solving, peer instruction, conceptual discussions, and laboratory explorations. Many active-learning techniques can be implemented in such a way that students first engage individually with the material and then engage with peers to discuss and defend their conclusions. A common approach is the Think-Pair-Share technique (Lyman, 1981; Johnson et al., 1998; Barkley et al., 2005) in which students first work on a problem or question alone, then join with a peer to discuss responses, and finally share collective responses with a larger group or the full class.

Making room for active learning in class requires pushing some traditional lecture out of the classroom. Moving lecture outside the class to allow time for active learning has motivated the now popular "flipped classroom" model. Although discussion of the flipped classroom often focuses on the means of delivering content that is flipped out of scheduled class meetings, the major pedagogical opportunity is the new activities that are flipped in to the class. That said, the displaced lecture content must appear in some form, and it can be delivered in a variety of ways. An increasingly popular approach to content delivery is via online videos. Videos allow students to absorb material at their own pace and to rewatch content several times if needed. They can also satisfy students' unquenchable thirst for examples. Videos are not the only option for content delivery, however. Lecture may also be flipped out of the classroom via more traditional delivery, reading the textbook. Learning new technical material by reading is an essential skill for a successful career. Technical fields progress rapidly, and even highly prepared students will need to learn new material within a few years of graduation. The fundamental medium of exchange for advanced technical ideas is still the written word (and written equation). We believe that failing to teach technical reading skills to students is doing them a profound disservice and setting them up for rapid technical obsolescence.

In advocating for active learning, we are not suggesting that lecture be abandoned entirely. For lecture to be effective, however, students must be prepared to absorb the material presented. In *A Time for Telling*, Schwartz and Bransford (1998) described how students need relevant prior knowledge to benefit from lecture-based instruction. To learn from a lecture describing techniques for solving problems, for example, students must first become familiar with the problems of interest, perhaps by trying to solve problems and identifying the challenges they need to address. Hence, active learning and lecture can and should coexist in college teaching. The professor, acting as DJ (**Figure 1**), must carefully mix these components to maximize student learning.

Students must complete the assigned reading (or assigned viewing) before class for active learning to succeed. A common approach for motivating students to prepare for class is to start each day with a short quiz on the assigned material. Equally important is to teach students about active reading and watching. Technical material cannot be absorbed with the casual reading or viewing habits students use for Facebook (www.facebook.com) or Netflix (www.netflix.com). Students should be encouraged to take notes on the content and to work problems while reading or viewing, covering the answer (or pausing the video) to see if they can complete a problem on their own. They should also be encouraged to engage in frequent self-quizzing by recalling definitions and formulas as well as solving new problems (Brown et al., 2014, pp. 34-45). These techniques will help them retain the material for use in class and beyond.

Implementing Active Learning

This section describes our implementation of active learning in engineering courses. The first paragraph describes the common structure of our active learning courses. Subsequent paragraphs discuss the variants in greater detail. All three of us begin with a short graded quiz to hold the students accountable for the required reading. We then review the reading quiz, providing an outline and overview of the topic for that day. We lecture in short 10- to 15-minute segments, reviewing fundamental or challenging aspects of the material. Students spend a majority of the time working collaboratively on problems in pairs or small groups while instructors (and TAs if available) circulate among the groups answering questions, providing feedback, and eavesdropping on students' conversation to assess their misconceptions. Grading these in-class student exercises holds students accountable and keeps them focused. Weekly homework assignments of more complicated problems build on the simple in-class problems and challenge students to develop their knowledge and skills in novel contexts. This high level structure is essentially unchanged from our prior descriptions of active-learning courses (Buck and Wage, 2005).

Our approach to the reading quizzes has evolved since 2005. The quiz may be on paper, online, or use automated response systems, generically known as "clickers," depending on class size and resources. The quiz may be open notes or closed book depending on the goals of the course. Open notes rewards note taking in active reading. Closed notes emphasizes mastery of fundamentals like complex number arithmetic. The quiz may include questions from the previous class to encourage review of previous material.

We vary in our lecture segment delivery as well. In some classes, we repeat two or three cycles, interleaving the short lectures with problem-solving sessions. In other classes, we deliver a short lecture at the start and then spend the rest of the class period in student problem-solving, possibly interrupting the student discussions to address a common misconception. Another strategy is to start with a problem-solving session directly after the reading quiz, break for a short lecture, and then return to problem solving. This approach exploits the deeper learning and longer recall activated by first struggling with a problem before learning the solution (Bjork and Bjork, 1992; Brown et al., 2014, pp. 67-101).

The in-class assignments also vary in format, scope, and assessment. For large sections in lecture halls poorly suited for group work, the students work multiple-choice problems in pairs, responding using clickers. Large-section problem-solving sessions may also include peer instruction through discussion, such as the Think-Pair-Share exercise cited above. In rooms configured for group work (**Figure 4**), students work short pencil and paper exercises in groups of three to four. When sufficient space is available, groups work on the board, facilitating discussion with peers and feedback from the instructor.

Our assessment strategies for the in-class problems try to balance low-stakes formative feedback for the students with sufficient group accountability to keep students engaged. In some classes, we grade the in-class problems on a tertiary scale of check/check plus/check minus. Other classes encourage group accountability by requiring all of the mem-

Figure 4. *George Mason University's Active Learning with Technology classroom is designed to support collaborative, student-centered learning. The whiteboards on the walls and projection to dedicated flat-screen displays encourages student interactions. Photo from Creative Services/George Mason University, with permission.*

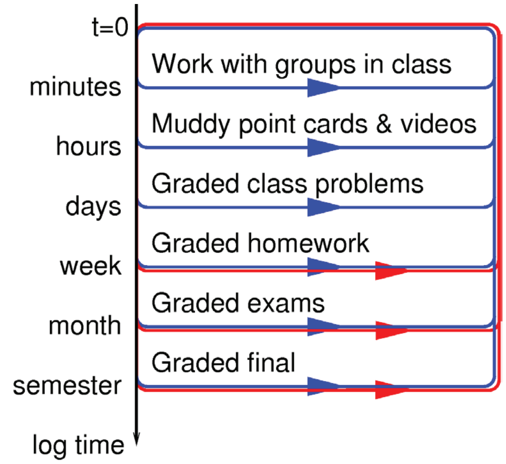

Figure 5. *Active-learning classes (blue) provide feedback to students about their understanding on many short timescales in addition to the traditional homework assignments and grades. Traditional lecture classes (red) only provide feedback on the longer timescales of weeks and months, resulting in less effective memory formation.*

bers of each group to submit their collaborative solutions, then grading one randomly chosen paper from each group (Johnson et al., 1998).

"Muddy point" cards offer an opportunity for students to provide feedback to instructors. We give students index cards at the end of class and ask them to write down something that is still confusing to them about the day's material. The cards are anonymous and provide immediate feedback to the instructor about the students' understanding. We can address the contents of the cards either by a short email later that day or by recording a video with some additional examples or instruction (see next section).

The integration of these active-learning techniques provides students with feedback on many time scales, shown in **Figure 5.** Starting from the introduction of a topic in class ($t = 0$), students receive feedback on timescales of minutes, hours, days, weeks, and months. Frequent feedback and recall leads to stronger memories, resulting in better student mastery of material (Brown et al., 2014, pp. 33-39). Instructors are also receiving feedback about the students' understanding on all of these timescales, allowing them to react and address misconceptions early in the learning process before they become entrenched (Brown et al., 2014, pp. 44). In contrast, a traditional lecture course provides feedback to students only on the longer timescales of weeks and months.

Video Killed the Lecture Star

The largest change to our implementation of active learning in the decade since publishing Buck and Wage (2005) is the incorporation of YouTube video lectures to supplement the classroom instruction. Ideally, these video lectures run 10-15 minutes in length. Our video lectures do not just duplicate classroom lectures but instead present examples or additional exposition to address a specific student misconception identified while grading in-class problems or homework or while reading muddy point cards. Some recordings cover examples we set aside from our old lecture notes to free time for in-class problem sessions. "More examples please" is a perennial refrain on student evaluations, and the videos offer one way to address this request. Finally, some recorded lectures cover secondary material that students should be able to digest once they master the major points in class. For example, after teaching the fundamentals of the Z-transform during the short in-class lecture, we relegate the discussion of various transform properties to video lectures for later viewing.

Our videos opt for a simple presentation. Inspired by the popular Khan Academy videos (www.khanacademy.org), we show writing on screen using a whiteboard program along with synchronous audio narration. This format emulates the experience of an instructor and student sitting side by side with a piece of paper during office hours. We believe this approach encourages student engagement. Moreover, we believe that other common presentation modes for instructional videos such as lecture hall recordings, narrated slides, or talking head videos with slides implicitly put students in the mind frame of more passive experiences, such as attending a large lecture or watching TV. Guo et al.'s (2014) study of MOOC videos supports our intuition on presentation format. Guo et al. found that short Khan-style videos and an informal style improved student engagement in online videos over narrated slides or lecture hall recordings.

Contrary to popular belief, producing instructional videos need not demand the time and resources required to

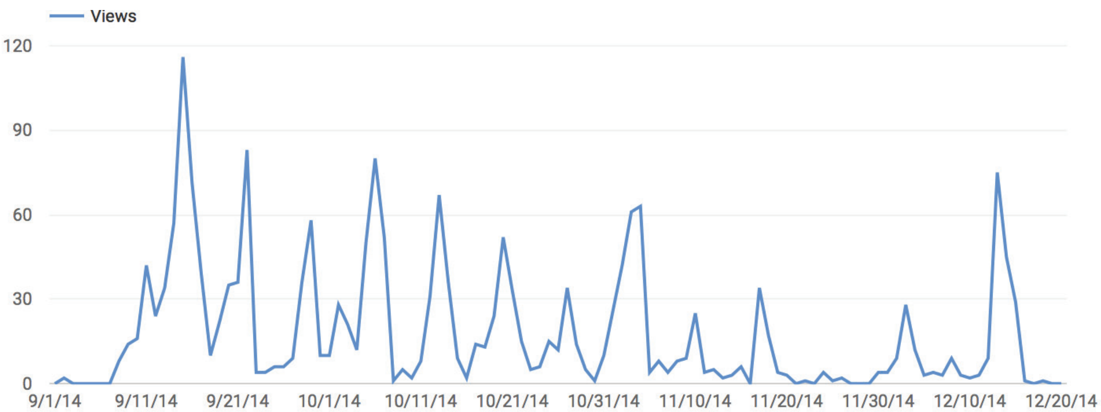

Figure 6. *Daily viewing of the ProfJohnBuck YouTube channel during the Fall 2014 semester with an enrollment of 67 students. The viewing data clearly show a strong signal in a seven-day period, consistent with the weekly homework due every Tuesday. The exams on 10/7, 11/4, and 12/15 increased student viewing.*

produce an Olympic opening ceremony pageant. There are many ways to capture synchronous screen and audio recordings. One author (KEW) employs the Doodlecast iPad app (http://doodlecastpro.com) with a wired clip-on microphone. Another author (JRB) uses the TechSmith (https://www.techsmith.com) capture software with a writing tablet, whiteboard program, and wired headset. The Khan Academy FAQ (https://goo.gl/9S7Lw2) lists the equipment Sal Khan uses to make his videos. Inspired by Sal Khan's comments (2013), we also choose not to edit our videos but leave our self-corrections in the recordings, reinforcing the informal in-person style. Students' responses to the videos were largely positive right from the start, rough as our early efforts appear to us now.

YouTube analytics confirm that students devote considerable time to watching the videos. YouTube does not provide individual students' viewing data but does report aggregate viewing by state as a function of time. We use this aggregate data from our university's home state during the dates of the semester as our best estimate of total viewing data. The combined Massachusetts viewers during the Fall 2013, Fall 2014, and Fall 2015 semesters spent 24,750 minutes watching videos on the ProfJohnBuck channel (https://goo.gl/EoPQpG). The combined enrollment of the UMass Dartmouth linear systems classes during these three semesters was 189 students, yielding a rough estimate of 130 minutes/student of viewing. For a class that meets 150 minutes/week, this average represents nearly a week of additional instructional time. Although we cannot be certain that all the Massachusetts viewers are students in these classes, the strong correlation between the YouTube time series and assignment due dates (**Figure 6**) suggests that the viewing data are predominantly students. End of semester evaluations for these three semesters also support this interpretation. For each semester, at least 60% of the students reported watching "some," "most," or "all" of the videos, and at least 75% of the students reported that the videos were "helpful" or "very helpful."

An unanticipated dividend to recording these videos is their popularity with a broader audience. The combined worldwide viewing for the ProfKathleenWage (https://goo.gl/4eER4C) and ProfJohnBuck channels over the last 30 months exceeds 500,000 minutes.

Although some instructors in flipped classrooms deliver all of the preclass preparation via video lectures, we remain conflicted about completely removing reading from our courses. Our sense is that most of our students would prefer to watch a video than read a textbook. However, we strongly believe that technical reading skills are essential, and we are concerned that requiring viewing without any reading will not equip our students with the self-directed learning skills required for long-term success.

The Road Forward

Where to go from here? If you are skeptical of the empirical evidence for active learning provided by Hake (1998), Buck and Wage (2005), and Freeman et al. (2014), then find a concept inventory for your course (Foundation Coalition, 2008) and administer it using the pre-/post- protocol described above. If there isn't a concept inventory for your area, read the FCI or SSCI to get a feel for how CIs work, then write a few conceptual questions of your own and give them to your students. Listen to your students' explanations of their answers and learn what misconceptions they still retain after taking your course. We've done this exercise ourselves, and it was eye opening.

If you are convinced by Hake (1998) and Freeman et al. (2014) or intrigued by our description of active learning, there are a number of ways to get started. One of us started by assigning a short "warm-up" problem at the beginning of class that built on material covered in a previous lecture. This gave students some practice in applying the concepts and gave us the chance to observe their confusions. The warm-up problems didn't take much time, and they provided both students and faculty with useful information. If you'd like to learn more about designing active classrooms, there are several resources we have found to be very useful. In addition to Mazur's classic book (1997), the boxed insert lists three resources for getting started with active learning. The resources in the insert provide low-risk and relatively painless entry points into active learning, but perhaps an equally valuable resource is a group of like-minded colleagues with whom to share the journey. One challenge for instructors is committing the time necessary to implement, assess, and revise new techniques in their courses. A community of practice populated by instructors exploring similar techniques can provide ongoing support and accountability during the process. Education theorist Etienne Wenger (2016) describes communities of practice as "groups of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly."

Online Resources for Starting with Active Learning

1. Hanford, E. (2011). *Don't Lecture Me.* American RadioWorks Podcast, September 2011. Available at https://goo.gl/u70FDp.
2. Mahajan, S. (2009), *Teaching College-Level Science and Engineering.* MIT OpenCourseware. Available at https://goo.gl/c3YJBJ.
3. Bruff, D., McMahon, T., Goldberg, B., and Campa III, H. (2014). *An Introduction to Evidence-Based Undergraduate STEM Teaching.* Center for the Integration of Research, Teaching, and Learning. Available at https://goo.gl/w0hssk.

Recent work in STEM faculty development has produced a model for ongoing teaching development groups to support adoption of evidence-based teaching practices. The SIMPLE design model builds on research results in both K-12 and college professional development (Jamieson and Lohmann, 2009; Loucks-Horsley et al., 2010). SIMPLE teaching development groups are guided by five principles: sustainable, incremental change, mentoring, people-driven learning environments, and design (Nelson and Hjalmarson, 2015). SIMPLE groups require very little infrastructure and are often realized as a group of faculty meeting over a weekly (or monthly) lunch to discuss new strategies they're using in their classes, share tips, and provide support. Creation of a community of practice can transform the often-isolating experience of trying new teaching strategies into a rewarding collaborative effort in which instructors learn from each other's challenges and successes.

Biosketches

John R. Buck is a Professor in the Electrical and Computer Engineering Department at the University of Massachusetts Dartmouth. His research studies signal processing, underwater acoustics, animal bioacoustics, and engineering education. John received his PhD from the MIT/ Woods Hole Oceanographic Institution Joint Program. He was a Fulbright Senior Fellow in Australia in 2003-2004 and received the 2005 IEEE Education Society Mac Van Valkenburg Early Career Teaching Award.

Kathleen E. Wage is a signal processor whose current interests are ocean noise, underwater acoustics, and engineering education. She is an Associate Professor of Electrical and Computer Engineering at George Mason University, Fairfax, VA. Kathleen obtained her BS in electrical engineering from the University of Tennessee, Knoxville and her MS and PhD in electrical engineering from the MIT/ Woods Hole Oceanographic Institution Joint Program. She received the 2008 IEEE Education Society Mac Van Valkenburg Early Career Teaching Award. Kathleen spent 55 days at sea for the PhilSea experiments and wishes the Olympic Committee would recognize "Sonobuoy Tossing" as an official sport.

Jill K. Nelson is an Associate Professor of Electrical and Computer Engineering at George Mason University, Fairfax, VA. Her disciplinary research lies in statistical signal processing, specifically detection and estimation in target tracking and physical layer communications. Her pedagogical research focuses on faculty development as a way to broaden use of evidence-based practices in STEM teaching. Jill earned a BS in electrical engineering and a BA in economics from Rice University, Houston, TX, and an MS and PhD in electrical engineering from the University of Illinois at Urbana-Champaign. She received the 2014 IEEE Education Society Mac Van Valkenburg Early Career Teaching Award.

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Acoustics '17 Boston

Photo courtesy of Greater Boston Convention and Visitors Bureau

25–29 June 2017

Joint Meeting of the

Acoustical Society of America

European Acoustics Association

The Acoustical Society of America (ASA) and the European Acoustics Association (EAA) invite acousticians from around the world to participate in **Acoustics '17 Boston** to be held 25-29 June 2017 in Boston, Massachusetts, USA. A broad range of topics in acoustics will be covered in technical sessions and keynote lectures. Presentations on emerging topics are especially encouraged. Social events, student events, and an accompanying persons program will be organized. The best features of meetings of both organizations will be combined to offer a premier venue for presenting your work to an international audience.

Boston is the capitol and largest city in Massachusetts and is one of the oldest cities in the United States. It is on the Atlantic coast and is home to many historic sites dating back to the American Revolution, in addition to many other cultural and recreational features. The climate in June is very pleasant and ideal for arranging visits before and after the meeting.

Please join us!

Violin Acoustics

Colin E. Gough

Postal:
School of Physics and Astronomy
University of Birmingham
Edgbaston, Birmingham
B15 2TT
United Kingdom

Email:
profgough@googlemail.com

The acoustics of thin-walled shallow boxes – a tale of coupled oscillators.

Introduction

This article describes how sound is excited by the violin and how the quality of its sound is related to the vibrations and acoustic properties of the body shell of the instrument.

The violin and the closely related viola, cello, and double bass are shallow, thin-walled, boxlike shell structures with orthotropic, guitar-shaped, doubly-arched plates, as illustrated in **Figure 1**. They therefore share very similar acoustical properties reflecting their similar shapes and symmetries. Violin acoustics is just a special example of the acoustics of any shallow boxlike structure.

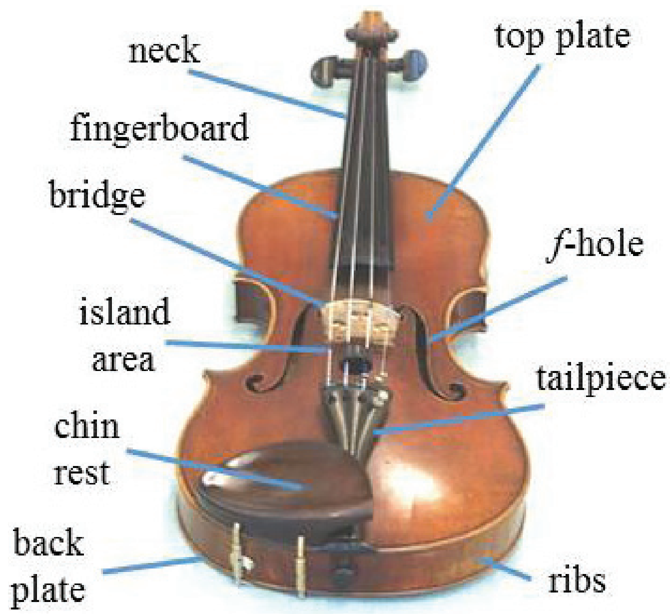


Figure 1. *A 19th century French violin with component parts labeled.*

The earliest known extant violin, now in the National Music Museum in Vermillion, was made by Andrea Amati (ca. 1505-1577), widely recognized for introducing the violin in its present largely unchanged form. It was made in Cremona in Northern Italy, which became the home of several generations of famous violin makers including Antonio Stradivari (1644-1737) and Guarneri del Gesù (1698-1744). Their violins still remain the instruments of choice of almost all top international soloists. They fetch extraordinary high prices; the "Vieuxtemps" 1741 violin by Guarnerius was reputably recently sold for around $18M.

In contrast, the highest auction price for a violin by a living maker was $130K in 2003 for a violin made by the Brooklyn maker Sam Zygmuntowicz, only recently surpassed in 2014 for a violin jointly made by the Ann Arbor, MI, makers Joseph Curtin and Greg Alf, which fetched $134 K. At the other end of the spectrum, a mass-produced student violin can be bought for around $100, with bow, case, and a cake of rosin included!

Can we tell the difference in the measured acoustic properties of instruments of such vastly different prices? Can we discover the acoustic secret, if any, of the old Cremonese master violins? Can a knowledge and understanding of the acoustical properties of the old violins help modern makers match the sounds of such violins? These are the major challenges for acousticians.

Despite the continuing reluctance of many violin makers to accept the intrusion of science into the traditional art of violin making, it is surely no coincidence that outstanding makers like Zygmuntowicz and Curtin have also played prominent roles in advancing our knowledge and understanding of the sounds of fine Italian instruments and their acoustic properties.

Today, as a result of strong collaborations involving violin makers, museum curators, players, owners, dealers, and acousticians, we have a wealth of information on the acoustical properties of nearly 100 classic Italian violins including many Stradivari and Guarneri violins, as well as many fine modern instruments, important knowledge that was missing until the last few years.

Such information establishes a "benchmark" for modern makers, if their instruments are to consistently match the sounds of the early Cremonese makers. Simple acoustic measurements in their workshops during the making of their instruments can help them achieve this.

Interestingly, Claudia Fritz and her collaborators (Fritz et al., 2014) recently conducted a rigorously designed psychoacoustic investigation of six fine Italian and six modern violins, which involved comparative listening tests and parallel vibroacoustic characterization. The outcome was that without visual clues even top international soloists were unable to reliably distinguish the old instruments from the new despite their huge disparity in value. This confirmed similar conclusions from a previous investigation involving a smaller number of instruments (Fritz et al., 2012).

The concept of a "Stradivari secret" known only to the classic Italian makers to account for the outstanding sound of many of their instruments is now largely discredited, not in the least because the sound of the instruments we listen to today are very different from when they were originally made. This is because they were "modernized" in various subtle ways in the 19th century by the use of metal-covered rather than pure-gut strings, a lengthened neck, a different standard tuning pitch, a modern bridge, and being played with a modern bow. This was in response to the need for instruments that could respond to the increasingly virtuosic demands of the player and project strongly over the sound of the larger orchestras and concert halls of the day.

Radiated Sound

In many ways, the acoustics of the violin is closely analogous to that of a loudspeaker mounted in a bass-reflex cabinet enclosure as described in many acoustics textbooks (e.g., Kinsler et al., 1982). The thin-walled body shell of the violin radiates sound directly just like a loudspeaker cone. The shell vibrations also produce pressure fluctuations inside the hollow body, which excite the Helmholtz *f*-hole resonance, the highly localized flow of air bouncing in and out of the *f*-holes cut in the top plate. The Helmholtz resonance frequency is determined by the size and geometry of the *f*-holes and compressibility of the air inside the body shell. This is similar to the induced vibrations of air through the open hole in a bass-reflex loudspeaker cabinet. In both cases, this significantly boosts the sound radiated at low frequencies, where radiation from the higher frequency body shell or loudspeaker cone resonances would otherwise have fallen off very rapidly.

Contrary to what many players believe, negligible sound is radiated by the vibrating string because its diameter is much smaller than the acoustic wavelength at all audio frequencies of interest. Nevertheless, the bowed string clearly provides the important driving force producing the sound of the instrument just like the electrical current exciting a loudspeaker cone. The quality of the radiated sound is therefore only as good as the player controlling the quality of the bowed string input!

Sound is excited by transverse "Helmholtz" bowed-string waves excited on the string, which exert a force with a sawtooth waveform on the supporting bridge as described below. Because of the offset soundpost wedged between the top and back plates, the transverse bowed-string forces the bridge to bounce up and down and rock asymmetrically backward and forward in its own plane on the island area between the *f*-holes cut into the top plate, as illustrated in **Figure 2**. The bridge and island area act as an acoustic transformer coupling energy from the vibrating string into the vibrating modes of the lower and upper bouts of both the top and back plates of the body shell.

The radiated sound is then strongly dependent on the coupling of the vibrating strings to the radiating

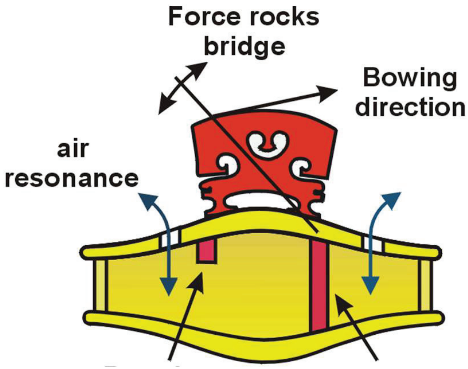


Figure 2. A schematic representation of the excitation of the vibrational modes of the body shell and Helmholtz f-hole resonance by the bowed string via the asymmetric rocking of the bridge.

modes of the body shell, which are only weakly perturbed by their coupling to other attached parts of the violin such as the neck, fingerboard, tailpiece supporting the strings, and even the player holding the instrument.

String Vibrations

Hermann von Helmholtz (1821-1894) was the first to both observe and explain the transverse vibrations of the bowed string. His measurements and their interpretation were described in *The Sensation of Tone* (Helmholtz, 1863), which laid the foundation for the discipline of psychoacoustics and our understanding of the perception of sound. Although a strongly bowed string appears to be vibrating as a simple half-wavelength sinusoidal standing wave, what we observe is only the time-averaged parabolic envelope of the much more interesting Helmholtz wave.

For an ideally flexible string with rigid end supports, Helmholtz showed that the waveform consists of two straight sections of the tensioned string rotating in opposite direction about its ends, with a propagating "kink" or discontinuity in the slope at their moving point of intersection. The kink traverses backward and forward at the speed of transverse waves, $\sqrt{T/\mu}$, reversing its sign on reflection at both ends, where T is the tension and μ is the mass per unit length of the string. The Helmholtz wave is therefore periodic with the same repetition frequency or pitch as the fundamental sinusoidal mode of vibration.

Such a wave can be considered as the Fourier sum of the sinusoidal eigenstates of an ideal string with rigid end supports, with "harmonic" partials ($f_n = nf_1$), and amplitudes varying as $1/n$, where n is an integer and f_1 is the frequency of the fundamental component. On an ideal string, such a wave would propagate without damping or change in shape.

In practice, the Helmholtz string vibrations are excited and controlled in amplitude by the high nonlinear frictional "slip-stick" forces between the moving bow hair and string similar to the forces giving rise to the squeal of car tires under heavy breaking. **Video 1** (http://goo.gl/UtNOI4) (Wolfe, 2016) illustrates the bowed waveform as it sticks to and then slips past the steadily moving bow.

To produce sound, the string vibrations clearly have to transfer energy to the radiating shell modes via the asymmetrically rocking bridge. As a result, each mode of the string contributing to the component partials of the Helmholtz wave will be selectively damped and changed in frequency by its coupling to the individual shell modes (Gough, 1981). Nevertheless, provided the coupling of the lowest partials is not too strong, the highly nonlinear, slipstick, frictional forces between the string and rosined bow can still excite a repetitive Helmholtz wave. Cremer (1984) showed that the kink is then broadened with additional ripples that are also excited by secondary reflections of the kink at the point of contact between string and bow.

If the fundamental string mode contributing to the Helmholtz wave is too strongly coupled to a prominent body resonance, even the highly nonlinear frictional force between bow and string is unable to sustain a repetitive wave at the intended pitch. The pitch then rises an octave or leads to a warbling or croaking sound, the infamous "wolfnote," which frequently haunts even the finest instruments, especially on fine cellos. This is an extreme example of the way the string-shell mode coupling affects the "playability" of an instrument (Woodhouse, 2014, Sect. 5), which is almost as important to the player as its sound.

The excitation and properties of Helmholtz waves on the bowed string are so important that Cremer (1984) devotes almost half his seminal monograph on *The Physics of the Violin* to a discussion of string vibrations. In Cambridge, UK, McIntyre and Woodhouse (1979) developed elegant computer simulations to investigate the physics involved, with more recent advances described by Woodhouse (2014, Sect. 2) in his recent comprehensive review of violin acoustics.

Major advances in our understanding of how the player and the properties of the bow determine the time evolution and shape of the circulating kink, hence the sound of the bowed string, were made by the late Knutt Guettler (2010), a virtuoso soloist and teacher of the double bass. The rapid excitation of regular Helmholtz waves on short, low-pitched,

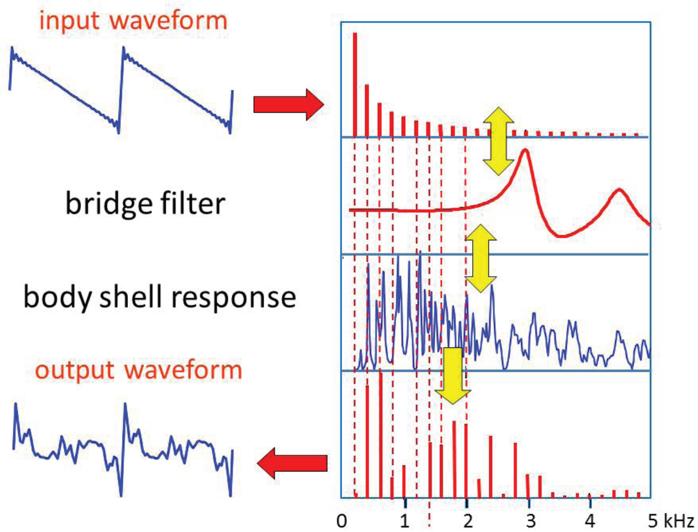


***Figure 3**. The transformation of the bowed string input waveform into the radiated sound by the bridge and body shell resonances for one selected note. Vertical dashed lines: Frequencies of the bowed string partials.*

bowed notes on the double bass is vitally important; otherwise, the note is over before it has even started! The ability to achieve a clean start to a bowed note is one of the skills of a really good player on any bowed instrument (Guettler and Askenfelt, 1997). This involves controlling the acceleration of the bow following contact with the string as well its velocity, position, and downward force. This is one of the most important factors differentiating the skills of a top soloist from those of a good amateur player, let alone a beginner.

The short audio extract (**Audio 1**, http://goo.gl/UtNOI4) of the sound produced by the piezoelectrically measured bowed string force acting on the bridge (Woodhouse, 2014) illustrates both the already violin-like sound of the driving force and the skill of an expert performer in controlling its subtle inflections of both amplitude and pitch.

Excitation of Body Shell Modes

The radiated sound of the violin is therefore determined by the overlap of the comb of harmonic partials excited by the Helmholtz wave on the bowed string and the multiplicity of resonant radiating body shell modes, with the bridge acting as an acoustic filter between, as illustrated schematically in **Figure 3**.

The isolated bridge resting on a rigid platform has two important in-plane resonances at around 3 kHz and 6 kHz, rotation of its upper half about its waist and bouncing up and down on its two feet. When mounted on the island area of the top plate, such resonances are strongly damped by their coupling to the body shell modes.

As many as 40 harmonic partials can be observed in the sound of the lowest bowed open string on a cello! The time-varying strengths of each of these partials, modified in amplitude by the player and the multiresonant acoustic filter response of the instrument, will then be processed within the cochlea of the ear and the highly sophisticated audio processes that take place in the brain. The resulting complexity of the signals reaching the brain ultimately determines the listener's perception of the quality of an instrument as played by a particular player.

Because of the multiresonant response of the violin, the waveform and spectrum of the radiated sound is very different from that of the input Helmholtz sawtooth force at the bridge, as illustrated by the computer simulation in **Figure 3**. It also varies wildly from note to note, and even within an individual note, when played with vibrato. Yet the sound of the violin perceived by the player and listener remains remarkably uniform, other than slight changes when bowing on different strings. This paradox suggests that the quality of an instrument cannot be determined simply by the frequencies and strengths of the individual resonances excited. This has encouraged the view that the frequency-averaged formant structure is perhaps the most important generic feature, with both the overall intensity and balance of sound radiated in the upper and lower frequency ranges being important.

However, if a single period of the recorded waveform of the recorded sound of a violin is selected and repeated indefinitely, the sound is like that of any crude Fourier synthesizer and nothing like a violin (**Audio 2**, http://goo.gl/UtNOI4). This suggests that the fluctuations in frequency, amplitude, and timbre, even within a single bowed note, strongly affect the perceived quality of a violin's sound. The "complexity" of the sound arises from the strongly frequency- and directional-dependent fluctuations in spectral content or timbre, the use of vibrato, noise associated with the finite width of the bow hair in contact with the string, frictional forces, and the superposition of reflections from the surrounding walls (Meyer, 1992). All such factors provide a continuously changing input to the ear. This allows the brain to focus on the instrument being played, which may be just as important as the overall intensity of the perceived sound in determining an instrument's "projection." Averaging the frequency response would clearly reduce the complexity of the radiated sound, hence interest to the listener.

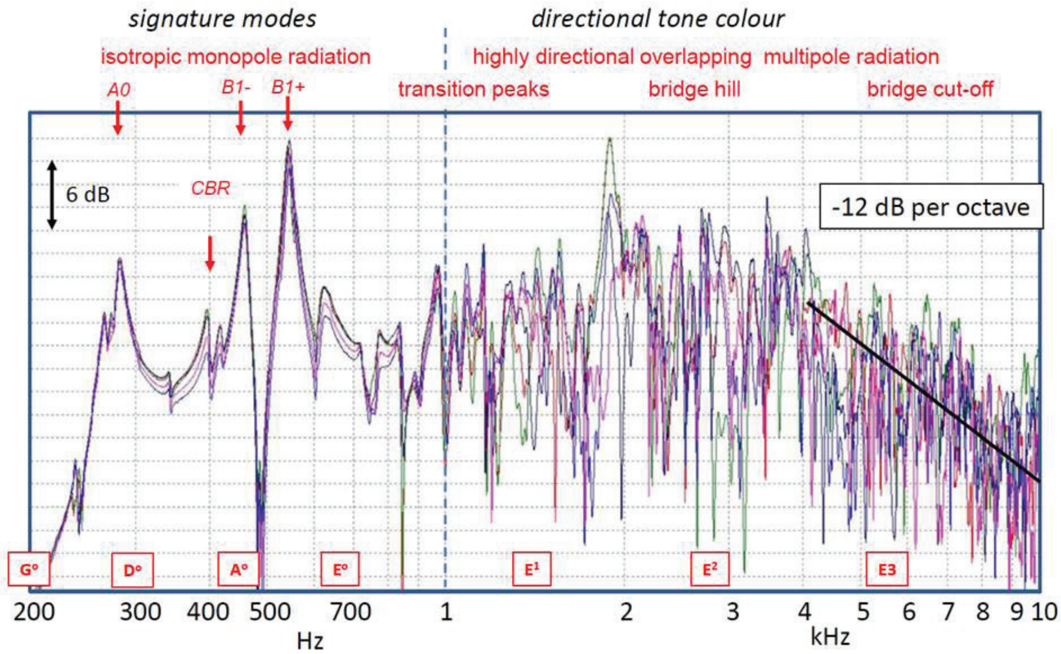


Figure 4*. RSuperimposed spectra of the radiated sound pressure measured in the bridge plane at 0°, ± 30° and ± 60° in front of the top plate of the Willemotte 1734 Stradivari violin. Red boxes: Frequencies of the open G0 to E0 strings and the first three octaves of the open E-string, E1 to E3. Data courtesy of Curtin, personal communication.*

The Acoustic Spectrum

Unlike loudspeakers designed to have as flat a frequency response as possible, the spectrum of the violin fluctuates wildly, with many strong peaks and troughs reflecting the relatively weakly damped, multiresonant responses of the instrument. This will vary markedly in detail from one instrument to the next, even between different Stradivari and Guarneri violins, giving each instrument its individual sound quality.

Figure 4 shows the radiated sound measured by Curtin in five different directions for the Willemotte 1734 Stradivari violin investigated in the Strad 3-dimensional project (Zygmuntowicz and Bissinger, 2009). The acoustic response was measured by tapping the bass-side top corner of the bridge in a direction parallel to the plates. This simulates the component of the bowed string force in the same direction. The fast Fourier transform (FFT) of the recorded sound has been normalized to that of the force of the light impact hammer exciting the violin modes. To simplify the acoustic response, the strings were damped, although string resonances can make a significant contribution to the quality of the radiated sound (Gough, 2005).

The observed resonances are those of the independent *normal* modes of the freely supported instrument, which have individual resonant responses just like a single damped mass-spring oscillator. They describe the coupled *component* mode vibrations of the body shell, the air inside the cavity, and all attached structures such as the neck, fingerboard, tailpiece, and strings (Gough, 2015b). To avoid potential confusion between the uncoupled *normal* and coupled *component* modes, capital letters will be used for the former (*A0, CBR, B1–, B1+,…*) and small letters for the latter (*f-hole, cbr, breathing, bending, …*).

The "coupled oscillators" text box illustrates how the coupling between coupled component modes result in the veering and splitting of the frequencies of the resultant normal modes describing the in- and out-of-phase vibrations of the component modes.

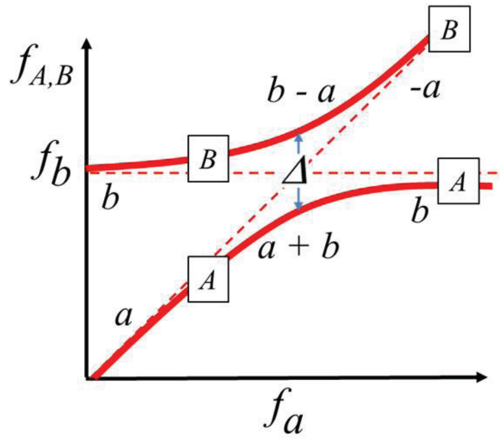
The radiated sound is the sum of the radiated sound from each of the excited *normal* modes. For typical *Q*-values (25-50), the amplitude and width of each resonant peak is damping limited over about a semitone or two of its resonant frequency. Because of the logarithmic sensitivity of the ear, each mode still contributes significantly to the perceived sound well away from its resonance, where its response is determined by its springiness and effective mass below and above its resonant frequencies.

The effective mass of the individual shell modes can be determined from the measured mobility or admittance (induced velocity/applied force) in the direction of the force at the point of excitation. For a given mode, the lighter the plates, the stronger the radiated sound. Curtin (2006) has suggested that one of the reasons for the general decline in quality of violins from around 1750 onward was the use of somewhat heavier plates than those of the Italian masters.

The radiated frequency response can be divided into three overlapping regions.

(1) A *signature* mode range over the first two octaves up to around 1,000 Hz, where there are a relatively small number of well-defined resonant modes such as the *A0, B1–, and B1+* modes indicated. Their resonant frequencies and intensities provide

Coupled Oscillators



Consider two coupled crossing-frequency *component* modes *a* and *b*. For simplicity, assume that some external constraint increases the frequency of mode *a*, which in the absence of coupling leaves the frequency of mode *b* unchanged, as illustrated in **Figure 5**, dashed lines. As soon as the coupling is "switched on," two uncoupled *normal* modes *A* and *B* are formed (solid lines) describing the in- and out-ofphase coupled vibrations of the *a* and *b component* modes. Well away from the crossing frequency (coincidence), the *normal* modes retain their characteristic *component* mode forms with only a small contribution from the other mode. However, as coincidence is approached, the normal modes acquire an increasing contribution from the other mode. This results in the illustrated veering in opposite directions of the *normal* mode frequencies away from those of the otherwise uncoupled *component* modes. At coincidence, the *normal* mode frequencies are split by an amount (Δ) determined by the coupling strength, with the two component modes vibrating with equal energy in either the same or opposite phases. Well above coincidence, the *normal* mode *A* continues to acquire an increasing *component b* mode character at the expense of mode *a*. Similarly, on passing through coincidence the character of *normal* mode *B* changes from *b* to *a*, as illustrated.

The vibrational modes of the violin can be considered as independent *normal* modes, with resonant responses identical to those of a simple harmonic oscillator, describing the coupled modes of the *component* modes of vibration of the top and back plates, the ribs, the cavity air modes, the neck and fingerboard assembly and their resonance, the tailpiece, and strings.

Figure 5. A schematic representation of the veering and splitting of normal mode frequencies describing the coupling of two component oscillators or vibrational modes.

an *acoustic fingerprint* for individual violins. They act as monopole sound sources radiating uniformly in all directions. Additional weak *CBR, A1*, and other higher frequency modes are also often observed but usually only contribute weakly to the radiated sound.

(2) A *transitional* frequency range from around 800-1,500 Hz, where there is a cluster of quite strong resonances that cannot so easily be characterized without detailed modal analysis measurements and analysis, such as those made by Bissinger (2008a,b) and Stoppani (2013). At these frequencies and above, the modes act as additional multipole sources, with the radiated sound fluctuating strongly with both frequency and direction. This results in what Weinreich (1997) refers to as *directional tone color*, with the intensity of partials or the quality of sound of bowed notes varying rapidly with both direction and frequency.

(3) A *high-frequency* range extending to well above 4 kHz, below which there is often a rather broad peak around 2-3 kHz, originally referred to as the bridge hill (BH) feature, although no longer considered a property of the bridge alone. The density of the overlapping damped resonances makes it increasingly difficult to identify individual resonances. Above around 3 kHz, there is a relatively rapid roll-off in the frequency response of around 12 dB/octave, as indicated by the solid line with slope −2. This is because the bridge acts like a strongly damped resonant input filter coupling the string vibrations to the radiating modes of the body shell.

The relative contributions and acoustic importance of the signature and higher frequency components to the sound of a violin are highlighted in **Audio 3**, http://goo.gl/UtNOI4, which illustrates the unfiltered recorded sound of a violin, then when the hard cut-off filters are applied first above and then below 1 kHz, and then with the their combined sounds repeated.

In the high-frequency range, a statistical approach arguably provides a more useful way of describing the acoustic response, with a relatively broad, formantlike frequency response, with superimposed fluctuations in amplitude dependent on mode spacing and damping (Woodhouse and Langley, 2012 , Sect. 3.3).

At a casual glance, all fine Italian violins and many later and modern instruments have very similar acoustic responses to those shown in **Figure 3**. Yet players can still recognize large differences in the sounds of even the finest Stradivari and Guarneri violins. Puzzlingly, it is currently still difficult to identify which specific features of the acoustic response correlate strongly with differences in perceived quality – other than at low and high frequencies.

At low frequencies, Dunnewald (1991) and Bissinger (2008a) found that poor violins usually have a very weak sound output, whereas at high frequencies, the response of all violins is strongly influenced by the vibrating mass of the bridge. This is easily demonstrated by adding a mute to the top of the bridge, with the increased mass increasing its high-frequency cut-off filtering action. This leads to a "softer," "warmer," and less intense sound, even for bowed notes played on the lower strings, which still involve important contributions from the higher frequency partials. The bridge mass and design can therefore strongly influence the sound of an instrument.

At low frequencies, the bowing forces cause the bridge to rock backward and forward on the island area. The resulting asymmetric rocking then allows components of the bowing force in the rocking direction to excite both antisymmetric and symmetric volume-changing modes. In particular, it enables the vibrating strings to excite a single, volume-changing, *breathing* mode primarily responsible directly and indirectly for almost all the sound radiated at frequencies in the *signature* mode frequency range (Gough, 2015b).

In addition to radiating sound directly, the *b1– breathing* mode excites the *a0* Helmholtz *f*-hole resonance. The coupling between the *component a0* and breathing modes results in a pair of *A0* and *B1 normal* modes describing their in- and out-of-phase vibrations.

Once the frequencies of the *A0* and *B1* modes are known, their monopole source strengths are automatically fixed. This follows from what is colloquially known as the "toothpaste effect" or zero-frequency sum rule (Weinreich, 1985). Well below the *a0* resonance, any inward flow of air into the cavity induced by the cavity wall vibrations will be matched by an equal outward flow through the *f*-holes. Because the source strengths of the coupled *f*-hole and *breathing* modes have to cancel at low frequencies, their contribution to the radiated sound is automatically determined throughout the signature mode frequency range, apart from the very small frequency range around their resonances when damping becomes important.

In practice, the strongly radiating *breathing* mode is also weakly coupled to the nonradiating *bending* mode of the body shell, illustrated to the right of the plot in **Figure 6**. This is a consequence of the different elastic properties of the arched top and back plates. When the shell breathes, the arched plate edges of the two plates move inward and outward by different amounts. This induces a bending of the body shell like the bending of a bimetallic strip induced by the differential expansion of the dissimilar metals. This is the origin of the coupling between the *b1– breathing* and *b1+ bending component* modes of the body shell. This results in the pair of *B1–* and *B1+* modes, with relative radiating strengths determined by the amplitude of the component *breathing* mode in each (Gough, 2015b). Such a model describes the dominant features of the typical low frequency acoustic response illustrated in **Figure 4**.

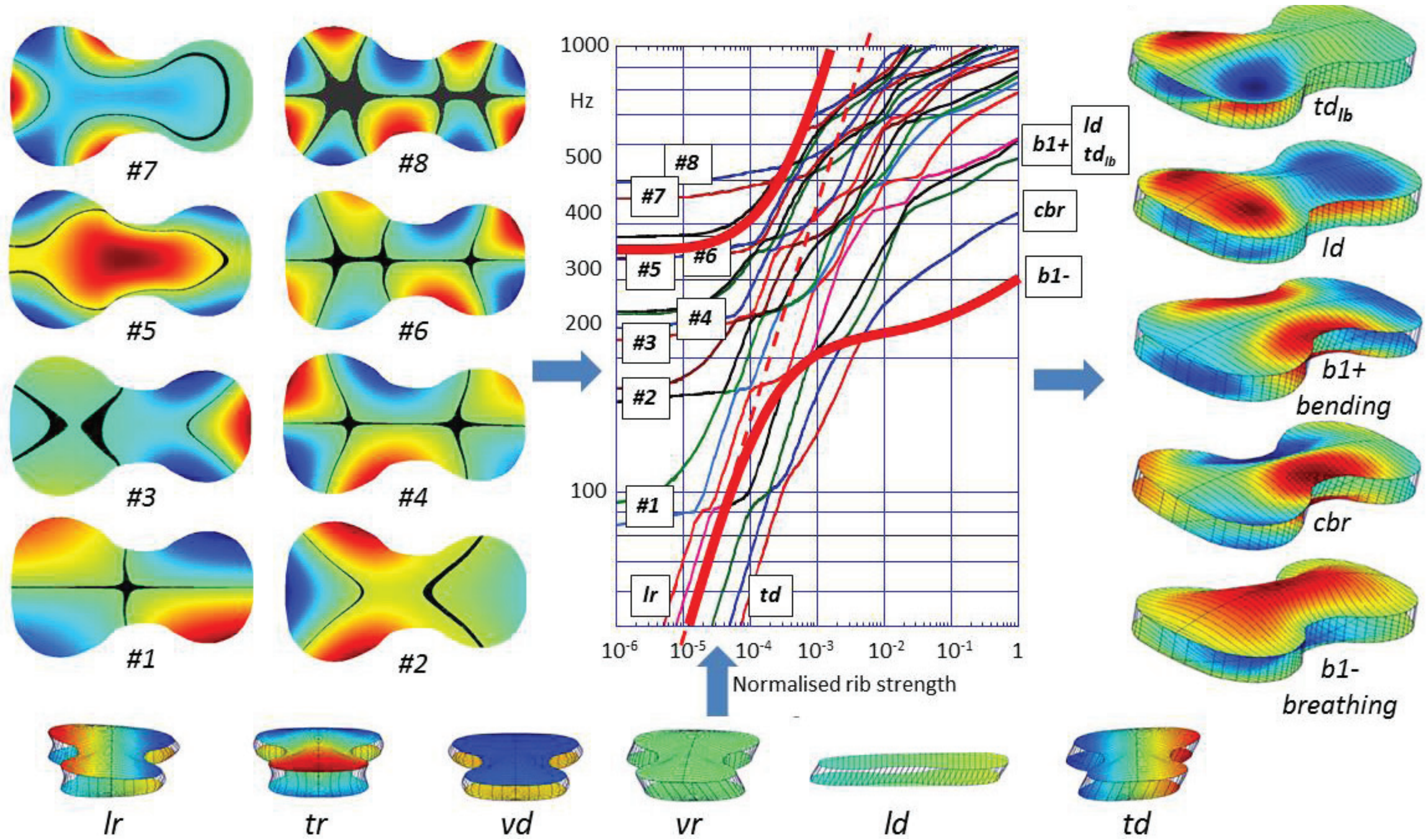
The introduction of the offset soundpost results in a localized decrease and asymmetry of the shell-mode shapes across the island area between the *f*-holes. This and coupling to the *f*-hole mode result in a large increase in the component *breathing* mode frequency, increasing its coupling to the component *bending* mode. It also accounts for the asymmetric rocking of the bridge, enabling horizontal components of the bowing forces to excite the strongly radiating *breathing* component of any its coupled modes.

The soundpost and enclosed air also induce coupling of the *breathing* modes to the other nonradiating body shell modes and to the vibrational modes of all attached components like the neck, fingerboard, tailpiece, and strings. This is responsible for the additional weakly radiating *normal* modes appearing as substructure in the acoustic response, as in **Figure 4**.

Modeling Violin Modes

A successful physical model for the resonant modes of the fully assembled violin needs to describe the relationship between the modes of the assembled body shell and those of the individual plates before assembly and to show how the body shell modes are affected by their coupling to the cavity air modes within the shell walls, by the offset soundpost wedged between the top and back plates, the strings, and all other attached components like the neck, fingerboard, tailpiece, strings, and even the player.

Such a model is described in two recently published papers on the vibrations of both the individual plates and the assembled shell (Gough, 2015a,b). COMSOL 3.5 Shell Structure finite-element software has been used to compute the modes of a slightly simplified model of the violin to dem-



onstrate and understand how the coupling between all its component parts influences the vibrational modes and their influence on the radiated sound. This has involved varying the influence of each component over a very wide range as an aid to understanding the nature of and effect of the coupling.

To give a flavor of this approach, **Figure 6** illustrates the transformation of the initially freely supported individual plates into the modes of the empty body shell as the rib coupling strength is varied over six orders of magnitude from close to zero to a typical normal value. The highlighted curves illustrate how the important radiating *breathing* mode of the body shell is transformed from the *component #5* plate mode and its extremely strong interaction with the rising frequency *bouncing* mode of the rigid plates that are constrained by the extensional springlike and bending of the ribs.

There are many perhaps surprising and interesting features that such computations reveal, which are described in the downloadable supplementary text *Modelling Violin Modes* (http://acousticstoday.org/supplementary-text-violin-acoustics-colin-e-gough/), which also gives suggestions for additional background reading. Here, I simply invite those interested to view **Video 2, Video 3,** and **Video 4** which illustrate the 3-dimensional vibrations of the *A0, CBR, B1−, B1+*, and higher frequency dipole modes computed first in vacuum, then with coupling to the air inside the cavity via

Figure 6*. Transformation of the modes of the freely supported top and back plates into those of the assembled empty shell as a function of normalized rib strength varied over six orders of magnitude.*

the Helmholtz *f*-hole resonance, and finally with the offset soundpost added.

Such computations validate and quantify a model for the violin and related instruments treating their modes as those of a thin-walled, guitar-shaped, shallow-box shell structure, with doubly-arched plates coupled together by the ribs, cavity air modes, soundpost, and coupling to the vibrational modes of the neck-fingerboard assembly, the tailpiece, and strings. This model can be understood by standard coupled oscillator theory and, I believe, accounts for all known vibrational and acoustic properties of the violin and related instruments.

Acknowledgments

I am particularly grateful to the violin makers Joseph Curtin, George Stoppani, and Sam Zygmuntowicz for access to their data and encouragement, to Jim Woodhouse and Evan Davis for invaluable scientific advice, and to all my colleagues at the annual Oberlin Violin Acoustics Workshops, who have provided valuable information and feedback during the lengthy development of the present model.

Biosketch

Colin Gough is an Emeritus Professor of Physics at the University of Birmingham, Birmingham, UK, where he researched the quantum wave mechanical, ultrasonic, and microwave properties of both normal and high-temperature superconductors. As a "weekend" professional violinist, musical acoustics has always been an added interest, publishing papers on various aspects of violin acoustics, teaching, and supervising courses and projects for undergraduate physics students. In recent years, he has been on the staff of the annual Oberlin Violin Acoustics Workshops. He contributed chapters on *Musical Acoustics* and *The Electric Guitar and Violin* for Springer's *Handbook of Acoustics* and *The Science of String Instruments*, respectively.

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Acoustics of Regionally Accented Speech

Ewa Jacewicz

Postal:
Department of Speech and Hearing Science
The Ohio State University
1070 Carmack Road
Columbus, Ohio
43210-1002
USA

Email:
jacewicz.1@osu.edu

Robert A. Fox

Postal:
Department of Speech and Hearing Science
The Ohio State University
1070 Carmack Road
Columbus, Ohio
43210-1002
USA

Email:
fox.2@osu.edu

Sociocultural variation in pronunciation is a fast-developing, captivating area of acoustic research as regional accents continue to diversify American speech.

Introduction

Speech communication typically takes place in a social context. Naturally, spoken language transmits not only a message but also indexical variation cueing social attributes of the speakers, such as their age, sex, socioeconomic status, education, or occupation. Variation of this kind reflects social aspects of language use within conventions imposed by both the individual and society.

But language use is also sensitive to more general cultural factors such as beliefs, attitudes, behaviors, customs, and values of a given group that are transmitted from one generation to the next. Indeed, cultural history has played an important role in the development of regional variation in English spoken in North America. The geographic patterns of early immigration from England were largely shaped in the 18th and 19th centuries as settlers constructed transportation systems facilitating the spread of their original English dialects westward. Settlement patterns had important linguistic consequences for the formation of American cultural geography and regional variation in American English (AE) and, to some extent, still exert a persistent influence on modern speech.

Traditionally, the development of AE dialects in the United States has been studied within the field of sociolinguistics, a branch of linguistics concerned with how language use is influenced by society. More focused work on regional dialects has been carried out within the subfield of dialectology. In seeking to determine features of regional dialects and understand their sociocultural context, both sociolinguists and dialect geographers examine speech samples and classify markers of differences in the lexicon (vocabulary), grammar, usage, and phonology (pronunciation). Phonological variants are fairly salient markers and, typically, have been identified by means of auditory ("by ear") judgments and described qualitatively. For example, the salience of the r-less speech feature of eastern New England associated with the Bostonian accent has often been captured orthographically ("Pahk the cah in Hahvahd yahd" for "Park the car in Harvard yard") or transcribed using phonetic symbols. But traditional descriptions tend to fail when faced with modern speech recognition applications (listen how to Siri deals with the Bostonian accent at https://www.youtube.com/watch?v=1wBpSWxPo6o).

This is where acoustic analysis of regionally accented speech has emerged as a welcome area of scientific inquiry. With the technological advancement over the last two decades and development of new analytic tools and methodologies, regional variation has been explored with a great deal of scientific rigor, producing new evidence and advancing the field of speech communication.

Here, we present a few key concepts and selected highlights from this rapidly developing area in speech acoustics. We focus here on AE because most of the acoustic studies have been conducted in North America. However, regional variation has become a fertile field not only in the remaining parts of the English-speaking world including the British Isles (Ferragne and Pellegrino, 2010), Canada (Boberg, 2005), Australia (Cox, 2006), and New Zealand (Watson et al., 2000) but is also emerging in languages and geographic regions worldwide. The growing interest is reflected in presentations at international conferences including the International Congress of Phonetic Sciences, INTERSPEECH, the Conference on Laboratory Phonology (LabPhon), and ASA meetings. Journal-length papers have also begun to document acoustics of regional variation in languages such as Dutch (Adank et al., 2007) and French (Schwab and Avanzi, 2015). The complexity of dialects in China, including subdialects of Mandarin, has been explored in MA theses and PhD dissertations around the globe, such as Li (2015) who used several acoustic metrics to examine rhythm patterns in 21 Chinese dialects.

The Concept of Speech Community

The central tenet of sociolinguistics is that the linguistic behavior of individual speakers cannot be understood without knowledge of the larger group, the speech community, to which they belong (Labov, 2001). Research in regional variation is thus concerned with the extent to which individuals conform to pronunciation patterns in their own speech community. There are different kinds of communities because each community is a group of people who uniquely share a specific pattern of language use that determines its size and location. For example, a speech community can be geographically defined and be relatively small (such as the island of Martha's Vineyard, Massachusetts) so that the pronunciation patterns may be viewed as a marker of local identity (Labov, 1963). A different kind of speech community has often been found in larger cities. Such communities consist of social networks or "ties" between individuals who speak a common variety to show their solidarity with one another and maintain group identity. For example, a study of Belfast English found that the local dialect features were preserved in individuals participating in dense networks (who shared the same social contacts) and interacted in multiple social contexts, whereas weak ties and loose networks stimulated the reduction of distinctive local accents, favoring standardization (Milroy, 1980).

In the United States, speech communities can be very large. The dominant pronunciation patterns in these major geographic regions spanning several states became the primary focus of acoustic analysis. The first and most comprehensive

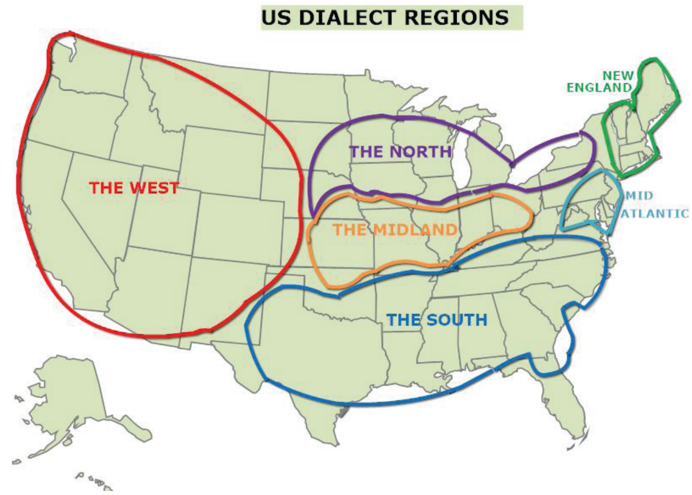

Figure 1. Map of the six major dialect regions in the United States.

overview of the major regional variants (or dialects) of English spoken in North America was provided in the *Atlas of North American English (ANAE)*, based on the acoustic analysis of 439 speakers recorded in the years 1992-1999 (Labov et al., 2006). Using a sociolinguistic sampling procedure by means of telephone interviews, the *ANAE* identified six broad dialect regions shown in **Figure 1**: North, Midland, South, West, New England, and Mid-Atlantic. Within these major varieties, there are also dialect regions identified on the basis of more specific variables such as vowel changes (known as shifts, mergers, and splits). In fact, the *ANAE* is predominantly a study of the pronunciation of vowels because it is primarily the vowels that differentiate regional variants in AE.

A particularly striking vowel pronunciation pattern has been found in large metropolitan areas around the Great Lakes in the North, extending from southeastern Wisconsin (Madison, Milwaukee, Kenosha) to northern Illinois (Chicago, Peoria), northern Ohio (Cleveland, Toledo), Michigan (Detroit, Grant Rapids), and New York State (Syracuse, Rochester, Buffalo). This large region with a population of about 34 million people constitutes a relatively uniform speech community known as the Inland North. The core feature of the dialect of the Inland North is a series of vowel pronunciation changes termed the northern cities shift (NCS; listen to Wisconsin speech, **Demonstrations 1** and **3**, at http://goo.gl/bOFDWw).

In sharp opposition to the Inland North is the Inland South, a much smaller community in the South whose regional accent has a particularly high concentration of core Southern features. The Inland South is a mountainous Appalachian region that includes parts of Tennessee, North Carolina, Georgia, and Alabama, whose homogeneity originates in its settlement history dating back to the 18th century. The region was populated primarily by Scotch-Irish migrants whose cultural identity has favored isolation and small-town values. The vowel system in the Inland South is affected by the Southern Shift, a distinct set of changes whose traces can be found across the whole American South. However, the features of Southern Shift are particularly robust in the Inland South and even more so in the speech of older speakers (listen to North Carolina speech, **Demonstrations 1** and **3**, at http://goo.gl/bOFDWw). These two contrasting speech communities, the large metropolitan Inland North and the smaller and relatively detached Inland South, provide two examples of adherence to different regional cultural patterns that underlie both the divergence of AE dialects in today's society and the survival of regional accents in the face of population mobility, television, and multicultural influences.

Sound Change

The divergent trends in AE dialects are in part due to the operation of distinct chain shifts in regional vowel systems (such as the NCS or the Southern Shift) that have stimulated audible changes in pronunciation patterns across generations of speakers and, to a large extent, predict further development of regional dialects. In the English language, sound changes of this kind have been known for centuries and documented by historical phonologists in descriptive terms. The most famous example of such diachronic sound change is the English Great Vowel Shift, which was a radical sound change affecting the English vowel system during the 15th to 18th centuries (Stockwell, 1978). Although the primary evidence for the diachronic change comes from historical scripts, it is the state-of-the-art of the acoustic analysis that enables progress in documenting sound change. The precision of acoustic measurements prevents misinterpretations and inaccurate assumptions. Also, knowledge of typical acoustic variation is essential to execute more systematic control in selecting speech materials for recordings and analysis, which has significant implications for a better understanding of sound change.

Ideally, sound change in a speech community ought to be studied in "real time," that is, longitudinally over a number of years, but there is an obvious difficulty in obtaining speech data from the same individuals repeatedly over several decades. A notable exception is an analysis of the annual Christmas broadcasts of Queen Elizabeth II over a 50-year period (Harrington, 2006). These broadcasts contain the Queen's annual addresses to Britain and the Commonwealth read in a similar style. A careful acoustic analysis revealed changes in the pronunciation of some of the Queen's vowels. Possibly, these changes reflect the Queen's adoption of certain features of a mainstream pronunciation and certainly are not associated with any specific geographic region. The acoustic exploration of the Queen's pronunciation patterns over time has a unique value and is an excellent example of a real-time study, even if it does not provide insights into sound change in a particular speech community. Admittedly, the eminent Queen's accent (also known as the Queen's English) represents upper-crust received pronunciation of British English (Wells, 1982), a nonlocalized variety spoken by a relatively small number of individuals belonging to the highest social class. The speeches can be found on the official website of the British Monarchy. The first televised broadcast was delivered in 1957 (https://www.youtube.com/watch?v=mBRP-o6Q85s) and the latest in 2015 (https://www.youtube.com/watch?v=8Mzor6Hf1tY).

To overcome the difficulties in obtaining longitudinal data, acoustic analyses of sound changes have been carried out in "apparent time," that is, cross-sectional. In those studies, the pronunciations of younger and older speakers were compared and any changes were interpreted as sound change in the community over the period corresponding to the age difference between the two generations. Such cross-generational comparisons provide sufficient evidence of sound change if the speakers have resided in their communities for most of their lives (Labov, 1994; Sankoff, 2005). A more recent example of an apparent-time study is a large-scale investigation of sound change in three distinct AE speech communities in southeastern Wisconsin, central Ohio, and western North Carolina (Jacewicz et al., 2011a). Using a common experimental protocol, speech samples were obtained from three generations: grandparents (66-91 years old), parents (35-51 years old), and children (8-12 years old). Acoustic analysis revealed robust changes in the pronunciation of vowels across the generations, providing new evidence and improved understanding of the most current sound changes that each speech community is undergoing (listen to **Demonstration 1** at http://goo.gl/bOFDWw).

Acoustic Measurements in Characterizing Regional Vowel Systems

A more systematic use of acoustic analysis for studying vowel production in sociolinguistic context was introduced in early 1970s when sociolinguist William Labov and his team at the University of Pennsylvania first utilized vowel formant measurements to characterize regional vowel variation (Labov et al., 1972). However, over the next three decades, the progress in this area has been relatively slow, hampered by time-consuming early-measurement techniques on one hand and by a general lack of theoretical or practical interest in studying language variation by speech scientists on the other.

A brief look at four important studies, all published in *The Journal of the Acoustical Society of America*, can help us appreciate how the attitude toward regional variation has gradually changed over the years. The first seminal acoustic study of vowel production by Peterson and Barney (1952) did not even consider that the variable regional background of the speakers could obscure the overall pattern of AE. A modern replication of the study by Hillenbrand et al. (1995) acknowledged and addressed this limitation by controlling for the dialect so that the majority of the speakers were selected from southern Michigan. Numerous differences between the two studies were found that may stem from the fact that the participants in Hillenbrand et al. (1995) spoke the regional variant of the Inland North affected by the NCS.

As research interest in socially motivated indexical variation in pronunciation intensified in the early 2000s (which was to some extent driven by advances in speech technology applications), acoustic explorations of regional vowel systems received a more serious consideration. To that end, Clopper et al. (2005) provided a comprehensive description of the acoustic differences among vowels in the six major dialect regions (see **Figure 1**). Further progress was stimulated by the discovery that regional accents utilize important acoustic details in the dynamic vowel structure that contribute to audible differences among dialects (Fox and Jacewicz, 2009).

Exploration of Acoustic Details in Regional Vowel Systems

Formant frequency analysis has been the primary approach to study the acoustic characteristics of vowels and has also been applied to regional variation. Traditionally, the frequencies of the first two formants, F1 and F2 (representing the two most prominent maxima in the vowel spectrum), have been measured at a vowel's center or "steady state" under the assumption that these measurements represent its canonical target values. This classic approach is shown in the left panels of **Figures 2** and **3**. The data points in these plots indicate mean F1 and F2 values for the vowels in the selected words. The dispersion of these data points tells us how the vowels are distributed in the F1 by F2 plane (or vowel "space") and how their configuration differs as a function of

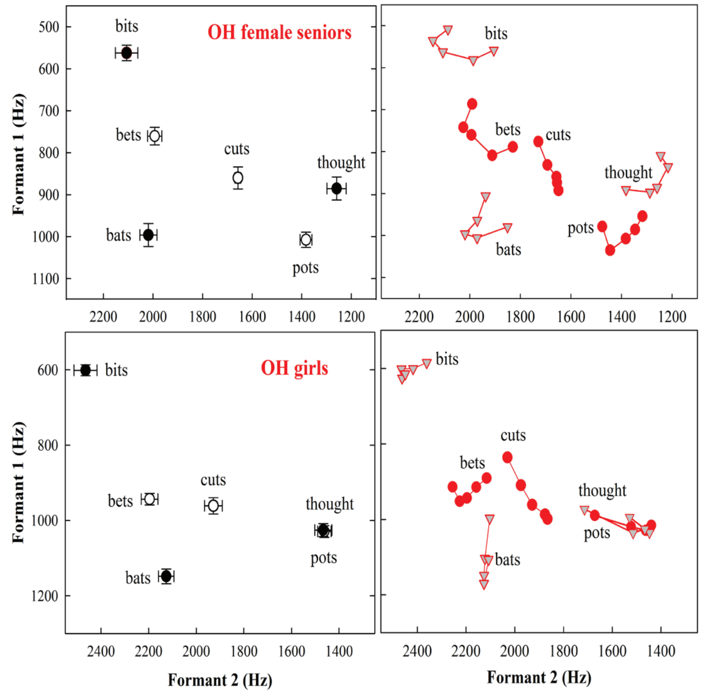

Figure 2. *Example of a formant plot showing a configuration of vowels measured in the selected words. Using speech analysis software, frequencies of the first two formants, F1 and F2 (representing the two most prominent maxima in the vowel spectrum) are measured and the plotted values reflect dialect-specific articulation patterns. Left: Each data point is the mean ± SE of several instances of the vowel in each word spoken by seven women in their 70s and 80s (top) and ten girls 8-10 years old (bottom) from central Ohio (OH). The relative positions of several vowels have changed in children's speech, reflecting cross-generational sound change in this speech community. For example, the vowels in "pots" and "thought" have merged in children, and this merger indicates that they cannot tell the difference between words such as "cot" and "caught." Right: The corresponding panels provide more details about time-varying spectral change in a vowel. The frequencies were sampled five times in equidistant time intervals to approximate formant trajectory shape. The acoustic proximity of the five points is interpreted as a degree of diphthongization. For example, the vowels in "bits" and "bats" have lost much of the formant movement in children relative to adults, becoming more monophthongal.*

dialect and speaker generation. This is how acoustic measurements inform us about regional variation. In particular, researchers examine and interpret changes in the relative positions of the vowels in the acoustic space, which may signal mergers (manifested as an acoustic overlap) or shifts (movement in a particular direction). But this approach assumes that vowels are purely monophthongal (such as when saying "iiiiiiiiiiiiii"). In reality, research has shown that even nominal monophthongs (and not only diphthongs such as in "my-cow-boy") display reliable amounts of spectral change (Nearey and Assmann, 1986).

Consider now the plots in the right panels of **Figures 2** and

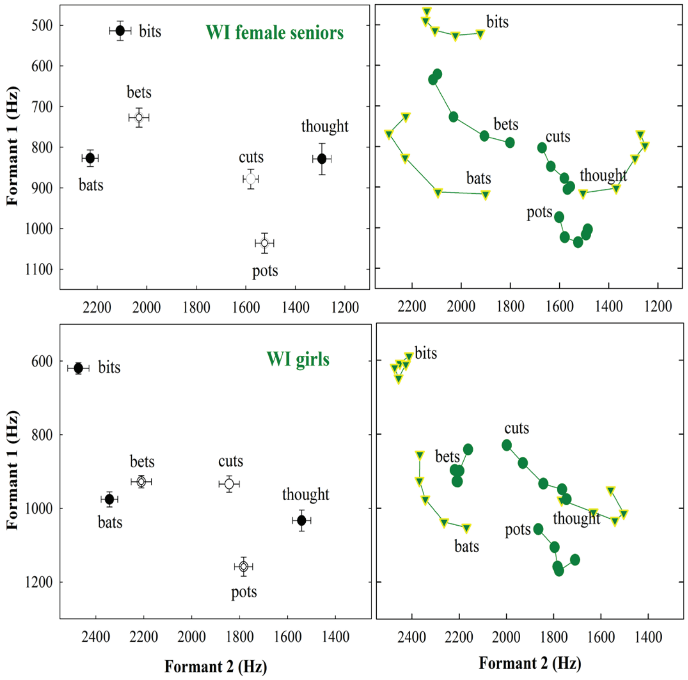

Figure 3. Configuration of vowels spoken by eight women in their 70s and 80s (top left) and ten girls 8-10 years old (bottom left) from southeastern Wisconsin (WI). Each data point is the mean ± SE of several instances of the vowel in each word. The dialectal differences between WI and OH (see ***Figure 2****) are in part due to the operation of the northern cities shift in WI. Right: The corresponding panels provide more details about time-varying spectral change in a vowel. Compare the relative positions of "cuts" and "pots" in WI and OH, the lack of the "pots/thought" merger in WI children, and the elevated position of "bats" relative to "bets" in WI. The dialectal differences are also reflected in the nature of formant dynamics.*

3. The points indicate mean F1 and F2 values sampled multiple times over the course of each vowel's duration. These multiple measurements allow us to observe the spectral change and estimate formant movement patterns for each vowel. Our lab has recently tested this approach with about 360 speakers from 3 distinct dialects spoken in southeastern Wisconsin (the Inland North), central Ohio (the Midland), and western North Carolina (the Inland South). We found that such detailed acoustic variations indicate dialect-specific use of dynamic information in vowels to enhance cultural differences and cross-generational sound change (Jacewicz et al., 2011a,b,c; Jacewicz and Fox, 2013).

A good example of the dialect-specific use of dynamic information is the differential pronunciation of the vowel in *bad* in Wisconsin and North Carolina as illustrated in **Figure 4**. The two variants may have similar midpoint frequencies but neither has a true "steady state." In fact, thinking of these two variants in terms of static vowel positions in the acoustic space is misleading. As shown in the right panel of **Figure 4**, it is the dynamic nature, direction, and extent of formant movement that is shaped by regional variation, and these acoustic attributes become markers of a regional accent (see **Demonstration 2**, at http://goo.gl/bOFDWw).

Modeling the Acoustic Variation

Over the past two decades, much work has been devoted to modeling variation in formant dynamics. Although descriptive approaches are informative in their own rights, statistical evidence is needed to increase the understanding of dialect-specific influences on the dynamic formant pattern. Although not necessarily common, curve-fitting parameterization has been generally accepted in modeling changes in formant trajectories. For example, in discrete cosine transform (DCT) modeling, the first coefficient represents a straight line whose slope value is proportional to the mean frequency of the original formant trajectory, a measure of basic vowel position; the second coefficient is a measure of tilt, and the third is a measure of curvature. In general, a 2-DCT model performed well in a number of studies (Zahorian and Jagharghi, 1993; Watson and Harrington, 1999), but these studies did not examine dialect-related variations. In our lab, we fitted several models to the North Carolina data (DCT and polynomials) and found a 3-DCT significantly outperforming a 2-DCT model. Although the effectiveness of this type of modeling still needs to be evaluated in the broader context of regional variation, it is clear that more sophisticated approaches need to be developed to separate the pure effects of regional accents from other sources of variation in formant movement coming from consonant environments, prosody, or speech tempo. A useful overview of the current work in this area, including modeling efforts, can be found in a volume from Springer's *Modern Acoustics and Signal Processing* series (Morrison and Assmann, 2013).

Consonants, Prosody, Tempo, and Perceptual Categorization of Dialects

Besides vowels, acoustic studies of regional variation in other aspects of AE have been far less systematic. Little is known about consonant variation (but see Purnell et al., 2005; Jacewicz et al., 2009) or about the use of prosody across dialects. Prosodic differences were found in the rising pitch accents between Minnesotan and southern Californian speakers (Arvaniti and Garding, 2007) and in pitch movement differences between midwestern and southern speakers (Clopper and Smiljanic, 2011) but far more work remains to be done. One area that has received considerable attention is temporal variation such as how speech tempo and tempo-

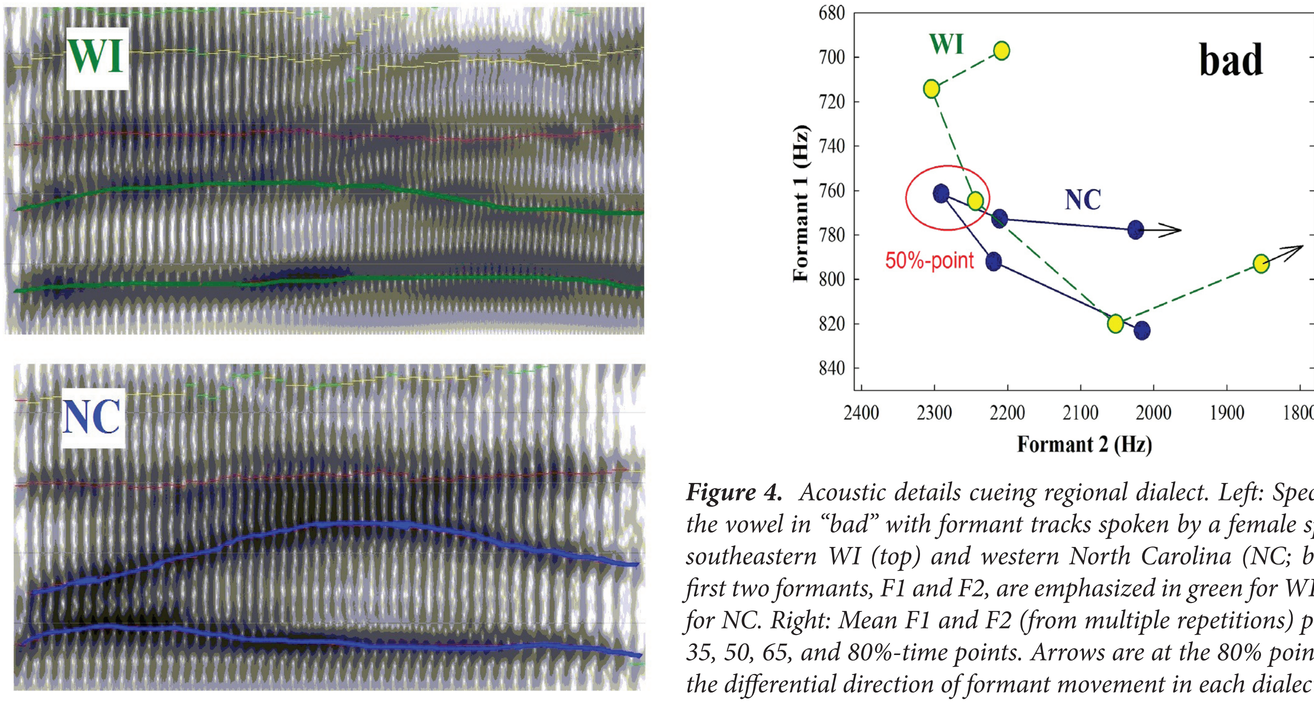

Figure 4. *Acoustic details cueing regional dialect. Left: Spectrograms of the vowel in "bad" with formant tracks spoken by a female speaker from southeastern WI (top) and western North Carolina (NC; bottom). The first two formants, F1 and F2, are emphasized in green for WI and in blue for NC. Right: Mean F1 and F2 (from multiple repetitions) plotted at 20, 35, 50, 65, and 80%-time points. Arrows are at the 80% point and depict the differential direction of formant movement in each dialect.*

ral patterns are shaped by regional variation. For example, Jacewicz et al. (2010) found that southern speakers have a significantly slower articulation rate than the northerners and that this difference is maintained across the life span. An important question is whether durations of individual segments (vowels and consonants) are globally reduced in the North because of the faster speech tempo and globally lengthened in the South given that the southerners speak slower. The mounting evidence suggests that the correspondence between segmental timing and speech tempo is not as straightforward and that temporal relationships are more complex. For example, the temporal distinction between long and short vowels (such as in "dad" and "kid," respectively) is manifested differently in different dialects irrespective of dialect-specific speech tempo (Fridland et al., 2014; Clopper and Smiljanic, 2015). A complicating factor is a dialect-specific use of pauses so that the temporal properties of the pauses, such as their frequency and duration and the resulting prosodic phrasing, may have a differential effect on the duration of vowels and consonants across dialects. Much more research needs to be done to better understand how complex temporal relationships are shaped by regional variation.

Naturally, acoustics of regional accents extends to their reception. Sociolinguists have studied dialect identification and intelligibility of individual dialects at least since the 1950s (Dickens and Sawyer, 1952), but it is the modern work in the perception of regional variation, notably by Clopper and Pisoni (2004), that introduced experimental rigor and methodological advancement. This work has examined the salience of acoustic information and listeners' strategies in perceptual categorization of dialects. For example, it was shown that untrained listeners have an explicit awareness of distinctive features of AE dialects and that "army brats" who lived in several dialect regions categorize talker dialect more accurately than "homebodies" who lived in only one place (Clopper and Pisoni, 2004). Also, intelligibility of regional dialects under difficult listening conditions such as in a background noise can vary as a function of dialect and talker gender, although General American, the more "standard" midwestern variety, seems to be more intelligible than other dialects (Clopper and Bradlow, 2008).

The Changing Demographics in the United States and Their Influence on Regional Variation

Media reports and folk perception have increasingly suggested that long-standing regional distinctions and many regional variants have been receding among younger people in favor of more General American forms. Thus, what is the future of regional dialects and how will the changing demographics in today's multicultural society affect the pronunciation patterns across the country? Researchers can only speculate at present and predict new developments on the basis of knowledge of both principles of sound change and sociolinguistic perspectives on human behavior, but the current evidence gives us reasons to believe that regional variation will not be erased in the next 20 years and that local pronunciation features will continue to diversify AE speech.

Earlier in this article, we emphasized the importance of the speech community in cross-generational transmission of regional features, suggesting that the survival of dialects is associated with the acquisition of cultural values. That is, dialect divergence is likely to persist if children are both able and willing to perceive, reproduce, and employ the patterns representing the target of language learning in their community. Some of those patterns can still be traced to the settlement history of the mid-19th century. Consider, for example, the strength of the cultural and linguistic boundary between the North and the Midland (Labov, 2010). The northern settlement stream came from New English Yankee communities, whereas the Midland was settled by the Quakers from Philadelphia and southern settlement spreading from Appalachia. Today, there is no shortage of communication between the northern cities such as Chicago and the Midland cities such as Columbus, Ohio, yet the vowel systems of children on either side of the boundary continue to diverge. Accounting for this divergence, Labov (2010) points out that it is the cultural clash between the Yankees and Midland settlers that established the differences in lifestyle and community norms. For example, Yankees built towns and cities and maintained a strong emphasis on literacy, whereas the Quakers formed farm communities rather than towns. The two regional dialects are thus associated with two different value systems and will be maintained as long as each successive generation acquires the knowledge of these cultural configurations and will be willing to follow the established sociocultural path.

An interesting current trend has been noted along the dialect boundary between East and West New England (Stanford et al., 2012). Namely, dialect features play a role in New Hampshire (East) and Vermont (West) state identities to the point that in a local shop near the state border one can buy a "New Hampsha" sandwich (spelling reflecting the r-less pronunciation) or a "Vermonter" sandwich (pronounced with a final "r"). The sharp distinction between the eastern and western New England speech is well documented (Kurath, 1939) and can be traced back to the social patterns of the founding settlers. Eastern New England developed the r-less pronunciation following the patterns of early settlers from southeast England, whereas a mixture of Yankee and Scotch-Irish families settled the r-pronouncing western New England. Although the Vermont-New Hampshire boundary is rooted in historical contrasts, modern lifestyle and increased contacts between younger residents have reduced the sharp dialectal differences in these populations. Younger eastern New England speakers do not want to sound old-fashioned and try to avoid r-less pronunciation in favor of the r-ful variant. Yet, a closer acoustic analysis shows that their speech has still retained less noticeable eastern features that, together with the r-ful variant, have constructed a more modern model of regional eastern New England identity. This example shows that, even if the most salient dialect features can be receding in young people, the regional varieties may not be fully merging into the General American, which lacks regional features.

Conclusions

Sociocultural variation in AE pronunciation patterns has become a new fascinating area of acoustic research. As American society becomes increasingly multicultural, much work needs to be done to understand the current and future changes in speech across the country and, increasingly, in the context of immigration. New questions arise. For example, will non-native speakers of English be able to acquire community patterns, and can such regional patterns be transmitted through non-native-accented English? Can they perceive subtle regional variations? If so, are such variations meaningful to them? Knowledge of regional variations can enhance work in related areas of acoustic research in speech communication, forensic science, signal processing and, perhaps, room acoustics and noise. But regardless of the background and area of scientific interest, we encourage readers of this article to test their implicit knowledge of regional accents the next time they go shopping, walk a dog, or stop at a pub. It can be a rewarding experience.

Biosketches

Ewa Jacewicz is a Research Associate Professor of Speech and Hearing Science at The Ohio State University in Columbus. She obtained a PhD in Germanic linguistics from the University of Wisconsin-Madison in 1999 and has pursued a research career in speech science since her first appointment as a Postdoctoral Research Fellow in 2000. Her interests are in speech acoustics and regional variation in American English with applications to speech development and disorders. She has been a member of the Acoustical Society of America since 2001. She served as an Associate Editor of the *Journal of Speech, Language and Hearing Research.*

Robert A. Fox is a Professor of Speech and Hearing Science at The Ohio State University in Columbus and, since 1995, Chair of that Department. He received a PhD in linguistics from the University of Chicago in 1978. He is a Fellow of the Acoustical Society of America and the American Speech, Language and Hearing Association and served as an Associate Editor of *The Journal of the Acoustical Society of America*. His research interests span a range of areas in speech perception and acoustics, including regional and nonnative variations, and speech changes across the human life span. He is also an expert witness in forensic acoustics.

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Regeneration of Auditory Hair Cells: A Potential Treatment for Hearing Loss on the Horizon

Rebecca M. Lewis

Postal:
Department of Otolaryngology/
Head and Neck Surgery
Virginia Merrill Bloedel
Hearing Research Center
CHDD CD176 Box 357923
University of Washington
Seattle, Washington 98195
USA

Email:
becky103@uw.edu

Edwin W Rubel

Postal:
Department of Otolaryngology/
Head and Neck Surgery
Virginia Merrill Bloedel
Hearing Research Center
CHDD CD176 Box 357923
University of Washington
Seattle, Washington 98195
USA

Email:
rubel@uw.edu

Jennifer S. Stone

Postal:
Department of Otolaryngology/
Head and Neck Surgery
Virginia Merrill Bloedel
Hearing Research Center
CHDD CD176 Box 357923
University of Washington
Seattle, Washington 98195
USA

Email:
stoner@uw.edu

Regeneration of cochlear hair cells is being investigated as a potential therapy for hearing impairments.

Introduction

The process of hearing involves a complex chain of events, and each one is important to ensure the proper detection and processing of sounds. In the first step, sound waves traveling through the environment enter the ear canal and vibrate the eardrum. This energy is transmitted through the three bones of the middle ear to the inner ear. Within the inner ear, the energy derived from the sound waves is transmitted to the basilar membrane of the cochlea, on which lies the sensory organ for hearing, the organ of Corti (**Figures 1** and **2A**).

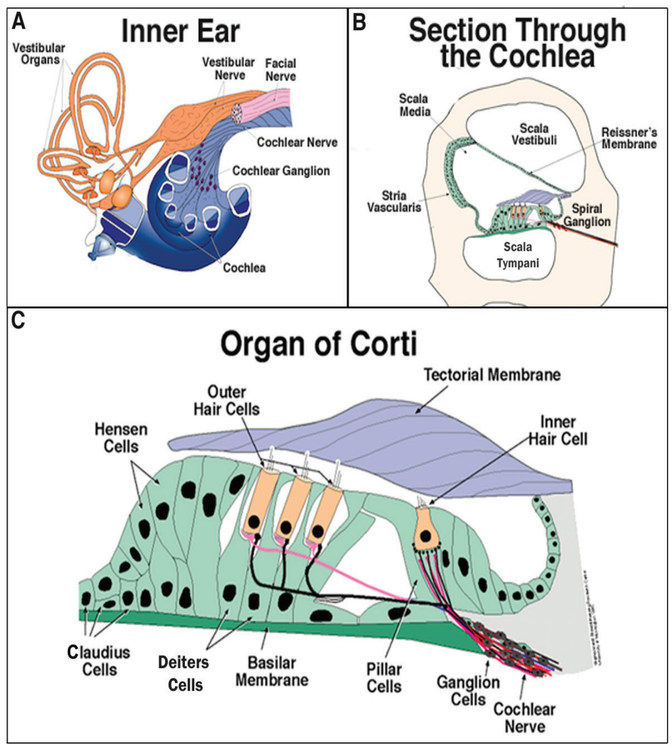

Figure 1. Schematic diagrams principal structures of the inner ear tissues (A), a slice through one turn of the cochlea (B) and the organ of Corti (C). Note that in the organ of Corti a single inner hair cell and three outer hair cells are shown along with the supporting cells. This pattern is repeated about 3,000 times along the spiraled cochlea in humans.

The organ of Corti is composed of sensory hair cells as well as a group of specialized cell types, collectively called supporting cells, and the peripheral processes of auditory neurons. Hair cells are sensory receptors. Responding to the mechanical signals derived from sound waves, hair cells transduce this energy into electrical signals that are transmitted via the auditory nerve to the brain. In the normal human ear, there are about 3,000 inner hair cells and 12,000 outer hair cells (Bredberg, 1967). Inner hair cells (**Figure 2B**) are the true sensory receptors. On stimulation, the inner hair cells activate auditory nerve fibers that in turn activate auditory brainstem nuclei. The major function of the outer hair cells (**Figure 2C**) is to modulate the function of the organ of Corti by enhancing signal processing of low-ntensity auditory signals. These two types of hair cells work together such that the auditory nerve

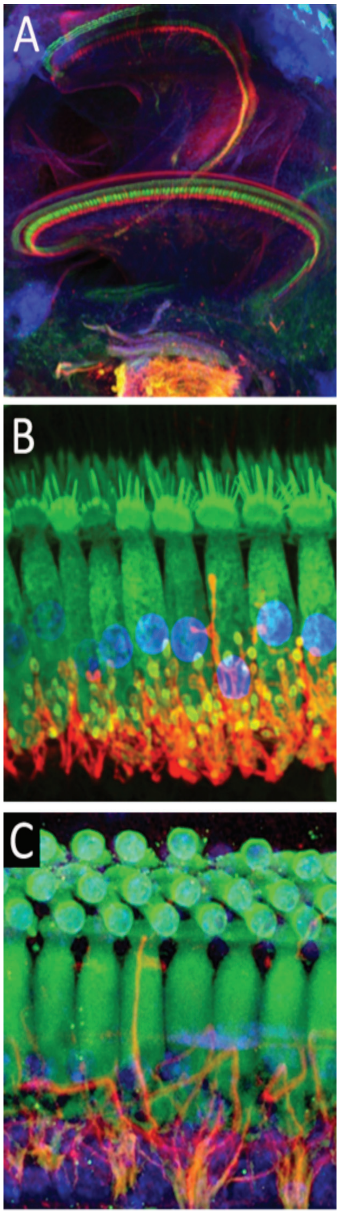

Figure 2. *A: Mammalian cochlea with hair cells (green), nerves (red) and spiral ganglion neurons (yellow/orange). B: Inner hair cells and stereocilia (green), with nuclei (blue) and nerve fibers of neurons that transmit information to the brain (red; McLean et al., 2009). C: Top of the three rows of outer hair cells (green dots at top) and the tubular single row of inner hair cells innervated by neural process (red/orange).*

transmits highly selective information about the frequency, timing, and intensity of sounds to the brain. Supporting cells are nonsensory cells that neighbor and isolate hair cells from one another. These nonsensory cells work with the surrounding structures to provide physical and molecular support to this elaborate sensory epithelium.

Hearing loss can result from a failure of acoustic signals to reach the inner ear (conductive hearing loss) or from damage to any part of the inner ear or the central auditory pathways in the brain (sensorineural hearing loss[SNHL]). Conductive hearing loss is usually treated by medical or surgical means. The most common form of SNHL results from damage or dysfunction of hair cells in the organ of Corti. When hair cells in the mammalian cochlea die, they do not regenerate; this form of SNHL is permanent (**Figure 3**). If hearing loss is moderate, patients can be fit with hearing aids, which amplify sounds to enhance hearing. If it is severe, patients can receive cochlear implants to bypass the injured hair cells and directly stimulate the auditory nerve. Neither form of treatment restores normal hearing or addresses the cause of hearing loss, the missing hair cells.

Around 30 years ago, the discovery that hair cells regenerate in birds raised the possibility that we could someday find away to replace hair cells in mammals, including humans. Since that time, many advances in our understanding of hair cell regeneration in birds, fishes, and mammals have been achieved. This article reviews the current state of research in the field of hair cell regeneration. Due to space limitations, we have removed all but the most essential citations. For further details and relevant citations, we encourage readers to examine the many review papers related to this field (e.g., Warchol, 2011; Groves et al., 2013; Rubel et al., 2013).

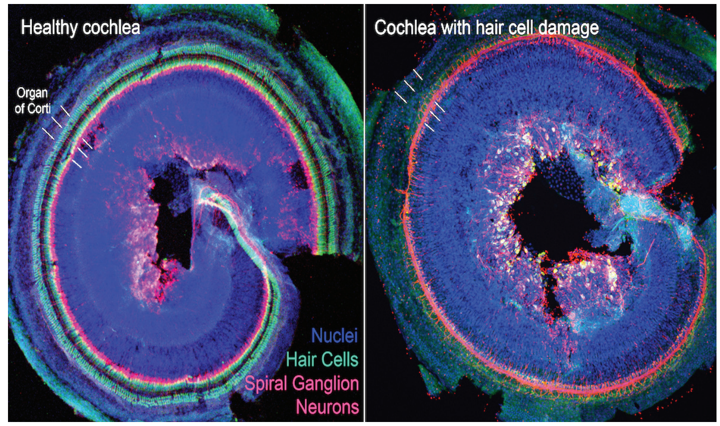

Figure 3. *Left: Surface view of a healthy cochlea with hair cells (green), neural processes (red), and nuclei (blue).Right:A damaged cochlea that no longer contains hair cells but has preserved neural processes and nuclei. White arrows: Organ of Corti boundaries.*

Cellular Processes of Hair Cell Damage and Regeneration

The sensory epithelium of the cochlea is a cytoarchitecturally elegant and delicate structure (**Figure 1**). The hair cells are commonly damaged by a variety of environmental events, some of which are known, including acoustic overstimulation from loud or prolonged noise or concussive stimuli. Several different types of medications kill hair cells when administered at high doses or for prolonged periods. These include, but are not limited to, aminoglycoside antibiotics such as gentamicin and heavy metal anticancer drugs such as cisplatin. Hair cells also die as we age; in most cases, this is due to unknown causes. Finally, genetic mutations exist that cause hair cells to die during embryonic development or at later stages of life.

Until 1985, it was believed that regeneration of inner ear hair cells was not possible in vertebrates. While studying processes of hair cell damage in the chicken auditory epithelium, however, investigators noted a reappearance of hair cells in the area of damage. The immature morphology of these cells appeared similar to that of embryonic hair cells in

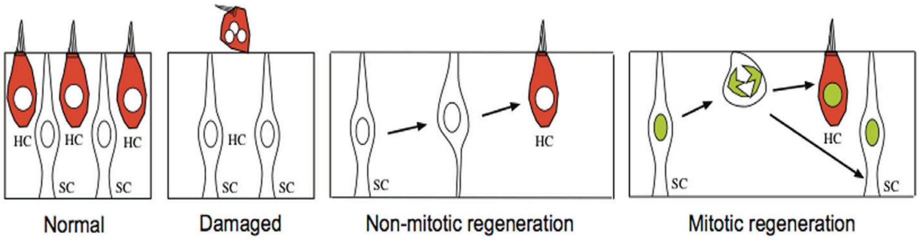

Figure 4. The undamaged auditory epithelium of the bird contains hair cells (HC; red) interdigitated with supporting cells (SC; white). On damage, hair cells are removed from the epithelium and supporting cells are triggered to regenerate hair cells. Nonmitotic regeneration allows a supporting cell to change its shape and genetic profile to that of a hair cell. Mitotic regeneration requires a supporting cell to divide and differentiate into two daughter cells, a hair cell and a supporting cell.

the cochlea of chickens (Cotanche, 1987; Cruz et al., 1987). During this same period, it was also discovered that regeneration of hair cells occurs readily in the vestibular portions of the avian inner ear (Jørgensen and Mathiesen, 1988). Soon, researchers learned that the hair cells of the inner ear and lateral line system of fish, frogs, and salamanders also readily regenerate after damage, which led to the conclusion that regeneration occurs in hair cell epithelia of all vertebrates except mammals. Further analysis revealed that the supporting cells that normally surround the hair cells are the source of these newly differentiating hair cells. Supporting cells may either mitotically divide to achieve hair cell differentiation or phenotypically convert to a hair cell in a process called direct transdifferentiation (**Figure 4**) (Corwin and Cotanche, 1988; Ryals and Rubel, 1988; Roberson et al., 1996). With these two methods of replacing hair cells, nonmammalian vertebrates provide valuable models to study these processes and their ability to restore hearing after sustained SNHL.

In mammals, the situation is quite different. When hair cells die in the mature mammalian organ of Corti, supporting cells fill in the gaps where hair cells were located to form permanent scars, and no new hair cells are formed. Moreover, supporting cells neither divide nor convert into hair cells after hair cell damage (e.g., Roberson and Rubel, 1994; Chardin and Romand, 1995).

In contrast to the organ of Corti, adult mammals can spontaneously replace a small number of hair cells in the vestibular organs of the inner ear. New hair cells are largely formed by nonmitotic regeneration (Forge et al., 1998; Kawamoto et al., 2009; Golub et al., 2012). There appears to be a small degree of supporting cell division triggered in response to hair cell loss (Li and Forge, 1997; Kuntz and Oesterle, 1998), but no newly formed cells become replacement hair cells (Oesterle et al., 2003).

The big challenge facing researchers today is to determine why hair cells are not readily regenerated in mammals. Regeneration could fail in the adult cochlea because the hearing organ loses the population of progenitor cells capable of forming new hair cells during development. Alternatively, cells with the potential to replace hair cells may exist in the cochlea but are unable to respond to damage due to active inhibition or lack of stimulatory signals.

Stimulating Native Progenitors to Form New Hair Cells in the Adult Cochlea

Researchers have examined whether the cells capable of forming new hair cells still exist in the cochlea of mature mammals. Many tissues in our body undergo continual renewal. One common feature of these tissues is that they contain stem cells that divide and form new specialized cells throughout life. Several lines of evidence show that the cochlea and vestibular organs possess stemlike progenitors to hair cells during early development but lose them as the organs mature (Oshima et al., 2007). Consistent with this, new hair cells can be formed by supporting cells from the organ of Corti of neonatal mammals (White et al., 2006; Cox et al., 2014), but not in adult mammals (e.g., Roberson and Rubel, 1994; Forge et al., 1998).

Investigators are using three general strategies to identify ways to trick supporting cells in the mature mammalian inner ear to regenerate hair cells. First, we are finding clues in cochlear development. Hair cells in the organ of Corti form during the embryonic period through a complex series of cellular steps controlled by a cascade of molecular interactions. Some researchers have postulated that, before any cell in the mature cochlea can form a new hair cell, it will need to relive these same stages of development.

Second, we look to other regenerative tissues. Many tissues in the body are continuously replaced under normal conditions and/or after damage, including cells in the skin, intestine, and some regions of the brain. We reason that many of the molecular cascades leading to regeneration in these other tissues could be co-opted to trigger regeneration in the cochlea.

Third, using the new tools of molecular genetics, we can directly query the molecular cascades that are activated in the sensory epithelia of nonmammalian vertebrates that do regenerate hair cells, such as birds and fishes. In the section below, we describe several genes and signaling pathways that met one or more of these criteria and were evaluated for their capacity to stimulate hair cell regeneration in mammals. These analyses revealed signaling molecules that are important for facilitating regeneration.

Forced Atoh1 Expression: Pushing Mature Supporting Cells to Transdifferentiate Into Hair Cells

A proneural transcription factor named atonal homolog 1 (Atoh1) is a potential therapeutic agent for promoting hair cell regeneration. Atoh1 helps to direct the generation of hair cell-specific proteins that give the hair cell its morphological and physiological identity (Cai et al., 2015). When the gene encoding Atoh1 is deleted, hair cells in the organ of Corti do not form (Bermingham et al., 1999). Thus, Atoh1 is a very powerful activator of hair cell features and could trigger cells to transdifferentiate into hair cells.

In tissues that regenerate hair cells, Atoh1 expression is activated in supporting cells shortly after hair cell damage (Cafaro et al., 2007; Wang et al., 2010; Lin et al., 2011). In cultured auditory organs from chickens, forced expression of Atoh1 influences supporting cells to form new hair cells by promoting division and direct transdifferentiation (Lewis et al., 2012). In rodents, forced expression of Atoh1 by viral injection into the organ of Corti or nearby regions of developing mice forces more cells to differentiate as hair cells (Zheng and Gao, 2000; Gubbels et al., 2008). These findings suggested Atoh1 misexpression might be sufficient to trigger supporting cells to transdifferentiate into hair cells after damage in the cochlea of adult mammals. Indeed, some studies suggest that Atoh1 may drive production of new hair cells in auditory (Izumikawa et al., 2005) and vestibular (Schlecker et al., 2011) organs, which might result in small improvements in hearing and balance function.

However, recent studies are less encouraging. Misexpression of Atoh1 in pillar and Deiters' cells, two supporting cell subtypes (**Figure 1**), in the mature mouse cochlea stimulates early stages of transdifferentiation into hair cells, but this process is not completed and many "forced" cells die (Liu et al., 2012). Indeed, Atkinson et al. (2015) noted no significant improvement in hearing after virally induced Atoh1 misexpression in the organs of Corti of guinea pigs. Hence, an important current challenge is to determine what factors

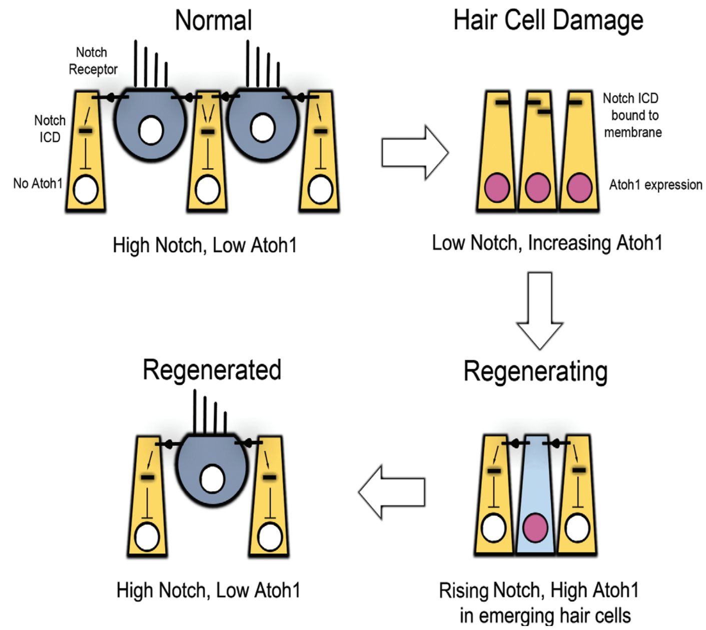

Figure 5. *Expression patterns of the Notch receptor and Atoh1 transcription factor in supporting cells (yellow) and hair cells (blue) under normal, damaged, and regenerating conditions. In supporting cells in undamaged epithelia, there is high Notch receptor activity and the Notch intracellular domain (Notch ICD) travels to the nucleus, inhibiting Atoh1 expression. In supporting cells after hair cell damage, Notch receptor activity is reduced, Notch ICD remains at the membrane, and Atoh1 levels increase, driving the supporting cell to transdifferentiate into a hair cell. Once the new hair cell matures, Notch activity is increased again and Atoh1 transcription is reduced to normal levels.*

limit the ability of Atoh to drive hair cell regeneration in the mature cochlea. Currently, a human clinical trial testing the ability of viral infection of Atoh1 to improve hearing is underway. Results are not available at this time.

Suppression of Notch Signaling: Can This Enhance Proregenerative Effects of Atoh1?

As discussed above, it is evident that, although Atoh1 misexpression reliably promotes supporting cells and other cells around the organ of Corti to become hair cells in neonatal mammals, unidentified factors appear to hinder the effects of Atoh1 in the mature organ of Corti. One likely suspect is the factor is signaling through the Notch receptor (Lewis, 1998).

Notch is a receptor on the surface of cells that is activated by molecules on adjacent cells (**Figure 5**). Notch has many functions in a variety of cells, but its most pertinent role with respect to hair cell regeneration is the inhibition of hair cell formation. During development, Notch ligands are expressed in young hair cells and influence surrounding supporting cells to maintain their identity rather than differentiate into hair cells (reviewed in Kelley, 2006). Notch signaling executes this function, at least in part, by blocking Atoh1 synthesis (Lanford et al., 2000). In the developing cochlea, inhibition of Notch signaling results in a significant increase in the number of hair cells (e.g., Hayashi et al., 2008; Doetzlhofer et al., 2009). Similar effects of Notch inhibition have been documented during hair cell regeneration in fishes (Ma et al., 2008), birds (Daudet et al., 2009), and mouse vestibular organs (Lin et al., 2011). One study suggests that infusion of Notch inhibitors into live mice can promote supporting cells to convert into hair cells in the organ of Corti of adult mice after hair cell damage (Mizutari et al., 2013). However, another study clearly describes a precipitous loss of efficacy of Notch inhibitors to stimulate hair cell regeneration (Maass et al., 2015). Hopefully, these apparently conflicting interpretations of Notch inhibition will be resolved in future studies.

Lifting the Blockade on Supporting Cell Division in Native Progenitors

As discussed above, supporting cells in the mature organ of Corti are strongly inhibited from dividing even after hair cells have been killed. Although Atoh1 misexpression and/or Notch inhibition appears to encourage supporting cells to form hair cell-like cells in mature animals, neither treatment has a significant effect on supporting cell division. Therefore, as a therapy alone, either manipulation would likely deplete supporting cells, which would almost certainly reduce the function of the organ of Corti. Investigators are attempting to determine how to promote supporting cells to divide mitotically and either replace themselves or form new hair cells. At this point, there are no known manipulations that have these effects in the mature organ of Corti. However, we know some ways in which supporting cell division can be promoted in the young cochlea.

For cochlear supporting cells to divide, they must exit their normal state of mitotic inactivity and enter the cell cycle. p27^{Kip1} is a molecule that blocks progenitor cells (or supporting cells) in the organ of Corti of mice from dividing during embryonic and postnatal development. Embryonic deletion of the gene encoding p27^{Kip1} causes an excess of cells to be formed in the organ of Corti, including hair cells (Chen and Segil, 1999; Löwenheim et al., 1999). In mature mice, blocking the synthesis of p27^{Kip1} causes a small but significant increase in cell division in some types of supporting cells in the organ of Corti (Oesterle et al., 2011). Inhibition of p27^{Kip1} and similar molecules is under investigation as a way to promote mammalian hair cell regeneration. It is particularly important at this stage that investigators determine if p27^{Kip1} deletion in adult rodents leads to the production of functional, stable hair cells.

Activity of p27^{Kip1} and other regulators of cell division is controlled by extracellular signaling molecules. One set of molecules that drives cell division in many tissues is Wnts, which binds receptors on the surface of cells and activates a transcriptional coactivator called ß-catenin (reviewed in Jansson et al., 2015). Wnt/ß-catenin signaling is required for progenitor cell division during cochlear development; when inhibited, significantly fewer hair cells form (Shi et al., 2014). Forced overexpression of Wnt promotes supporting cells in the organ of Corti to divide in very young mice but not in mature mice (Chai et al., 2012; Shi et al., 2013). Therefore, activation of Wnt alone cannot overcome other inhibitory signals present in the mature mammalian organ of Corti. In contrast, pharmacological activation of Wnt promotes hair cell regeneration in lateral line functional neuromasts of larval zebrafish (Head et al., 2013; Jacques et al., 2014).

Epidermal growth factor (EGF) is another molecule that drives supporting cell division in the supporting cells in the organ of Corti of neonatal mice as well as in supporting cells in the regenerating auditory epithelium of mature chickens (White et al., 2012). Treatment of cultured organs of Corti with EGF in newborn rats increases the formation of supernumerary hair cells (Lefebvre et al., 2000). Once again, this effect rapidly declines with age (Hume et al., 2003).

Could Transient or Combinatorial Treatments Improve Hair Cell Regeneration?

As discussed above, we now know several powerful genes or signaling pathways that, when manipulated in very young rodents, cause supporting cells to divide and form new hair cells. But these same manipulations have very little effect or even deleterious effects in mature rodents. These findings tell us that promotion of hair cell regeneration in mature humans will be more challenging than originally thought. One strategy that scientists are testing is whether transient activation or suppression of gene activity has a better outcome than sustained alterations. During development, signals turn on and off in cells, whereas many of the manipulations discussed above are permanent and therefore unnatural. Modern techniques for transient gene silencing, such as siRNA, might enhance the effects of treatment by better recapitulating nature. Another hypothesis being tested is whether combinatorial manipulations of genes and pathways can more effectively promote regeneration than single manipulations. This has proven to be fruitful in the cochlea of neonatal rodents in experiments that activate Atoh1 and inhibit Notch simultaneously (Zhao et al., 2011) or activate Atoh1 and Wnt simultaneously (Kuo et al., 2015). These dual approaches acknowledge the complexity of growth regulation in mature tissues as well as the critical interactions that occur between pathways.

Transplantation of Cells to Replace Hair Cells

In the prior section, we discussed strategies for promoting native cells in the damaged organ of Corti to divide or directly transdifferentiate to replace lost hair cells. It is possible, however, that a responsive population may not persist in the adult cochlea. On the other hand, we may fail to find appropriate treatments to stimulate resident cells to regenerate hair cells. In either case, it will be necessary to adopt an alternative approach and to transplant cells to the inner ear that can replace hair cells. The obvious choice is to transplant stem cells, which have the potential to divide and differentiate into a range of mature cell types. Stem cells can be grown in a dish and guided toward a desired cell fate (in this case, hair cell) by certain chemical agents or culture conditions. Stem cells hold great promise for treating several types of pathology, including heart disease, blindness, and leukemia.

Some of the first studies to test the usefulness of different types of stem cells to replace damaged hair cells were performed with pluripotent stem cells or neural stem cells derived from mouse embryos. Li et al. (2003) conditioned mouse embryonic stem cells with various compounds in culture to drive them to differentiate hair cell-like features. On transplantation into the embryonic chicken ear, conditioned cells incorporated into hair cell epithelia and acquired hair cell-like properties. Fujino et al. (2004) found that neural stem cells introduced into cultured inner ear organs from rats integrated into the sensory epithelia of vestibular organs but not the cochlea. Subsequently, Oshima et al. (2010) identified treatments that drive induced pluripotent stem cells (derived from fibroblasts) to differentiate advanced features of hair cells in culture, including hair bundles and mechanotransduction currents. More recently, stem cells from human embryos were found to be capable of forming hair cell-like cells in culture (Ronaghi et al., 2014).

The true test of the therapeutic usefulness of a stem cell is whether it can become integrated into the organ of Corti, become innervated by the auditory nerve, differentiate mature features, and survive. Introduction of stem cells into the organ of Corti is a challenge because the organ is surrounded by a fluid-filled cavity that is embedded within the temporal bone and is easily disrupted by surgical intervention. It would seem very difficult to place transplanted cells into the organ of Corti given the tiny nature and delicacy of the tissue and the fact that fluid barriers would need to be disrupted. Nonetheless, several approaches for cell delivery are under investigation. Scientists have introduced embryonic stem cells into the fluids of the organ of Corti (scala media) and into the perilymphatic spaces surrounding the scala media (Coleman et al., 2006; Hildebrand et al., 2005). Although some stem cells seem to persist in these spaces and integrate into some tissues around them, there is little evidence that stem cells integrate into the organ of Corti. However, Parker et al. (2007) reported that neural stem cells injected into the noise-damaged cochlea became incorporated into the sensory epithelium. Clearly, more studies are needed to identify ways to coax stem cells to integrate into damaged hair cell epithelia, acquire mature features, and restore function.

Clinical Considerations

Although progress toward hair cell regeneration has been significant given the limited time elapsed since its discovery, several challenges remain to determine how effective hair cell replacement could be for improving hearing in humans. For instance, we do not know how many hair cells of each type must be regenerated to adequately restore hearing in impaired individuals. Although we know that inner hair cells are critical, we can only guess how well they will restore hearing in the absence of outer hair cells. Many forms of hearing loss are caused by selective destruction of outer hair cells; regeneration of outer hair cells alone could be helpful in such patients. Furthermore, we lack the capability to accurately test which type of cells need repair in patients. This assessment requires development of more cell-specific and noninvasive diagnostic procedures. In addition, high-resolution imaging of the inner ear, enabling quantitative assessment of each cell type, would be very helpful and is currently under investigation. Although there are challenges to restoring hair cells after damage in mammals, many hurdles have already been conquered, with promising research on the horizon to introduce a potential treatment for hearing loss.

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Biosketches

Rebecca M. Lewis studied speech and hearing sciences during her undergraduate training at the University of Washington, Seattle. She is currently enrolled in the dual AuD/PhD program at the University of Washington in speech and hearing sciences and is being mentored by Jennifer Stone in otolaryngology. She is enrolled in her clinical externship at the Veterans Affairs Puget Sound Health Care System and completed her AuD/PhD graduate training in May, 2016. She plans to continue practicing clinical audiology while remaining engaged in research in further treatments for audiology patients with sensorineural hearing loss or vestibular balance disorders.

Edwin W Rubel received PhD in physiological psychology from Michigan State University, Lansing. Since 1986, he has been a Professor in the Departments of Otolaryngology and Physiology and Biophysics and Adjunct Professor in the Department of Psychology at the University of Washington, Seattle. He is the founding Director of the Virginia Merrill Bloedel Hearing Research Center and currently holds an endowed Chair. His research interests include development and plasticity of the central and peripheral auditory system, inner ear hair cell regeneration, and modulation of inner ear hair cell death. His laboratory, along with Dr. Douglas Cotanche, discovered hair cell regeneration in birds.

Jennifer S. Stone studied biology and studio art at Skidmore College, Saratoga Springs, NY, and then completed PhD graduate training in anatomy and neurobiology at Boston University. She performed a postdoctoral fellowship in otolaryngology at the University of Washington School of Medicine, Seattle. Now, she is a Research Professor in Otolaryngology at the University of Washington School of Medicine.

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NEWS *from the* Acoustical Society Foundation Fund

Leo and Gabriella Beranek

Leo Beranek's manifest contributions, as discussed in Acoustics Today, Volume 10, Issue 4, are legend. In resonance with Leo, Gabriella Beranek, Leo's wife, shared these observations recently: "Of course we love to hear great performances in fine concert halls, but many other aspects of our acoustics environment deserve study and attention."

She and Leo together are referring to noise control in public spaces, reducing outdoor noise pollution, building better harmony in multifamily dwellings, understanding human perception to sound in spaces, and much more—all related to the fields of architectural acoustics and noise control.

They recognize that achieving these hopes depends on the training and education of future generations of acousticians. So they have chosen to support these goals through a significant donation to the Acoustical Society Foundation Fund (ASFF). The Leo and Gabriella Beranek Scholarship in Architectural Acoustics and Noise Control will be initiated by the first $30,000 stipend in 2016.

Your donation to the ASFF can be in tune with the Beraneks to provide similar support for the many educational opportunities funded through ASA.

Carl Rosenberg
Chair, Acoustical Society Foundation Board
crosenberg@acentech.com

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TECHNICAL COMMITTEE REPORT

Physchological and Physiological Acoustics

Andrew J. Oxenham

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

Email:
oxenham@umn.edu

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 biology, 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 functional 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 underexplored 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.

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Standards Committee Meeting

Reports:
ISO/TC 43 (Acoustics) and ISO/TC 43/SC 1 (Noise), Milan, Italy, September 2015

Robert D. Hellweg, Jr.
13 Pine Tree Road, Wellesley, Massachusetts 02482 USA
Hellweg@HellwegAcoustics.com

Jeff G. Schmitt
ViAcoustics, 2512 Star Grass Circle, Austin, Texas 78745 USA
jeffs@ViAcoustics.com

Laura Ann Wilber
422 Skokie Boulevard, Wilmette, Illinois 60091 USA
l-wilber@northwestern.edu

Background

The objective of the Acoustical Society of America (ASA) "Robert W. Young Travel Awards for Support of the Development of International Standards in Acoustics" is to provide limited financial support to assist individual experts to participate in the development of International Standards prepared by International Standards Organization Committees ISO/TC43 (Acoustics) and ISO/TC43/SC 1 (Noise) as well as by the International Electrotechnical Commission (IEC) Committee IEC/TC29 (Electroacoustics).

An ASA member who is expert in a technical field applicable to one or more working groups (WGs) of IEC/TC29, ISO/TC43, or ISO/TC43/SC1 and is willing to commit to contribute to the development of drafts and to actively participate in WG meetings may apply for this award. Recipients shall be US citizens living in the United States and be self-employed, an employee of a small firm, semiretired, or retired.

The 2015 Robert W. Young Travel Award recipients were Robert Hellweg, Jeff Schmitt, and Laura Ann Wilber.

Highlights of Meetings

TC43, SC1, and most of their WGs meet at approximately 18-month intervals to address issues and ensure progress in standards development. Their most recent meetings were in Milan, Italy, in September 2015.

The United States was also represented in the WGs by Elliott Berger, Patricia Davies, Kevin Lai, Travis McColley, Douglas Moore, Brad Moulton, Chadwyck Musser, Paul Schomer, and Douglas Winker. The United States participated in all three of the TC43/WG meetings and seven of the nine SC1/WG meetings.

***Figure 1**. The United States delegation to ISO/TC43/SC1 plenary meeting in Milan on September 17, 2015. Left to Right: Douglas Moore, Laura Ann Wilber, Kevin Lai, and Robert Hellweg.*

TC43/WG1 (Threshold of Hearing), with Wilber participating, discussed several standards in the International Standards Organization (ISO) 389 series, some of which are being revised. Most of the standards considered by WG1 are contained in American National Standards Institute (ANSI) S3.6 (Audiometers). ISO has a standard for each transducer, whereas ANSI S3.6 has it all in one document. Generally, the reference equivalent threshold sound pressure levels (RETSPLs) are the same in the ISO and ANSI standards.

There was a discussion on voting on ISO/DIS 7029 (Statistical Distribution of Hearing Thresholds as a Function of Age) in which the United States voted negative because there was not enough information on why the standard needed to be changed and exactly what information went into the change. The project leader agreed to prepare a paper describing the threshold calculation procedure in detail along with a resolution of comments in addition to a proposed layout of ISO/FDIS 7029.

TC43/WG8 (Anechoic Qualification), with Schmitt as convener, and SC1/WG28 (Machinery Noise), with Hellweg as convener, met jointly and covered the following:

- The final draft amendments on the two standards for qualification of anechoic and hemi-anechoic chambers (ISO 26101 and ISO 3745 Annex A) were approved for international balloting. The first edition of ISO 26101 closed a loophole in ISO 3745 Annex A; however, it inadvertently caused many laboratories that met the criteria in ISO 3745 without using that loophole to no be longer be qualified. The United States discovered this problem and proposed amendments to correct it. Schmitt and Winker provided data that were instrumental in the approval of both of these revisions.

- ISO 3744 is one of the more popular sound power level standards; however, it is considered too complicated by general practitioners. WG28 began working to simplify ISO 3744.

- Because there is no IEC standard on requirements for computerized data-acquisition systems, a proposed instrumentation guide for the TC43 measurement standards was discussed. The guide, prepared in part by Schmitt, would address requirements for the use of multichannel computerized data-acquisition systems as an alternative to the IEC 61672 standards on sound level meters, which are not applicable to computerized systems.

TC43/WG9 (Loudness), with Wilber as convener, is developing two standards as a revision to the Zwicker method in ISO 532:1975: ISO/CD 532-1 (revised Zwicker method) and ISO/CD 532-2 (Moore-Glasberg method), which do not yield the same results. The United States proposed Part 2, which is similar to ANSI/ASA 3.4-2007. Comments were discussed, and for both methods, it was agreed to prepare draft standards for international voting after resolution of the remaining comments. Work will begin on Part 3 for determining the loudness for time-varying signals based on the Moore-Glasberg method.

SC1/WG45 (Environmental Noise), with Hellweg participating, began work on a standard for measuring and evaluating wind turbine noise in the environment. Two ASA/ANSI standards are relevant: draft S12.9 Part 7 (Low Frequency and Infrasound) and S12.100 (Background Sound in Quiet Areas). WG45 also began working on a standard to determine the prominence of impulsive noise.

TC43 and SC1 Plenary Meetings

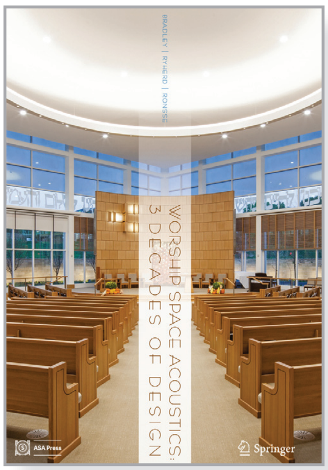
The US delegates to TC43 and SC1 plenaries were Hellweg, Lai, Moore, Wilber, and Davies (only SC1). TC43 and SC1 confirmed several standards and approved the circulation of numerous draft standards. SC1 approved the circulation of a ballot to form a new WG on "Tonal Prominence," and the United States will actively participate in this WG.

Summary

It is important for the United States to have effective representation at the ISO WG meetings because the responses to comments on draft standards are determined during these meetings. The authors believe we were successful overall in accomplishing our goals and are thankful to have received the ASA Robert Young Travel Award. If you wish further information, please contact the authors.

NEW Books from ASA Press *ASA Press is a meritorious imprint of the Acoustical Society of America in collaboration with the major international publisher Springer Science + Business Media. All new books that are published with the ASA Press imprint will be announced in Acoustics Today. Individuals who have ideas for books should feel free to contact the ASA Publications Office to discuss their ideas.*

Worship Space Acoustics: 3 Decades of Design



Authors: D.T. Bradley, E.E. Ryherd, L.M. Ronsse (Eds.)
ISBN: 978-1-4939-3096-8; 978-1-4939-3097-5 (eBook)
Pages: 367
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Publication Date: 1st. ed. 2016
Publisher: Springer-Verlag New York

- Provides detailed acoustic and architectural information for 6 worship space venues from 12 major religions directly from the acousticians who designed the spaces
- Features contributions from acoustical consulting firms and worship space designers worldwide, with spaces indexed by consulting firm and by geographic location
- Includes high-resolution photos and renderings, full-page architectural drawings, scientific data, an overview of acoustic design for worship spaces, and a glossary of common worship space acoustics terminology

This book takes the reader on a wide-ranging tour through churches, synagogues, mosques, and other worship spaces designed during the past 30 years. The book begins with a series of essays on topics ranging from the soundscape of worship spaces to ecclesiastical design at the turn of the 21st Century. Perspective pieces from an architect, audio designer, music director, and worship space owner are also included. The core of the book presents the acoustical and architectural design of a wide variety of individual worship space venues. Acoustical consulting firms, architects, and worship space designers from across the world contributed their recent innovative works in the area of worship space acoustics. The contributions include detailed renderings and architectural drawings, as well as informative acoustic data graphs and evocative descriptions of the spaces. Filled with beautiful photography and fascinating modern design, this book is a must-read for anyone interested in religious architecture, acoustical design, or musical performance.

Reviews

"*Worship Space Acoustics: 3 Decades of Design* is a beautiful collection of recent work. This is a comprehensive compendium that far surpasses previous publications in the field in its depth, design, and information. Worship spaces of all major U.S. religions are covered. This book should be an obligatory reference for any consultant involved in church architecture and acoustics."

-Mendel Kleiner, author of Worship Space Acoustics, Acoustics: Information and Communication Series *(J. Ross Publishing 2010)*

"All involved in their design will appreciate this presentation of recent rooms for religious worship."

-Leo L. Beranek, author of Concert Halls and Opera Houses: Music, Acoustics, and Architecture *(Springer-Verlag 2004)*

"Through descriptions, photos, drawings, and acoustical data, this book provides valuable information on existing worship spaces designed during the past thirty years. This very well-edited book, including the Editors' Preface and six excellent essays from key people involved in worship space design, provides valuable information and ideas on the aesthetic, acoustic, and liturgical design of worship spaces for a number of faiths and in several countries."

-Robert Coffeen, principle at R. C. Coffeen, Consultant in Acoustics LLC, Lawrence, Kansas

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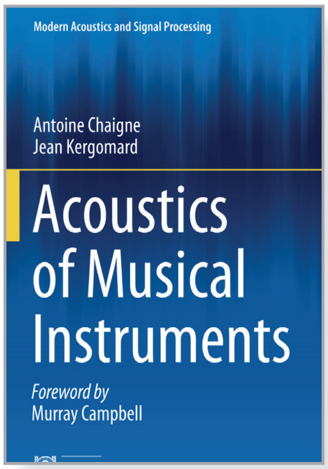

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Publication Date: 1st. ed. 2016; *Translation of Acoustique des instruments de musique, Second Edition,* (C) Éditions
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► Casts new light on the physics of musical instruments
► Includes up-to-date research published in the field of musical acoustics in the last fifteen years
► Outlines new methods developed in other fields such as complex modes and nonlinear normal modes
► Represents the only book on the physics of musical instruments to include practice exercises, catering to a broad audience of graduate students and researchers
► Brings the essential *Acoustique des instruments de musique* to an English audience for the first time

This book, the first English-language translation of *Acoustique des instruments de musique, Second Edition,* presents the necessary foundations for understanding the complex physical phenomena involved in musical instruments. What is the function of the labium in a flute? Which features of an instrument allow us to make a clear audible distinction between a clarinet and a trumpet? With the help of numerous examples, these questions are addressed in detail. The authors focus in particular on the significant results obtained in the field during the last fifteen years. Their goal is to show that elementary physical models can be used with benefit for various applications in sound synthesis, instrument making, and sound recording. The book is primarily addressed to graduate students and researchers; however it could also be of interest for engineers, musicians, craftsmen, and music lovers who wish to learn about the basics of musical acoustics.

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Obituary | Georg Elias Ioup | *1939-2016*

George Elias Ioup, a physicist and a Fellow of the Acoustical Society of America, passed away on January 20, 2016, in his New Orleans home after a two-year fight with cancer. George was born on March 26, 1939. In 1962, he received an SB degree in physics from the Massachusetts Institute of Technology and in 1968 a doctorate in physics from the University of Florida. His dissertation research advanced our understanding of low-energy atomic and molecular collisions through semiclassical elastic-scattering calculations and deconvolution of data. In 1969, George joined the physics faculty of the University of New Orleans (UNO) where he remained for 48 years.

By the early 1980s, the development of deconvolution techniques for acoustic and electromagnetic signals was a dominant topic of George's research endeavors. The methods of inverse problem solution are important in many research fields and George's expertise brought him many fruitful collaborations in acoustics, seismology, and radar observations. At the beginning of the millennium, George saw new research opportunities for the Gulf of Mexico state universities and a critical need for understanding the anthropogenic impact on the Gulf ecosystem. In 2001, George and his lifelong colleague and friend, Dr. Grayson Rayborn, founded the Littoral Acoustic Demonstration Center (LADC), with objectives to study the evolution of acoustic soundscapes in the Gulf and its impact on the environment utilizing passive acoustic monitoring. As the first data-processing results came to light, the group realized that collected acoustic recordings were rich not only in anthropogenic noise but also in marine mammal phonations. George was among the first scientists who wanted to tackle a very complex problem of identifying individual whales from their phonations. He worked tirelessly on this challenge and inspired many colleagues to follow. His group has made considerable progress in this direction. And if one day we have an acoustic library of individual whales, we shall always remember that George was the first to be convinced that this problem can be solved. George was actively working as a Co-PI on the 2015-2017 project sponsored by the Gulf of Mexico Research Initiative to study the long-term effects of the spill on deep-diving marine mammals using passive acoustics (www.ladcgemm.org).

One of the most important contributions a scientist can make is helping to create future generations of scientists. His guidance went beyond effectively teaching foundational courses and thoughtfully directing research projects. His mentorship guided many successfully through those important years of transition from student to scientist. His legacy of scientific integrity and professionalism as both a teacher and a researcher continues through the scientists he fostered. We will remember George not only as a great scholar but also as the kindest, most tolerant, and caring human being we came across during our life journey.

Selected Articles by George E. Ioup

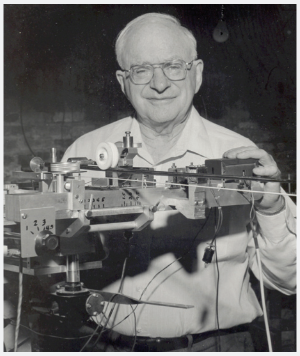
Ackleh, A. S., Ioup, G. E., Ioup, J. W., Ma, B., Newcomb, J. J., Pal, N., Sidorovskaia, N. A., and Tiemann, C. O. (2012). Assessing the Deepwater Horizon oil spill impact on marine mammal population through acoustics: Endangered sperm whales. *The Journal of the Acoustical Society of America* 131, 2306-2314.

Ioup, G. E. (1982). An introduction to deconvolution. *The Louisiana Physics Teacher* 7, 1518.

Tashmukhambetov, A. M., Ioup, G. E., Ioup, J. W., Sidorovskaia, N., and Newcomb, J. J. (2008). Three-dimensional seismic array characterization study: Experiment and modeling. *The Journal of the Acoustical Society of America* 123, 4094-4108.

Tiemann, C. O., Jaffe, J. S., Roberts, P. L. D., Sidorovskaia, N. A., Ioup, G. E., Ioup, J. W., Ekimov, A., and Lehman, S. K. (2011). Signal and image processing techniques as applied to animal bioacoustics problems. *Acoustics Today* 7(3), 35-43.

Written by:
Natalia A. Sidorovskaia, *Email:* nas@louisiana.edu



Norman was born on July 9, 1916, in Brooklyn, NY, where he attended school through high school. His love for music was kindled early by his mother at whose side, at the piano, he learned to read music. At the insistence of his father he studied engineering. Early in life, he set his heart on becoming a violinist and began playing at age 7, but an accident in his youth shattered that dream. However, his aspirations were not totally denied. With a degree in engineering from the Newark College of Engineering (later the New Jersey Institute of Technology) in 1936, he entered Juilliard with a scholarship and honed his skills as a horn player to the point that he was hired by the newly formed Indianapolis Symphony. Later, he continued to play as a professional, freelancing in New York. Norman is survived by his wife, Barbara Goldowsky, an accomplished writer and poet, whom he married in 1979; children from previous marriages: a daughter, Judith Crow, and three sons, David, Fredrick, and Rolf; two stepsons, Alexander and Boris Goldowsky; and numerous grandchildren and great-grandchildren.

Norman is the textbook example of the modern Renaissance man. His varied career includes working for C. G. Conn (now Conn-Selmer), a leading manufacturer of musical instruments in Elkhart, IN, where he helped to design mostly brass instruments including a very successful French horn model. During the war, Norman worked for the Sperry Gyroscope Company that had converted the Conn plant to produce aircraft instrumentation. His efforts eventually led to vibration control designs in Boeing 707s and 747s. In 1948, he was one of the founders of the Audio Engineering Society, which grew into an international organization. In 1949-1950, he did graduate work in acoustics under Harvey Fletcher at Columbia University. While working in a laboratory at Southampton Hospital, Norman developed instrumentation for ultrasound diagnostic techniques in eye examinations. In 1980, he returned to his first love, the violin. He served as president of the Violin Society of America, conducted research on the tone quality of bowed string instruments, and did consulting work for the "D'Addario" company, a prominent manufacturer primarily of guitar strings. In the course of his research, he built numerous violins and violas. He was particularly proud of his mechanized bowing machine, which made consistent research on bow-string interactions possible.

The development of the "Pickering cartridge," however, will likely be remembered by the world of music as his most significant contribution. Motivated originally by the poor tone quality of professional recordings and broadcasts, he replaced steel needle pickups with lighter and harder materials with a diamond tip. The reduction in record wear, accompanied by an increased electronic response, led to an unexpected consumer demand for a product that originally was designed for professional use. At its peak, his manufacturing company employed over 150 people.

Among Norman's many awards are recognition as a Fellow by the Audio Engineering Society and the Acoustical Society of America; special awards from the Violin Society of America, the Audio Engineering Society, and the Catgut Acoustical Society; and an Honorary Doctor of Science from the New Jersey Institute of Technology.

Selected Articles by Norman C. Pickering

Pickering, N. C. (1980). Results of mechanical bowing tests. *Journal of the Violin Society of America* 6, 59-64.

Pickering, N. C. (1983). Anomalies in the frequency-length function in violin strings. *Journal of the Audio Engineering Society* 31, 145-150.

Pickering, N. C. (1985). Physical properties of violin strings. *Journal of the Catgut Acoustical Society* 44, 6-8.

Pickering, N. C. (2003). *The Violin World*. Keener's East End Litho, Inc., East Hampton, NY.

Written by:

Uwe J. Hansen, *Email:* uwe.hansen@indstate.edu
Indiana State University

On July 4, 2015, our colleague Roelof Johan (Roel) Ritsma passed away at the age of 90 after a short illness. Roel was a member of the Acoustical Society since 1967.

In 1941, Roel was admitted to the Faculty of Sciences at Utrecht University (UU), The Netherlands. His physics study was interrupted by World War II from the beginning of 1943 until the end of the war in 1945. He returned to Holland in July 1945 from a forced labor period in Germany. In 1949, he finished his Master's study of physics at UU. It was followed by a PhD study, and he presented his thesis on *Electrometers* at same university in 1955. Next, he became involved in the teaching of physics and later also in teaching the teachers.

In 1958, Roel returned to fundamental research at the Institute for Perception Research in Eindhoven, The Netherlands, obtaining an associate professor position at the Eindhoven University of Technology. His contributions to auditory perception started in 1962 with a number of papers in *The Journal of the Acoustical Society of America* (Ritsma, 1962, 1963, 1967; Schouten et al., 1962). These all addressed properties of the so-called tonal residue. At the time, it was clear that the pitch of a complex sound did not require the presence of a component at the fundamental frequency nor was it exactly determined by periodicity information, viz., pitch strength decreased at very high harmonics where temporal information would be retained. The contradiction was largely resolved when Julius Goldstein proposed a spectral pattern recognition interpretation. During this research phase, Roel spent half a year at the Bell Laboratories in Murray Hill, NJ, in active contact with Newman Guttman and Aaron Rosenberg.

Roel Ritsma moved to Groningen, The Netherlands, in 1969 where he was appointed as chair of the Audiology Section of the ENT Department at the Academic Hospital (now the University Medical Center Groningen). He succeeded Henk Huizing, the first professor of audiology in The Netherlands. Roel actively promoted the field of audiology. In The Netherlands, he chaired the Dutch Audiological Society (NVA), and around 1970, he initiated the use of wireless equipment in schools for the hard of hearing.

Roel stimulated audiological research in relationship to the education of audiologists. Soon after the initiating research on otoacoustic emissions by David Kemp, the phenomena were verified in Groningen (Wit and Ritsma, 1979). He also remained interested in time-frequency properties of the auditory processing of complex signals such as speech in noisy environments (Horst and Ritsma, 1981).

Roel was married to Marietje van Buren from 1951 until her death in 2012. He is survived by three children and nine grandchildren.

Selected Articles by Roelof J. Ritsma

Horst, J. W., and Ritsma, R. J. (1981). Anomalous auditory filter bandwidth derived from direct masking of complex signals. *The Journal of the Acoustical Society of America* 69, 1770-1777.

Ritsma, R. J. (1962). Existence region of the tonal residue. I. *The Journal of the Acoustical Society of America* 34, 1224-1229.

Ritsma, R. J. (1963). Existence region of the tonal residue. II. *The Journal of the Acoustical Society of America* 35, 1241-1245.

Ritsma, R. J. (1967). Frequencies dominant in the perception of pitch of complex sounds. *The Journal of the Acoustical Society of America* 42, 191-198.

Schouten, J. F., Ritsma, R. J., and Cardozo, B. L. (1962). Pitch of the residue. *The Journal of the Acoustical Society of America* 34, 1418-1424.

Wit, H. P., and Ritsma, R. J. (1979). Stimulated acoustic emissions from the human ear. *The Journal of the Acoustical Society of America* 66, 911-913.

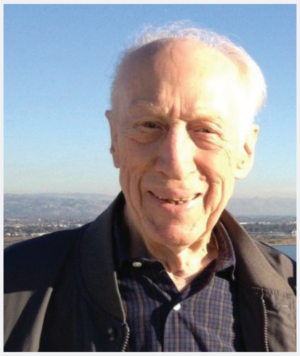
Written by:

Diek Duifhuis, *Email:* H.Duifhuis@rug.nl

Hero Wit, *Email:* hero.wit@ziggo.nl

Pim van Dijk, *Email:* P.van.Dijk@umcg.nl

University Medical Center Groningen



Ewart (Red) Wetherill, a Fellow of the Acoustical Society, passed away at his home in Alameda, CA, on November 14, 2015. Red was highly respected for his knowledge and professionalism in architectural acoustics as well as his ever-present kind-hearted humor when addressing anyone.

Red's work and reputation as an acoustical consultant was far reaching. He worked at the Cambridge, MA, and Los Angeles offices of Bolt, Beranek, and Newman, Inc. (BBN), before comanaging their San Francisco office with Warren Blazier in 1967. Leo Beranek said of Red, "He was an important member of BBN. We depended on him to manage the west coast architectural acoustics clients. He was a marvelous person. Clients were always pleased with the results of his consultations." He also worked at other consulting firms in the San Francisco Bay Area. He was introduced to architectural acoustics and its application to buildings by Robert Newman at the MIT School of Architecture and Planning.

Red's contributions to the profession, in particular to the ASA, are well-documented. He joined the ASA in 1962, was elected a Fellow in 1986, and served over five decades on the Technical Committee on Architectural Acoustics (TCAA), which he chaired from 1986 to 1989.

Red's work encompassed practically all areas of controlling sound in and around buildings, but he focused his concentration on four areas: performing arts auditoria, worship spaces, building noise control, and education spaces. His work typically had historical context and was very practical and educational.

In the architectural acoustics community, as soon as the name "Red" was mentioned, everyone knew exactly who was being spoken about. Architectural clients actually looked forward to consultations with Red. He made his recommendations easy to understand and convinced clients on the necessity of heeding recommendations for the long-term benefits and future users of the buildings, whether it was a school of music, a hospital, or a worship space.

Red attended the University of British Columbia as an undergraduate and obtained his Masters of Architecture from MIT. He held teaching positions at Clemson University, the University of British Columbia, and the University of California, Berkeley. He also guest lectured around the world. His presentations were always up-to-date using personal case studies and humorous anecdotes that reinforced the technical points involved.

Red will always be known for his creative free-hand drawings and buildable details for acoustical recommendations and solutions that were admired by his clients, architects, and peer consultants alike. His projects always looked as well as sounded good.

In addition to his dedication to the profession of acoustics, Red was dedicated to his family and his many friends and neighbors. He was president of the Citizen's League for Airport Safety and Serenity (CLASS) until just before his death. In October 2015, the Oakland Airport Noise Forum publicly recognized his efforts and his contributions in promoting airport noise compatibility with the community.

His wife Jinny, brother William, granddaughter Nikki, and grandson Raice survive Red.

Selected Articles by Ewart Wetherill

Purcell, J. B. C., and Wetherill, E. A. (1965). Acoustics of the Civic Center Theatre, San Diego, California, *The Journal of the Acoustical Society of America*, 37, 1202.

Wetherill, E. A. (1964). Acoustical considerations in church design. *Worship and Arts Magazine.*

Wetherill, E. A. (1965). Reduction of plumbing noise in a multistory building. *The Journal of the Acoustical Society of America*, 38, 936.

Wetherill, E. A. (2005). Forty years of plumbing noise control. *The Journal of the Acoustical Society of America*, 118, 1855.

Written by:

Dennis Paoletti, *Email:* dpaoletti88@gmail.com

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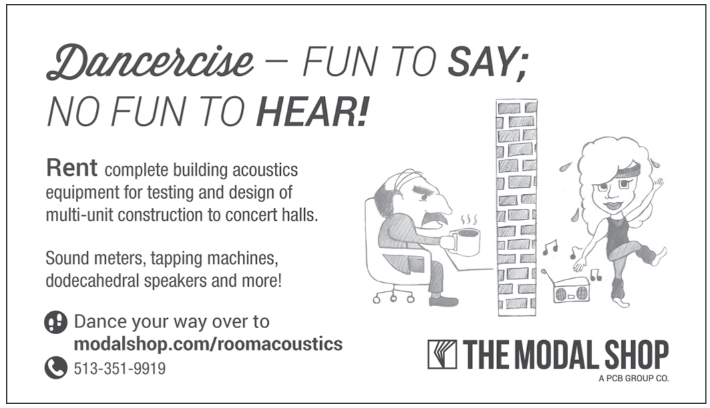

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