EPOS BrainAdapt™ A Dual Task Study

The effect of noise attenuation on listening effort, efficiency, and reaction time, while performing a dual task

Scientific Whitepaper
2023

The clinical study presented in this scientific whitepaper evaluated the potential benefits of noise attenuation in audio devices while people performed a dual task consisting of understanding speech while reacting as fast as possible to a visual task.

BrainAdapt™

Scientific Whitepaper EPOS

Introduction

People often perform more than one task at a time, without even realizing it. Many situations in everyday life involve understanding speech and, at the same time, solving a task visually. For example, in a professional context, one may need to listen to a colleague speaking while identifying information on a screen. Similarly at home, one may want to listen to someone talking while doing other tasks at the same time. Despite being common situations, performing more than one task at a time is often challenging, and one may need to prioritize one task over the other(s) to maintain a certain level of performance. This is because performing one or more tasks requires using cognitive capacity. Since cognitive capacity is a limited commodity, allocating additional resources to one task will reduce the resources available to perform the other tasks. Though we may not realize it, understanding speech when there is poor audio and noise requires additional cognitive resources. This, in turn, may limit the amount of cognitive resources that can be used to perform other tasks.

The study presented in this scientific whitepaper evaluated the potential benefits of noise attenuation in audio devices while people performed a dual task consisting of understanding speech while reacting as fast as possible to a visual task.

This type of in-depth scientific research has been a key element in the development of audio solutions built on EPOS BrainAdapt™ technology, which supports the brain's natural way of processing sound (Christiansen and Ng, 2022). The custom-made components, acoustics and sophisticated algorithms that go into EPOS solutions ensure optimized 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:

- IMPACT 1060 ANC
- IMPACT 1060T ANC
- IMPACT 1061 ANC
- IMPACT 1061T ANC
- ADAPT 600 Series
- GTW 270 Hybrid
- H3PRO Hybrid
- H6PRO Closed

Scientific Background

In a dual task paradigm, two tasks (a primary and a secondary one) are performed alone and simultaneously. Each individual has a certain amount of cognitive resources available. If the total resources required to perform both tasks exceed the maximum resources available, the participant will need to prioritize the primary task and a decrease in performance will be observed on the secondary task.

This decrease in performance on the dual task relative to the task performed in isolation is used to index the cost of performing two tasks simultaneously. This difference in performance can be considered an indirect estimate of listening effort (Gagné et al., 2017).

Using a dual task paradigm, consisting of a speech recognition task and a visual reaction time task, Sarampalis et al. (2009) demonstrated that listeners with normal hearing reacted faster in the visual reaction time task when noise attenuation was activated, compared to when it was not. This finding suggests that noise attenuation frees up cognitive resources that would otherwise have been needed for recognizing speech, to be used for other tasks (i.e., to react faster in the visual task). In other words, noise attenuation decreases listening effort (Ng et al., 2013, 2015; Sarampalis et al., 2009).

In the study presented here, we expand on the findings by Sarampalis et al. (2009), by combining the dual task paradigm with subjective ratings of listening effort and pupillometry. Pupillary responses measured during a speech recognition task have been shown in previous studies to be a physiological indicator of listening effort (Ohlenforst et al., 2018; Wendt et al., 2017). In this study, pupil dilation is measured during the dual task; hence, it reflects the cognitive resources overall allocated to perform a speech recognition task as well as a visual reaction time task.

Aim of the Study

The aim of the study was to evaluate the potential benefits of noise attenuation on reaction time (RT), accuracy, speech-in-noise recognition, listening effort, and overall cognitive resource allocation during a dual task, consisting of a primary auditory task and a secondary visual task (Bianchi et al., 2023).

Materials and Methods

Participants
Twenty-six participants (15 males; 11 females) with self-reported normal hearing were included in this study. The mean age of the participants was 35 years (range: 23-51 years, SD = 9.2 years).

Assessment Tools
Three measures were included in the current study: the dual task, the subjective listening effort rating and pupillometry.

1. Dual Task

   a. **Primary speech-in-noise recognition task**
   Target sentences (Danish Hearing in Noise Test, HINT; Nielsen & Dau, 2011) were presented in a background noise composed of four-talker (4T) babble. The HINT sentences have a duration of approximately 1.5 seconds (s) and consist of recordings of a male speaker, while the 4T babble consists of recordings of two female and two male speakers reading different newspaper passages. The 4T babble started 3 s prior to a sentence and continued for 3 s after the sentence. The task was to verbally repeat the target sentences as accurately as possible after the offset of the 4T babble.

b. Secondary visual reaction time task
Concomitantly with target sentence onset, a digit between 1 and 8 appeared on a screen, either on the right- or left-hand side of the screen. The task was to press the arrow key on a keyboard as fast as possible towards the digit if it was an even number, and away from the digit if it was an odd number. Hence, the correct arrow key depended on both the digit appearing on the screen (i.e., even vs. odd) and the positioning of the digit on the screen (i.e., right vs left). The participant had to press the arrow key as fast as possible and before the end of 4T babble. Figure 1 shows an illustration of one trial of the dual task.

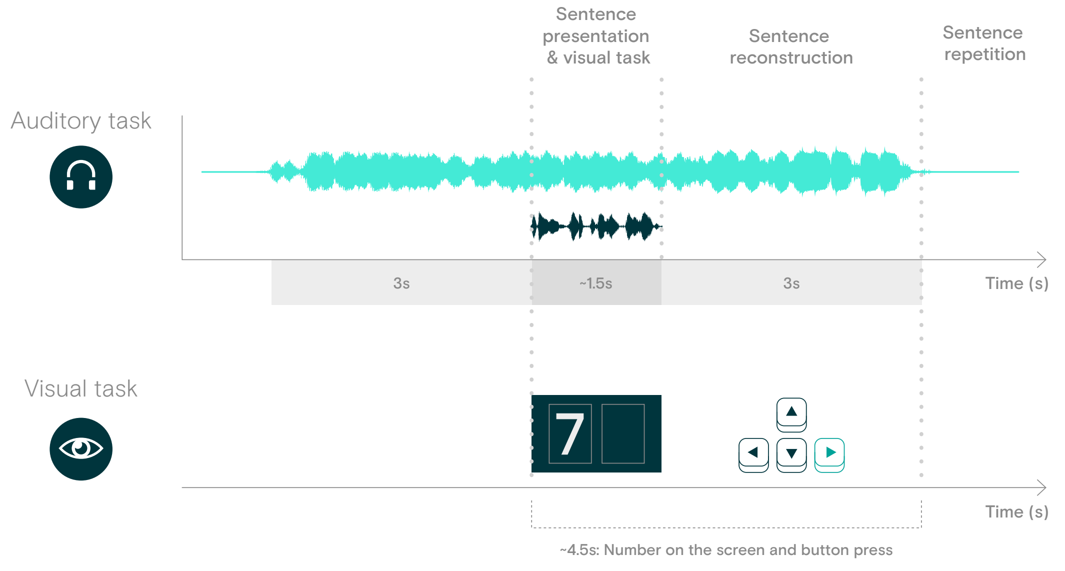


Figure 1: Illustration of the structure and timing of one dual task trial.

2. Subjective Listening Effort Rating

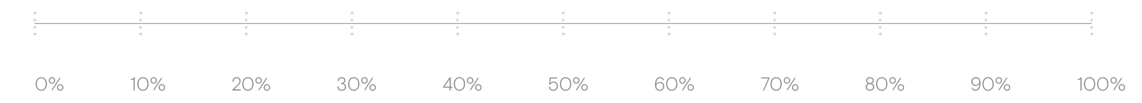
The subjective listening effort rating consisted of three questions that the participants filled out after each condition of the dual task (see Figure 3). The three questions were related to invested listening effort, self-perceived performance in speech recognition, and tendency to give-up understanding:

1) How much effort did it require from you to hear the sentences?

2) How many of the words do you think you understood correctly?

3) How often did you give up understanding the sentence?

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



3. Pupillometry

Pupil dilation was measured while the participants performed the dual task, as well as during the visual task performed in isolation pre- and post-test (see test procedure and Figure 3). Pupillary responses have been found to be a sensitive measure to capture changes in listening effort measured during speech-in-noise paradigms (Ohlenforst et al., 2018; Wendt et al., 2017), as well as a physiological marker for visual target detection (Privitera et al., 2010).

Experiment Set-up

The participants were seated in a sound treated room and were instructed to fixate their gaze on a focus point in front of them. The HINT sentences and the 4T babble were played through a pair of headphones. The digits were presented on a screen mounted on a wall in front of the participants. The keyboard was placed in front of the participant. 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. Figure 2 shows the experimental set-up.

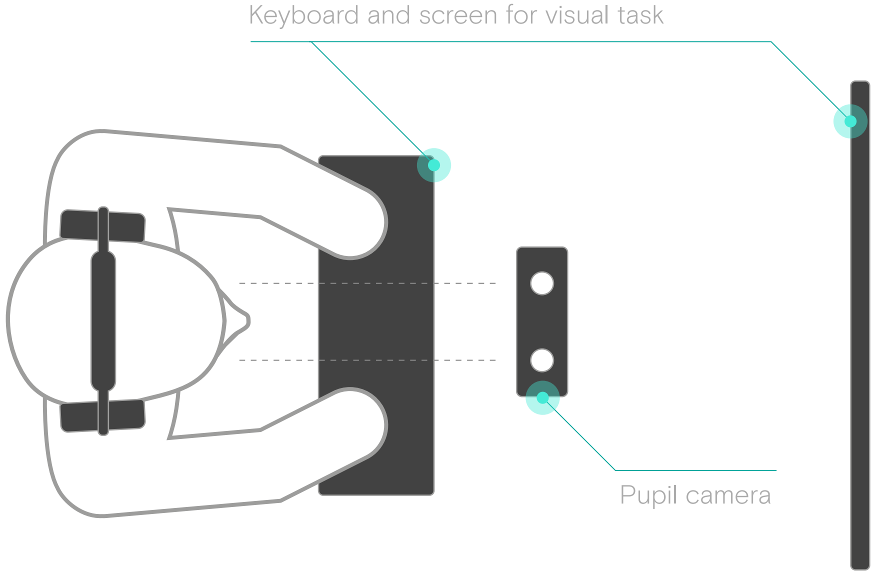


Figure 2: Illustration of the experimental set-up.

Test Conditions

The HINT sentences were presented at two speech levels, 60 dB SPL and 64 dB SPL. Two noise conditions were tested: unprocessed 4T babble presented at 70 dB SPL (No Attenuation condition), resulting in signal-to-noise ratios (SNRs) of -10 dB and -6 dB, and 4T babble pre-processed with passive damping (Attenuation condition).

Test Procedure

The test session started with training on the visual task only, which consisted of 25 trials. This was followed by a training on the dual task with unprocessed noise, which consisted of two lists of 25 HINT sentences (i.e., 50 trials in total).

After training, 25 trials of the secondary visual task were performed as a baseline condition (visual pre-test). This was followed by the dual task, which consisted of 50 trials for each of the four tested conditions (two speech levels and two noise attenuation conditions). The noise attenuation conditions were presented in a blocked design: all trials with noise attenuation in one block and all trials without noise attenuation noise in another block. Half of the participants started with the block with noise attenuation, and half of the participants started with the block without noise attenuation. The order of the speech levels was randomized within each block. After each condition of the dual task, the participants filled out the subjective rating of effort. After the dual task, another 25 trials of the secondary visual task were performed (visual post-test). Figure 3 illustrates the test procedure.

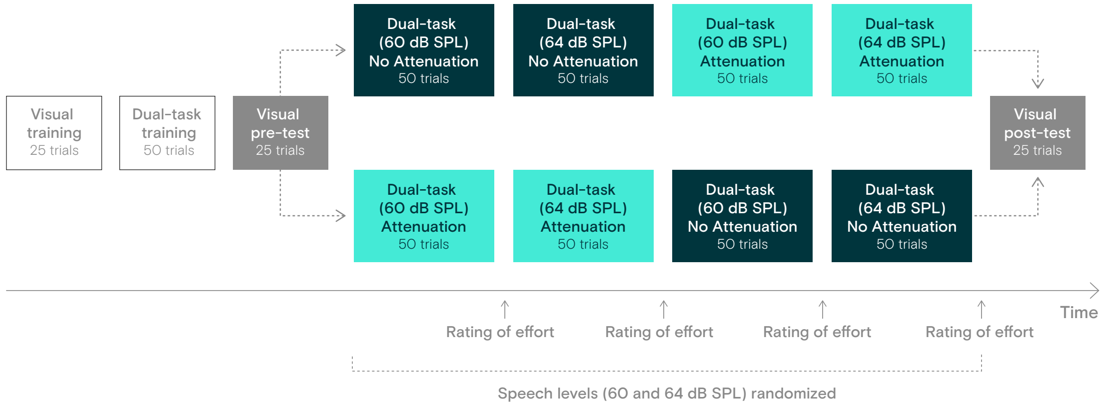


Figure 3: Illustration of the test procedure.

Statistical Analysis

The models Linear mixed effects models were used for the statistical analyses. The models contained speech level and noise attenuation condition as fixed effects and test participant (N = 26) as the random effect. One model was built for each of the outcomes of interest: speech recognition performance, accuracy, reaction time, efficiency, as well as for each question of the subjective listening effort rating. Pupillary responses were analyzed using temporal Bayesian analysis of pupil responses (Hershman et al. 2022). Note that the pupil data were analyzed for 25 participants as a technical error occurred during the measurement of the last participant and no pupil data was saved.

Results

Speech-in-noise Recognition
Table 1 and Figure 4 show the mean speech-in-noise recognition performance for each speech level and noise attenuation condition. In the No Attenuation condition, the mean speech recognition performance was of 51.6% when the speech level was 60 dB SPL (SNR = -10 dB) and 84.4 % when the speech level was 64 dB SPL (SNR = -6 dB). The percentage refers to how many words the participants could repeat correctly out of the all the sentences played for that condition. In the Attenuation condition, speech recognition performance increased significantly ($p < 0.0001$) up to 99.8% and 99.9%, for speech levels of 60 and 64 dB SPL, respectively. In other words, applying noise attenuation led to a significant improvement in speech recognition, on average, up to 48.2 percentage points (99.8% - 51.6%).

	Speech level = 60 dB SPL	Speech level = 64 dB SPL
No Attenuation	51.6% [SD = ±10.8]	84.4% [SD = ±8.5]
Attenuation	99.8% [SD = ±0.1]	99.9% [SD = ±0.6]

Table 1: Mean speech-in-noise recognition performance in percentage at each speech level and in each noise attenuation condition. The standard deviations are indicated in brackets.

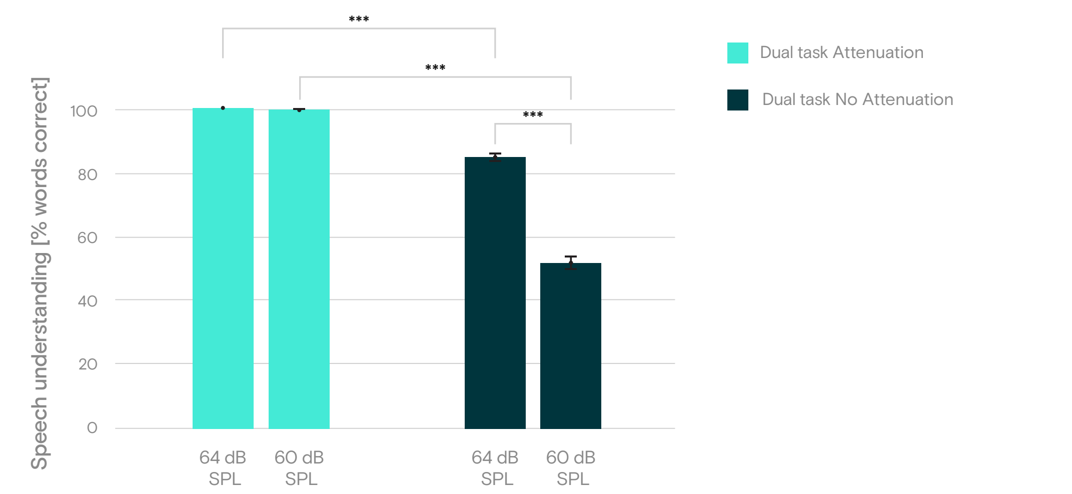


Figure 4: Mean speech-in-noise recognition performance for each test condition of the dual task. Error bars indicate the standard error of the mean. The asterisks indicate a significant difference between conditions (*** $p < 0.0001$).

Reaction Time
Figure 5 shows the mean reaction time for each test condition of the dual task, as well as during the visual task performed in isolation pre- and post-test as baseline condition. When performing the visual task alone, participants pressed the arrow key, on average, 710 ms after the visual stimulus presentation, with no significant difference between pre- and post-test conditions. When adding the speech recognition task to the visual task, reaction time was significantly higher ($p = 0.0001$) for the No Attenuation condition (on average, 900 ms and 1000 ms, at 64 and 60 dB SPL, respectively).

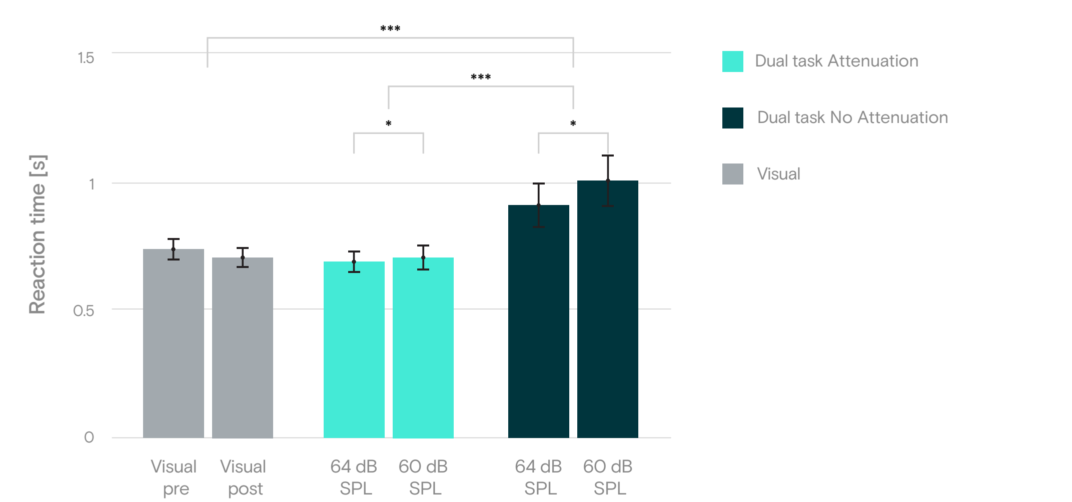


Figure 5: Mean reaction time for each test condition of the dual task, as well as during the visual task performed in isolation pre- and post-test as baseline condition. Error bars indicate the standard error of the mean. The asterisks indicate a significant difference between conditions (*** $p <= 0.0001$; * $p < 0.05$).

This finding indicates that additional cognitive resources needed to be diverted from the reaction time task (leading to a longer reaction time) to understand the sentence for the No Attenuation condition. In the Attenuation condition, reaction time was, on average, 680 ms and 700 ms, at 64 and 60 dB SPL, respectively, which was significantly lower ($p < 0.0001$) relative to the reaction time in the No Attenuation condition, while it did not significantly differ to the reaction time in the visual only task.

In other words, when the background noise was attenuated, there were enough cognitive resources available to perform both tasks at a very high level of performance (speech recognition almost at 100% and similar reaction time as in the visual only task). Hence, in the Attenuation condition, there was no "cost" of performing dual task, because performance did not decrease relative to the visual task performed in isolation.

In conclusion, applying noise attenuation led to significantly faster reaction time (i.e., the arrow key was pressed significantly faster), on average, up to 23.9% (300 ms) relative to No Attenuation.

Accuracy

Accuracy on the visual task (i.e., pressing the correct arrow key) was very high for all conditions, ranging from 97.2% when the visual task was performed in isolation to 98.4% when the visual task was performed within the dual task (both in the Attenuation and No Attenuation conditions).

Since there was no difference in accuracy between Attenuation and No Attenuation conditions, one can conclude that applying noise attenuation led to faster reaction times without any compromise on accuracy.

Efficiency

Reaction time and accuracy were also combined in one unique measure of efficiency, which was calculated as the inverse of the Inverse Efficiency Score (IES; see Bruyer and Brysbaert, 2011). For each participant and condition, the mean button press accuracy was divided by the mean reaction time of the correct responses. On average, noise attenuation increased efficiency up to 40.6% relative to the No Attenuation condition ($p < 0.0001$).

$$\text{Efficiency} = \frac{1}{\text{IES}} = \frac{\text{Button press accuracy}}{\text{Reaction time of correct responses}}$$

Subjective listening effort rating

The outcomes of the subjective listening effort rating are presented in figure 6. The outcomes show that invested listening effort (on average, 17.6% and 19.0% in the Attenuation condition, 71.4% and 86.5% in the No Attenuation condition, at speech levels of 64 and 60 dB SPL, respectively) and tendency to give up (on average, 1.4% and 1.1% in the Attenuation condition, 23.7% and 54.5% in the No Attenuation condition, at speech levels of 64 and 60 dB SPL, respectively) were significantly lower with attenuation than without ($p < 0.0001$). Hence, applying noise attenuation led to a significant decrease in perceived listening effort, on average, up to 67.5 percentage points relative to No Attenuation (86.5% - 19.0%).

Additionally, the perceived performance was significantly higher ($p < 0.0001$) in the Attenuation condition (on average, 97.1% and 97.8%, at speech levels of 64 and 60 dB SPL, respectively) than for the No Attenuation condition (on average, 65.6% and 39.3%, at speech levels of 64 and 60 dB SPL, respectively).

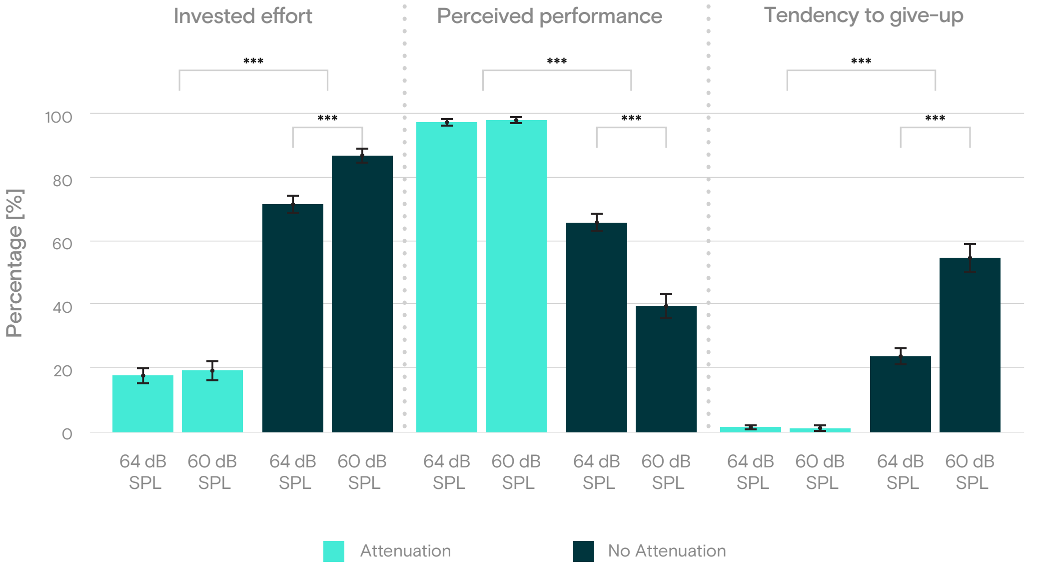


Figure 6: Mean subjective effort ratings for each question in each test condition. Error bars indicate the standard error of the mean. The asterisks indicate a significant difference between conditions (*** $p < 0.0001$).

Pupillometry

Figure 7 shows the mean pupil curves for the Attenuation (mint curve) and No Attenuation (petrol curve) conditions of the dual task, as well as for the visual task performed in isolation (gray curve). The horizontal bars indicate what conditions are significantly different for each time sample.

The curves for the dual task show a larger pupil dilation than for the visual task within the dual task window, indicating the extra cost of adding a listening task to the visual task. Specifically, for the No Attenuation condition, the extra effort for listening to the sentence in noise is allocated immediately because it is important to understand the first part of the sentence. The visual task is then performed afterwards (average button press between 0.9 and 1 s). However, for the Attenuation condition, the background noise is low, and the sentence can be easily understood. Hence, the participants can perform the visual task immediately (average button press around 0.7 s) and process the sentence afterwards.

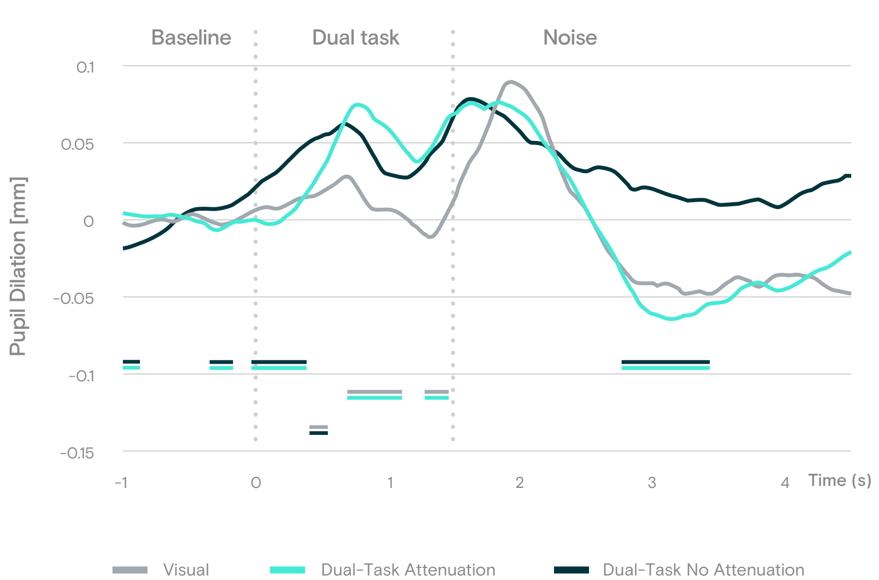


Figure 7: Mean pupil curves as a function of time. Time zero indicates the onset of the visual task as well as the start of the sentence ("Dual task window" for the Attenuation and No Attenuation conditions). After 1.5 s the sentence stops while the noise continues for 3 additional seconds (until 4.5 s). Between 1.5 s and 4.5 s ("Noise window") the participant needs to prepare for repeating the sentence back after 4.5 s. The Attenuation and No Attenuation curves are averaged across the two speech levels, and the Visual curve is averaged across pre- and post-conditions. The horizontal bars indicate what conditions are significantly different for each time sample.

Finally, a large difference in pupil dilation can be observed in the "Noise window", i.e., when the participants need to keep the sentence in working memory, rehearse it, and possibly reconstruct those words that were not heard, in order to repeat as many words as possible after 4.5 s. The pupil dilation in this time window is an indicator of how many cognitive resources are needed to prepare the response. The results show a rapid release of effort for the Attenuation condition and for the Visual condition (i.e., the pupil quickly drops below zero), suggesting that the sentence was fully understood and there was no need to allocate resources to reconstruct it. However, a significantly larger pupil dilation was observed for the No Attenuation condition, indicating that extra cognitive resources needed to be allocated for sentence reconstruction when the noise was not attenuated.

Hence, when the background noise was high (No Attenuation condition), not only extra cognitive resources needed to be allocated immediately for understanding the speech signal, thereby delaying reaction time to the visual task, but also a more sustained use of cognitive resources was needed afterwards to reconstruct the sentence (see illustration in Figure 8).

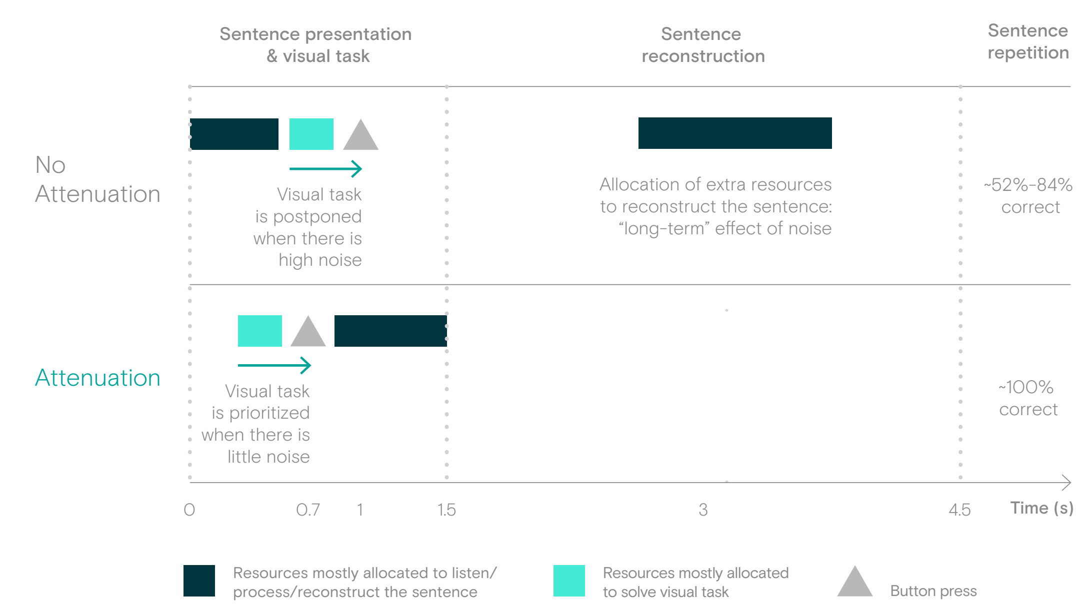


Figure 8: Illustration of cognitive resource allocation during the dual task.

Conclusions

The results of this study indicate that noise attenuation provides several benefits for participants with normal hearing when performing a dual task is required.

When noise was attenuated during a dual task, speech-in-noise recognition improved up to 48.2 percentage points and reaction time on the visual task improved up to 23.9% (i.e., the key was pressed 300 ms faster) without compromising accuracy, leading to an increase in efficiency up to 40.6%.

Additionally, applying noise attenuation led to a significant decrease in perceived listening effort, on average, up to 67.5 percentage points relative to No Attenuation, as reflected by the subjective listening effort ratings.

The pupil dilation results showed that when noise was not attenuated, extra cognitive resources needed to be allocated immediately for understanding speech, thereby delaying reaction time to the visual task. Attenuating the noise led to a significantly lower pupil dilation while listening to the beginning of the sentence (i.e., significantly reduced listening effort). Freeing up cognitive resources allowed the participants to quickly and accurately perform the visual reaction time task. Pupillometry results also indicated that after listening to the sentence, there was a rapid release of effort in the Attenuation condition, while pupil dilation was significantly higher for the No Attenuation condition, indicating that there was a longer and more sustained allocation of cognitive resources to reconstruct the sentence and prepare a response with no attenuation.

These findings demonstrate that noise attenuation reduces listening effort when individuals with normal hearing are required to understand speech in background noise. This, in turn, frees up cognitive resources that would have been needed for understanding speech in background noise to be used for other tasks (e.g., the visual reaction time task).

This study is just one example of decades of psychoacoustic research conducted by the Demant Group, of which EPOS is proud to be a part. The learnings collected in this study and others, including a recent study of the benefits of noise dampening, are applied in ongoing development of EPOS BrainAdapt™ solutions, which are designed to support the brain's natural way of processing sound.

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

The Benefits of EPOS Noise Attenuation

48%

better recognition of speech-in-noise*

People can understand speech better when the noise is attenuated.

67%

reduction of listening effort**

Users spend less effort listening, and therefore, have more available cognitive capacity for other tasks.

40%

increase in efficiency***

Noise attenuation increases efficiency by improving reaction time without loss of precision.

23%

improved reaction time****

With less energy spent listening, users can act faster.

*48% better recognition of speech-in-noise as indicated by percentage of correctly repeated words.
**Up to 67% reduction of listening effort, on average, as reflected by the subjective listening effort ratings.
***Up to 40% increase in efficiency, as reflected by the ratio between accuracy and reaction time for the correct responses.
****Up to 300 ms faster reaction to a visual-cognitive task without loss of precision.

Implications for gamers
Gaming requires people to perform several tasks simultaneously, such as communicating with team members while solving challenging visual and motoric tasks, as accurately and quickly as possible. Communicating with a team member in noisy environments increases listening effort, which may result in fewer available cognitive resources to be allocated to the actions required in the game.

This can slow down and impair the gaming performance. This effect is illustrated in section A of Figure 9 (adapted from Lunner et al., 2009). An effective noise attenuation system is able to reduce the cognitive resources used for listening – hence, allowing the gamer to both communicate with team members and gaming without experiencing a dual task cost.

Implications for business professionals
In calls and hybrid meetings, business professionals often need to listen to a colleague speaking while reviewing and processing information being presented on a screen.

Noisy environments, such as open offices, make it harder for the brain to perform simultaneous audio and visual tasks. This reduces call efficiency and productivity as people have a lower cognitive capacity to both communicate and solve tasks at the same time.

Advanced noise attenuation technology effectively blocks out disturbing noise, allowing people to listen, process information, and efficiently perform tasks, enabling professionals to make the most of their workday.

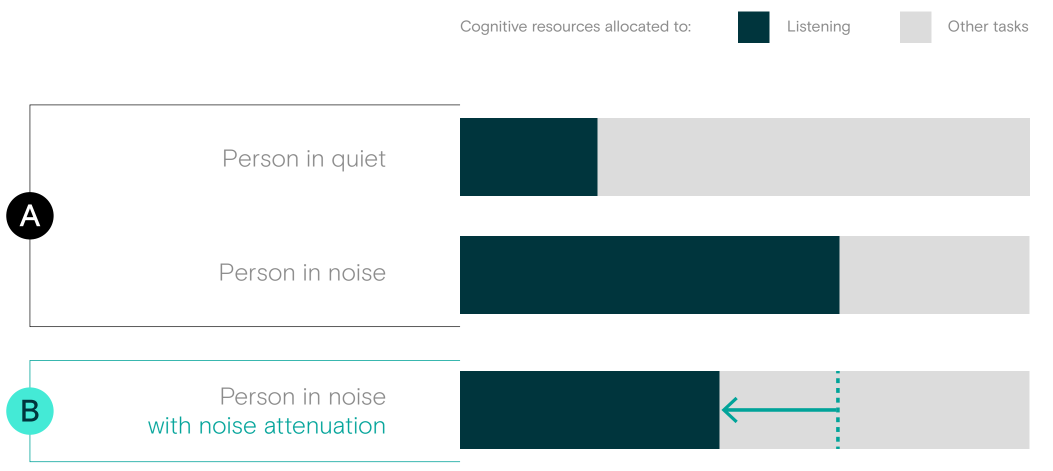


Figure 9: Section A in the above chart shows the tradeoff between resources allocated for listening and for other tasks, depending on what type of sound environment the person is in. In a very noisy environment, a person spends more listening effort, resulting in less cognitive resources that can be used on other tasks. Section B in the chart shows that noise attenuation decreases listening effort – hence, freeing up cognitive resources for other tasks.

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