

Cognition, Spatial Sound & Noise Reduction: 2016

By Douglas L. Beck Au.D.
Director of Academic Sciences
Oticon Inc, Somerset, NJ

INTRODUCTION

In 2016, the science upon which audiology and hearing aid dispensing practices are built is changing and evolving rapidly. In this article, we'll review contemporary aspects of Cognition, Spatial Sound and Noise Reduction, as these three concepts are often under-rated and under-valued in modern hearing aid fittings – yet, they are remarkably important.

Take the continuing education quiz on page 55.

Cognition, Hearing & Listening:

The American Psychological Association (APA, 2016) defines cognition as the process of knowing, including attending, remembering, and reasoning (and more). That is, cognition is multi-faceted, it involves



AMERICAN
PSYCHOLOGICAL
ASSOCIATION

top-down and bottom-up processes. Top Down processes include executive functions, whereas bottom-up processes include the five sensory systems which supply the brain with all the input it receives (audition, vision, tactile, smell and taste). In some respects, one might say bottom-up drives the whole system, as the brain can only organize and process information which it has received via bottom-up pathways.

To maximally understand the interaction of cognition and amplification, it's important to consider the differences between hearing and listening. HEARING can be simply defined as perceiving sound. Perceiving sound is a relatively simple function (i.e., sound is present or sound is not present) as compared to listening. Listening

involves hearing and the ability to apply meaning to sound (Beck, 2015). Applying meaning to sound is a highly complex ability and involves working memory, vocabulary, attention, neural processing and much more. Beck (2014) reported listening can be defined as “applying meaning to sound.” To apply meaning to sound requires 1 – the sound must be heard, and 2 – vast amount of cognitive initiatives must occur rapidly and accurately.

To maximally understand speech in speech noise, the sound must be heard by two ears; all speech sounds must be audible; the signal-to-noise ratio (SNR) should be maximal. *(In general, a minimal SNR of 10-12 dB is required for people with normal hearing. For people with mild-moderate hearing loss, 15 to 20 dB is often required. As hearing loss increases, so too, should the provided SNR. See Dillon, 2012.)* The sound must be identified by its spatial characteristics (including Interaural timing and Interaural loudness differences); the brain must attend to (focus on) the sound of maximal interest; the brain must use short, long-term, and working memory and linguistic knowledge to apply definitions of known words and context; and the brain must prioritize important and trivial sounds—all in an instant. Thus, listening is a cognitive



event. Listening occurs in tandem with the many brain centers which interact as neurobiologic information (all of which started with hearing) traverses both cerebral hemispheres, the frontal, parietal, temporal and occipital lobes and interacts with language, meaning, emotion, semantics, vocabulary, context, long, short and working memory and much more.

Kurzweil (2006) noted the human brain has one hundred trillion interneuronal connections (more than any computer, even in 2016) and the human brain runs “parallel processing” constantly to maximally access and alter neurons. The human brain re-invents and rewires

itself constantly, and as if that’s not enough, the human brain is constantly predicting. Indeed, Hawkins & Blakeslee (2004) state prediction is the primary function of the neocortex and prediction is the foundation of intelligence.

In many respects, one can argue the first hundred years of audiology have been about hearing. Of course, I don’t mean to trivialize or minimize hearing –hearing is astonishing. However, once the vast and intermingled neurons throughout the brain gets hold of sound...everything changes! The brain creates meaning from hearing, which we refer to as listening. Indeed, the phrase “Listening is Where

Hearing Meets Brain” (Beck & Flexer, 2012) reflects and underscores this phenomena. As we have a vast and well-founded scientific knowledge of hearing, I believe the next hundred years should be focused on *listening*.

The Surprising Importance Of Spatial Sound:

One of the primary functions the brain must perform to make sense of speech in noise is to compare and contrast the input from the two ears in real time, to determine where to focus the brain. That is, all sounds

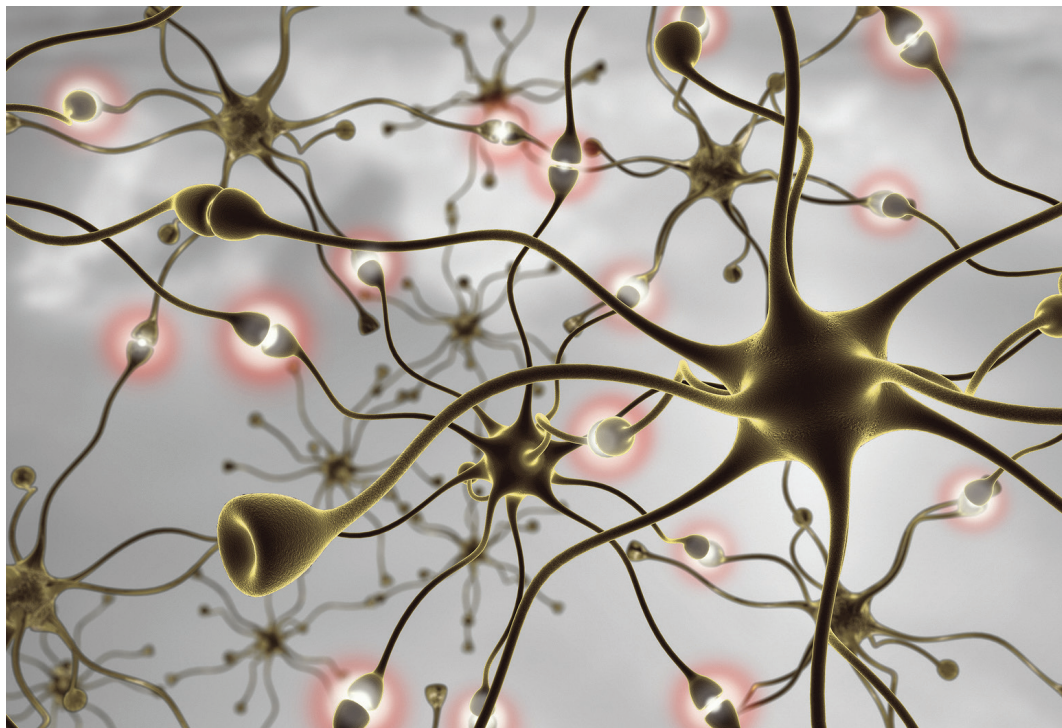
Continued on page 15

come from somewhere. Indeed, every sound has a spatial signature and decoding the spatial signature to locate the origin of sound helps the brain to focus on the specific, most important, sound source (via binaural summation and other acoustic cues) while simultaneously allowing the brain to ignore or dismiss sounds from other, less important, non-threatening sources (via binaural squelch and other processes).

Of course, in an equal and entirely horizontal world, there are 360 degrees from which sound can originate. Of note, only at 0 degrees and 180 degrees are sounds perfectly equal in the left and right ears. At all other locations (358/360 degrees, or 99% of all sounds originating across the horizontal axis) sound is louder in the left or the right ear, and sound reaches one ear earlier and one ear later.

Differences of loudness and timing are referred to as Interaural Loudness Differences (ILDs) and Interaural Timing Differences (ITDs), respectfully. ILDs and ITDs are processed continually, and the preservation of these acoustic cues allows the listener to know where to focus their brain/attention. However, although the vast majority of people with normal hearing and normal cognitive function can process spatial cues without difficulty, as cognition declines and as hearing loss increases, the ability to accurately resolve spatial cues declines (see Glyde, Cameron, Dillon and Hickson, 2014).

In 2005, Kidd and colleagues examined the role of focused attention along the horizontal dimension while multiple talkers were speaking. The listener's



task was to identify words from a target talker in the presence of other talkers, all of whom were speaking simultaneously. Of note, the person listening had no prior knowledge as to where the target talker would be, and as one might expect, the listener's ability to identify the key words from the target talker was quite poor. When the location of the talker was identified prior to the listening task, a statistically significant improvement occurred with regard to identifying the key words. The authors reported "the focus of attention along the spatial dimension can play a very significant role in solving the 'cocktail party' problem." That is, simply knowing the location (i.e., knowing where to focus one's attention) significantly improved listening ability.

Schneider and colleagues (2007) stated that to effectively participate in conversation that occur in speech noise, "listeners not only have to hear

the individual words and phrases spoken by each person, they must also integrate this information with past input and world knowledge to extract each person's meaning and point of view." They point out that to accomplish these speech in noise tasks in a complex acoustic environment, the listener must either "focus attention on one stream and suppress the information coming from other sources, or 2) attempt to simultaneously process more than one stream at a time. If it becomes difficult for the listener to inhibit the processing of irrelevant information or to simultaneously process more than two information streams, the listener is likely to require a higher SNR for speech comprehension..."

Middlebrooks (2015) notes ITDs and ILDs are "analyzed in specific brainstem pathways and then

Continued on page 16

integrated as cortical representation of locations.” Further, he reports the ability of the brain to determine the distance to/from a sound source is less accurate than our ability to determine horizontal and vertical locations and of note, “Cortical representation of sound locations is highly distributed, with no evidence for point-to-point topography. Spatial representation is strictly contralateral in laboratory animals that have been studied, whereas humans show a prominent right-hemisphere dominance.”

In essence then, it is important for hearing aid amplification systems to be able to recognize, capture and maintain ILD and ITD differences, attenuate unnecessary noise, all while performing their primary function (amplification of sound). That is, because the human brain depends on these acoustic cues to make sense

of sound, it is important to choose an amplification system which has the ability to allow accurate and sophisticated ILDs and ITDs to be maintained – so the person wearing the system can tell where to focus their brain, facilitating better speech understanding in noise.

Unfortunately, traditional hearing aid systems do not have the capability or processing power to maintain ILDs and ITDs, although some contemporary hearing aid systems do. Specifically, some hearing aids have been designed to maintain natural acoustic information to help the brain orient, recognize, separate and balance sounds, through sophisticated technologies and the maintenance of naturally occurring acoustic information such as ILDs and ITDs, and other factors (i.e., spectral cues and more).

Noise Reduction in the Real World:

Clearly, noise reduction systems from decades ago, and to some extent recent modern digital noise reduction (DNR) systems do not totally eliminate noise from the experience of the hearing aid wearer. Nonetheless, DNR has been proven to be an important part of hearing aid success. How can these two seemingly contradictory statements both be correct? DNR systems positively impact cognitive processes as demonstrated below:

Stelmachowitz and associates (2010) evaluated 16 children with mild to moderately severe hearing loss who listened to speech in noise with noise reduction systems engaged and disengaged. They reported noise reduction “on-or-off” was not statistically significant and indeed, the noise reduction circuit did not have a “differential effect” with regard to the children’s ability to correctly identify speech in noise. That is, noise reduction systems did not negatively impact the perception of speech sounds.

Pittman (2011) reported DNR circuits do not negatively impact speech perception and perhaps surprisingly, they found DNR significantly improved word learning rates for some children.

Ng, Rudner, Lunner, Pedersen & Ronnberg (2013) reported “competing speech” disrupts recall of speech which occurred in challenging acoustic environments. Of note, this same effect was reduced while using DNR for people with better working memory capacity. The authors reported the DNR circuit “virtually canceled out” the disruptive effect of the competing





speech with respect to recall, stating “noise reduction can reduce the adverse effect of noise on memory for speech and DNR allowed quicker word identification and facilitated enhanced encoding of heard material into working memory.

Rudner and Lunner (2013) reported DNR essentially facilitates a “release” of “cognitive resources” allowing improved memory coding to occur. Importantly, they stated DNR facilitates improved recollection of speech heard in noise.

Desjardins and Doherty (2014) evaluated listening effort for 12 adult hearing aid wearers and reported “The DNR algorithm used in this study significantly reduced” listening effort in the most difficult listening situation and the “NR algorithm used in the present study did not improve speech

recognition scores in babble, it also did not degrade performance...”

Lowery and Plyer (2013) reported Acceptable Noise Levels (ANLs) were improved with DNR engaged and listeners with the worst baseline ANL scores benefited the most from DNR. Ng, Rudner, Lunner and Ronnberg (2015) concluded “noise reduction improved memory for speech heard in competing speech for hearing aid users.”

Although one cannot demonstrate improvements on word recognition in quiet or in noise, the advantages of digital noise reduction are vast (see above) and importantly, the primary impact appears to be more on “cognitive” aspects of listening, rather than on traditional aspects of “hearing.” That is, to see the benefits of DNR, one has to look deeper than

hearing, to find the cognitive benefits associated with DNR, one must evaluate listening.

Innovation in Noise Reduction:

Significant innovation is happening in noise reduction technology. As an example, Oticon is in the process of releasing a new product with 50 times faster processing than ever before, across 64 frequency channels, while completing a full environmental analysis 100 times per second and managing 1.2 billion calculations per second. This allows two key features to improve on spatial perception and minimizes the intrusiveness of noise in a wide range of listening environments. It compares four separate frequency bands, 21 times per second, to maximally

Continued on page 18

maintain ILDs with remarkably high resolution. Preliminary (and as-of-yet unpublished) results indicate that this new technology will make it easier to listen to speech in challenging acoustic environments, because (as noted above) knowing where to listen is important with regard to understanding speech in noise. The latest hearing aid technology helps support the ability to know where to listen and focus attention, as it often removes noise from the same direction as the speaker. Additionally, it can even remove noise between words, syllables and phonemes (depending on the rate of speech, background noise levels and other factors). In addition to providing a more clear speech sound, Oticon adheres to a BrainHearing approach



Douglas L. Beck, AuD

Dr. Beck earned his master's degree at the University of Buffalo (1984) and his doctorate from the University of Florida. His professional career began in Los Angeles at the House Ear Institute in cochlear implant research and intraoperative cranial nerve monitoring. By 1988, he was Director of Audiology at Saint Louis University. Eight years later he co-founded a multi-office dispensing practice in St Louis. In 1999, he became

President and Editor-In-Chief of AudiologyOnline.com, SpeechPathology.com and HealthyHearing.com. Dr. Beck joined Oticon in 2005 as Director of Professional Relations. From 2008 through 2015, Beck served as Web Content Editor for the American Academy of Audiology. In 2011, he became Adjunct Professor of Audiology at Lamar University and in 2015 he became an adjunct Associate Professor of Audiology at University of Hawaii. In 2016, Beck was appointed Senior Editor for Clinical Research at the Hearing Review and Director of Academic Sciences at Oticon Inc. Dr. Beck is among the most prolific authors in audiology with 152 published articles and more than 1250 abstracts, interviews and op-eds written for the AAA (2008-2015) and Audiology Online (1999-2005) addressing a wide variety of audiology and professional topics. More information, a free copy of THE HANDBOOK OF INTRAOPERATIVE MONITORING and numerous PDFs are available at www.douglasbeck.com.

which makes it easier for the brain to handle complex listening environments while maintaining continual access to all surrounding speech sounds, thus enhancing the ability to better understand speech in noise and improve on important brain functions, which are essential for functioning well in typical situations with background noise.

Discussion:

Cognition, Spatial Sound and Noise Reduction are of tremendous importance in modern hearing aid fittings. Certainly one must hear before one can listen – but simply hearing sound is not enough. The human brain craves and thrives on the multiplicity of acoustic information provided via normal hearing, and as technology progresses, the preservation and delivery of these same acoustic cues is of paramount importance,

particularly when the discussion turns to understanding speech in noise. To maximally understand speech in speech noise requires two ears and one brain and maximal acoustic information, so the brain can orient, recognize, separate and balance sounds through advanced and coordinated technologies, to maintain and deliver naturally occurring acoustic information.

Certainly the first century of audiology has been about understanding hearing, hearing-based diagnostics, and hearing aids which delivered basic sounds. However as we move deeper into the 21st century, we're better able to understand and address listening, because "Listening is Where Hearing Meets Brain" (Beck & Flexer, 2012), and when the brain locks onto speech sounds, everything changes! ■

References and Recommendations

- American Psychological Association (2016): <http://www.apa.org/research/action/glossary.aspx>
- Beck, DL (2009): Audition, Cognition, Ageing and Listening Success. *ENT & Audiology News*, Sept.1/Oct edition, Volume 18, No 4, pages 101-103.
- Beck, DL. (2010): Cognition and Audition: Introductory Concepts. *The Hearing Professional*, Journal of the International Hearing Society. October-November-December, Pages 23 to 25.
- Beck, DL. (2014): Brain Hearing–Maximizing Hearing and Listening. *Hearing Review*, March.
- Beck, DL. & Clark, JL. (2009): Audition Matters More as Cognition Declines: Cognition Matters More as Audition Declines. *Audiology Today*. March/April 2009. Pages 48-59.
- Beck, DL. Flexer, C. (2011): Listening Is Where Hearing Meets Brain in Children and Adults. *Hearing Review*. February, Pages 30 to 35. http://www.hearingreview.com/issues/articles/2011-02_02.asp
- Beck, DL (September, 2015): Guest Editor for September Edition of *Hearing Review*. Expert Roundtable: Cognition, Audition, and Amplification: 2015 <http://www.hearingreview.com/2015/08/expert-roundtable-cognition-audition-amplification-2015/>
- Beck, DL. & Sockalingam, R: (2010): Facilitating Spatial Hearing Through Advanced Hearing Aid Technology. *Hearing Review*. April, Pages 44-47 http://www.hearingreview.com/issues/articles/2010-04_03.asp
- Beck, DL. (2015): BrainHearing: Maximizing Hearing and Listening. *Hearing Review*. <http://www.hearingreview.com/2015/02/brainhearing-maximizing-hearing-listening/>
- Beck, DL., Edwards, B. & Pichora-Fuller, K. (2011): Exploring the Maze of the Cognition-Audition Connection. *The Hearing Journal*. October, 2011 Volume 64, Issue 10. Pages 21 to 27.
- Beck, DL. et al. (2012): Expert Roundtable: Issues in Cognition, Audition and Amplification – Exploring the Fascinating Links Between Cognition and Hearing Healthcare. *The Hearing Review*. September, 2012. <http://www.hearingreview.com/continuing-education/17302-expert-roundtable-issues-in-audition-cognition-and-amplification>
- Beck, DL. (2014): On the Importance of Working Memory with Regard to Hearing, Listening, Amplification, Prodigies, and More. <http://www.audiology.org/news/Pages/20140420.aspx>
- Beck, DL (September, 2015): Guest Editor for September edition of *Hearing Review*. Expert Roundtable: Cognition, Audition, and Amplification: 2015 <http://www.hearingreview.com/2015/08/expert-roundtable-cognition-audition-amplification-2015/>
- Dillon 2012. In *Hearing Aids*. Boomerang Press. Page 7.
- Desjardins JL, Doherty KA. (2014) The Effect of Hearing Aid Noise-Reduction on Listening Effort in Hearing Impaired Adults. *Ear & Hearing* 35(5):600-610.
- Glyde H, Cameron S, Dillon H, Hickson L. (2014) Remediation of Spatial Processing Deficits in Hearing-Impaired Children and Adults. *Journal of the American Academy of Audiology* 25 (6): 549-561.
- Hawkins, J. & Blakeslee, S. (2004): *On Intelligence*. Published by Holt. New York.
- Kidd, G., Arbogast, TL., Mason, CR. & Gallun, FJ. (2005): The advantage of knowing where to listen. *J Acoust Soc Am*. 2005 Dec;118(6):3804-15.
- Kurzweil, R (2006): *The Singularity Is Near: When Humans Transcend Biology*. Paperback: 672 pages. Publisher: Penguin Books (September 26, 2006) ISBN-10: 0143037889
- Lowery KJ, Plyler PN. (2013) The Effects of Noise Reduction Technologies on the Acceptance of background noise. *Journal of the American Academy of Audiology*. 24:649-659.
- Middlebrooks, JC (2015): Sound Localization. In *Handb Clin Neurol*. 2015;129:99-116. doi: 10.1016/B978-0-444-62630-1.00006-8.
- Ng EHN, Rudner M, Lunner T, Pedersen MS, Ronnberg J. (2013) Effects of Noise and Working Memory Capacity on Memory Processing of Speech for Hearing Aid Users. *International Journal of Audiology* 52:433-441.
- Ng, EHN., Rudner, M., Lunner, T. & Ronnberg, J. (2015): Noise Reduction Improves Memory for Target Language Speech in Competing Native but not Foreign Language Speech. *Ear & Hearing*. Volume 26, Number 1. Pages 82-91.
- Rudner M, Lunner T. (2013) Cognitive Spare Capacity as a Window on Hearing Aid Benefit. *Seminars In Hearing* 34(4).