



Expert Roundtable: Cognition, Audition, and Amplification: 2015

This article is a review of the key points addressed during the 2015 AudiologyNOW! featured session titled “Issues, Advances, and Considerations in Cognition and Amplification” on March 26, 2015, San Antonio, Texas.

As moderator for this exciting event, I was honored to work with my friends and colleagues Brent Edwards PhD, Jason Galster, PhD, Andrea Pittman, PhD, Gabrielle Saunders, PhD, Christian Füllgrabe, PhD, and Gurjit Singh, PhD. Indeed, this feature session was enthusiastically attended by some 400 audiologists from across the globe. Of course, an event of this size requires immense coordination and cooperation, and I am especially grateful to my friend and colleague Jason Galster, who co-chaired and co-managed the session. Special thanks to Jason for his friendship, insight, expertise, and willingness to make and receive phone calls and emails in the wee hours of the night.

— Douglas L. Beck, AuD, guest editor

The State of the Art: Hearing Impairment, Cognitive Decline, and Amplification

Chapter 1: A review of contemporary research...and what it might imply for our future

BY DOUGLAS L. BECK, AuD

New and important information addressing hearing, listening, the brain, cognition, amplification and more will be presented here. I would argue the time has come to re-define the goal from “hearing” to “maximal listening.” That is, our task is to provide a maximal bottom-up (ie, sensory) signal, so the top-down (ie, cognitive) task is easier and more efficient. When the brain receives a more natural and accurate auditory signal, it requires less brain power to untangle and interpret the same.

Hearing is a basic sensory, bottom-up (BU) function and may be defined as the perception of sound. Humans are not very good at hearing when compared to many other animals (dogs, cats, whales, and more). However, humans have an amazing and unmatched ability to *listen*. Listening is a highly sophisticated cognitive, top-down (TD) process which may be defined as applying meaning to sound.

As hearing healthcare professionals, I believe we need to change the focus of our interventions from simply “hearing” to “maximal listening.” Of course, hearing is a prerequisite to listening, and indeed, “Listening is Where Hearing Meets Brain.”¹

Clearly, the primary complaint we each address daily is our patients’ inability to understand speech in noise. Of note, the ability to understand speech in noise requires two ears and one brain. That is, the ears’ task is to deliver accurate (ie, undistorted), natural, complete sound to the brain (ie, “hearing”). The brain’s task is to compare and contrast the sound from the left and right sides (with respect to loudness and timing/phase) and to process, interpret, and apply meaning to the delivered sounds (ie, “listening”).

Multiple studies have indicated that hearing loss may be a significant causative factor with regard to cognitive decline in older adults. Further, although admittedly

speculative, it has been proposed the association between hearing loss and cognitive impairment could be the result of an underlying common pathology. That is, could the etiology of hearing loss and cognitive decline share a common foundation, such as vascular disease? The relationship between cognitive function, cognitive decline, hearing, hearing loss, listening ability—and the potential to maintain or (perhaps one day) improve cognitive ability through amplification remains promising, but essentially unknown and as of yet unproven, in 2015.

Certainly we know brains change and “re-wire” as a result of auditory deprivation, and we know when the brain is not stimu-



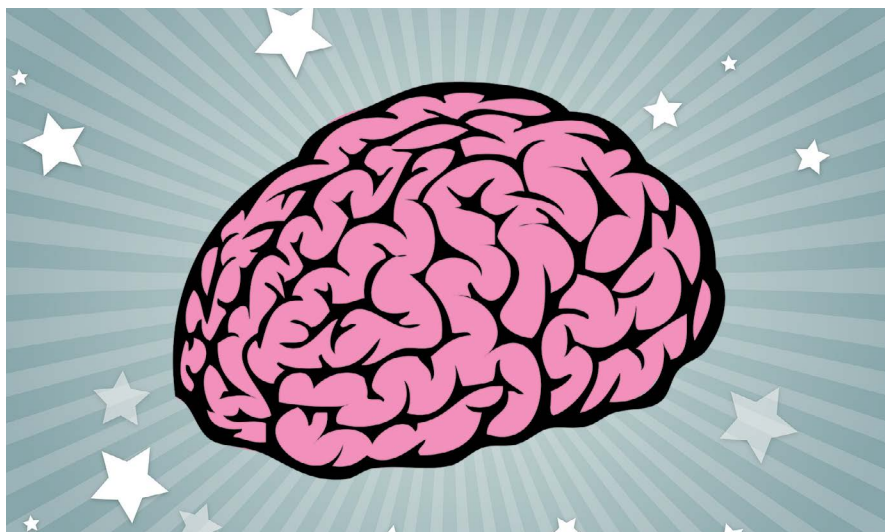
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lated via audition, the auditory processing centers in the temporal lobe can (and do) become recruited to perform other brain functions such as somatosensory and visual processing functions.² Although it appears that amplification may offer promise for the hearing-impaired patient to help maintain or improve cognitive function, those studies are as yet incomplete. However, new and important information specifically addressing these (and related) concerns are being published, availing a stream of interesting and related information.

For example, Lin³ reported in the *Journal of the American Medical Association (JAMA)* that hearing loss is independently associated with accelerated cognitive decline. That is, for older people with hearing loss, cognitive decline is more apparent than for older people with normal hearing.

In a recent study of people with cochlear implants, Mosnier et al⁴ concluded that hearing rehabilitation through cochlear implantation “results in improvements in speech perception and cognitive abilities and positively influences their social activity and quality of life.” Clearly, there are differences in patients who receive cochlear implants (CI) and those who receive hearing aids. In general, cochlear implant patients have experienced auditory deprivation for longer periods of time, and the CI patient is arguably more likely than the hearing aid patient to have experienced social isolation, depression, anxiety, and significant degradation with regard to quality of life (in general), thus rendering the CI patient different from the typical hearing aid patient.

Likewise, in a study published this year, Deal et al⁵ tested the hypothesis that hearing impairment (HI) is associated with lower cognitive function. The researchers evaluated 253 people (mean age of 77 years) with respect to their pure-tone averages and their cognitive status over a 20-year period. Cognitive evaluations were performed in 1990-1992, 1996-1998, and in 2013. Better-ear pure-tone averages (PTAs) from 500 to 4,000 Hz were also evaluated. Subjects were grouped into gross categories according to their PTAs as having either normal, mild, or moderate-to-severe hearing loss. Of note, when comparing people with normal PTAs to those with moderate-to-severe hearing loss, the rate of decline over the 20-year period differed by approximately one-half of a standard deviation with regard to memory,



and one-third of a standard deviation with respect to global function. The authors report cognitive declines were greatest among participants who had hearing loss but had not worn hearing aids.

However, Deal et al report the effect of amplification on cognitive decline remains unknown. They concluded in their study a “moderate association between moderate-to-severe hearing impairment and memory performance...this association was strongest among persons with moderate-to-severe HI who reported not wearing a hearing aid.”⁵

As such, unraveling the relationship between cognitive ability, cognitive decline, and hearing loss is receiving increasing and significant attention from researchers across the globe.

When I look into my crystal ball (always a dangerous thing to do!), I must admit it appears the loose ends are being tied together and it seems extremely likely we will soon have peer-reviewed scientific data which is likely to support the presumption that improving the quantity and quality of sound received by the human brain (ie, preserving and delivering the highest quality, least distorted sound possible) will make the brain’s auditory tasks easier and more accurate.

Specifically, our goal as hearing healthcare professionals may soon be redefined from simply making sound audible, to the *provision of maximal natural auditory information*—to provide a maximal “bottom-up” or “sensory” acoustic image which maintains interaural loudness and phase relationships and more. This auditory information would require less energy (less processing power) to recognize amplified sounds, thus allowing

more cognitive resources to interpret (apply meaning to) sound.

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Cognitive Function and the Patient Landscape

Chapter 2: Adding cognitive function changes the fitting paradigm

BY BRENT EDWARDS, PhD

The complexity with which we consider patient needs and benefit from treatment has increased over the past decade through the added consideration of cognitive function. To fully understand patient treatment, we must now consider the relationship between cognitive function and hearing ability and the relationship between cognitive function and hearing aid technology.

Historically, the approach to understanding the needs of patients with hearing loss and their treatment has been focused on the relationship between hearing ability and hearing aid technology (Figure 1a). Hearing ability and hearing aid technology can affect each other, as discussed below.

(1) Hearing Aid Technology → Hearing Ability

There is no doubt that hearing aid technology significantly affects a patient’s hearing ability, most notably increasing audibility and improving speech understanding. Some effects of technology on hearing can be difficult to quantify, such as the impact of technology on spatial hearing, pitch perception, and other complex auditory functions.

(2) Hearing Ability → Hearing Aid Technology

Hearing ability, as measured by the audiogram, grossly reflects the hearing ability of an individual and grossly indicates the benefit a patient may receive from amplification for simple speech stimuli in quiet. The audiogram is a poor predictor, however, of a patient’s ability to understand speech in noise.¹ Further, the audiogram is a poor

predictor of the benefit patients will receive from advanced hearing technology in complex listening situations.² Therefore, the need to fine-tune hearing aid technology to the unique needs of each individual is apparent.

Recently, findings addressing “hidden hearing loss” suggest that those with greater hidden hearing loss could have significant deficits to the coding of sounds in the periphery,³ which potentially limits the benefit provided by hearing aid technology.

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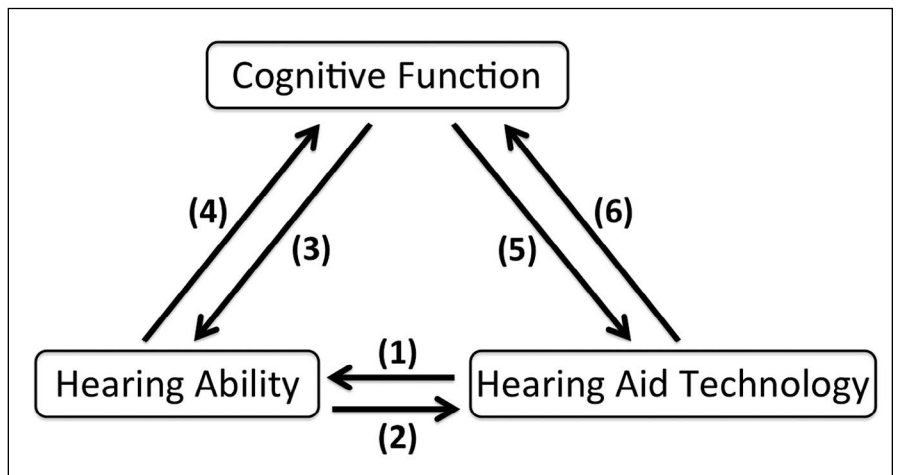
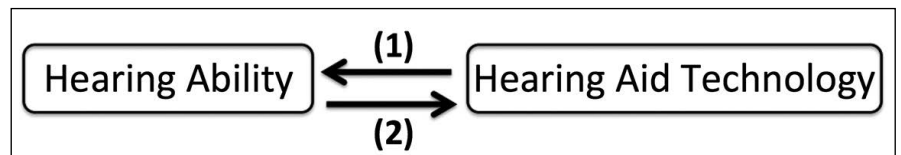
This change to the patient landscape is reflected in Figure 1b. To fully understand patient treatment, we must now consider the relationship between cognitive function and hearing ability and the relationship between cognitive function and hearing aid technology.

(3) Cognitive Function → Hearing Ability

Cognitive function affects hearing ability in very direct ways. For example, the ability to focus attention on different talkers in a crowded room is one top-down benefit that cognitive function provides to hearing ability. That is, knowing where to focus one’s attention in a crowded acoustic landscape is an important attribute.

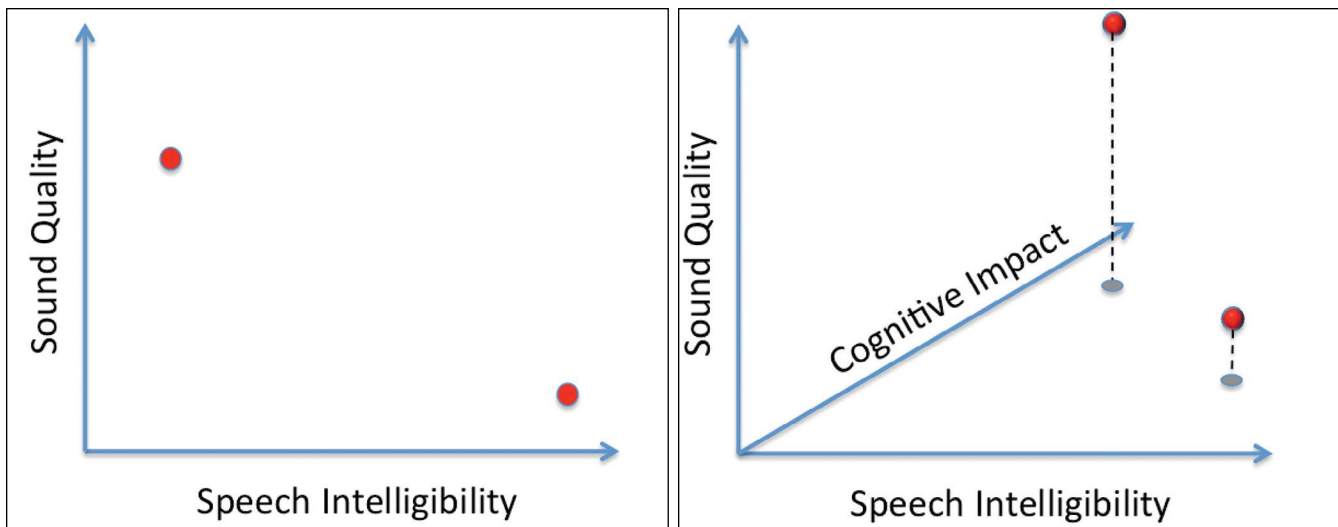
(4) Hearing Ability → Cognitive Function

Less obvious is the fact that hearing ability can affect cognitive function. McCoy et al⁴ demonstrated that hearing loss can degrade memory ability by increasing the load on working memory (WM). WM is responsible



Figures 1a-b. The traditional focus of hearing care has been to understand the needs of patients with hearing loss, with treatment focused on the relationship between hearing ability and hearing aid technology (top, Figure 1a). However, with the addition of cognitive function, we’re now adding a new level of complexity and interaction in hearing healthcare (bottom, Figure 2b).





Figures 2a-b. In the past, much of our research and amplification strategies have focused on speech intelligibility and sound quality (Figure 2a). Today, we are now adding a third dimension: the cognitive impact on the hearing aid user (Figure 2b). When combined with the more complex patient landscape of Figure 1a-b, what should emerge is a better understanding of the patient with hearing impairment and a more nuanced picture of their technology needs.

for information processing and memory storage/retrieval. WM has limited resources, however. Therefore, as more resources are required to interpret sound, fewer resources are available for other cognitive functions.

Lin⁵ has suggested that hearing loss may result in accelerated cognitive decline. Of note, it may be that hearing loss and cognitive ability degrade together because of a common cause, such as poor cardiovascular function. Additional research is necessary to determine whether or not hearing loss is the cause of accelerated cognitive decline.

(5) Cognitive Ability → Hearing Aid Technology

Evidence is growing that the cognitive ability of a patient affects the benefit they receive from hearing aid technology. Lunner and Sundewall-Thoren⁶ found that the level of someone's cognitive ability determined whether they would benefit more from fast or slow-acting compression. Cognitive ability can be a better predictor of hearing aid benefit to speech understanding in complex listening environments than the audiogram, where cognitive function is necessary to separate the talker from other simultaneous talkers and focus attention on that target speaker.⁷

(6) Hearing Aid Technology → Cognitive Function

Recent breakthroughs in research have demonstrated that hearing aid technology can have a beneficial impact on the cogni-

tive function of the hearing aid wearer. In 2014, Desjardins and Doherty⁸ demonstrated that hearing aid noise reduction can reduce cognitive load, making listening to speech in noise easier for the hearing aid wearer even if speech understanding isn't improved. Reduction in listening effort over a period of time can have the effect of reducing listening fatigue,⁹ a problem experienced by many people with hearing loss because they have to concentrate more to follow conversations in a noisy environment and are more mentally exhausted as a result.

With technology starting to focus on better spatial hearing by hearing aid wearers, research has also found that access to spatial cues allows the listener to segregate talkers and focus on the target talker better, reducing listening effort even when speech understanding doesn't improve.¹⁰

These results and others help us understand how hearing ability, hearing aid technology, and cognitive function are all tied together. While we used to describe benefit from technology in two dimensions, focusing on whether and how much a technology affects sound quality and speech understanding (Figure 2a), we now can describe the benefit that technology provides in three dimensions (Figure 2b). This view of hearing aid benefit combined with the more complex patient landscape of Figure 1b enables us to better understand the needs of people with hearing loss and how to better treat them with technology.

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Beyond Audibility: The Role of Supra-threshold Auditory Processing and Cognition in Presbycusis

Chapter 3: The interactions between aging, cognition, and listening ability

BY CHRISTIAN FÜLLGRABE, PhD

Studies demonstrate that, even in the absence of elevated audiometric thresholds, various levels of speech processing are affected by age and co-occur with changes in cognition and a decline in the sensitivity to supra-threshold temporal cues. From a clinical perspective, these findings indicate a need for diagnostic tests in addition to the audiogram when assessing the hearing of older people.

Among the hallmarks of aging in adults are difficulties in understanding speech, especially in noisy and reverberant conditions.¹ It has long been known that hearing sensitivity, as measured by the pure-tone audiogram, worsens with increasing age² and that this is associated with poorer speech intelligibility.³

The standard treatment for these difficulties is the provision of hearing aids which, at least partially, restore audibility of those sounds that would not otherwise be perceived by the hearing-impaired person. While hearing aids generally improve speech identification, the observed benefit often falls short of what would be expected based on the audibility of the speech (for a review, see Humes and Dubno⁴). One possible explanation for this is that age-related changes in supra-threshold auditory processing and cognition—that is, factors not captured by a traditional audiometric assessment—contribute to the speech-identification difficulties of older people.

To study these age effects, researchers generally compare older listeners to younger controls. Due to the high prevalence of sensorineural hearing loss in the older population, establishing audiometric equality between these age groups is not easy. Consequently, alternative solutions have been sought to

match audibility across listeners, including spectrally shaping the speech signal for the older listeners, or statistically removing the effect of hearing loss. However, these approaches do not control for possible “central effects of peripheral pathology”⁵ in the older listeners (ie, physiological and anatomical changes in the central auditory system induced by peripheral pathology).

In a study⁶ published this year, we investigated whether aging is associated with reduced speech intelligibility even for listeners with normal audiograms (ie, audiometric thresholds ≤ 20 dB HL up to and including 6 kHz in each ear). Older (60-79 years) and younger (18-27 years) listeners, matched in terms of audiogram, years of education, and non-verbal intelligence were tested on speech identification (consonants and sentences) in quiet and in interfering maskers (unmodulated and modulated noise and speech babble) of varying levels, as well as on supra-threshold auditory processing (sensitivity to temporal-fine-structure and temporal-envelope cues) and cognitive abilities (including memory, attention, and processing speed). The results showed that speech identification performance was consistently lower for the older than for the younger normal-hearing listeners across all masker types and levels.

Somewhat surprisingly, these deficits were not reflected in the self-ratings of the listeners’ hearing abilities on standard questionnaires (such as the SSQ and APHAB). Sensitivity to both types of temporal cues was reduced in older listeners and correlated positively with masked speech identification; however, this was not due to a reduced ability to listen in the temporal dips of the fluctuating maskers.

Many, but not all, cognitive abilities were lower for the older listeners, and better overall cognitive performance was associated with higher intelligibility of masked speech (see, however, Füllgrabe and Rosen,⁷ showing that working memory is not associated with speech-in-noise intelligibility in younger normal-hearing listeners). For the linguistically more complex sentence material, intelligibility in noise was best predicted by composite measures of cognition and, to a lesser extent, sensitivity to temporal fine structure.

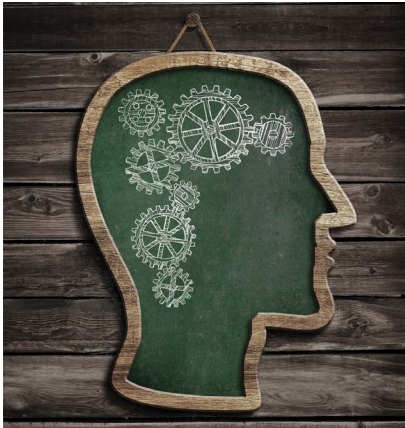
An important implication of these findings is that current knowledge of the perceptual consequences of peripheral hearing loss on speech perception is likely biased by age effects, as most published studies have compared younger normal-hearing to older hearing-impaired listeners, with age differences up to 50 years between the listener groups!

The results of this “proof-of-concept” study constitute important evidence that age-related deficits indeed exist independently of the ubiquitous decline in hearing sensitivity, but the use of two discrete age groups did not allow us to determine *when exactly* during adulthood these deficits can first be observed. This question is currently being investigated in a large-scale study of audiometrically normal-hearing listeners sampled continuously across the adult lifespan, using a battery of speech, temporal-processing, and cognitive tasks. The preliminary data suggest that age-related changes in all three domains are already present in midlife, with the earliest deficits (for listeners aged 30-39 years) observed for a binaural task of temporal-fine-structure processing.⁶

Taken together, these studies demonstrate that, even in the absence of elevated audiometric thresholds, various levels of speech processing—from phoneme identification to paragraph comprehension—are affected with age. These deficits co-occur with changes in cognition and a decline in the sensitivity to supra-threshold temporal cues. From a clinical perspective, these findings indicate a need for diagnostic tests in addition to the



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audiogram when assessing the hearing of older people.

Key Points

- 1) Aging is associated with a reduced ability to understand speech even when the standard measure of hearing—the audiogram—remains normal.
- 2) Poorer speech understanding is associated with lower general cognitive functioning and reduced abilities to discriminate sounds that are clearly audible.

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Hearing Aid Outcomes and the Influence of Non-auditory Factors

Chapter 4: Strategies for addressing unique patient needs

BY GABRIELLE SAUNDERS, PhD

Because factors like cognition, health literacy, vision, and hearing aid handling ability influence hearing aid outcomes, professionals have a responsibility to address these issues during hearing aid instruction and counseling.

Non-auditory factors such as cognition, memory/recall, manual dexterity, tactile sensitivity, health literacy, and vision influence hearing aid outcomes. Research shows these factors are not independent. Specifically, cognitive decline, age-related vision loss,¹ poor motor skills,² and decreased health literacy³ are often associated with each other. This suggests that older patients with diminished cognitive ability are likely to demonstrate other deficits like those above.

Data from an ongoing study in our laboratory illustrates these intertwined relationships and, more importantly, their association with hearing aid outcome. In this study, we are characterizing participants before they receive their first pair of hearing aids using a variety of non-auditory test measures, and then assessing hearing aid outcome 4 to 8 weeks after the hearing aid fitting. Outcome is measured with the International Outcome Inventory for Hearing Aids (IOI-HA)⁴ and the Hearing Aid Skills and Knowledge (HASK) test. The IOI-HA is a 7-item self-report measure on which seven dimensions of outcome are rated (Use, Benefit, Residual Activity Limitations, Satisfaction, Residual Participation Restrictions, Impact on Others, and Quality of Life). Higher scores

on the IOI-HA indicate better outcome. The HASK was developed specifically for this study to measure both knowledge and skills for hearing aid management. Individuals answer questions about hearing aid management (Knowledge) and then demonstrate the activity (Skill) to the tester. The HASK is scored as a percentage correct for Knowledge and Skill separately.

To date, data are available from 103 veteran participants with mild-to-moderate sensorineural hearing loss, aged between 50 and 86 years. Scores on the non-auditory measures show the sample to be heterogeneous in their performance. Specifically, cognitive function measured using four subtests from the Rivermead Behavioral Memory Test (RMBT)⁵ shows that only one third (34%) of participants performed within age-based norms on all four subtests, with 33% performing below age-based norms on one subtest, 25% on two subtests, and 8% on three or four subtests. The subtests we used assess skills required for hearing aid management—the ability to learn and recall how to conduct a new task (Novel Task Immediate and Delayed subtests), the ability to recognize visual materials (Picture Recognition subtest), and the ability to recall spontaneously when to do a required action (Belongings subtest). A similar pattern was seen for performance on the Discourse Comprehension Test (DCT)⁶ on which a third of participants (37%) performed below clinical norms. The DCT measures the ability to comprehend, draw inferences from and recall the content of short stories.

As applied to hearing aids, our preliminary results suggest that over a third of the population could have considerable difficulty understanding and applying information provided during hearing aid instruction. In addition, a third of participants (36%)



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had poor manual dexterity (performed >1SD below mean of norms) as measured by the Grooved Pegboard test,⁷ 74% had poor sensitivity in their dominant hand index finger and/or thumb as measured by the JVP Domes test,⁸ and 82% scored outside of age-based norms on a test of visual contrast sensitivity (Smith-Kettlewell Institute Low Luminance or SKILL card).⁹ On a positive note, 94% of participants had adequate health literacy as measured with the Short Test of Functional Health Literacy in Adults (S-TOFHLA).¹⁰ Together these findings suggest that, among a typical population of older first-time hearing aid users, there will be many individuals who encounter difficulties handling and learning to manage their new hearing aids.

Our outcome data show this concern is more than hypothetical. Stepwise, multiple linear regression showed that hearing aid outcome is highly related to hearing aid handling ability and to health literacy, in that the HASK Skill score explained 30% of the variance in IOI-HA total score, with S-TOFHLA scores explaining a further 9% of the variance. Scores on the Novel Task and Picture Recognition subtests of the RMBT, and performance on the DCT, SKILL, and JVP Domes tests were also significantly correlated with IOI-HA scores, and HASK Skills scores were significantly correlated with manual dexterity. In sum, it is clear that cognition and other non-auditory factors impact hearing aid outcome.

What do these findings mean for hearing care professionals and clinical practice? Audiologists and dispensing professionals have a responsibility to address these issues during hearing aid instruction and counseling. This can be achieved in several simple ways. Here are some suggestions: 1) Provide take-home materials to assist patients with memory issues; 2) Ensure all information shared is in accordance with “health literacy universal precautions”¹¹ which benefit all patients, especially those with poorer health literacy; 3) Always emphasize the need for good lighting when cleaning and maintaining hearing aids to help the many patients with diminished contrast sensitivity; 4) Counsel patients about the need to be patient when handling their hearing aids, especially those with poor manual dexterity and tactile sensitivity, and 5) Involve a spouse, family member, or caregiver during hearing aid instruction and orientation. This will provide additional support for the patient, regardless of their basic abilities.

An excellent resource that addresses many of these issues is the AHRQ Health Literacy Universal Precautions Toolkit.¹¹ It provides evidence-based guidance for medical professionals on spoken communication, written communication, self-management, and empowerment and supportive systems.

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Examining Relationships Between Cognitive Status and Hearing Aid Factors

Chapter 5: Lower cognitive function may be a risk factor for lower satisfaction with hearing aids

BY JASON GALSTER, PhD

It appears likely that patients with lower cognitive function would benefit from a longer period of counseling, education, and training on topics such as expectations for hearing rehabilitation, hearing aid care, and use of hearing aids, including manual adjustments and battery changes.

With the escalation of audiology-related research in cognition, audiologists have begun to wonder if understanding a patient's cognitive ability would offer a meaningful contribution to the development of an individualized treatment plan. This is a reasonable curiosity and one toward which we have gained some insight.

Between our research centers in Minneapolis and Berkeley, Calif, we maintain an active database of almost 1,200 volunteer research participants with hearing loss. At the time of qualification for research participation,

all volunteers complete a battery of assessments, the results of which are logged in the database. One component of the qualification is the Montreal Cognitive Assessment (MoCA).¹ The MoCA is a 13-item screening tool which can be administered in 10 minutes; it is available as a one-page document and is designed to measure cognitive abilities including attention, memory, language, and visuospatial functions. The MoCA has a maximum score of 30. Scores above 26 are considered to be within the normal range; scores below 26 indicate the possibility of cognitive impairment, and scores below 22 indicate the possibility of more significant cognitive impairment. (See www.MoCAtest.org for details.)

We completed a retrospective analysis of relationships among a variety of participant and hearing aid factors and global scores on the MoCA. Some examples of the assessed factors are age, gender, high-frequency pure-tone average (PTA), aided Hearing-in-Noise

Test (HINT) performance, and overall satisfaction with hearing aids. Some of these relationships will be discussed here.

The participant sample included 61 adults with hearing loss, who had recently completed a multi-week hearing aid field trial. For this reason, subjective and objective hearing aid outcomes reflect participants' experience with a single hearing aid type, whereas the physical hearing aid style and ear-coupling configuration varied across participants. Ages ranged from 55 to 84 years. For the purpose of analysis, participants were grouped into proportionally distributed age quartiles.

Figure 1 shows a scatterplot of participants' MoCA scores plotted as a function of age. Individual colors represent each of four age quartiles; gender is shown as symbol type. The fitted line shows a linear regression between the two variables. The linear regression model indicates that age accounts for approximately 25% of variance in the MoCA scores. This is an important observation as it reinforces the expectation that age is a dominant factor in participants' cognitive abilities.

Figure 2 shows participants' satisfaction with their hearing aids plotted as a function of MoCA score. Satisfaction ratings were recorded on a

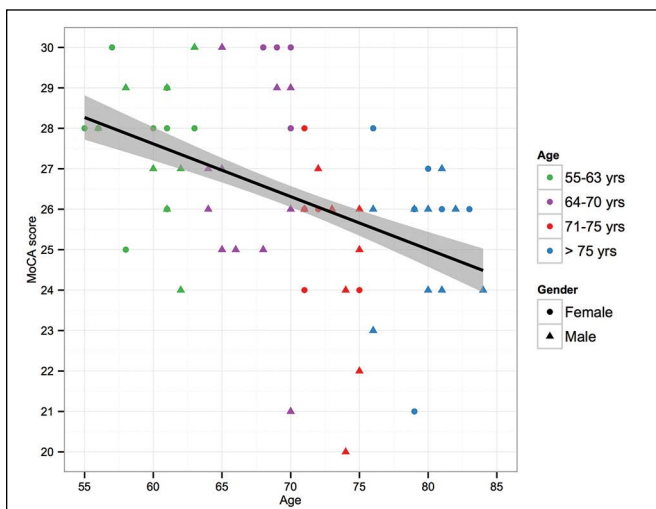
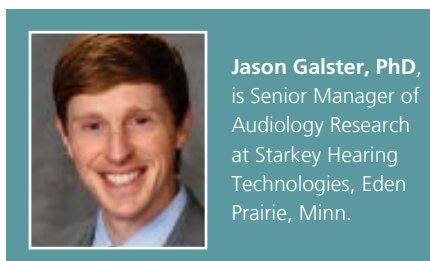


Figure 1. MoCA scores are shown as a function of participant age, with each of the four age groups represented by different colors and gender represented by different symbols. Box plots show quartile distributions around the mean. A linear regression of MoCA score and age is also plotted.

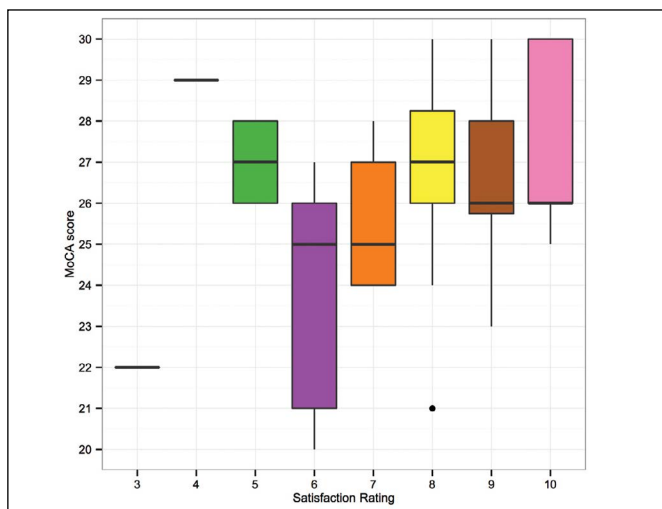


Figure 2. MoCA scores are shown as a function of overall hearing aid satisfaction. Boxplots show quartile distributions around the mean.



scale of 1 to 10, in response to the item “Please rate your overall satisfaction with the hearing aids.” Satisfaction rating correlated positively with MoCA score ($p < 0.05$), indicating that participants with higher cognitive ability reported greater satisfaction with their hearing aids.

The relationship between hearing aid satisfaction and cognitive ability is perhaps one of the most intriguing results of this study. This relationship suggests that patients with lower levels of cognitive functioning may be at greater risk for poor satisfaction with and possible rejection of their hearing aids. We do not yet have validated recommendations for modifying a clinical routine to meet the needs of a patient with lower cognitive ability, as these results warrant further investigation. However, it is likely these patients would benefit from a longer period of counseling, education, and training on topics such as expectations for hearing rehabilitation, hearing aid care, and use of hearing aids, including manual adjustments and battery changes.

The results of this study, including analyses not reported here, indicate that the MoCA is sensitive to a variety of demographic and audiologic factors. However, this does not suggest that the MoCA should be used as part of an audiologic assessment. Reliance on this screening tool is impacted by the auditory interaction between administrator and patient, and has been shown to introduce bias and yield inaccurate outcomes.² Based on these observations, the inclusion of cognitive assessment in future audiologic outcome measures may provide insight that could be leveraged to better develop individualized treatment plans.

Acknowledgements

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The Amplification of New Information

Chapter 6: To learn new things, you need a clear message

BY ANDREA PITTMAN, PhD

The first and best thing we can do for people with hearing loss is to provide them with a well-amplified speech signal. Even subtle improvements like widening the bandwidth can make a significant difference and provide patients with more information about the words they hear.

Words are one of the fundamental building blocks of knowledge and communication. Most of the words we know we learned in childhood¹ through a series of steps. Those steps allowed us to incorporate new words into our vocabularies and to strengthen our understanding of other words through experience.²⁻⁴

The first step in the process is detection of unknown words that, interestingly, occurs most often through direct and indirect communication with others.^{5,6} Detection triggers a configuration process in which the acoustics and the semantics (meaning) of new words are bound together. Configuration may not be perfect at first, but through multiple exposures and through interaction with other words in our vocabulary (ie, engagement), we eventually become comfortable with new words and incorporate them into conversation. This process happens dozens, perhaps hundreds, of times a day such that the average high-school graduate knows upwards of 20,000 words.⁷

But what if a child can't hear well? A number of studies have examined the vocabularies of children with different

degrees of hearing loss and compared them to children with normal hearing. Most studies use the Peabody Picture Vocabulary Test (PPVT)^{8,9} to quantify receptive vocabulary in terms of vocabulary age and standard score. PPVT data from our laboratory indicate that children with mild-to-moderate hearing losses tend to have vocabularies 2 years behind their normal-hearing peers.¹⁰ That's equivalent to a child entering 3rd grade with a 1st grade vocabulary (not a great situation for the kid).

Research from Australia reported vocabularies of children with moderate-to-profound hearing loss were as much as 4 years behind their peers, putting them into a whole different category academically.¹¹ A recent study in the UK showed that these vocabulary deficits persist through the college years.¹² One interesting thing about the UK study is the college students thought they knew the meaning of many more words than they actually did. So, if a child can't hear well, the fundamental building blocks of knowledge and communication are unstable.

To address this problem, we need to understand what it is about hearing loss that interrupts the steps to learning new words. We recently developed a series of experimental paradigms in our lab to examine each step closely. These steps include: 1) The recognition of familiar words; 2) The ability to categorize words as either familiar or new; 3) The detection of new words within sentences, and 4) The rapid learning of new words. For these tasks, nonsense words serve as proxies for “new” words so we don't have to worry about which words listeners do and do not already know.



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To date, we've used these tasks with children and adults with mild-to-moderate hearing losses and found similar results (we include adults in our studies because, like children, they regularly learn new information too). Our research shows that the effects of hearing loss are pervasive and reduce performance on every task.

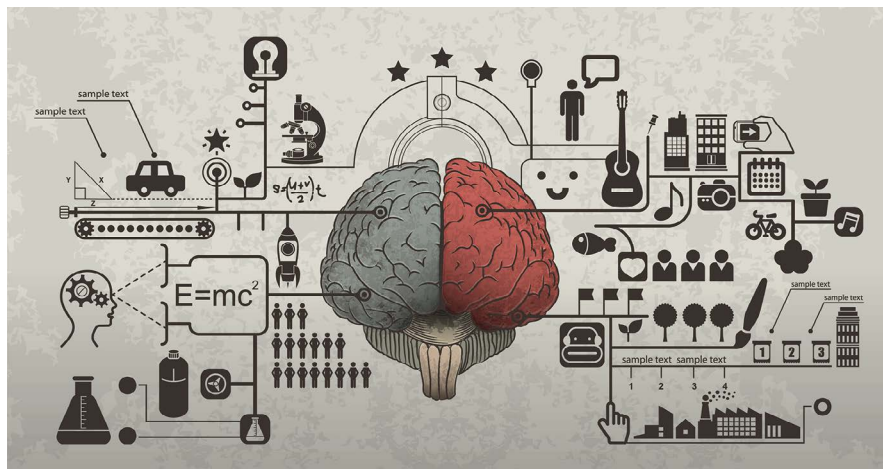
The results of the second task—the ability to categorize words as either familiar or new—is a good example of the problem. In this task we asked listeners to repeat real and nonsense words. The test is administered just like a clinical word recognition test where perception is judged by the accuracy of the words produced. However, traditional word recognition tests are not without problems. First and foremost is the fact that two people (patient and clinician) are doing the perceiving, and both of them can make errors. By including nonsense words as stimuli, scoring accuracy can get out of hand quickly if it's not done with care. We record the responses (via audio recordings) of the listener and have an independent examiner score the responses after the fact.

In addition to repeating each word, the listeners indicate if they heard a real or a nonsense word. This extra piece of information complicates the analyses compared to a word recognition test, but the results are worth it. It turns out that, for each type of word (real or nonsense), there are 5 different ways that a listener can get it wrong and only 1 way to get it right.

Our results show that listeners with normal hearing rarely make errors, and the errors they do make appear to be random. Listeners with hearing loss, on the other hand, make many errors and those errors tend to fall into two categories, both involving nonsense words. First, they recognize that the word they heard was nonsense and they say a nonsense word, but they don't say it correctly. That kind of error appears to be a simple misperception of the nonsense words. When this happens, the listener may just need to hear the word again ("What?").

The second kind of error is more troubling. For many of the nonsense words, listeners indicated they heard a *real word* and then they said a real word. This kind of error suggests that the listeners were automatically (unknowingly) repairing the nonsense words to be real.

The results make sense when you think about hearing loss and how listeners have to fill in missing information that they can't hear. This kind of listening strategy probably keeps them in a conversation longer, but the same strategy may undermine their ability to identify words which



they could be learning. Their listening and learning strategies are literally competing against one another. For children, this could be especially detrimental in academic environments.

But here's the interesting thing: providing the right kind of amplification reduces these errors. Specifically, listeners with hearing loss made the most errors when they weren't using hearing aids. Those errors were fairly evenly distributed between the two types of errors described above; yet when the listeners used hearing aids, their misperception errors went up and their repair errors went down.

That doesn't sound like a good thing, but it is. Amplifying the speech signal allowed the listeners to recognize nonsense words for what they were, even though they couldn't repeat them exactly right. Without hearing aids, they often didn't know they were hearing nonsense words. When we improved their access to the speech signal further (by widening the amplification bandwidth to at least 8 kHz) their errors in both categories fell to equally low levels, the lowest for all listening conditions.

That's *really good news* because it means the first and best thing we can do for people with hearing loss is to provide them with a well-amplified speech signal. Even the subtle improvements from widening the bandwidth made a significant difference and provided them with more information about the words they heard. The alternative is less attractive because it means that, when individuals with hearing loss aren't receiving optimal amplification, they may be missing opportunities to learn new words. This could be responsible, in part, for the poorer vocabularies we see in children compared to their peers.

Although these results represent a small part of the word-learning process, the take-

home message is applicable to nearly every aspect of learning. That is, a clear message helps individuals make the most out of every opportunity to learn new information.

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Why Cognition Matters For Hearing Care Professionals

Chapter 7: Three hot research topics in cognition and hearing healthcare that could fundamentally change our field

BY GURJIT SINGH, PhD, CASLPO

At least three research areas related to cognition and hearing loss show great promise for changing how we view hearing loss and apply hearing care solutions: 1) The use of cognition to assess auditory perception; 2) The links between individual differences in cognition and hearing, as well as hearing devices, and 3) The possible causal relationship between hearing and cognition, and whether hearing aids can delay the onset of cognitive decline.

One of the frontiers in audiology is the increasing recognition of the critical connections between the brain and our sense of hearing. Importantly, there are several ways cognition might matter for the person who is hard-of-hearing. This article outlines three hot topics currently under investigation.

1) The Use of Cognition to Assess Auditory Perception

Historically, listening performance was assessed using relatively simple signals (eg, pure-tones) and relatively simple outcome measures (eg, detection tasks). Over the past several decades, there has been an increased understanding that communication in everyday contexts encompasses a number of other processes, including comprehension and the development of appropriate responses to our conversation partners.

The development of more ecologically valid research paradigms is largely founded in cognition. They now recognize the role of linguistic context,¹ the presentation of sound from different and moving spatial locations,² the use of cognitively-based outcome measures,³ and the role of vocal emotion identification.⁴

2) The Links between Individual Differences in Cognition and Hearing and Hearing Instruments

Broadly speaking, the literature supports the view that individual differences on measures assessing cognition are associated with performance on measures of speech perception in those who are hard-of-hearing^{5,6} (for a review, see Besser et al⁷). Further, the literature also supports the view that individuals with better cognitive abilities tend to be able to extract listening benefit from hearing instruments with more complex signal processing strategies than individuals with poorer cognition. Such benefits are observed on a number of tasks, including those assessing speech understanding, memory for spoken language, and perceptual-motor tasks (eg, reaction time).

Relationships between individual differences in cognition and hearing instruments have been and continue to be established for different signal-processing technologies, including amplitude compression, frequency compression, and digital noise reduction. Currently, there are a number of important and yet to be resolved issues:

- 1) The identification and evaluation of the set of cognitive processes that are most relevant for performance on different speech tasks. While most work has focused on working memory capacity, there is still much to learn about its role in speech understanding, let alone the roles of other cognitive processes (eg, attention, inhibition, executive function, etc) required for listening and comprehension.

- 2) Precise mapping between performance on tests of cognition and the development of hearing instrument fitting guidelines (eg, establishing appropriate “cut-offs” on tests of cognition).
- 3) A better understanding of which signal-processing strategies in hearing instruments are related (or not) to cognition. To date, most research has focused on the relationship between time constants associated with dynamic range compression and cognition; there is a growing amount of research investigating the relationship between cognition and digital noise reduction. Relatively few articles have investigated the possible relationship between cognition and other signal-processing technologies, including directional microphone processing, frequency compression, and environmental sound classification systems.
- 4) The development and validation of clinically-feasible tests of cognition which can be both administered quickly and interpreted by hearing healthcare practitioners. It should be noted that rather than testing cognition directly, chronological age has been used as a proxy-measure of cognitive abilities. Given the variability in cognition observed in older adult populations, this approach likely leads to inappropriate hearing instrument fittings for older adults with good cognition. Surely, we can do better. Hearing care professionals do not assume audiometric thresholds based on age, and similarly, we should not assume cognitive abilities based on age.

3) The Possible Causal Relationship between Hearing and Cognition, and Whether Hearing Aids Can Delay the Onset of Cognitive Decline

Currently, there is good correlational evidence that supports the view of a link between hearing and cognitive deficits, such as demen-



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tia.^{8,9} Importantly, there is a lack of experimental evidence that supports the view that hearing declines are causally linked to long-term cognitive deficits, let alone the notion that hearing aids can delay such cognitive declines.

Currently, there are randomized controlled trials underway or in the planning phase that will shed light on these issues. For example, research led by Frank Lin, Terry Chisolm, and Ann Eddins (among others) is investigating whether rehabilitation of hearing loss (eg, with hearing aids) can reduce the risk of developing cognitive decline. Stay tuned—the results from this and other groundbreaking studies should be known by 2021.

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