WHITE PAPER - PRIMO 2015

Understanding BrainHearing™

ABSTRACT

TECHNOLOGY FOCUSED ON REDUCING LISTENING EFFORT

People frequently say, "I hear fine, but I don't always understand what is said". When hearing care focuses on making sound audible, it is easy to forget that the brain interprets what we hear. Oticon's BrainHearing™ technology supports the way the brain makes sense of sound and allows listening with less effort. Our technology gives access to the details in sound so the total communication experience is more natural, helping your patient to understand more of what is said, rather than just hear more sounds.

Cognitive Hearing Science is an interdisciplinary field which integrates physiologic and cognitive research to explain the complex interplay of the incoming auditory signal, signal processing, the auditory system, memory and cognition in speech understanding. Since its creation in 1976, the Eriksholm Research Centre, a division of Oticon, has taken an active role in establishing and expanding the Cognitive Hearing Science field. Oticon has applied the fascinating discoveries from Eriksholm and other researchers by introducing BrainHearing™, as an evidence-based approach to supporting how the brain makes sense of sound.

Take a moment to explore the most recent, peer reviewed research supporting BrainHearing™.

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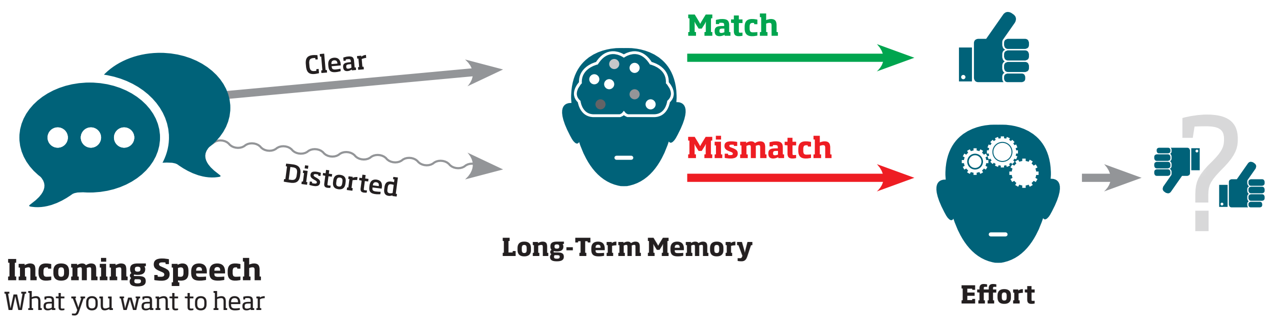
PEOPLE FIRST

DON'T FORGET THE BRAIN

You may have had a teacher at one point tell you "garbage in - garbage out", but this phrase is only partially correct when it comes to the complex computer called the brain. When both our auditory system and cognitive function are intact, speech can even be distorted in multiple ways and still be understood (Davis et al 2005). All modern hearing technology changes the signal in some fashion to improve audibility. However, when the speech signal is manipulated too much, it can become distorted and actually interfere with our brain's ability to comprehend. Therefore, we believe it is critical to provide signal processing techniques that support the brain's natural cognitive processes. Research into the relationship between cognition and audition first began more than 30 years ago. Since then, landmark studies in Cognitive Hearing Science have shown us how cognitive factors could be incorporated into the design of hearing technology (Rönnberg et al 2011). **We call this BrainHearing™.**

DETAILS MATTER WHEN CONDITIONS ARE SUB-OPTIMAL

Consider a typical clinic situation: A new patient says, "I can't understand my favorite television show unless I turn it up". With a little questioning, you find out her favorite show is a British comedy and she speaks with an American southern accent. Her difficulty in understanding the British accent is an example of a sub-optimal listening condition. What she hears doesn't sound like the patterns of speech stored in her long term memory. Any mismatch requires extra work for the brain. The Ease of Language Understanding (ELU) model explains how speech is processed by the brain in both easy and challenging listening conditions (Rönnberg et al 2008; Rönnberg 2003). Implicit processing is largely automatic and effortless when nothing interferes with the speech signal (optimal conditions).



We use explicit processing when conditions are sub-optimal. The speech does not match our stored knowledge of language. This can happen due to interference in the speech signal before it reaches our ears or due to alterations from our auditory system. Explicit processing requires the use of working memory which serves as a mental "blackboard". We temporarily work on what was heard and try to decipher it. If we can't figure out what was said, we can keep holding the information we heard in working memory, erase our mental blackboard and try again. If it takes too long to decipher, we can miss the next thing that is said. Also, if we don't have enough working memory to keep what was heard available until we solve the puzzle, understanding is lost. (Rönnberg et al 2011; Rudner et al 2011a; Rudner et al 2011b; Rönnberg et al 2008). Explicit processing requires effort and more cognitive resources (Pittman et al 2014; Ng et al 2013; Rudner et al 2012). It is like having to do mental gymnastics at the same time you are listening. McGarrigle and colleagues (2014) proposed a definition of listening effort as "the mental exertion required to attend to, and understand, an auditory message".

Listening effort has been evaluated using a variety of methods. The listener can rate or report how they feel, try to understand speech while completing one or more additional tasks, or measurements can be made of their body's physiologic responses to listening. Functional Magnetic Resonance Imaging (fMRI) studies have found more of the brain must participate in the explicit processing effort (Davis et al 2014; Husain et al 2011). These studies showed that when listening effort is necessary to understand what is said, the brain recruits additional areas. With aging or hearing changes, an area of the brain called the anterior cingulate is activated and there is increased bilateral brain activation. The anterior cingulate is area of the brain believed to be associated with error detection and conflict monitoring. Activation of this area indicates the brain recognizes there is a mismatch of what is heard compared to what is stored in long term memory. This implies that listening effort is a physical phenomenon related to increased mental energy use. Increased listening effort is thought to cause fatigue, stress, and more stress-related absences from work (Natchtegaal et al 2012; Natchtegaal et al 2011; Kramer et al 2006; Hetú et al 1988). Increased listening effort also negatively impacts the person's ability to multi-task. (Sarampalis et al 2009). The BrainHearing™ approach to design of compression has been shown to reduce listening effort for both children and adults in the difficult listening situations of background noise, including when both speech and unwanted sound occur at the same time and in the same location (Pittman et al 2014). Very few hearing instruments actually employ the BrainHearing™ based technology of linking compression functions between the ears. Research has shown how linking compression binaurally improves the ability to hear in background noise. (Ibrahim et al 2013; Wiggins & Seeber 2012).

> The **BrainHearing™** approach to hearing technology design **reduces listening effort** for both **children** and **adults.**

People have difficulty understanding because we don't live in an "optimal" world. Sub-optimal conditions cause the redundancy of details inherent in speech to be reduced or lost. When we are in sub-optimal conditions, our auditory system and cognitive functions lose effectiveness. We need to use every detail in speech redundancy at our disposal to figure out what is said. This is when having access to every little detail matters. When what is heard doesn't match what we know, we have to quickly access our cognitive "blackboard" and expend mental effort to decipher what was said.

HOW DETAILS ARE LOST

We have known for years that the brain has a unique ability to process, separate and interpret sound if it receives a robust signal that is full of detail. As you know, hearing technology modifies sound so that it is more audible, but it can also modify sound in ways that further diminish or lose these critical details. Oticon's technology is designed to provide the clearest, purest sound details to decode. Secondly, its sound processing is designed to maintain and enhance the fine details necessary for the brain to understand and interpret sound with less effort.

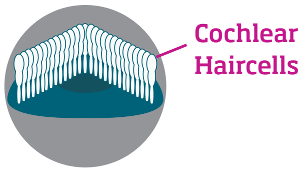
Oticon hearing technology is designed to provide the **clearest**, **purest sound** details necessary for the **brain** to **interpret** speech with **less effort**.

You may wonder, "If speech is highly redundant and understood even with distortion, why would the details in speech need to be preserved?" Remember, we are not dealing with a perfect auditory system in an optimal hearing environment. We work with a pathway from the ear to the brain introducing transmission loss and distortion. Oticon applies research in order to help make lost speech details available to the brain.

In order to more fully understand how thinking "brain first" in hearing technology can improve understanding, let's take a quick look at recent research illustrating how details in speech are distorted or lost. You might find it surprising

Noise Exposure: The most preventable change to hearing acuity is noise exposure. As clinicians, we tend to think of noise exposure causing two types of hearing changes, permanent and temporary. We see the permanent changes from noise exposure as decreased sensitivity on audiograms and otoacoustic emissions testing, which never recovers. This indicates the cochlea's hair cells are damaged or destroyed (Liberman & Dodds, 1984). Interestingly, hair cells continue to suffer damage or destruction for days after loud sound exposure (Wang et al, 2002).

Before permanent noise damage



After permanent noise damage

With permanent hearing changes from noise exposure, the damage affects much more than hair cells. The damage continues up the hearing pathway to the auditory nerve. From the spiral ganglion cells of the cochlea, on up to the brainstem cochlear nuclei, noise exposure causes damage to the outer sheath of the nerve. This slows the speed at which nerves send signals from the ear to the brain.

Noise induced **changes don't stop** at the hair cells.

It also causes a change in the timing information received from the ear. The disruption to timing information plays a part in decreasing the ability to locate where a sound is coming from. (Tagoe et al, 2014; Kim et al, 2013; Zeng et al, 2005). So now there are less hair cells to carry the speech signal to the auditory nerve, as well as timing distortion added to what it receives.

Sometimes, noise exposure can cause a Temporary Threshold Shift (TTS) and hair cells recover quickly over the course of weeks (Miller et al, 1963). Most of us have attended a great concert, only to walk out afterwards with our ears feeling clogged and ringing. A few hours or days later everything seemed to have returned to normal, so we think "no harm, no foul". Unfortunately, those temporary symptoms are the outcries of thousands of auditory nerve cells trying to tell us "Help, save me, we're dying".

The hair cells may return to normal, giving audiogram and otoacoustic emissions test results in the normal range.

However, we now know permanent damage has occurred. Similar to permanent hearing loss from noise, "Temporary" Threshold Shift also causes permanent damage to the auditory nerve. The damage to the cochlear afferent neurons and spiral ganglion cells can occur months after the noise exposure and possibly continue for years to come (Kujawa & Liberman, 2006 and 2009). The changes from noise exposure don't stop at the auditory nerve. The auditory cortex can be re-organized by chronic sound exposures even at moderate levels considered "safe" (Pienkowski & Eggermont 2012).

So, when you are taking a case history which includes noise exposure, it is now easier to understand why patients report difficulty understanding in sub-optimal conditions with noise induced hearing changes or even a "normal" audiogram.

Presbycusis: As we age, the entire auditory system is affected. We lose hair cells in the cochlea and auditory nerve fibers. The stria vascularis, the "battery" of the cochlea, degrades causing poor transduction of sound into the electrical code necessary for the nerves (Frisnia 2001). The loss of hearing with age also causes a lot more than changes to the cochlea. Decreases in the number of hair cells and auditory neurons directly causethe auditory brainstem to be affected in ways unrelated to the central aging process (Frisina 2001). There are many more subtle effects which degrade the ability to hear in difficult conditions (Akeroyd 2008). It has been known for quite some time that our ability to understand degraded speech decreases in the fourth decade of life, even before the audiogram shows changes (Bergman 1980). When the timing is disrupted by the auditory system due to aging there is a significant decrease in the ability to identify words in background noise (Pichora-Fuller & MacDonald 2007). This is why reduced peripheral acuity cannot be simply restored by turning up the volume. In order for older adults to understand speech in background noise, they have to pull on many more cognitive resources (Wingfield et al 2005). Just by having changes to hearing, the risk for cognitive impairment is 24% greater, even when the study controls for factors such as age, gender, education, race, diabetes, smoking history and cardiac condition (Lin, 2011; Lin et al, 2011a, Lin et al 2011b). The greater the changes are to hearing thresholds, the greater the risk of cognitive decline. The mechanisms behind cognitive decline accelerated by hearing changes are not yet clear. Yet, there are significant links between loss of gray matter volume in the auditory areas of the brain, peripheral hearing ability, and related neural activity (Peele et al, 2011). It is generally accepted that grey matter volume declines with age. Despite this, undistorted and completely audible speech is easily comprehended throughout our lifespan (Davis et al, 2014). This is why turning up the sound level can work well when you are in a quiet room. However, when the speech signal is compromised, more cognitive processing is required and grey matter volume becomes more important (Rudner, et al 2011).

> As we **age**, we use **more cognitive** resources to understand **speech** in **background noise**.

Health Choices and Conditions: Other than aging and noise exposure, general health issues like smoking, poor cardiovascular health, and a high body mass index can affect the auditory system. Adults between 40 and 69 years of age who smoke tobacco or have regular passive smoke exposure show increased difficulty hearing with background noise compared to non-smokers. The degree of difficulty correlates with the amount of tobacco use or exposure (Dawes et al, 2014). Smoking even has an additive effect to noise induced hearing changes (Agrawal, et al 2009). Poor cardiovascular health has also been associated with damage to entire auditory system including the brain (Agrawal, et al 2009; Hull 2010). Diabetes appears to also carry an increased risk of hearing changes (Agrawal, et al 2009). Maintaining a healthy body mass has been shown with comparative studies in college age students to be related to better hearing acuity (Cramer 2012).

You have now seen many examples of where the auditory system can lose the details of speech and introduce distortion just from experiencing changes to hearing. Providing audibility is obviously not enough. What is important is HOW you provide audibility to give more access to what is heard. Let's discover how technology can work with these changes to give unparalleled access to sound.

The Application of BrainHearing™ in Hearing Technology

Hearing technology is designed to give improved access to sound. Adjusting the amplification to fit the thresholds from a hearing evaluation ensures incoming speech is reaching the cochlea, however as you have read, there is a lot more to consider than simply making sound audible. As we have reviewed together, sound can be disrupted as it travels through the auditory system in many ways. Hearing technology can also change the sound entering the auditory system, both in ways that are beneficial or detrimental. Decades of dedicated auditory research at the Eriksholm Research Centre in how the brain understands what it hears has helped us gain insight into the best methods for modifying sound with technology. This important research has led to the BrainHearing™ concept.

Oticon has identified four key areas where technology can support BrainHearing™:

- advanced compression to give the brain access to the details in speech while decreasing listening effort and minimizing non-linear amplification side effects;
- more natural noise reduction which allows the brain to focus on understanding;
- preservation of cues to locate a sound in the environment;
- personalization of sound processing for the individual's needs.

Oticon's core hearing technology features were created to fill these key areas.

SPEECH GUARD

All nonlinear hearing instruments change gain as the input level changes. However, the control over the timing of these changes is key. Historically, hearing care professionals have had to choose between slow acting and fast acting systems, invariably making compromises to the quality or clarity of the speech signal.

Traditional approaches to compression can cause some information in the speech signal to get lost or distorted. Speech Guard E controls the dynamic properties of Oticon's multichannel nonlinear hearing instruments, applying gain and compression in a way that is designed to fully preserve the details of the speech waveform.

Research has shown that Speech Guard E provides better speech understanding, especially in complex listening environments. The better we can preserve the details in the speech waveform, the easier it is for the brain to fully understand the speech signal.

SPATIAL SOUND

When the patient's two hearing instruments can exchange large amounts of data very quickly, new signal processing possibilities are opened up. Complex signal processing is only available when using a high speed communication link between instruments and is not feasible using Bluetooth or 2.4 GHz data transmission technologies.

Some manufacturers have chosen to use communication between instruments to create an artificial,situation specific, narrow directionality mode. In contrast, Oticon uses high speed data sharing to balance the gain and compression response between the two hearing instruments. This allows the instruments to preserve the on-going, ear-to-ear level differences in sound that are so vital to localization.

The better the patient is at identifying where sound comes from, the easier it is for the listener to distinguish where all the sources of sound in the environment are located. They can then choose which one to attend to and which ones to ignore. The auditory system is a binaural system and Spatial Sound is the first hearing instrument technology to fully support the natural localization process.

FREE FOCUS DIRECTIONALITY

The brain loves a good signal-to-noise ratio. Patients also prefer the sound quality of a device that does not put artificial restrictions on the sound that passes through. The key is to know when to apply directionality and when to allow a natural, full sound picture to be presented to the patient.

Research has shown that patients prefer directionality when it helps improve speech understanding, but they prefer an omni-directional response all other times. The intelligent decision making in our Free Focus directional system will automatically activate directionality when it can improve the signal-to-noise ratio for the patient. At all other times, it will provide the excellent sound quality of an omni-directional response. All of this happens automatically without the need to push a button to change settings.

PERSONALIZATION

The only person who knows how sound sounds through a hearing devices is the user. Many different factors will affect the type of processing that any given patient wants and needs.

Oticon has developed a fitting approach that is designed to efficiently account for the natural variability from person to person. Our Personalization process affects many functions in the devices, including the aggressiveness of our noise reduction and directional systems, the extra protection provided for high level inputs, and the amount of access to softer sounds of speech. The sum total is a hearing system that fully reflects how each individual patient experiences sound.

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People First

People First is our promise
to empower people
to communicate freely,
interact naturally and
participate actively

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