

EPOS

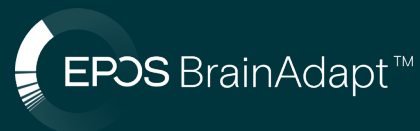
EPOS BrainAdapt™ New Evidence

The effects of noise attenuation
on listening effort and arousal



Scientific Whitepaper
2022

This whitepaper presents the results of a clinical study that investigated the benefits of passive damping technology used in EPOS Enterprise and Gaming solutions. The intent was to demonstrate how damping effects the listening effort exerted by the study's participants.



Introduction

During the study, a group of 19 people participated in the Dagmar-Asta-Tine (DAT) test and Sentence-final Word Identification and Recall (SWIR) testing, two established methods of measuring speech intelligibility in noise, listening effort and speech retention. In both tests, participants listened and responded to auditory stimuli played through a pair of EPOS headphones.

By analyzing the results of the tests, we can conclude that the passive noise reduction performance of EPOS headsets leads to a reduction in effort listening, better memory recall and higher levels of word recognition.

This type of in-depth scientific research has been a key element in the development of audio solutions built on EPOS BrainAdapt™ technology, which support the brain's natural way of processing sound. The custom-made components, acoustics and sophisticated algorithms that go into EPOS solutions ensure maximum cognitive performance, even in challenging sound environments.

EPOS product innovation is driven by psychoacoustic research

In the EPOS product innovation process, we start by defining the sound profile that supports the best cognitive performance in specific use cases. To ensure that EPOS solutions provide the most balanced, clear, and natural soundscape possible, we draw on more than a decade of research into how the brain perceives sound and how the brain's cognitive load can be lowered in various sound situations.

As we move into product development, we implement fine-tuned acoustics and sophisticated algorithms into our solutions. We look at the product holistically, integrate technical features and the right set of custom-made components to provide the best conditions for your brain.

Finally, before launch, we conduct psychoacoustic research in collaboration with the Demant Group to validate that EPOS users obtain the maximum cognitive benefit intended. The following pages present the results of a recent study that will help EPOS continue deliver superior audio and video solutions with audio designed for the brain.

The technology tested in this study is featured in the following EPOS products:

- ADAPT 600 Series
- GTW 270 Hybrid
- H3PRO Hybrid
- H6PRO Closed

Abstract

Research shows that background noise affects how well people perceive speech (Mattys et al.,2012). When we listen to someone speak, other conversations or background sounds increase the signal-to-noise ratio (SNR). As the SNR increases, it becomes proportionally difficult to comprehend the words of the speaker we are trying to pay attention to.

The neural tracking of “to-be-attended” and “to-be-ignored speech” has been quantified in electroencephalogram (EEG) studies which demonstrate that neural responses related to the to-be-attended speech increases when the signal-to-noise ratio is decreased (Das et al., 2018). When noise increases, the brain's neural responses decrease.

In addition to EEG studies, pupillometry (the measuring of the pupil dilation) has also been found to be a useful tool to measure listening effort, since pupil dilation reflects a person's arousal level, which has a direct correlation to speech comprehension.

Arousal is fundamental in regulating key aspects of human behavior, including our levels of attention, anxiety, stress, and motivation. Dampened arousal leads to fatigue and inattention, while heightened arousal can facilitate improved cognitive function and information processing.

An individual's baseline pupil dilation reflects typical state of arousal, while peak pupil dilation (PPD) has been shown to reflect peak listening effort (Ayasse & Wingfield, 2020). Research shows that peak pupil dilation is significantly lower in quiet conditions, indicating improved speech intelligibility. (Kramer et al., 2016).

Applying the established method of pupillometry testing, our study tested how passive damping technology affects speech perception and comprehension. The findings have been directly applied in the design of EPOS Enterprise and Gaming solutions in order to help EPOS users communicate better and improve their performance while minimizing fatigue and distraction.

Aim of the Study

This study aimed to examine the effect of passive damping technology (which is referred to as attenuation in the description of the study) on speech intelligibility and listening effort. In addition, we investigated if such effect may change after performing high cognitive demand tasks. Therefore, we measured speech intelligibility in noise and listening effort with and without passive damping technology activated before and after a cognitive load block. Both objective and subjective measures are used.

Materials and Methods

Participants

Nineteen Danish speakers (eight females and 11 males) who reported having normal hearing took part in the study. The average age was 36 years (range: 22-53, SD = 10). Participants were asked beforehand not to consume caffeine on the day of the test, since this can affect pupillary responses (Winn et al., 2018).

Setup

The test took place in a sound treated room. The light level was adjusted to 250 lux. The participants were seated in a chair and were instructed to fix their gaze on a focus point in front of them. The auditory stimuli was played through a pair of headphones. The pupillary responses were recorded using the iView X RED (Senso-Motoric Instruments) eye-tracker, which continuously tracks both eye and head movement via an infrared camera. The participants were equipped with a microphone with which they could communicate with the experimenter, who was seated in the test chamber outside the sound studio.

Test conditions

The study included two test conditions. In one condition, a filter was applied to attenuate the background noise. In the other condition, the background noise was not attenuated. Figure 1 shows the attenuation as a function of frequency (Hz).

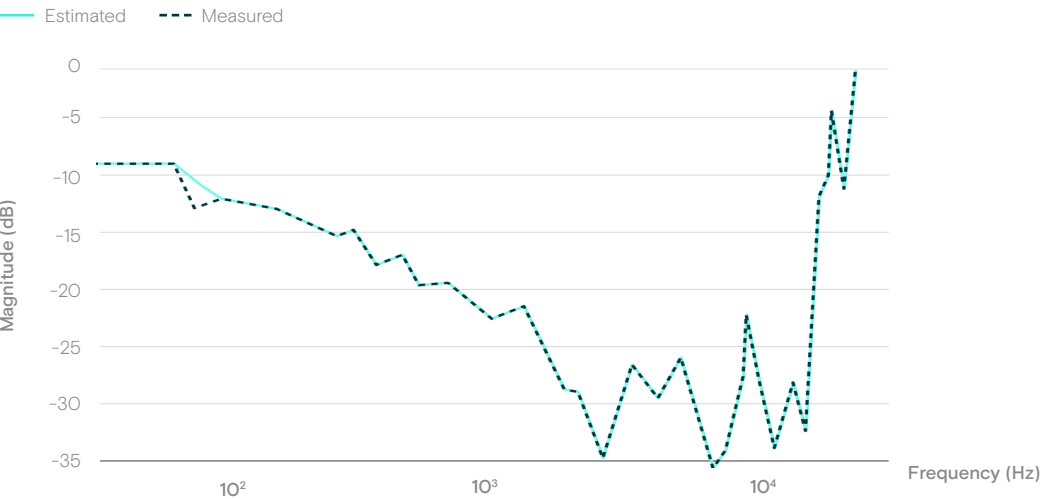


Figure 1: Illustration of the attenuation as a function of frequency (Hz)

Assessment Tools

Two measures were included in this study, the Dagmar-Asta-Tine (DAT) and the Sentence-final Word Identification and Recall (SWIR test).

1. Dagmar-Asta-Tine (DAT):

The participants’ task in this measure was to repeat two arbitrarily selected nouns within a series of sentences, each of which followed the same structure.

The DAT corpus consists of audio samples starting with either “Dagmar”, “Asta” or “Tine” (Bo Nielsen et al., 2014)1065–1066]. However, these studies typically result in very low (i.e., negative. In this study, only the samples starting with “Dagmar” were used. All sentences follow the same structure: “Dagmar thought of a/an ____ and a/an ____ yesterday (In Danish: “Dagmar tænkte på en/et____ og en/et____ i går”).

Two different mono-, bi- or tri- syllabic nouns are inserted in each sentence (e.g. station, plan). Each DAT list contains 20 sentences presented in a randomized order. The combination of the two words is always the same in a sentence.

The participants were instructed to indicate if they were not able to hear a target word. A sentence was scored as correct if both target words were accurately repeated. The final score indicates the percentage of correctly repeated sentences.

2. The Sentence-final Word Identification and Recall (SWIR) test:

The SWIR test (Ng et al., 2013) is an auditory recall test. The participants listened to lists of 7 sentences. The task is to repeat the last word after each sentence and when the list is done, cued by a beep tone, recall as many of the repeated words as possible, regardless of order and with no time limit. The participants are instructed to indicate when they cannot recall any more words. In this study, the SWIR test is considered as a cognitive load block, so that we can examine whether speech intelligibility performance and the effect of attenuation would differ before and after the load block. The details and results of the SWIR test are not reported in this whitepaper.

3. Pupillometry:

The pupil data was processed using MATLAB 2020b (MathWorks, Natick, MA). The first three trials from each DAT list were removed from the analysis. Data cleansing was then performed by initially detecting blinks as values three standard deviations below the trial mean. The data was interpolated 80 ms before and 150 ms after a detected blink, followed by a 5-point moving average filter to remove high frequency artifacts and smooth the signal.

Trials consisting of more than 20% interpolated or missing data were excluded from the analysis. Only one eye was used for further analysis, that being the eye with more valid trials or defaulting to the right eye. All remaining traces were corrected by subtracting the mean pupil size measured within 1s before the talker onset from each individual trace.

Two pupillary responses were extracted from the data: The peak pupil dilation (PPD) and the baseline pupil dilation (BPD). The BPD was calculated as the mean value within 1s prior to talker onset and was averaged within subject x condition x block combinations. The PPD dilation was calculate from an aggregated pupil trace of the individual traces within subject x condition x block combinations, as the maximum pupil dilation within a 5s interval from talker onset. The aggregated pupil traces for each condition x block are shown in Figure 2.

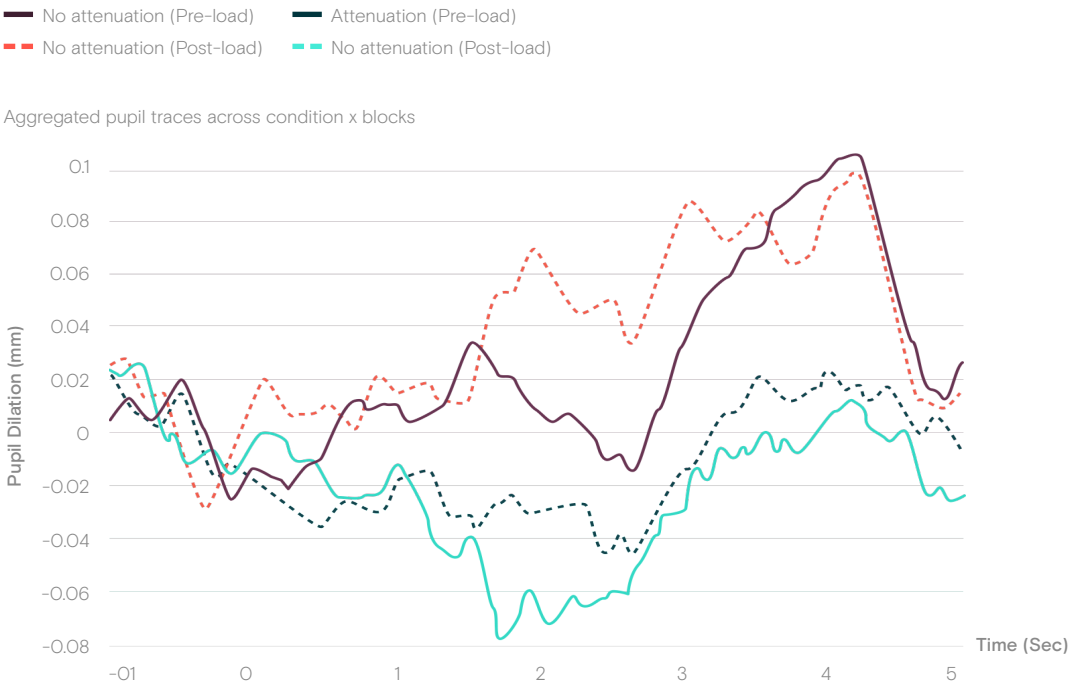


Figure 2: Pre- and post-load sequence aggregated baseline-corrected pupil traces.

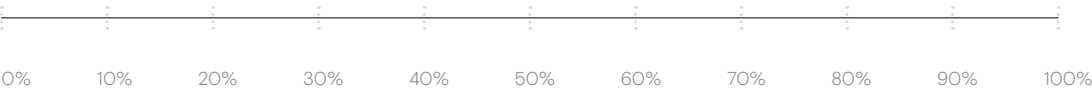
Stimuli

4. Subjective effort rating:

The subjective effort rating includes three questions (translated from Danish):

- How much effort did it require from you to hear the sentences?
- How many of the words do you think you understood correctly?
- How often did you give up understanding the sentence?

The answers are marked at any location of the following scale:



Background noise

The stimuli of the DAT test and the SWIR test were presented in a background noise of four-talker (4T) babble. The 4T babble is composed of recordings of two male and two female speakers reading different passages of a newspaper article. The level of the background noise remained fixed at 70 dB SPL for both tests.

1. DAT

Figure 3 illustrates the duration of a trial in the DAT, i.e. a sentence presented in background noise. The background noise started 3 seconds before the beginning of a sentence and ended 3 seconds after the sentence was finished. The DAT stimuli consist of recordings of a female speaker. The level of the sentences was individualized for each participant to yield an SNR level estimated to correspond to 80% speech intelligibility when no attenuation was applied (see procedure).

Representation of a DAT trial

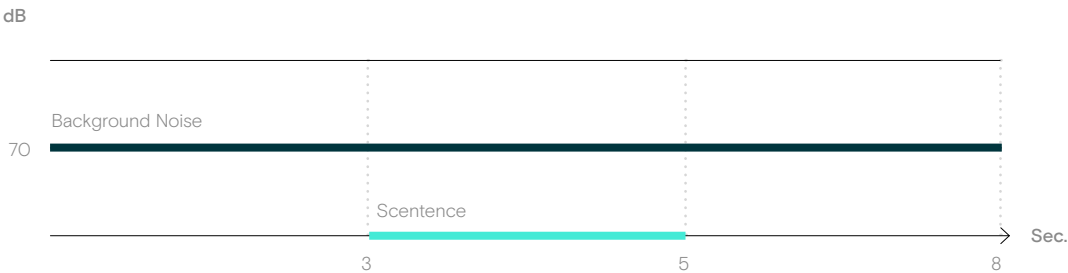


Figure 3: Representation of a DAT trial. The sound level is shown on the y-axis in decibel [dB] and time is shown on the x-axis in seconds [s].

2. SWIR test

The stimuli of the SWIR test consist of recordings of a male speaker. The level of the target talker was fixed to 71 dB SPL, resulting in an SNR of 1 dB when no attenuation was applied. The noise began 1s before the sentence onset, except for the very first sentence in a list, where the noise began 3s prior to the sentence onset. The noise continued for 1s after each sentence.

Test Procedure

The test procedure is described in the following section. Figure 4 illustrates the structure of the test session.

1. DAT training and SNR level estimation

Two DAT lists were administered without noise attenuation using a modified adaptive procedure in order to estimate the individual SNR level corresponding to 80% speech intelligibility. The SNR level was decreased by 0.8 dB after correct repetition of a sentence and increased by 3.2 dB after incorrect repetition of a sentence. The step size was double for the first five sentences in a list. The first list served as procedural training. The SNR level obtained after the second list was used for the remainder of the DAT.

2. Pre-load block

The pre-load block consisted of four DAT lists. Two consecutive lists were presented with noise attenuation and two consecutive lists without noise attenuation. The order of the test conditions was randomized and balanced across participants. After the two DAT lists presented in the same condition, the subjective rating questionnaire was administered.

3. Break

All participants were asked to take a break after the pre-load block. The remainder of the test session was conducted without breaks.

4. Load block

Seven SWIR test lists were administered in each condition (total = 14 lists). The condition order was randomized across participants.

5. Post-load block

Immediately after the load block, four DAT lists were administered. The condition order was the same as in the pre-load block for each participant and the subjective effort rating questionnaire was administered after each condition.

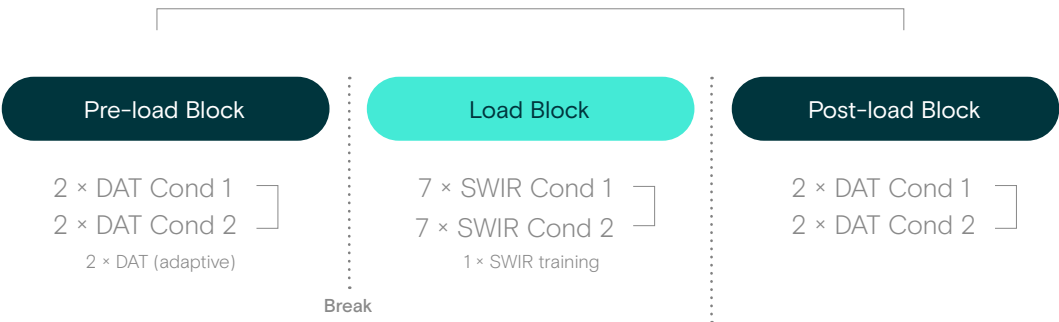


Figure 4: Illustration of the test procedure.

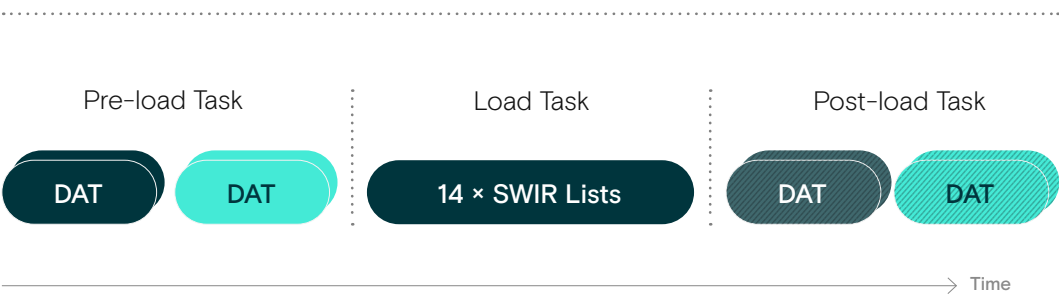


Figure 4: Illustration of the test procedure. The mint and petrol color represent the different noise attenuation test conditions.

Statistics

Linear mixed effects models (LME) were used for the statistical analysis with test condition and block as the fixed effects and test participants as the random effect. The model assumptions were not fulfilled for the data concerning speech recognition performance, as well as the second and third questions in the subjective effort ratings, so the non-parametric Friedman ANOVA was used in these cases only.

Results

Speech recognition

Table 1 shows the results of the DAT. The mean SNR at which the DAT was performed was -9.97 dB (SE = 0.36) in the condition in which no noise attenuation was applied. Friedman ANOVA indicated that there was a significant effect of test condition on speech recognition ($p < .05$). The post-hoc analysis showed that speech recognition was overall significantly better ($p < .001$) with attenuation (mean = 99.30%, SE = 0.03) compared to no attenuation (mean = 75.65%, SE = 2.60). However, there was no difference in speech recognition between blocks for either condition.

	Pre Load	Post Load
w/o Noise Attenuation	76.2% [±2.1]	75.1% [±3.1]
Noise Attenuation	99.2% [±0.3]	99.4% [±0.3]

Table 1: Results (mean and standard error, SE) of the DAT in the two test conditions in the pre- and post-load blocks.

Pupillary response during speech recognition

Figure 5 shows the difference in PPD between test conditions and blocks. The mean PPD was significantly larger ($p < .05$) when the background noise was not attenuated (mean = 0.193 mm, SE = 0.031) compared to when attenuation applied (mean = 0.116 mm, SE = 0.026). These results indicate that the listening effort is higher when background noise is not attenuated, regardless of block.

Figure 6 shows a comparison of the mean BPD between test conditions and blocks. There was a significant decrease ($p < .01$) from pre- (mean = 6.090 mm, SE = 0.261) to post-load block (mean = 5.891, SE = 0.239). Although there was no significant difference between test conditions, the BPD was higher in the pre-load block and the decrease was steeper when no attenuation was applied compared to when the background noise was attenuated. In general, this finding suggests that the arousal levels decreased after the load task.

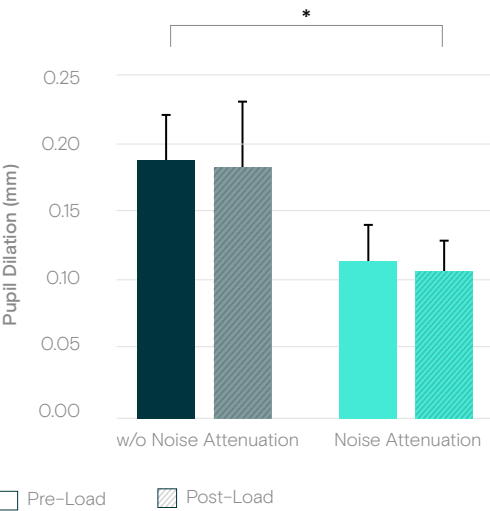


Figure 5: The average PPD in the pre- (plain column) and post-load (dashed column) blocks with (blue columns) and without (red columns) attenuated background noise. The error bars represent the standard error. * $< .05$

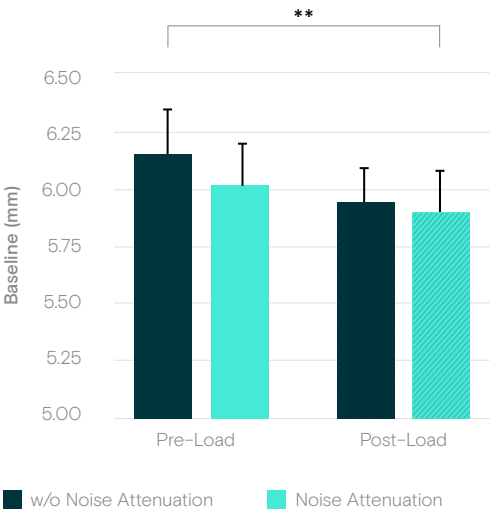


Figure 6: The mean BPD in the pre- and post-load blocks with (blue columns) and without (red columns) attenuated background noise. The error bars represent the standard error. ** $< .01$

Subjective ratings

The different panels of figure 7 show the outcomes of each question of the subjective effort rating. The statistical analysis showed that participants reported investing significantly less effort ($p < .001$) when attenuation was applied (mean = 21.70%, SE = 4.31) compared to when it was not (mean = 62.5%, SE = 3.77) regardless of the block. The order of the test conditions did not have any effect on the rating. Furthermore, the Friedman ANOVAs showed that there was a significant effect of test condition on perceived performance and tendency to quit ($p < .05$). The findings showed that the participants reported understanding significantly more words ($p < .001$) when the background noise

was attenuated (mean = 93.90%, SE = 1.38) compared to when it was not (mean = 73.67, SE = 3.34) regardless of block. The participants reported a significantly higher tendency to give up ($p < .001$) when background noise was not attenuated (mean = 17.79%, SE = 3.24) compared to when attenuation was applied (mean = 3.53%, SE = 1.22) regardless of block. It should be noted that one participant was excluded from the subjective ratings analyses, as they rated the tendency to quit much higher than the rest and was identified as an outlier.

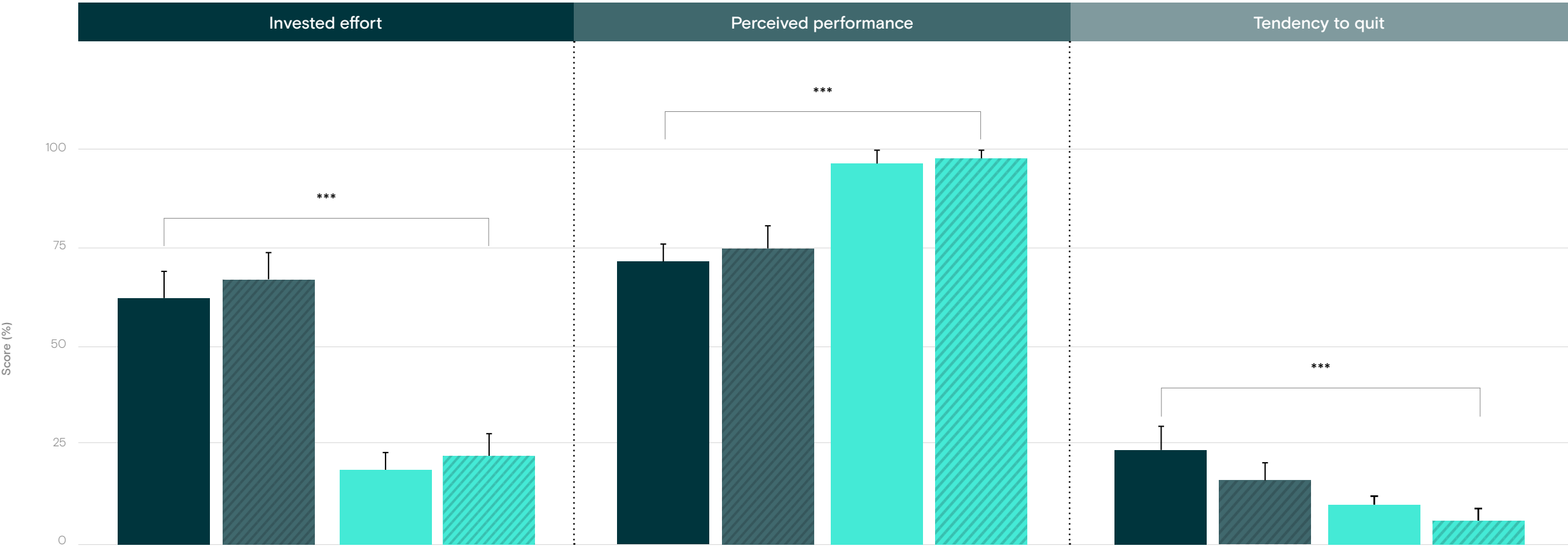


Figure 7: The subjective ratings between blocks and test conditions. The red columns represent the ratings without noise attenuation while the blue curves represent the ratings with noise attenuation. The plain columns represent the pre-load block and the dashed columns the post-load block. The error bars represent the standard error. *** < .001

Conclusions

The results confirm that passive noise damping has a quantifiably positive effect on speech intelligibility and required listening effort. The magnitude of this positive effect does not change after performing a cognitive demand task. We were also able to see what level of passive noise damping creates the optimal effect, supporting improved cognition and memory, while minimizing fatigue.

The task which tracked pupil dilation as a proxy for listening effort showed results that were consistent both subjectively and objectively. This means that the test subjects' own appraisal of their performance generally matched the results of the pupillometry.

The damping made a noticeable difference in the participants' performance. This reflected in the measurement of 35% less listening effort required by the test subjects when listening through the EPOS headsets.

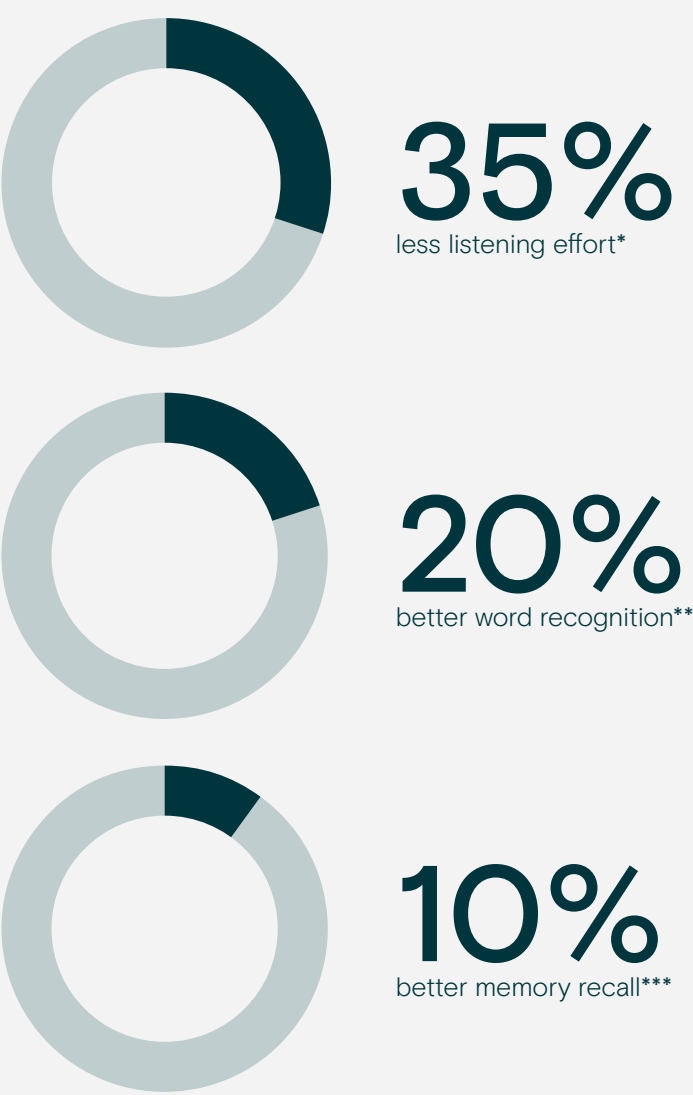
In the listening comprehension test, subjects were asked to listen to a set of speech material with varying levels of competing background noise. When listening through the EPOS headsets, the participants displayed levels of up to 20% higher word recognition, with an average of up to 10% better memory recall.

This study has been crucial in further optimizing the performance of EPOS headsets that built on EPOS BrainAdapt™ technology.

The results of this study have been presented and reviewed at scientific conferences including the International Hearing Aid Research Conference (IHCON) 2022, Lake Tahoe, USA and the International Conference on Cognitive Hearing Science for Communication, Linköping, Sweden.

To learn more about EPOS solutions and the science behind them, visit eposaudio.com/brainadapt

The Benefits of EPOS Noise Damping



* 35% less listening effort, as indicated by the subjective rating, and supported by the objective measure of pupillometry.
** 20% better word recognition, as indicated by both objective and subjective measures. This means in certain noisy listening situations, one may miss out every 5th word (on average), and passive damping technology can help avoid missing out
*** 10% better memory recall as indicated through the results of the SWIR test (The results will be reported in a separate whitepaper)

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