In Review

The Academy Research Conference (ARC) is a one-day conference designed to bring scientists and clinicians together so that current topics in science can be discussed from multiple translational perspectives. This year the topic was “Hearing Aids and the Brain.” With fellow members of the ARC Program Committee, Catherine McMahon (Macquarie University, Australia), Ruth Bentler (University of Iowa), Derek Stiles (Rush University), and Brett Martin (City University of New York), we invited a diverse group of speakers who approached this topic from different perspectives. We asked our speakers to address the following questions:

1. What is needed in the area of pediatric amplification and is there a place for brain measures to fill this gap?

2. How might the addition of brain measures add to clinical protocols and what would the impact be on time and expense?

3. What can the brain (cognition and neuroimaging) tell us about adult amplification?

4. What are important future directions in neuroscience as they relate to hearing aid amplification and hearing aid design?

5. Would clinicians use physiological measures such as listening effort in the clinic? If so, how?

Harvey Dillon (National Acoustic Laboratories, Australia), Susan Small (University of British Columbia, Canada), and Susan Scollie (University of Western Ontario, Canada) highlighted research relevant to the clinician by discussing the many ways in which auditory-evoked potentials can be of use to fill gaps in the area of pediatric amplification. Some examples included the use of auditory evoked brain activity to estimate aided audibility, to assess speech discrimination in infants, and to quantifying in physiological responses to changes in hearing aid signal processing. The speakers reviewed current and future test protocols that could fill these gaps in service in ways that are both time and cost efficient for the clinician.

Curtis Billings (National Center for Rehabilitative Auditory Research) expanded on these topics in relation to adult amplification. He showed how evoked brain activity not only provides information about the neural detection and discrimination of speech sounds but also how the auditory system processes amplified sound. One example has to do with the fact that hearing aids not only amplify the signal of interest but also the noise floor. Alterations in signal-to-noise ratio (SNR) can interfere with important...
biological codes responsible for encoding stimulus intensity level. This information is relevant to the design of future hearing aids and might even shed light on performance variability across individual hearing aid users.

Knowing that hearing aid users function in a noisy environment, in addition to amplified noise levels, Jessica Sullivan (University of Washington) highlighted some of the challenges children with hearing loss encounter when listening to speech in a typical noisy classroom. She described the many cognitive processes (e.g., working memory) that are negatively impacted when listening to speech in noise, and how children with better working memory are less susceptible to the effect of noise at poorer SNRs. She went on to describe how improving working memory, through listening exercises, is one intervention example that is being explored to help children learn how to make better use of the speech they hear in noisy environments.

Thomas Lunner (Eriksholm Research Centre, Oticon, Denmark) continued with the theme of working memory by emphasizing that a poor representation of a signal in the neural pathways will lead to activations of the (effortful listening) working memory system. People with hearing loss have to rely much more on effortful working memory resources to understand what has been said, when compared to people with normal hearing. He also described how physiological measures of listening effort can provide valuable information to the clinician and also be used to guide future generations of hearing aids that rely on brain-computer-interface systems.

I would like to take this opportunity, on behalf of the planning committee, to thank each presenter for sharing his or her expertise with us and for advancing science in a way that serves both theory and practice. I would also like to congratulate the six travel award recipients who presented posters on related topics. Thanks also to David Brown, Academy Research Committee Chair; Jennifer Shinn, ARC grant PI; and Meggan Olek, Academy director of professional advancement, who oversaw the many administrative aspects involved in making ARC happen. The day was a great success. Over 250 people were in attendance, and many more were requesting standing-room spots in a sold-out room. Based on the enthusiasm and collaborative spirit experienced at this seminar, there is every reason to believe that the gap between hearing aids and neuroscience is being narrowed and people with hearing loss will benefit from these advances.

 Kelly Tremblay, PhD, was the ARC14 chair and is a professor in the Department of Speech and Hearing Sciences, University of Washington, and an affiliate of the Center for Integrated Neuroscience and the Virginia Merrill Bloedel Hearing Research Center.

### Beyond Newborn Hearing Screening: Brain Implications for Pediatric Amplification

Congenital hearing loss fundamentally alters the auditory experience for infants and children who are born with this condition. Universal newborn hearing screening provided an important initial step in making sure that children who are born with hearing loss can have improved auditory access through hearing aids. With the widespread implementation of universal hearing screening programs in the United States, many more children who are hard of hearing are diagnosed with hearing loss at earlier ages. Amplification is often fit by six months of age. Despite this progress, our longitudinal study of communication development in children who are hard of hearing has revealed improved outcomes, compared to previous generations of children who are hard of hearing, but also persistent areas of vulnerability for some children. These observations led to a primary question: Now that children have more consistent ages of identification and fitting with amplification, what factors predict individual differences in communication and auditory development?

Based on the idea that amplification provides the basis for auditory stimulation in children who are hard of hearing, we hypothesized that individual differences in the audibility for speech provided by amplification and the consistency of hearing aid use across children may help to account for variability in outcomes that are observed among children who are hard of hearing. Children with better audibility through their hearing aids and more consistent hearing aid use have been found to have improved auditory and communication outcomes compared to peers with poorer audibility or less consistent hearing aid use. The audibility of speech provided by hearing aids can be optimized for hard of hearing children through the use of validated prescriptive approaches and verification techniques. Audiologists can also help to encourage hearing aid use by working with families to identify challenges to establishing consistent use. Our future research in this area will seek to apply auditory evoked potentials and brain imaging techniques to explore the neural correlates of the behavioral changes that we have documented in our cohort of children who are hard of hearing.

Ryan W. McCreery, PhD, is the director of audiology and director of the Audibility, Perception and Cognition Laboratory at Boys Town National Research Hospital.
Physiological Measures and Their Potential for the Assessment of Pediatric Hearing Needs

Infants are diagnosed with hearing loss and fitted with amplification at a very young age. Accessibility to spoken language is critical to optimize speech and language development; consequently, confirmation of hearing aid benefit in terms of speech processing capacity is a priority. Researchers and clinicians are interested in developing an objective tool to assess the detection and discrimination of speech sounds in young infants. Cortical auditory evoked potentials (CAEPs), such as the slow cortical response to the onset of a stimulus, and the acoustic change complex (ACC), which is elicited to a change within a stimulus, are potentially well suited to these applications. The purpose of this presentation was to discuss what CAEPs can tell us about infant hearing, with and without hearing aids, and to highlight current limitations in the interpretation of these responses.

Studies have shown that CAEPs can be elicited in most infants in response to speech stimuli in cases of normal hearing and for a range of hearing loss, both unaided and aided. These data support that the presence of a response can be interpreted as auditory information reaching the auditory cortex. The presence of a response, however, does not predict where the speech stimulus fits within the infant’s dynamic range because CAEP amplitude is only related to audibility for a limited range of stimulus levels. Another significant hurdle is the interpretation of absent responses. Several studies have noted that CAEPs are absent in approximately 25 percent of infants with hearing loss when audibility was expected with their hearing aids in use. Further research is needed to explain why cortical responses are not elicited in these infants. One area of inquiry is the potential effects of hearing-aid processing on the stimulus used to elicit the CAEP. Several studies have reported changes to the onset characteristics of the stimulus related to hearing-aid processing effects that then resulted in changes to the CAEP. Other studies have determined that signal-to-noise ratio will determine the characteristics of the CAEP.

Only a few studies have investigated the ACC as a possible tool for assessing discrimination of speech contrasts. Promising results for ACCs elicited to contrasting English and Hindi consonant-vowel (CV) pairs were found for normal-hearing infants when the stimulus duration for each CV was long (410 msec); results were less consistent for a shorter duration (256 msec). ACCs were also elicited in some young children with normal hearing and hearing loss (unaided and aided) to changes in vowel pairings, confirming that it is indeed possible to elicit an ACC in infants with normal hearing and hearing loss. More infant ACC studies are needed to determine which stimuli and recording parameters would be optimal for assessing hearing-aid benefit for a range of hearing losses.

CAEPs can be used to predict the detection of a speech sound, but caution should be taken when responses are absent. The ACC is in its early days of development but shows great potential for assessing speech discrimination in infants. More research is needed to optimize the use of CAEPs in the clinic.

Susan A. Small, PhD, is the Hamber Professor of Clinical Audiology in the School of Audiology and Speech Sciences at the University of British Columbia.
Aided-Evoked Potentials: Effects of Hearing Aid Signal Processing

Recent guidelines for pediatric hearing aid fitting suggest that aided evoked potentials may be one component of assessing hearing aid outcomes for young children. Specifically, such measures are indicated mainly for those children who cannot provide reliable feedback through behavioral testing (Academy, 2013). Routine electroacoustic verification and behavioral outcome evaluation remain the procedures that are used in most cases. Aided evoked potentials (EPs) remain of interest in research contexts, allowing us to examine how evoked potentials change in response to changes in hearing aid signal processing. One example is changes in aided EPs to high frequency stimuli when a frequency lowering signal processor was used with older children who had steeply sloping hearing losses (Glista et al, 2012). However, hearing aid signal processing can also interact with the stimuli used to measure EPs, either by changing the stimulus onset characteristic or by making unwanted changes to the levels of individual phonemes when they are presented briefly and in isolation (Easwar, Glista, et al 2012; Easwar, Purcell, et al 2012). Some of these changes may be important to consider when selecting the aided cortical EP as the measure of interest. More recently developed EP paradigms use running speech rather than brief tones or phonemes. Early results on this type of paradigm were presented.

Susan Scollie, PhD, is an associate professor at the National Centre for Audiology at the University of Western Ontario in London, Ontario, Canada.

Objective Cortical Evaluation of Infants Wearing Hearing Aids

Children who receive cochlear implants have the best language outcomes at age five years if they are implanted by their first birthday, so evaluation of aided hearing during the first year of life is critical if implantation is to be both early and appropriate.

An infant’s ability to detect speech can be estimated by measuring the cortical potentials evoked by speech sounds at conversational levels in the free field while the infant wears hearing aids or cochlear implant(s). The presence of a response indicates that neural signals initiated by the stimulus have progressed through the device and auditory system at least to the primary auditory cortex. New methods of signal analysis and statistically-based automatic detection of waveforms can distinguish true cortical responses from random noise more accurately than expert observers, and so make the use of evoked cortical responses clinically viable. When cortical responses are detected with only a very tiny probability of them being unrelated to the stimulus, they provide the clinician and parents with great confidence that speech sounds are being processed in some way by the baby’s brain. There can be many reasons for an absent cortical response, however, probably including some that have no adverse functional implications for the infant.

The amplitude of cortical responses grows with sensation level of the stimuli. In people with hearing loss, this is determined by the amplitude of the stimulus in the ear compared to the person’s hearing thresholds, so aiding generally increases cortical response amplitude. When people with normal hearing are aided, the stimulus is partially masked by internal hearing aid noise, which is also amplified, so aiding generally has no effect on cortical response amplitude.

The latency of the cortical response is determined by the extent of previous exposure to auditory stimulation. Those children with present cortical responses and normal latency when aided are more likely to derive benefit from hearing aids than those with absent or delayed responses, including, or even especially, children with auditory neuropathy. In some infants with auditory neuropathy, it is possible to reliably measure cortical potentials at levels much lower than the minimum levels at which an auditory brainstem response is observed, and these levels are consistent with behavioral thresholds.

When cortical responses are measured on people with cochlear implants, the measurement system (hardware and software) must be adapted so that electrical currents...
generated by the implant do not mask or impersonate cortical responses.

With the current state of knowledge, measurement of cortical responses in infants can materially add to a clinician's ability to manage hearing impaired infants by giving information about the detection of speech sounds when the infant is unaided, aided, or both. Cortical response measurement of infants to assess detection of speech following aiding is now routine in Australia. Cortical response measurement has much more potential, however, and current research is investigating high-rate presentation, use of more complex stimuli, and discrimination of sounds.

Harvey Dillon, PhD, is director of the National Acoustic Laboratories.

What Aided Auditory-Evoked Potentials Can Tell Us About the Aided Auditory System

There is growing interest in having a physiological measure to assist in the hearing aid fitting/verification process, or to improve our understanding of how the brain changes over time with amplification (for a review see Billings, 2013). Cortical auditory evoked potentials (CAEPs) are passively evoked brainwaves similar to the auditory brainstem response, but occurring later in time, that have been used increasingly over the last decade to characterize neural encoding of amplified signals. Such a physiological measure that is collected while patients wear their hearing aids would be beneficial especially for pediatric or other in hard-to-test populations for whom reliable behavioral responses are often not possible.

The obstacle to the clinical use of aided CAEPs, however, is that findings from several aided CAEP studies over the last 40 years are quite mixed and variable. Recent research demonstrates that varied outcomes across studies, individuals, stimuli, and hearing aids can be explained, in part, by whether a detection approach or a discrimination approach was taken (Billings et al, 2012). When the purpose has been to determine whether an acoustic signal is detected physiologically using aided CAEPs, outcomes are predictable and generally match whether a stimulus is audible or not; however, when the purpose has been to physiologically discriminate between the CAEPs resulting from two suprathreshold aided stimuli or two hearing aid settings, outcomes can be misleading and problematic. For example, increasing hearing aid gain from 10 to 30 dB may not change the amplitude and latency of a patient’s CAEP as a clinician might expect (Billings et al, 2011). The causes of these unexpected results are acoustic changes to the evoking stimuli that are made by the hearing aid. For example, hearing aid processing will amplify and introduce background noise as well as amplify the target signal, affecting the signal-to-noise ratio (SNR) of the signal, or they can modify the onset characteristics of a signal. Such modifications are important, because changes to SNR and stimulus onsets can cause unexpected changes (or lack of changes, as the case may be) to CAEPs.

In conclusion, aided CAEPs can be used clinically to determine whether a stimulus is being encoded by the cortex (i.e., physiological detection). However, currently clinicians should avoid using aided CAEPs to make decisions beyond simple audibility, such as those focused on physiological discrimination (e.g., is the amount of gain or the frequency response of the hearing aid appropriate). Such suprathreshold changes to the stimulus may not be reflected in the aided CAEP as expected. Hearing aid processing modifications and how they interact with CAEP generation need to be understood better and considered carefully before aided CAEPs are used clinically as a biomarker for discrimination or to understand how the brain changes over time with amplification.

Curtis J. Billings, PhD, is a research investigator at the National Center for Rehabilitative Auditory Research, Portland Veterans Affairs Medical Center.

References


Bridging the Gap Between Audibility and Comprehension for Little Ears

There is a gap between audibility and comprehension in noise for children with hearing loss. While modern hearing-assistive technology has made a considerable impact on the access to auditory input and language development, children with hearing loss still have great difficulty with speech recognition in noise. Researchers consistently report that even with proper amplification, children with hearing loss experience difficulty listening in the classroom because of the effects of reverberation and ambient noise levels (Crandell and Smaldino, 2000). Hearing impairment not only affects the access to auditory information but also places an increased demand on cognitive resources such as working memory (Glaseberg and Moore, 1989). Working memory is critical for speech and language development, and other mental processing is closely linked to the effect of age in children (Pickering et al, 2001; Pisoni and Cleary, 2003). The effect of noise on working memory is most harmful at poor signal-to-noise ratios (SNRs) and can influence other processes such as auditory comprehension. This is a significant problem because children are still developing and being educated in less-than-optimal listening environments. The working memory could be an important process in both speech recognition in noise and perceptual learning.

In a series of experiments, we are examining the role of working memory and how it relates to auditory comprehension in noise for children. We found that noise negatively impacts working memory in both low and high complexity tasks for children with typical hearing across SNRs. Results indicated there was a systematic decrease, approximately 10 percent, in working memory on backward digit and listening recall as noise conditions became poorer (Osman and Sullivan, 2014). In addition, noise negatively affects working memory in both auditory and visual domains for children with and without hearing loss. Moreover, children with better working memory are less susceptible to the effect of noise at poorer SNR.

We recently developed a novel intervention based on the concept that auditory training in interrupted noise can aid in the development of glimpsing skills (Sullivan et al, 2013). Glimpsing is a process in which individuals are able to take advantage of the fluctuations in background noise to understand the message being communicated. Our work to date has shown that auditory training in interrupted noise improves speech recognition skills in the trained and untrained noise conditions for children with HL, and those changes are maintained three months post treatment.

Jessica Sullivan, PhD, is an assistant professor in the Department of Speech and Hearing Sciences, University of Washington

References


Don’t Forget the Brain: Hearing Loss and Hearing Aids

Working memory is important for online language processing in a dialogue. We use it to store, to inhibit, or to ignore what is not relevant, and to attend to things selectively. The Ease of Language Understanding (ELU) model describes the role of working memory capacity (WMC) in complex listening situations and with hearing impairment to explain findings on, for example, the relationship between WMC and speech signal processing and short-term retention. A poor representation of a signal in the neural pathways will, according to the ELU model, lead to activations of the (effortful) working memory system. Hearing impaired persons must rely much more on effortful working memory resources to understand what has been said, compared to normal hearing persons who can rely more on effortlessly highly over learned automatic speech recognition systems, which is a reason why the hearing impaired become exhausted after a day of listening.

Performance of hearing aid signal processing is often assessed by speech intelligibility in noise tests, such as the HINT sentences presented in a background of noise or babble. Usually such tests are most sensitive at a signal-to-noise ratio (SNR) below 0 dB. However, in a recent study by Smeds et al (2012) it was shown that the SNRs in ecological listening situations (e.g., kitchen, babble, and car) were typically well above 0 dB SNR. SNRs where the speech intelligibility in noise tests are insensitive. Therefore new measures are needed that can show eventual benefits of hearing aid processing in the +5–15 dB range.

Cognitive Spare Capacity (CSC) refers to the residual capacity after successful speech perception. In a recent study by Ng et al (2010), we defined the residual capacity to be number of words recalled after successful listening to a number of HINT sentences, inspired by Sarampalis et al (2009). In two recent studies with 26 and 25 hearing impaired test subjects, respectively, we showed that close to 100 percent correct speech intelligibility in a four-talker babble noise required around +7–9 dB SNR. At that SNR it was shown that a hearing aid noise reduction scheme improved memory recall by about 10 percent. Thus, this kind of memory recall test is a possible candidate for assessment of hearing aid functionality in ecologically relevant (positive) SNRs.

In a given listening situation, the mental/cognitive state may be different in the same acoustic environment if the cognitive tasks differ including single task versus dual task, time of the day, fatigue, or attention to different sources. The different mental states during listening indicates that for a hearing aid it might not be enough with just measuring acoustics; it might be necessary to monitor cognitive parameters and make decisions on hearing aid settings, that is, cognition-driven hearing aids. New technological developments relevant for auditory processing include physiological monitoring via, for example, the electroencephalogram (EEG). In the presentation it was shown that so-called EEG alpha waves (typical when relaxing) could be picked up from the ear canal. Furthermore, in a review it was shown that EEG may be used to determine which out of several competing sources the listener is attending to, which may open up new ways to control hearing aids.

Thomas Lunner, professor at the Eriksholm Research Centre, Oticon A/S, Denmark, and Linnaeus Centre HEAD, Linköping University, Sweden.

References


Amplification and the Brain: Current Knowledge and Future Directions

For the person with hearing loss, listening to and comprehending speech is challenging and effortful, especially when listening in a background of noise. The greater the degradation to the signal, the more cognitive resources the listener needs to use in order to understand the speech. There are several different approaches to measuring listening effort: subjective ratings of effort, behavioral methods using measures of response time to speech, measures requiring simultaneous performance of a speech recognition task and a secondary task, and measures of physiologic reactions to task difficulty.

The studies reviewed in the presentation focused on how researchers used behavioral measures of listening effort to evaluate changes in top-down processing associated with digital noise reduction processing. The dual-task paradigm is often used to measure changes in listening effort. The listener is asked to perform a speech recognition task (primary task) while simultaneously performing a second task (different tasks are used in different experiments). Because there are limited, cognitive resources for understanding speech are allocated differently between the primary and secondary task depending on listening difficulty. Changes in the cognitive load are inferred from changes in performance on the secondary task.

Sarampalis et al (2009) and Ng et al (2013) used a word identification/memory task. The listener was asked to identify the final word of the test sentence, followed by recall of the test words after every eighth sentence. Testing was carried out in quiet and in noise (with and without noise reduction). In a second experiment, Sarampalis et al (2009) used a response time/decision measure to a visually presented digit, and Desjardins and Doherty (2014) used visual tracking of a moving trace on the computer screen as the secondary task.

All three studies revealed that measures of listening effort provide information about changes in listening effort due to noise reduction processing that are not evident from tests of speech recognition performance. None of the three noise reduction strategies resulted in improved speech recognition performance in noise. Sarampalis et al (2009) and Ng et al (2013) showed that recall of the test words was significantly poorer in noise than in quiet (indicating increased cognitive load, increased listening effort). Noise reduction processing improved recall of test words under certain conditions. Both Sarampalis et al (2009) and Desjardins and Doherty (2014) showed that performance on the secondary task was poorer at poorer signal-to-noise ratios and improved with noise-reduction processing. Change in performance on the secondary task with noise-reduction processing is indicative of reduced listening effort or reduced cognitive load.

Results of these studies show the benefit of assessing listening effort as a dimension of hearing aid benefit. These measurements can reveal important information about how signal processing in the hearing aid affects the use of top-down processing. Further research is necessary to determine how any of these measures might be adapted for clinical use.

Arlene Neuman is a research associate professor at the Department of Otolaryngology, New York University School of Medicine.

References

