WHITEPAPER
2017

Pushing the noise limit

New Opn evidence on speech understanding and listening effort

SUMMARY

The primary complaint of people with hearing loss is understanding speech in noise. A new study measuring brain activity in complex sound scenes shows that people with hearing loss have difficulty organizing complex sound scenes into a primary speech sound and other secondary "noise" sounds. The overlap of primary and secondary sounds places an extra processing load on the brain as it tries to make sense of the relatively undifferentiated primary and secondary speech sounds.

Here, we report data which shows how noise processing in OpenSound Navigator (OSN, in Oticon Opn) makes a significant difference. Results show an improvement in speech intelligibility and indicate a reduction of the processing load on the brain across noisy environments. These same data also suggest that OSN supports people with hearing loss by allowing them to regain access to noisy places, which were previously too difficult and too frustrating to participate in.

Additionally, we report how OSN is superior to directional and narrow directionality technologies with regard to better understanding speech. We used a speech-in-noise protocol which more realistically represents the challenges of a conversation among multiple people in a noisy environment.

Nicolas Le Goff Ph.D.
Senior Researcher
Oticon A/S, Denmark

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

oticon
PEOPLE FIRST

Introduction

Recent scientific publications reveal a story which is increasingly clear; hearing loss affects not only hearing, but also the overall health of people with hearing loss. Indeed, cognitive ability, depression, anxiety, reduced quality of life (and more) have been associated with hearing loss. This means that for people with hearing loss *hearing care is health care*.

Qian et al. (2016) reported that hearing loss negatively affects quality of life and increases social isolation. It has been suggested that these factors play an intermediate role in the acceleration of cognitive decline. Hearing loss is an acknowledged risk factor associated with dementia in proportions that are still discussed, between 9% (Livingston et al. 2017) and 33% for Lin (2016, AAAS). Evidence that hearing aids *may* play a role in slowing/delaying cognitive decline is also emerging. The underlying idea is that hearing aids support communication and, as one communicates more easily, cognitively stimulating social interactions are more likely to occur, which may slow or delay cognitive decline (Amieva et al. 2015). The Journal of the American Medical Association (JAMA, 2017) has also shown that mild cognitive impairment (MCI) can be slowed through cognitively stimulating activities and exercises.

> Hearing loss is an acknowledged risk factor associated with dementia in proportions that are still discussed, between 9% and 33%

Social interactions are, of course, different for each person. It may include going to work, visiting a friend, attending a family dinner, bringing children to school, or going to social gatherings. The sounds of the places we visit every day create our personal sounds scenes. Similar to how an injured knee negatively affects our ability to move on rough terrain, hearing loss makes it difficult or impossible to navigate the noisy places of our sound scenes. In the event of a knee injury, we seek the best treatment and rehabilitation, aiming to quickly recover without restriction. Given hearing loss, we also seek the best hearing care so we can participate in noisy situations, which were previously too demanding or even impossible. Just as we would not accept a prosthetic knee which would only allow us to walk on smooth sidewalks but not on dirt roads, hearing aids should allow patients to communicate easily in quiet places as well as noisy places where many social activities take place, e.g., noisy restaurants.

The primary complaint of people with hearing loss, and the primary complaint of people wearing hearing aids, is speech understanding in noise. That is, when a primary speech signal is mixed with secondary sounds, the task of the listener increases dramatically and includes not just hearing sounds, but also the organization of the complex sound scene.

Speech in Noise & Selective Attention

In quiet environments, the speech sound of interest (primary speech) is present in isolation. The acoustic information is clear and well-defined, largely because it has no competition. Therefore, understanding speech is generally effortless because the sole primary acoustic signal can be automatically matched with speech sounds and meaning stored in long-term memory (see the Ease of Language Understanding model, ELU model, Rönnberg et al., 2008).

In noisy environments (restaurants, bars, cocktail parties, etc) the primary speech sound is acoustically mixed with multiple secondary speech sounds (i.e., background noise) at the ears. To solve this dilemma, the brain attempts to organize and prioritize sounds present in the sound scene by focusing on the primary speech sounds while ignoring all others, i.e. secondary sounds. This process is called ***selective attention*** (e.g. Shinn-Cunningham and Best 2008).

Petersen et al. (2016) elegantly illustrated how selective attention works in a beneficial manner for people with normal hearing – and how it often fails for people with hearing loss. Petersen and colleagues used high-resolution EEG to measure speech encoding on the brain of 27 participants with various degrees of hearing loss. The quality and the strength of speech encoding was evaluated by comparing EEG signals to the acoustical speech signals present at the ears using a cross-correlation function, resulting in what the authors call "neural speech tracking". The authors recorded neural speech tracking as participants listened to two streams of speech simultaneously, and were asked to focus on one stream (the attended speech, here the primary speech) while ignoring the other (the unattended speech, here the secondary speech). Participants with hearing loss wore hearing aids, providing amplification fitted to their audiogram.

As shown in Fig.1, the attended speech (blue line) is equally well encoded in the brain, regardless of the presence of hearing loss or its severity (up to 70 dB HL). However, neural tracking of the unattended speech (red line) varies significantly with hearing loss. For people with better hearing, there was a large difference in the neural tracking of attended and unattended speech, indicating listeners with better hearing are more able to attend selectively to the primary speech while ignoring the unattended speech.

As hearing loss increases, the difference in neural tracking between attended and unattended speech significantly decreases. For listeners with more significant hearing loss, there is no significant difference in the encoding of the two speech signals, thus indicating that people with hearing loss, are less able to ignore the disturbing secondary speech (i.e., background noise).

Although intuitively it might seem that for people with hearing loss, neural representation of both speech signals would be worse, the results suggest that the two speech sounds are encoded in the brain, and only people with hearing loss (here using amplification) are unable to ignore the secondary sound, indicating a failure of selective attention.

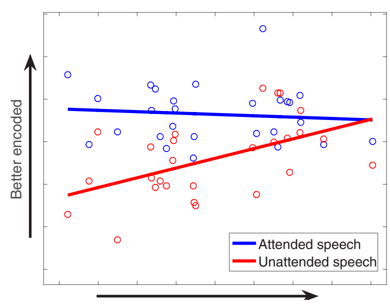

Figure 1: Neural speech tracking as a function of hearing loss. Data from Petersen et al. 2016

The failure of selective attention is not completely understood. However, studies suggest that the spectral and temporal resolution of the cochlea is reduced with hearing loss. Therefore, the transfer of the acoustic signal into electrical spikes on the auditory nerve is not as robust as it would be within a well-functioning cochlea, and the information sent to the brain is less robustly encoded (e.g., Shinn-Cunningham and Best 2008, Tremblay and Ross 2007).

That is, given significant hearing loss, the ability to make sense of sounds (listening and transforming acoustic signals into meaningful information) will be negatively affected. The result likely corresponds to the "muddy" or "blurry" perception often reported by people with hearing loss in noisy places. Understanding the primary speech puts a higher load on the brain as the organization and segregation of the sound scene is compromised.

How can hearing aids help?

Hearing aids cannot change how the cochlea or the brain work, but hearing aids can change the sound that enters the ears.

It is reasonable to assume that the majority of hearing aid wearers with mild to moderate hearing loss, when properly fitted with modern hearing aids, will communicate well in quiet environments. However, as stated above, the primary complaint of people with hearing loss, and the primary complaint of people wearing traditional hearing aids, is difficulty understanding speech in noise.

The work of Petersen et al. (2016) indicates that hearing aids should support selective attention. That is, hearing aids should simplify the sound scene by reducing disturbing secondary sounds (i.e. noise) to support the brain's ability to organize complex sounds, and thereby better focus on the primary speech sound.

For decades, hearing aids have reduced noise with directionality (more recently narrow directionality) and noise reduction. Without a doubt, these systems have delivered benefits in terms of comfort and speech understanding in noise, particularly in a simple one-to-one scenario. However, they have also had limitations and even drawbacks, particularly in unpredictable complex environments (see Le Goff et al. 2016a). With the increased processing power available on the Velox platform, these systems have significantly evolved, allowing the development of a next generation of noise processing with the OpenSound Navigator.

OpenSound Navigator

The most important tools that patients have to better understand speech in noise is their residual hearing and their own brain. However, patients need support. As discussed above, in complex sound scenes, the brain needs a reduction of the disturbing noise to reduce the load and facilitate the organization of complex sound scenes. BrainHearing technologies such as OpenSound Navigator (OSN) are designed to support this process by effectively reducing disturbing noise and support the brain naturally focus on the primary acoustic information.

One key improvement of OSN (over traditional directional processing) is how noise (i.e. the unwanted secondary sounds) is more precisely assessed, identified, and attenuated.

In OSN, noise is estimated using two microphone input channels (rather than typically one). This provides a better estimation of noise sources which allows the *balance and noise removal* stages of OSN to be more efficient at attenuating noise (Le Goff et al. 2016a). The precision of the OSN noise detection system enables an efficient reduction of unwanted secondary sounds while preserving desired distinct speech sounds, thus creating a "re-balanced" 360° sound scene. In this way, OSN supports the natural and residual selective attention of the human brain, which not only makes it easier to understand speech in noise, but also helps the patient to focus on the desired distinct speech (i.e., primary) within the complex sound scene.

The Oticon OSN approach substantially improves upon traditional directional and noise reduction technologies (see evidence below). Traditional directionality aims at creating a focus in front of the patient. In the most aggressive form, narrow directional systems almost "bypass" the residual selective attention of the patient by creating a strong focus straight ahead (or wherever the "beam" is focused) while attenuating other sound sources.

> Narrow directional systems almost "bypass" the residual selective attention of the patient by creating a strong focus straight ahead

Pushing the noise limit

Documenting the benefits of HA technology in laboratory conditions and drawing conclusions on the daily life of patients is always a delicate matter. The main challenge is to develop and use representative tasks and acoustical environments (see Keidser 2016).

Ohlenforst et al. 2017a provides what is (likely) the most comprehensive data set on speech understanding in noise and the associated cognitive effort associated with understanding speech in noise over a broad range of noisy conditions for people with hearing loss.

The study involved 24 participants and the overall method to measure speech understanding and listening effort is in line with Ohlenforst et al. (2017b) and Wendt et al. (2017). Data were obtained with participants using HA with amplification only, or with amplification and OSN.

The data obtained with amplification only, (not using OSN) is shown by the orange solid lines in Figure 2. Intelligibility is shown via a typical S-shaped curve. SNRs above 8dB perceptually correspond to "quiet" environments where there is a single distinct speech source of interest (e.g., a TV set broadcasting the news) while the rest of the environment is relatively quiet.

Above 8dB SNR, intelligibility is high, and the effort shown (solid blue line) is low and somewhat constant. Acoustically, the speech is substantially louder than the noise and this indicates a situation of good speech understanding with low listening effort.

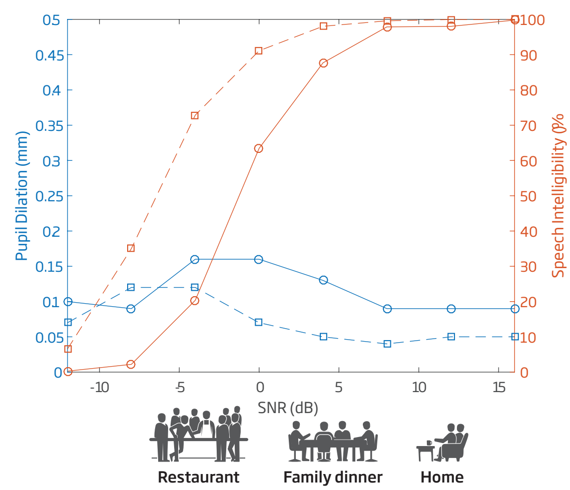

Figure 2: Speech intelligibility (right y-axis, orange) and peak pupil dilation (blue y-axis, left) indicating the effort associated with listening in various noise levels. Data shown here were measured with a 4-talker masker. Solid lines show results obtained with amplification only. Dotted lines show results obtained with amplification and OSN. It is apparent that with OSN engaged, superior intelligibility is achieved, and less listening effort is realized. Data from Ohlenforst et al. 2017a.

SNRs worse than 0 dB (as shown on the left side of Figure 2) correspond to noisy and very noisy environments such as noisy restaurants where simultaneous speech sources are present and have been measured as low as -7dB SNR (Zhang et al. 2015). In these situations, the noise is louder than the primary speech and speech understanding rapidly approaches zero. Interestingly, listening effort also drops once speech understanding goes below 50%. However, this does not mean the task is easy! Rather, the task is so difficult that participants give up.
Motivation theory explains there are two opposite forces at play when it comes to engaging effort in a task, such as understanding speech in noise;

1. The task difficulty or demand, and
2. The motivation driven by the attainable success (Brehm & Self, 1989).

Here, the task difficulty increases with noise, and when the noise effectively masks the speech, it becomes impossible to understand the primary speech, despite how hard one tries. The motivation in the task, and thereby listening effort decreases, because it is impossible to understand.

Intermediate SNRs between 0 and 8dB SNR often correspond to places which have multiple relevant speech sources, such as dinner with friends or family. Acoustically, the noise partly masks the speech and at 0dB SNR noise and speech have equal power. Data show that speech intelligibility degrades from 8dB SNR downwards and reaches about 50% intelligibility around 0dB SNR. At the same time, we observe a significant increase in listening effort due to poorer acoustic conditions. Effectively, as the SNR decreases, the acoustic signal carrying speech information becomes corrupted and less clear. In this situation, the brain can no longer automatically match the stream of speech information with information stored in long-term memory. Given this situation, the process referred to as *explicit processing* occurs (Rönnberg et al., 2008). It is important to note increased effort is not to be interpreted as negative, but rather indicates a healthy sign of motivation to fight degradation of the acoustic condition.

We can therefore define a “tipping point” (TP) corresponding to the lower SNR value for which one can successfully communicate. As such, the TP corresponds to the SNR where the listening effort is approximately maximal, yet speech intelligibility is about 50%, in this dataset. As shown in Figure 2, the TP is close to 0dB SNR for the condition with amplification only.

For SNRs higher than the TP, understanding speech is easy with lower effort, or more difficult but possibly with extra effort. For SNRs lower than the TP, patients believe speech understanding is impossible and they are not motivated to try. In daily life, the TP translates into the limit between environments where patients can engage, participate and be active from those where it’s too hard to do so, which they would prefer to avoid, or in which they give up!

Looking at the data obtained with participants wearing Opn with amplification and OSN active (dotted lines), we observe several significant effects.

The whole S-curve of speech intelligibility is pushed towards lower SNRs (significantly different at SNRs between -8 and 4dB). As for the effort curve, it is significantly lower (here 0 and +4dB – see Ohlenforst et al 2017a for data obtained with steady-state noise), and, remarkably, the peak of listening effort (TP) is also shifted by about 5dB SNR towards noisier conditions.

This indicates that OSN improves speech understanding and reduces the cognitive effort associated with understanding speech in noise consistently over a broad range of SNRs (in line with data reported in Wendt et al. 2017). Further, with OSN, the TP is pushed further by about 5dB. That is, the range of SNRs for which patients can communicate and actively participate is extended by about 5dB towards noisier environments. Thus, by improving the TP, restaurants, cafés, and other large gatherings are much more accessible to people with hearing loss. The most dramatic benefits are observed for SNRs between -4 and 0dB, where speech intelligibility surges from about 20% (a value too low to support effective communication) to about 75% – while listening effort goes from “giving-up” to “I am putting in additional effort, and I can understand.”

> For SNRs between -4 and 0dB, speech intelligibility surges from about 20% to about 75% – while listening effort goes from “giving-up” to “I am putting in additional effort, and I can understand

Behavioral psychology explains that once one has put effort into doing something and has obtained a reward for doing so, one will repeat the pattern to enjoy the reward again (i.e., getting back to and enjoying noisy environments which were previously inaccessible). These data show that OSN should facilitate this positive pattern.

Comparing technology

How does OSN compare to directional technology and in particular to narrow directional beamformers?
Is OSN really the best strategy in a realistic multiple speaker scenario?

To answer these questions, an independent study was conducted in which speech intelligibility was tested in a realistically inspired scenario of a conversation between 4 people in a loud, noisy environment.

Method:
25 people with mild to moderate hearing loss participated. Speech reception thresholds (SRT-50) corresponding to 50% intelligibility were measured for a fixed noise level of 75dB SPL. The noise consisted of two ISTS speech sources placed at +/-30 degrees and a steady-state noise placed at 180 degrees. The target speech (OLSA speech corpus) was randomly presented from one of three loudspeakers placed at -60, 0 and +60 degrees - see Figure 3. Participants were free to turn their head. All patients used power domes for all 3 hearing aids.

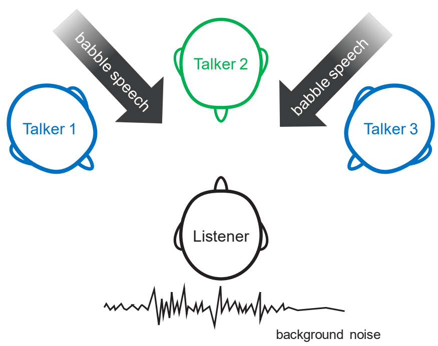

Figure 3: The realistically inspired scenario of a conversation between 4 people in a loud, noisy environment.

Figure 4 shows speech intelligibility was significantly improved with the narrow beamformer, when compared to the directional system (0.6 dB improvement on SRT-50, or about 7% improved speech understanding). Results also show that speech understanding with OSN was better than the directional system (1.4 dB improvement over directional, or about 18% improved speech understanding) and OSN was also better than the narrow directionality (0.8 dB improvement, or about 11% improved speech understanding). These differences are all statistically significant ($p<0.05$).

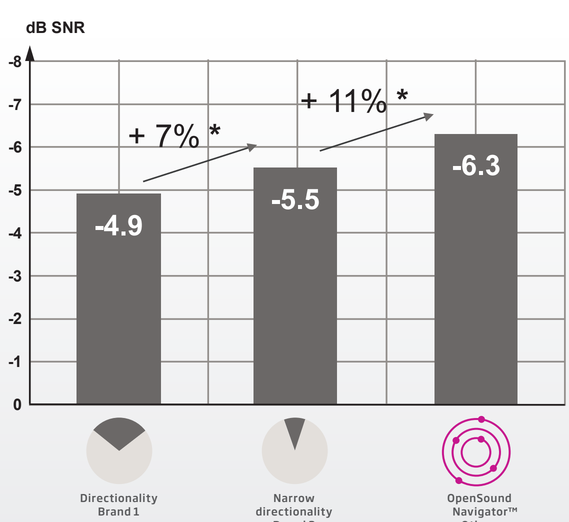

Figure 4: SRT-50s for 3 different technologies. Lower SRT-50s indicate better performance.

Performance for the speaker in the center and for the speakers on the side (shown in Figure 5) offers additional insight as to how OPN outperforms the others. Comparing the upper and lower panels, one can see that for all technologies, the intelligibility for the center speaker is worse than for the speakers on the side. This is due to the fact the side speakers only have babble noise source on one side, compared to the center speaker which has babble speech noise sources on both sides - see Figure 3.

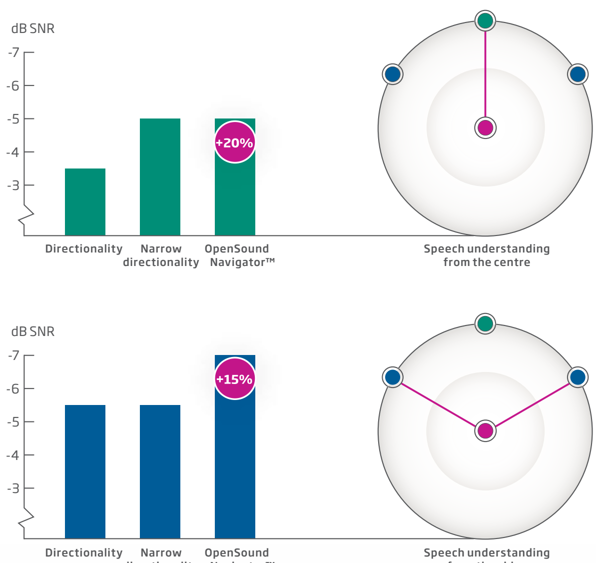

Figure 5: Speech reception threshold for center speaker (upper panel), and side speakers (lower panel)

The goal was to compare speech intelligibility with HAs using 3 different technologies, from 3 different manufacturers, with their noise processing (including directionality and noise reduction-based technologies) set to the maximum setting. HA from manufacturer A used a traditional directionality system, HA from manufacturer B used a binaural beamformer (a.k.a. narrow directionality) and the 3rd HA was Oticon Opn 1 with OSN.

In the top panel of Figure 5, the SRT-50 corresponding to the center speaker shows that narrow directionality and OSN are on par for the center position (the 0.2 dB difference is not statistically different) and both systems outperform the directionality system by approximately 1.8 dB SNR-50, or 20% speech understanding. Further, with narrow directional systems, patients experience the down side of narrow beamformers. That is, the front speaker may be unfortunately acoustically and spatially isolated from the entire acoustic scene. However, OSN delivers access to distinct speech from all directions, as shown in the lower panel.

In the lower panel, results indicate the narrow directionality system does not improve access to the side speakers compared to the directional system. However, with OSN, an improvement in SRT-50 of about 1.3 dB or 15% speech understanding occurs.

It is reasonable to assume that not knowing where the next target speaker will be located, participants tend to face straight ahead, as this "neutral position" provides the quickest time to turn to face any of the three potential speakers. The absence of improvement in speech intelligibility for the side speakers with narrow directionality reflects the cost of the narrow beam. That is, the cost is attenuation of the side speakers, while providing benefit for the center speaker.

> In this realistic communication scenario OSN provides the best access to all speakers, compared to other directionality technologies

In this realistic communication scenario between four people, OSN provides the best access to all speakers (front, as well as left and right sides). This means that overall, patients will experience maximal support in conversations between friends and family members with OSN, than with any other current technology – due to improved access to all speakers.

For more information, see Beck & Le Goff 2017, Hearing review.

Supporting active participation

More than 100 years ago, hearing aids were designed to only amplify sounds. Over the next decades it became clear that simply making sounds louder didn't solve the speech in noise dilemma. As technology improved and as experience was gathered, it became apparent, something more should be done to address this major challenge for people with hearing loss. Engineers designed directional and noise reduction systems with some success and limitations.

New data has revealed specifically what noise processing should aim to do; reduce the disturbance of noise to help the brain organize complex sound scenes and support selective attention.

There is no doubt that as our understanding of hearing loss and listening evolves, technology will be better able to support the complex and multiple aspects of hearing loss and speech in noise issues. As of today, noise processing, with OSN, has made significant progress and the new evidence presented here adds to the growing corpus of Opn Evidence (Beck and Behrens, 2016, Le Goff et al. 2016b, Wendt et al. 2017, Ohlenforst et al. 2017b).

By doing a better acoustic analysis, OSN provides better noise reduction and delivers a 360° re-balanced sound to allow patients to focus on the primary sound they want to listen to. Data shows consistent benefits including less listening effort and better speech understanding over a broad range of noisy conditions, and of note, OSN is more efficient than other approaches in realistic acoustic environments.

For patients, OSN offers substantial communication support and allows active participation in noisy conditions. While there is always a limit as to how much noise one can cope with (even for persons with normal hearing), data shows that OSN extends the limit, allowing patients to participate in noisy environments which were previously too difficult and frustrating without OSN. Studies have suggested that remaining socially active is among the most important factors for healthy aging (Livingston et al. 2017). By supporting participation in noise, OSN also plays an important role in this process, as hearing care is health care.

References

1. Amieva, H., Ouvrard, C., Giulioli, C., Meillon, C., Rullier, L., and Dartigues, J.F. (2015), "Self-Reported Hearing Loss, Hearing Aids, and Cognitive Decline in Elderly Adults: A 25-Year Study", The American Geriatrics Society
2. Beck, D.L., and Behrens, T., (2016), "The Surprising Success of Digital Noise Reduction", Hearing review
3. Beck, D.L., Le Goff N. "Speech-in-noise test results for Oticon Opn", Hearing Review. 2017;24(9):26-30
4. Brehm, J.W., and Self, E.A., (1989), "The Intensity of Motivation", Annual review of psychology
5. Keidser, G., (2016), "Introduction to Special Issue: Towards Ecologically Valid Protocols for the Assessment of Hearing and Hearing Devices", Journal of the American Association of Audiology
6. Le Goff, N., Jensen, J., Pedersen, M.S., Callaway, S.L., (2016a), "An introduction to OpenSound Navigator™", Oticon Whitepaper
7. Le Goff, N., Wendt, D., Lunner, T., and Ng, Elaine, (2016b), " Opn Clinical Evidence", Oticon Whitepaper
8. Lin, F. (2016), "Hearing Loss and Dementia: Who's Listening?", Amercian Association for the Advancement of Science, Washington DC
9. Livingston, G., Sommerlad, A., Orgeta, V., et al. (2017), " Dementia prevention, intervention, and care", The Lancet
10. Ohlenforst, B., Wendt, D., Lunner, T., Zekveld, A.A., Naylor, G., Wang, Y., Kramer, S.E., (2017a), "Impact of SNR, masker type and noise reduction on processing effort as indicated by the pupil dilation", CHScom, Linkoping
11. Ohlenforst, B., Zekveld, A.A., Lunner, T., Wendt. D., Naylor, G., Wang, Y., Versfeld, N., and Kramer, S.E., (2017b), "Impact of stimulus-related factors and hearing impairment on listening effort as indicated by pupil dilation", Hearing Research
12. Petersen, E.A., Wöstmann, M., Obleser, J., Lunner, T., (2016) "Neural tracking of attended versus ignored speech is differentially affected by hearing loss", Journal of Neurophysiolohy
13. Qian, Z.S., Wattamwar, K., Caruana, F.F., Otter, J., Leskowitz, M.J., Siedlecki, B., Spitzer, and J.B., Lalwani, A.K., (2016) "Hearing Aid Use is Associated with Better Mini-Mental State Exam Performance"
14. Rönnberg, J., Rudner, M., Foo, C., and Lunner, T. (2008). "Cognition counts: a working memory system for ease of language understanding (ELU)". International Journal of Audiology
15. Shinn-Cunningham, B.C., and Best, V., (2008), "Selective Attention in Normal and Impaired Hearing", Trends in Amplification
16. Tremblay K, Ross B. (2007), "Effects of age and age-related hearing loss on the brain." Journal of Communication Disorder
17. JAMA (2017), "Can Mentally Stimulating Activities Reduce the Risk of MCI in Older Adults?", Journal of the American Medical Association
18. Wendt, D., Hietkamp, R.K., Lunner, T., (2017), "Impact of Noise and Noise Reduction on Processing Effort: A Pupillometry Study.", Ear and Hearing
19. Zhang, S., Zhou, X., and He, H. (2015), "Study on Chinese restaurant interior acoustics environment", Processings of ICSV22, Florence

26659UK / 2018.07.02

oticon.global/evidence

oticon
PEOPLE FIRST