WHITEPAPER
2018

Closing another gap to normal hearing

New BrainHearing evidence on speech understanding and listening effort

SUMMARY

For people with hearing loss, understanding speech in noise is known to be exhausting. While processing speech in quiet may be effortless even for people with hearing loss, understanding speech in noise becomes increasingly exhausting as the noise increases. People with normal hearing can also experience difficulties understanding speech in noise, with increased effort as the noise level rises.

A recent study investigated the listening effort and speech understanding in normal-hearing listeners using the objective measurement of pupillometry. The study examined the point at which normal-hearing listeners will 'give up' trying to complete a task. Giving up can occur when a task becomes too difficult and the benefit does not outweigh the listening effort required, such as extremely difficult and complex listening situations.

In addition to providing useful knowledge about listening effort in a normal-hearing population, this study may be used in the future as a reference to studies that investigate listening effort in people with hearing loss.

April, 2019.

Note: The investigations described in this white paper revolve around the effects of the OpenSound Navigator. As per February 2019, OpenSound Navigator is available in Oticon Opn S as well as Oticon Opn. OpenSound Navigator has additional benefits in Opn S (see Opn S Clinical Evidence White Paper); it is therefore expected that the effects of the OpenSound Navigator in Opn S is equal to or greater than Opn. Therefore, the results found in this study relating to closing a gap to normal hearing on listening effort, and delivering speech understanding on par with normal hearing, applies to both Opn and Opn S.

Josefine Juul Jensen, *M.A.*
Clinical Research Audiologist
Centre for Applied Audiology Research, Oticon A/S

oticon
PEOPLE FIRST

Introduction

For many years, speech intelligibility has been used as a benchmark in audiological research for measuring speech understanding (Keidser, 2006). While speech intelligibility as a measurement certainly gives a great deal of information, it may not provide enough aspects of the cognitive process that goes behind making sense of speech in everyday communication. When communicating in noisy environments, more cognitive resources are engaged in order to focus on and recognize speech, ignore the noise, interpret the meaning, and remember the speech (Rönnberg et al., 2013). In these situations, people may experience higher listening effort because of the increased need for cognitive resources.

Effort and motivation

According to Mattys et al. (2012), effort may depend on the interaction of two factors: those imposed by the demands of the task, and listener-related factors. Task-related demands can be a type of noise, such as steady-state or multi-talker babble, or the acoustic environment in a given situation. An example of an easy acoustic environment is when the speech is louder than the noise, and a difficult acoustic environment is when the noise is louder than the speech. Factors related to the listener can be whether they have normal hearing or hearing loss. Keeping these factors in mind, it is necessary to include the factor of motivation. Motivational intensity theory (Brehm & Self, 1989) describes motivation in relation to pursuing a goal. The theory explains that people conserve their resources by only investing resources in tasks where the goal can be pursued successfully. When task conditions become too difficult, people will at some point just 'give up'. That is, when a person realizes that they are not getting enough success out of solving a task compared to how many resources they are investing, they will discontinue allocating mental resources to solving the task (Pichora-Fuller et al., 2016). We can interpret this situation as the 'tipping point' or the 'give up point'.

Pupillometry

Pupillometry is a useful and objective measurement for measuring listening effort, including when an individual 'gives up' on a task. (e.g. Beatty, 1982; Zekveld et al., 2010; 2011; Wendt et al., 2017; Ohlenforst et al., 2017). Pupil dilation is continuously recorded (Kramer et al., 2013, as cited in Pichora-Fuller et al, 2016). Pupil dilation has previously been shown to quantify effort (please see Opn Clinical Evidence white paper, Le Goff et al., 2016). Pupillometry can measure effort because the pupil dilation is partly connected with areas of the brain that govern the 'fight or flight' response (McCorry, 2007). Essentially, when a person needs to put in effort to solve a task, the sympathetic nervous system, which is known as the system for fight or flight responses, triggers physiological changes in the body such as pupil dilation. Thus, when presented with speech in noise, the person either invests resources to 'fight' the noise, or give up trying to process the speech in noise.

A previous study investigated the effects of the acoustic environment on the pupil dilation in a group with hearing impairment (Ohlenforst et al., 2017). The study found that the pupil dilation changes as a function of signal-to-noise ratio (SNR) in an inverse U shape curve. In other words, when going from very difficult SNRs to easy SNRs, the peak pupil dilation increases until a certain point, and then decreases again, suggesting that people 'give up' when the task becomes too difficult. The study showed that people with hearing loss give up trying to process speech at sound environments of around -1 dB SNR (Ohlenforst et al., 2017). This means that many opportunities for socializing are sacrificed, because situations like conversing in a restaurant has an SNR of -5 dB or even poorer. However, the same study also found that the OpenSound Navigator™ (OSN) can facilitate moving the point of giving up to situations with lower SNRs, meaning that OSN enables people wearing hearing aids to actively participate in more social situations (see white paper Pushing the Noise Limit, Le Goff & Beck, 2017). Results from another pupillometry study have shown that OpenSound Navigator can reduce the listening effort for people with hearing loss even in environments where the level of noise is relatively low (see Opn Clinical Evidence white paper, Le Goff et al., 2016; Wendt et al., 2017). These studies using pupillometry indicate that OSN in Opn hearing aids reduces listening effort significantly, making communication less exhausting for these hearing aid users, and moves the give up point for understanding speech in noise, enabling them to participate actively in even more social situations.

This study investigated listening effort and speech understanding in a normal-hearing population.
By investigating the gap between normal-hearing listeners and listeners with hearing loss, we can attempt to determine how much effort these two groups use for speech understanding in noisy environments.

Pupillometry study on normal-hearing listeners

Method

Twenty-nine individuals between the ages of 50 and 77, with a mean age of 65.7 years, participated in this study. All participants were deemed to have normal hearing for their age group. The participants performed the Danish Hearing in Noise Test (HINT, Nielsen & Dau, 2011), in which everyday sentences are presented in noise. The babble noise consisted of four competing talkers (two males, two females), where each talker was presented from a loudspeaker (see figure 1). The participants were told to listen to and repeat each sentence, while an eye-tracking camera continuously recorded their pupil response. The speech and noise stimuli were presented in a spatial set up, which is visualized in figure 1. For both types of noise stimuli, the sentences were presented at eight different SNRs. The eight SNRs were randomized, and ranging from -20, -16, -12, -8, -4, 0, 4, to 8 dB SPL, changing in 4dB increments. Overall, data on speech understanding and listening effort was obtained from a total of 16 conditions. There were two outcome measures in the experiment: speech understanding, measured by word recognition in percent, and pupil response, measured by peak pupil dilation. Three practice trials were performed prior to the experiment, consisting of 3x20 sentences.

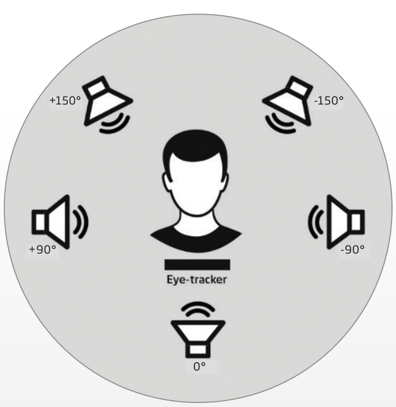

Figure 1 Spatial setup, with speech presented from the front (0°), and noise from loudspeakers to the sides and the back (+/- 90° and +/- 150°). Participants were seated in the middle, with an eye-tracking camera in front of them that continuously recorded their pupil dilation. The distance from the participant to the loudspeaker(s) was 1.2 m., and from the participant to the camera was ≈60 cm.

[1] ISO 7029-2017

Analysis and Results

The analysis of the pupil data is based on a study by Wendt and colleagues (2017) (see also previous white papers, e.g. Opn Clinical Evidence, Le Goff et al., 2016, and Tinnitus and Pupillometry, Juul Jensen, 2017). For each participant and condition, peak pupil dilation (PPD) was calculated (see Figure 2, which visualises normalized pupil dilation over time). Data processing was measured for 25 trials in each condition. For each condition, the first three trials were removed in order to remove training effects from the beginning of the condition. For the remaining trials, a baseline correction was performed by subtracting a baseline value that was estimated by the mean pupil size within one second previous to the onset of the sentence. By correcting to baseline, pupil artifacts related to aspects like nervousness and excitement were controlled. Furthermore, pupil data consisting of greater than 20% of blinks, eye movements, or missing data were excluded from further analyses. A linear interpolation and a smoothing filter were passed over the remaining trials, thus removing eye blinks and high frequency artifacts. The mean and standard deviation of the pupil dilation was calculated from the noise onset to the noise offset. The total time of pupil dilation was thus from 1 to 7 seconds, in which the sentence onset was at 3 seconds.

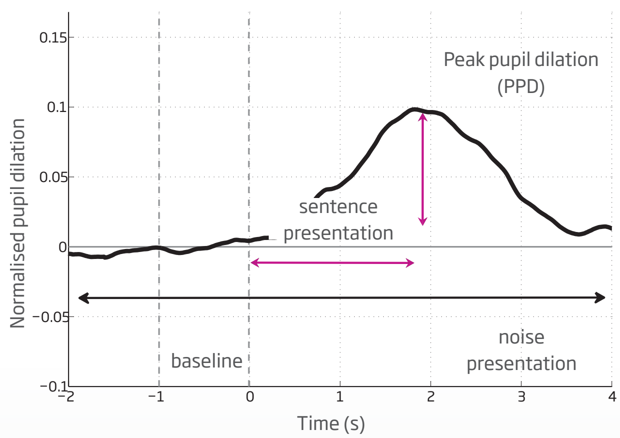

Figure 2 Normalized pupil dilation (mm.) over time (s.), indicating the pupil baseline, the peak pupil dilation, and the time onset for noise and sentence presentation.

When testing the pupil response and speech intelligibility in a variety of SNRs, the typical result would be something like the graph shown in figure 3 (random SNRs are chosen for the example). That is, the PPD as a function of SNR presents itself in an inverted-U shape, with the maximum PPD around the middle and the gradual decrease of PPD on each side of the maximum. The maximum PPD indicates the acoustical environment in which listeners expend the most effort. The bottom part of the figure shows a typical psychometric function of speech intelligibility in different SNRs, ranging from 0% to 100%. The inverted-U and -S shapes shown in figure 3 are characteristic shapes from these two measurements.

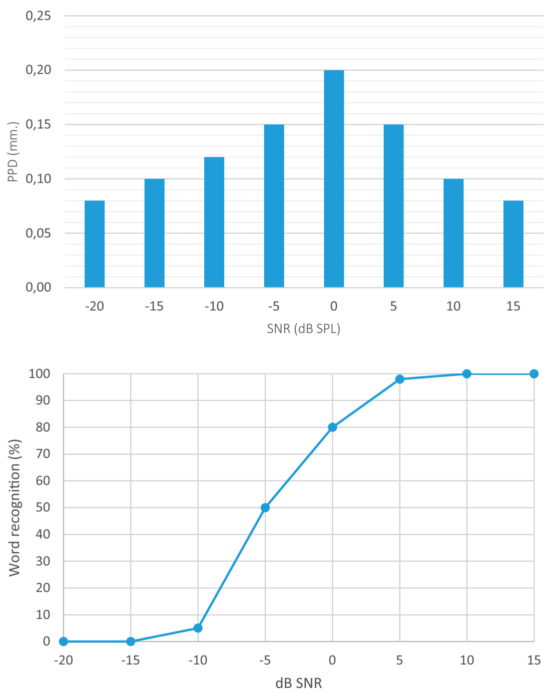

Figure 3 Examples of PPD (top) and speech intelligibility (bottom) as a function of SNR

Selected results from the condition with babble noise with normal-hearing listeners and hearing impaired listeners from the previous study are presented in figure 4. Roughly put, the higher the PPD, the higher the effort, and the higher the point on the word recognition scale, the better speech understanding.

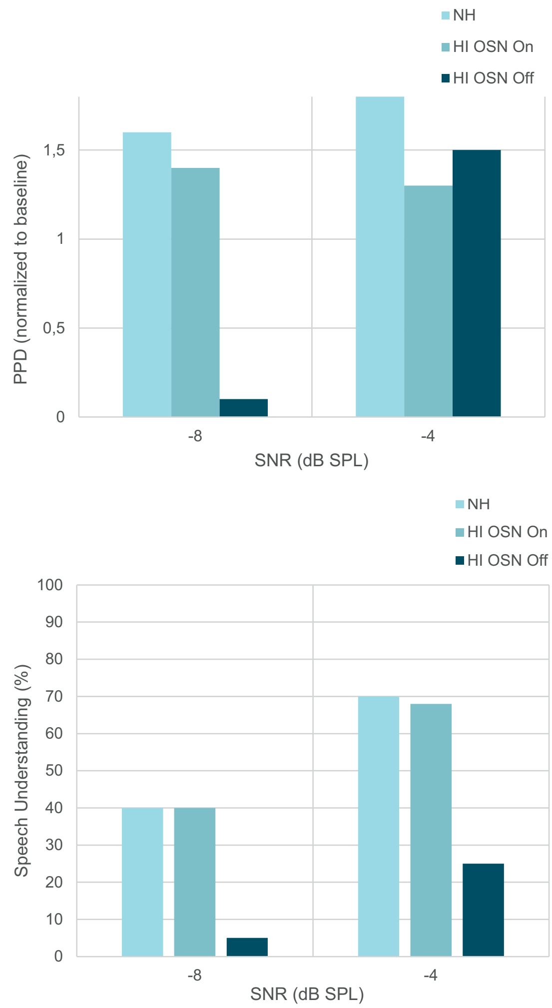

Figure 4 Condition with babble noise. The top figure shows the average peak pupil dilation for -8 and -4 dB SNR. The bottom figure shows average scores for word recognition in percent, indicating speech understanding in -8 and -4 dB SNR.

The results from the normal-hearing listeners show that the word recognition is at 40% at -8 dB SNR, and increases to approximately 70% at -4 dB SNR. The pupil dilation data showed a maximum PPD at -4 dB SNR, indicating the maximum allocation of effort of all the conditions. Going from -4 to -8 dB SNR (a harder acoustical condition), the PPD decreases.

Interpretation

This study investigated the speech understanding and listening effort in persons with normal hearing. There were two aims with the study: to examine when these listeners reach the 'give up-point' of allocating effort, meaning when the listeners start to give up trying to make sense of the speech, and to compare this with a similar study that used listeners with hearing loss. It was found that the normal-hearing listeners expended the most amount of effort around 70% word recognition score (-4 dB SNR, where the PPD was at the maximum). After this point, data suggested that the listeners started to give up putting in the effort (around -8 dB SNR), because it was seen that the PPD began to decrease together with a decrease in word recognition below 50%. Figure 5 visualizes what the difference of OSN can mean for hearing impaired listeners: with OSN, the amount of effort allocated to a task is similar to that for normal-hearing listeners. Without OSN, the hearing impaired listeners will give up much quicker than the normal-hearing listeners (for more details, see Le Goff & Beck, 2017).

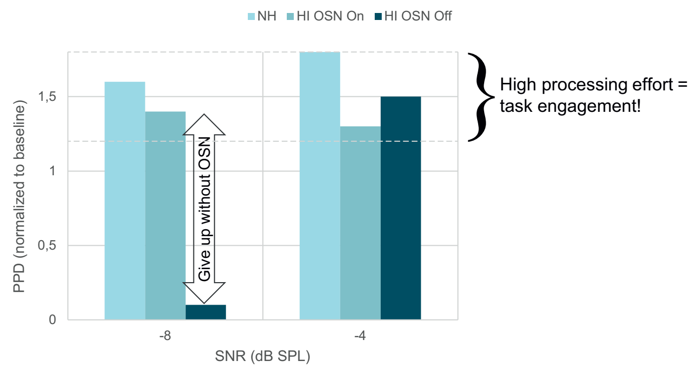

Figure 5 Visualization of the difference for hearing impaired listeners when OpenSound Navigator is activated in their hearing aids. High PPDs indicate high processing effort – a positive sign of continuous task engagement!

Listening effort in normal-hearing listeners compared to Opn users

Results from this study alone are interesting, but they become even more exciting when compared to the results from a similar study with the same experimental setup of people with hearing loss (see white paper Le Goff & Beck, 2017). Comparing the two studies, which used similar methodology but different populations (normal-hearing listeners and listeners with hearing loss, respectively, who were age-matched), the collective evidence shows that the point of giving up for persons with hearing loss with OpenSound Navigator activated is the same point of giving up as for persons with normal hearing. This is visualized in figure 6.

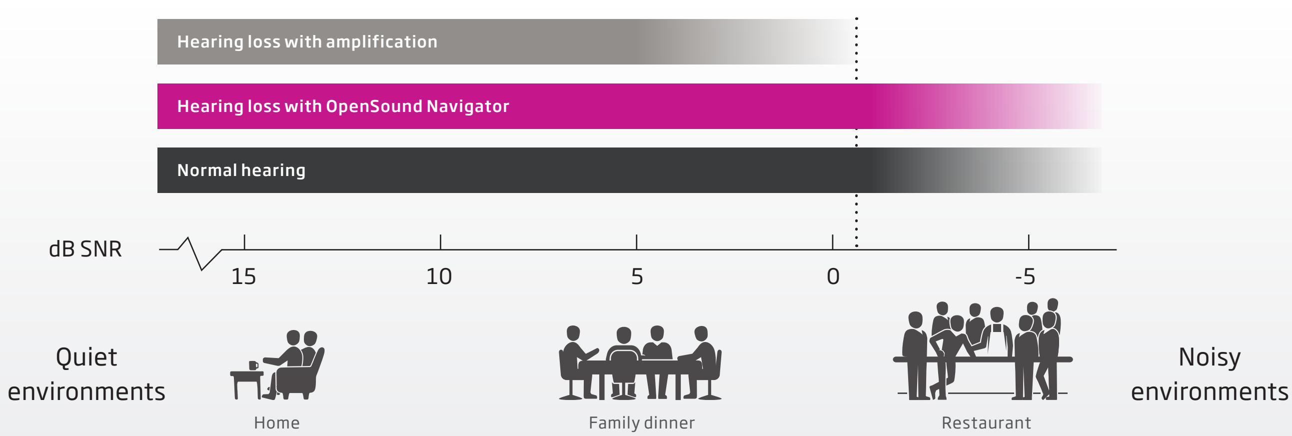

Figure 6 Comparison of the giving up point from studies using listeners with hearing loss using Opn and normal-hearing listeners . Environments that correspond to different signal-to-noise ratios are visualized.

Short discussion of closing another gap

Based on the normal hearing data, we can establish a give-up point of roughly -8 dB SNR. This is similar to the give-up point observed in the study with OpenSound Navigator, as also indicated in figure 6 above.

One of the barriers that people with hearing loss constantly face is that they avoid going to social situations where listening becomes too difficult – so difficult that they are no longer willing to invest effort in following conversations. Eventually, they give up and thus withdraw from these situations. As previously mentioned, normal hearing is the toughest benchmark available, and these two studies together show that OpenSound Navigator breaks the barrier in listening scenarios and empowers users to participate in the same social situations as their normal-hearing peers. In other words, OpenSound Navigator is closing another gap to normal hearing, both in terms of speech understanding, and in terms of listening effort. This is important because it is possible for people with hearing loss using Opn hearing aids to have active communication in difficult listening situations. Therefore, clinicians can encourage people using Opn hearing aids to explore listening and social situations they may have avoided or given up on in the past.

References

Aston-Jones, G., Cohen, J. D., 2005. An integrative theory of locus coeruleus-norepinephrine function: Adaptive gain and optimal performance. Annual Review of Neuroscience 28, 403–450

Beatty, J., 1982. Task-evoked pupillary responses, processing load, and the structure of processing resources. Psychological Bulletin 91, 276–292.

Juul Jensen, J. 2017. Benefits of Oticon Opn for people with hearing loss and tinnitus. Oticon White Paper.

Keidser, G. 2016. Towards Ecologically Valid Protocols for the Assessment of Hearing and Hearing Devices. JAAA

Kramer, S.E., Lorens, A., Coninx, F., et al. 2013. Processing load during listening: The influence of task characteristic on the pupil response. Journal of Language Processing, 28, 426-442

Le Goff, N., Ng, E., Wendt, D. & Lunner, T. 2016. Opn Clinical Evidence. Oticon White Paper

Le Goff, N. & Beck, D. 2017. Pushing the noise limit. Oticon White Paper.

Mattys, S.L., David, MH., Bradlow, A.R. & Scott, S.K. (2012). Speech recognition in adverse conditions: A review. Language and Cognitive Processes. Vol. 27, pp. 953-97

McCorry, L.K. (2007). Physiology of the Autonomic Nervous System. American Journal of Pharmaceutical Education, Vol. 71(4)

Nielsen, J. B., Dau, T., 2011. The Danish hearing in noise test. International Journal of Audiology 50, 202–208.

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

Pichora-Fuller, M.K., Kramer, S.E., Eckert, M.A., Edwards, B., Hornsby, B.W., Humes, L.E., Lemke, U., Lunner, T., Matthen, M., Mackersie, C.L., 2016. Hearing impairment and cognitive energy: The framework for understanding effortful listening (FUEL). Ear and hearing 37, 5S-27S.

Rönnberg, J., Lunner, T., Zekveld, A.A., Sörqvist, P., Danielsson, H., Lyxell, B., Hahlström, Ö., Signoret, C., Stenfelt, S., Pichora-Fuller, K.M., Rudner, M., Rudner, M., 2013. The Ease of Language Understanding (ELU) model: theoretical, empirical, and clinical advances. Frontiers in Systems Neuroscience 1–17

Wendt, D., Hietkamp, R.K. & Lunner, T. (2017). Impact of noise and noise reduction on processing effort: A pupillometry study. Ear & Hearing

Wendt, D., Koelewijn, T., Książek, P., Kramer, S.E. & Lunner, T. Toward a more comprehensive understanding of the impact of masker type and signal-to-noise ratio on the pupillary response while performing a speech-in-noise test. Submitted for review.

Zekveld, A., Kramer, S., Festen, J., 2010. Pupil Response as an Indication of Effortful Listening: The Influence of Sentence Intelligibility. Ear and hearing.

Zekveld, A. A., Kramer, S. E., Festen, J. M., 2011. Cognitive load during speech perception in noise: The influence of age, hearing loss, and cognition on the pupil response. Ear and hearing 32, 498–510.

15013 15555-10253/05.19

www.oticon.com

oticon
PEOPLE FIRST