EPOS

EPOS BrainAdapt™

The Effects of Industry-leading Voice Pick-up on Conversation Quality and Efficiency

Scientific Whitepaper
2024

The study presented in this scientific whitepaper evaluated the impact of microphone voice pick-up technology with noise reduction. The research analyzed the potential benefits for listening effort, concentration difficulty, and conversation efficiency between users engaging in virtual calls via a Unified Communications Platform when background noise is reduced.

BrainAdapt™

Introduction

In today's workplace, professionals are using digital tools and platforms to communicate, share, and co-create with colleagues, clients, and partners. The modern workforce is reliant on these digital tools and platforms to enable successful communication, including clear calls where both sides of the conversation can be heard. Although video collaboration tools have gained popularity quickly, audio is and will always be the most important tool for successful verbal communication. The purpose of this study is to understand the impact of background noise on a conversation through a Unified Communications Platform and whether headsets with noise-reduction microphone technology provide benefits to the speakers.

For people working in noisy environments, like the open office, noise in the background can be sent through to the receiver, making it difficult for both speakers to have a clear, natural, and efficient conversation. Though people may not realize or think about it while on calls, understanding speech in noise requires additional cognitive effort. This, in turn, limits the amount of cognitive resources that can be used to listen, process, and have an efficient conversation.

The study presented in this scientific whitepaper evaluated the quality of conversation dynamics (how the study participants interacted) while collaborating on a shared task via a Unified Communications Platform, as well as study participants' subjective experiences (listening effort and concentration difficulty). Working in pairs, the study participants sat in two separate rooms and were each given a picture. Study participants each wore an IMPACT 1000 headset and joined a Microsoft Teams call. The task for the pair was to identify how their pictures differed from each other's. The pairs performed the same task in both quiet and noisy environments and with the microphone noise reduction both on and off.

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, Bianchi and Christiansen, 2023, Jonsson, Larsen, Christiansen, Ng, Micula, 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, 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 and 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 1000 Series
- IMPACT 800 Series
- IMPACT 700 Series

Scientific Background

An important aspect of having a conversation with another person is the ability to switch turns between one another. This skill is developed early in life and is a central part in developing social skills. Nowadays, conversations are not only taken face to face but also through communication devices (i.e. telephone, video conference). When the conversation is being held through a communication device, additional aspects such as the system's delay or the noise captured by the respective microphones can negatively affect the communication success (Tomprou et al., 2021) and increase listening effort (Wells, 2018).

In those cases where there is surrounding noise and the individuals are not in the same room, a noise suppression system in the voice pick-up can be a good solution to improve the conversation dynamics. To estimate communication success objectively, previous studies have often looked at the duration of different events in the turn-taking, such as pauses, gaps, or turns.

Conversational dynamics have been investigated in several previous studies, either for face-to-face conversations (e.g., Petersen et al., 2022) or for conversations from different rooms (e.g., Sørensen, 2021a). The typical response time (i.e. gaps between the turns of the individuals) for adults is around 250 ms with some variation around this average (Heldner and Edlund, 2010; Levinson and Torreira, 2015; Stivers et al., 2009). Extended response times are commonly associated with misunderstandings or negative responses to invitations (Bögels et al., 2015; Kendrick and Torreira, 2015).

Additionally, it has been suggested that extended gaps can be indicative of difficulty in holding the conversation (Mertens and Ruiter, 2021). Furthermore, an excessive cognitive load is also associated with longer duration of utterances or interpausal units (IPU) (see Figure 1 for illustration). This was previously shown in the studies of Beechy et al. (2018) and Sørensen et al. (2021), where the study participants were tested in challenging conditions. If the IPUs of a speaker are longer, this can be indicative of not having sufficient time to plan their turn. Therefore, the reason for speaking with longer IPUs can be attributed to an increased working memory load because they continue planning their turn while already speaking.

Figure 1 shows an example of the turn-taking behavior and the classifications of the different parameters (turns, IPUs, gaps, pauses and overlaps) in a conversation. The upper panel shows normal temporal dynamics in a conversation, while the bottom panel shows a sketch of the turn-taking in a more difficult situation, which is mainly indicated by longer utterances and longer gaps between turns.

In the current study, the goal is to evaluate the effect of noise reduction (specifically, the effect of de-noising the input signal) on conversational dynamics. The question we aim to answer is: Does a "cleaner" input signal lead to socially appropriate conversational dynamics and more efficient communication?

Research Question

Does a "cleaner" input signal lead to socially appropriate conversational dynamics and more efficient communication?

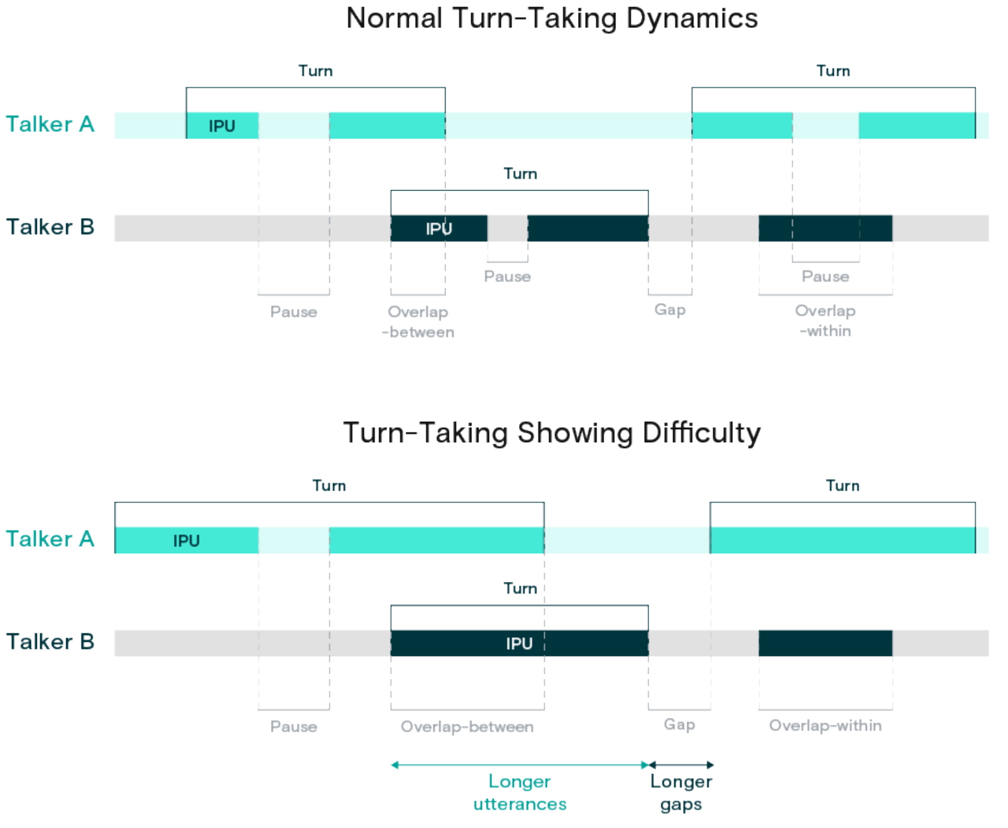

Figure 1: Illustration of the classification of gaps, overlaps-within, overlaps-between, pauses, interpausal units (IPU or utterances), and turns during conversations between Talker A and B. A person's turn is measured from the onset of the IPU following a floor transfer to the offset of the IPU followed by a floor transfer. There are two floor-transfer offsets (FTOs): the overlap-between and gap. Illustration inspired by Sørensen et al. (2021).

Aim of the Study

The primary objective of this study was to explore the impact of noise reduction technology, specifically designed to enhance voice pick-up, on the dynamics of conversation and the listening effort required for communication during a collaborative task. This involved assessing how this feature influences the flow of conversation, the ease of turn-taking, and the overall self-perception of the clarity of communication. Additionally, the study aimed to understand whether the use of this noise reduction feature reduces the cognitive load on the study participants, thereby making the collaborative task more efficient and less strenuous.

Materials and Methods

Study Participants
Forty native-Danish speakers (14 females and 26 males) participated in the study divided in a total of 20 pairs. The study participants reported not having any hearing or cognitive impairment. The average age was 39 years (range 21-55, SD = 10).

Assessment Tools
The benefits of the voice pick-up noise suppression technology were assessed using subjective and objective measures. For this study we used Diapix (van Engen et al., 2010, Baker and Hazan, 2011), which is a game-like 'spot the difference' picture task used for facilitating spontaneous speech interactions between two study participants. Study participants have to identify 12 differences between their two pictures while not being able to see their partner's picture (University College London, 2023).

1. **Questionnaires: subjective ratings**
   A questionnaire was filled out by the study participants after each experimental run. The questionnaire consisted of seven questions. For each question the study participants answered using a visual-analog scale from 0 to 100% that contained statements at different percentage points. The questionnaire includes the following questions on listening effort (questions 1-4) and conversation effort (questions 5-7) (translated from Danish):

   1. How much effort did it require from you to hear your partner?
   2. Did you have to concentrate a lot when you were listening to your partner?
   3. How often did you give up because you did not understand your partner?
   4. How much effort did it require from you to communicate with your partner?
   5. How disturbing was the background noise from your partner's room when you were talking together?
   6. How successful do you rate your communication with your partner?
   7. How satisfied are you with the overall communication experience?

2. **Diapix task: measures of conversational dynamics**

In analyzing the conversational dynamics, we examined the percentage of correctly identified differences that pairs reached in each condition after 3.5 minutes. We also considered the time it took study participants to find the first five differences. Additionally, we employed an offline voice activity algorithm to detect speech in the conversation. This allowed us to measure various parameters, such as the Floor-Transfer Offset (FTO), which is the time between overlaps and gaps in speaker turns, and the Inter-Pausal Unit (IPU), defined as continuous speech surrounded by a certain amount of silence as part of a turn (see Figure 1 for illustration).

Experimental Setup
Figure 2 illustrates the experimental setup. The experiment took place in two separate rooms, each of them with an identical set-up. However, the dimensions of the two rooms were different. One room was 5.8 x 3.75 m, and the other was a big open office where the setup was in one quadrant of the office.

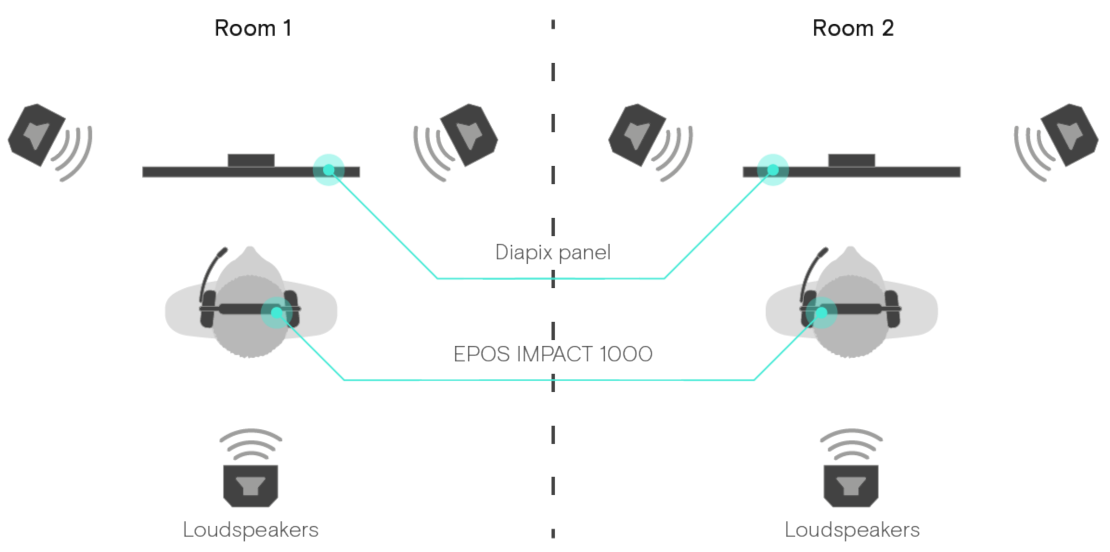

Figure 2: Experimental Setup (this is a conceptual drawing of the setup) The study participants are seated in front of the Diapix panel (1) in two separated rooms with an identical loudspeaker array configuration (2). Each speaker is wearing an EPOS IMPACT 1000 headset (3) together with a reference microphone.

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The test study participants were seated on a comfortable chair at the center of a spatial loudspeaker setup consisting of three loudspeakers: one located in the back (180°) and the other two located at ±80°. The loudspeakers were placed 1 m from the head of the study participant. The Diapix pictures were placed on the study participants lap on a laminated plastic tabloid.

In the current study, the two study participants had to converse through Microsoft Teams (audio only) while wearing IMPACT 1000 Series headsets. Importantly, all the noise reduction features of Microsoft Teams were deactivated. Besides the headset, the study participants wore a reference microphone (on the opposite side relative to the IMPACT 1000 microphone) to record the study participant's voice. This was done to capture the speech signal directly from each of the participants separately, rather than from the transmission line (i.e., Microsoft Teams).

Test conditions

In total, the test included four experimental conditions. These consisted of two acoustic scenarios (Quiet and Noise) and two noise reduction (NR) configurations (ON and OFF). The Quiet condition served as a reference condition because no difference was anticipated to occur between noise reduction ON and OFF in the absence of background noise. Each condition was repeated two times, and the duration of the task was limited to 3.5 minutes for all four conditions.

In contrast, the Noise acoustic scene consisted of 2 talkers presented via two loudspeakers positioned at ±80°. Each talker was presented at 65 dB SPL, resulting in an overall level of 68 dB SPL. Additionally, ICRA7 noise (Dreschler et al., 2001) emitted from all three loudspeakers positioned at 180°, ±80° each at a level of 55 dB SPL. The ICRA7, developed by the International Collegium of Rehabilitative Audiology, is a type of noise that mimics the spectral and temporal characteristics of speech and it's designed to reflect the modulation patterns found in a 6-talker cocktail party noise, making it an ideal tool for example for audiology.

In the Noise Reduction ON condition, the IMPACT 1000 headset operated as the commercial product with its proprietary NR applied to the Voice Pick-up. However, in the Noise Reduction OFF condition, a single headset microphone was utilized, bypassing the use of the voice pick-up with noise reduction.

Test procedure

The test took approximately 1.5 hours to complete. The test flow reported below was followed. The training was conducted in a fixed order identical for all study participants, while the four experimental conditions were tested in a randomized and balanced order across study participants and blocks.

1. **Training**. The experiment started with two training trials of the Diapix task. The first was performed in the Quiet scenario with the NR voice pick-up turned ON. The second trial was carried out in the Noise scenario with the NR turned OFF. It's important to note that during these training trials, study participants were not required to complete any questionnaires.

2. **Test**. The test was divided into two blocks. Each block included one repetition of each of the four experimental conditions: Quiet + NR ON, Quiet + NR OFF, Noise + NR ON, Noise + NR OFF. After each run, the study participants were asked to fill out the questionnaire.

Each block consisted of four runs, each containing the 4 experimental conditions. Each of these experimental conditions, which are combinations of acoustic scenarios and NR conditions, were conducted with different variations of the same picture theme (i.e., with beach, street or farm). After completing four runs (i.e., one block), the study participants were given a break. After the break, the next block with four runs was performed with a different picture theme.

Data processing

Data processing
The speech signal from the reference microphones was used in the analyses of the conversation dynamics. Since the Noise conditions introduced a substantial amount of noise in the room, which was captured by the microphones, a noise gate and noise suppression algorithms were applied to the input signal. Once all the recordings were curated, we examined the turn-taking looking at the waveforms finding out that some of the conversations had a clear unbalance between the turns of the two study participants. While some of the conversations had interventions of short-mid length with the two talkers taking turns on the so-called “floor”, other conversations had one study participant dominating the floor during the entire test run and the other just said monosyllables to confirm what the other speaker was saying. This is depicted in Figure 3.

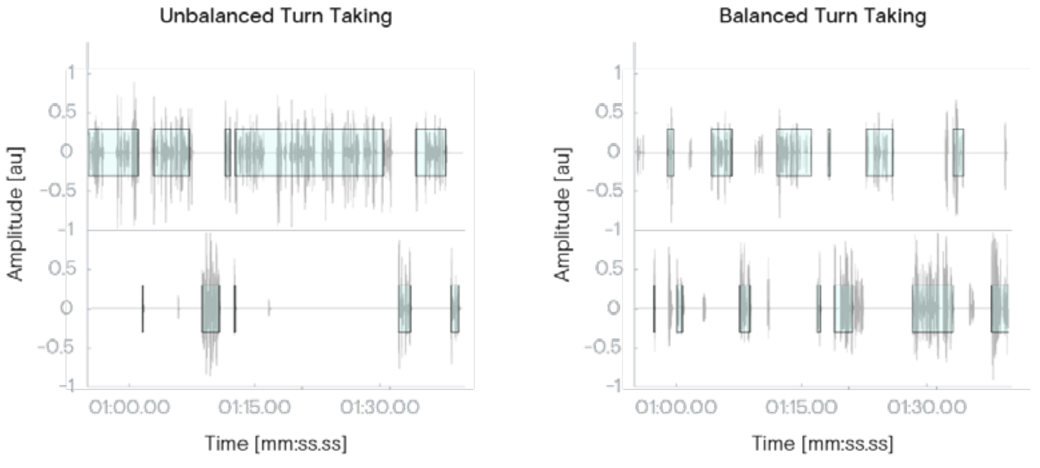

Figure 3: Comparison of an unbalanced turn-taking run (left panel) and a balanced turn-taking run (right panel). Each panel displays the two study participants (one at the top and the other at the bottom). The green areas indicate the detected turns.

After quantifying the number of occurrences of unbalanced turn-taking behavior, we discarded the recordings of 5 pairs who consistently exhibited this behavior in more than 4 test runs. We defined an unbalanced turn taking as the one where the difference in number of IPUs between both study participants is larger than the mean. We made this decision because successful communication should be balanced and not dominated by one person (Abramczuk et al., 2023, Li et al., 2022). Moreover, analyzing the conversation dynamics of recordings characterized by a dominant participant may potentially lead to erroneous interpretations.

The recordings were processed using a MATLAB toolbox (Sørensen, 2023) with the output metrics primarily focused on the timing of turn-taking events, including floor transfer offset functions, gaps, inter-pausal units (IPUs), pauses, and turns.

Performance and completion time

The examiner annotated the data regarding the number of correct differences found by the study participants during a run of the Diapix task. Additionally, the examiner analyzed the timing corresponding to the duration required to find 1 to 5 differences. This analysis was conducted by listening to the recordings and reviewing the transcripts of the conversations.

Statistical analysis

All the outcomes of the study were evaluated using mixed linear models. The model consisted of the acoustic scenario (Quiet vs. Noise), the noise reduction condition (ON vs. OFF), and their interaction as fixed factors, along with the pair number as a random factor. In the case of individual outcomes, the interaction between the pair number and participant number is considered as the random effects.

Results and discussions

Objective Evaluation

Conversation dynamics
The performance outcomes, i.e., the number of correct responses and the completion times, did not reveal significant differences across conditions. On average, participants required 18 seconds to spot the first difference and managed to identify five differences within the first 90 seconds. The average performance was 83%, which corresponds to 10 out of 12 differences identified within a span of 3.5 minutes.

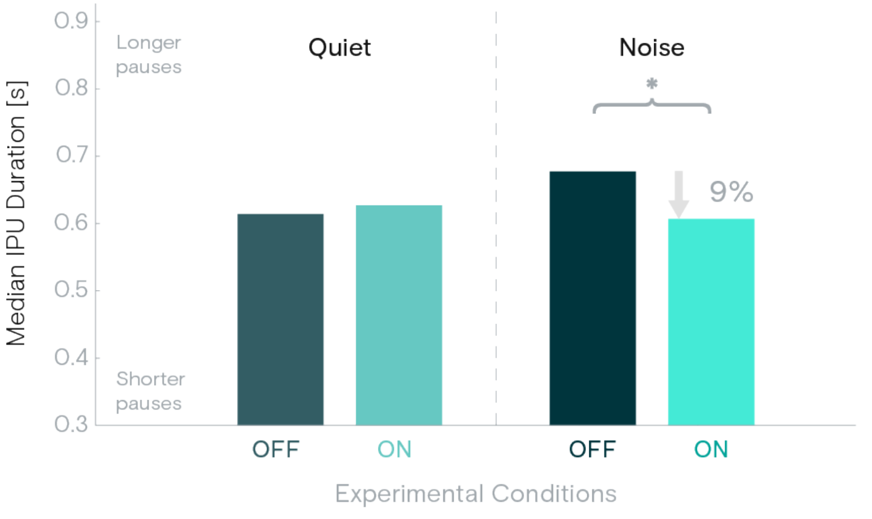

Figure 4: Median Inter-pausal unit (IPU) duration for the four conditions tested experimental conditions (voice pick-up Noise Reduction ON versus NR OFF for the Quiet and Noise scenarios). Left subpanel: Quiet condition. Right subpanel: Noise condition. Error bars show the standard error. * $p < 0.05$

The completion times were also quite similar among the four experimental conditions. Although we expected to see longer gaps in the NR OFF condition, the median gap duration for all conditions was approximately 550 ms. This substantially longer duration compared to previous studies such as Sørensen et al. (2021) can be attributed to the use of Microsoft Teams in the study, which introduces an effective block delay that might affect the conversation dynamics more than the experimental conditions. The only significant difference was found in the duration of the inter-pausal units (as shown in Figure 4).

Figure 4 shows the median IPU durations for the Quiet (left subpanel) acoustic scenarios compared to the Noise (right subpanel) acoustic scenario. In each subpanel we can see the median IPU duration for the conditions with NR turned ON and turned OFF. In the Quiet scenario, the effect of the NR on the IPUs duration can be disregarded. In contrast, in the Noise condition, the IPUs duration is approx. 70 ms longer (9% relative decrease in time when NR is ON) when the NR is turned OFF. The statistical analysis revealed that the interaction between the acoustic condition and the NR conditions is significant ($F(1,88) = 4.14$; $p<0.05$) which suggests that the NR OFF negatively impacts the conversation dynamics only in the Noise condition, which is reflected in the longer IPUs. This also implies that median IPU duration for the NR ON in Noise did not differ from those in the Quiet scenario.

This observation reflects the cognitive demands of conversation study participants need simultaneously to understand and predict the end of their partner's turn while planning their own response. This task requires the brain to listen and prepare the response concurrently (e.g., Donnarumma et al., 2017). Sørensen (2021a) also observed longer IPUs when the study participants converse in noise. This suggests that additional resources are spent on planning a response and that the planning phase might overlap with the time when the turn has already started.

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Subjective Evaluation

Listening Effort and Concentration Difficulty

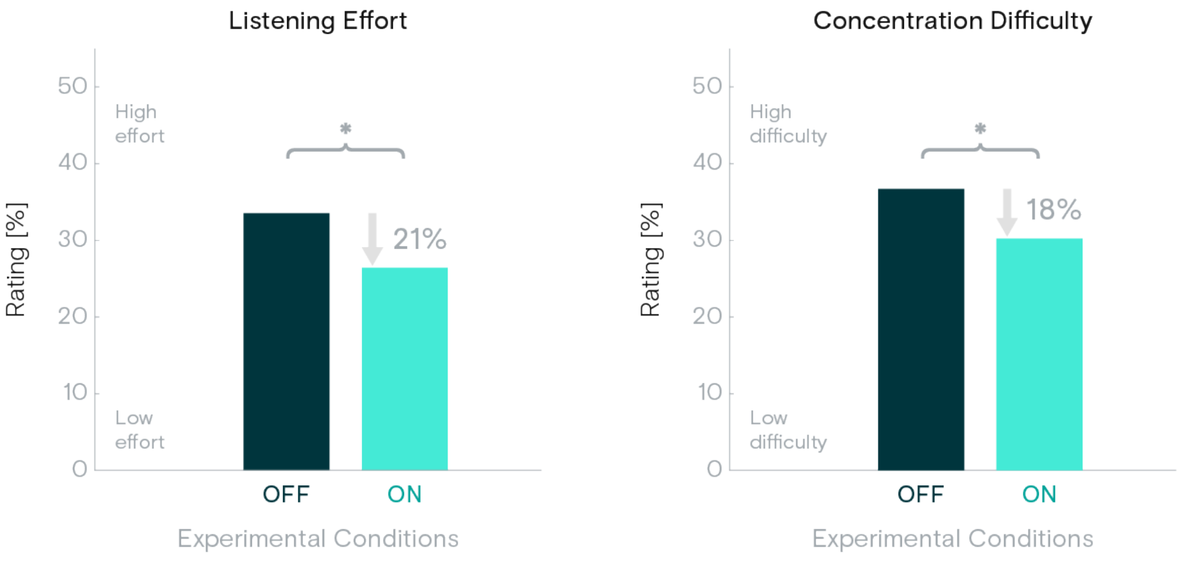

Figure 5: Results of the subjective ratings. Left panel, listening effort for only the Noise scenario and for the conditions NR ON and NR OFF. The rating reflects the participant's experience where 0% is no effort and 100% is very effortful. Right panel shows the concentration difficulty for the same conditions.

For the listening effort rating, statistical analysis revealed a significant effect of the NR condition ($F(1,277)=4.7$; $p<0.05$) , together with a significant interaction ($F(1,277)=10.0$; $p<0.01$) with the acoustic environment indicating that the effect of NR was only significant in the presence of background noise (Noise condition) but not Quiet condition as originally anticipated. Figure 5 shows the subjective evaluation of the NR voice pick-up feature in the Noise scenario only. In the left panel, we see that NR contributes to a relative 21% decrease in listening effort. When NR was activated, the average rating was 26%, compared to 33% when it was deactivated.

For the concentration difficulty rating, the statistical analysis showed a significant effect of the NR condition ($F(1,277)=3.7$; $p<0.05$) along with a significant interaction with the acoustic scenarios ($F(1,277)=7.3$; $p<0.01$). Again, this indicates that the effect of NR was only significant in the Noise condition but not in Quiet. The right panel of Figure 5 shows a relative 18% better ability to concentrate with NR. The average concentration difficulty rating was 30% when NR was ON, and 37% when it was OFF.

To conduct this study, we had to introduce a significantly loud external noise. This was done to ensure that the microphone would pick up and transmit this noise to the other room when NR was turned OFF. To prevent the external noise from being more disruptive than the noise transmitted through the line, Active Noise Canceling was employed. This had the advantage of reducing the listening effort by 67%. (Bianchi & Christiansen, 2023). However, this approach might not have been sufficient to fully capture the effectiveness of the NR voice pick-up.

Conclusion

The findings from this study, based on analysis of the conversations as well as study participants' evaluation of their experience, not only support each other but further prove the significant benefits industry-leading microphone voice pick-up technology can have on virtual communication.

The objective findings of the conversation dynamics analysis showed that the participants took significantly shorter pauses while speaking when the microphone noise reduction was ON compared to when it was OFF when subjected to the same level of background noise. This correlation between noise reduction and shorter speaking pauses is also supported by the study participants' subjective responses to how much effort was required to communicate with their partner.

Although the performance (i.e. identifying differences between the images) from the study participants did not significantly differ whether the noise reduction was ON or OFF, data from the conversation analysis proves that participants still benefited from having a microphone that suppressed background noise. Additionally, study participants reported an increase in listening effort and greater difficulty concentrating when the microphone voice pick-up was turned OFF.

With the microphone noise reduction ON, the conversation dynamics such as turn-taking and pauses were more natural and simulated a conversation in a quiet environment (i.e. no background noise). Together, these findings show the positive impacts that microphone noise reduction has on conversation dynamics and conversation efficiency, leading to a natural and more collaborative experience.

In this study, the measured benefits for study participants when microphone noise reduction was ON were:

- **21% reduction in listening effort**: The study participants reported a significant reduction in listening effort when the noise-reducing voice pick-up was activated.
- **18% reduction in concentration difficulty**: The participants reported a reduction in the difficulty they experienced while trying to focus on the conversation, helping them to engage more easily in the discussion.
- **9% increase in conversation efficiency**: The participants can better understand and predict the end of their partner's turn speaking while simultaneously planning their own response.
- The conversation dynamics between participants, such as turning-taking and pauses between speaking, simulated the conversation dynamics when having a conversation in a quiet environment.

Implications for Business Professionals

For businesses where people spend many hours a day on calls or work in hybrid organizations, one of the most critical considerations is how effectively people can communicate with each other. In meetings where not everyone is sitting in the same location and conversations are happening through Unified Communications Platforms, there are additional challenges and considerations. In a research survey conducted by EPOS in collaboration with IPSOS, 26% of employees reported misunderstanding due to poor audio (IPSOS 2021) and 95% of today's workers admitted that their concentration and efficiency at work have suffered due to sound issues (IPSOS 2020).

A challenge in virtual conversations is the quality of the conversation and the potential negative effects on the call caused by background noise. Are there disturbances in the background that make it difficult to maintain a natural conversation? Can people on the call hear each other clearly? During a conversation, whether in person or virtual, people need to listen, process, and plan their own response. In virtual conversations using headsets, poor microphone voice pick-up can impact people's ability to listen, process, and plan their responses efficiently.

Not only is it important for the efficiency of the call that people can hear each other clearly, but the quality of sound can also have an impact on the way people feel they appear. In a survey asking people about their sound experiences at work, 17% believed they appear unprofessional because of poor sound experiences (IPSOS 2021). In situations where a professional appearance is important, for example in calls with important clients, customers, or key stakeholders, the quality of the conversation is vital.

For businesses where hybrid work and virtual calls are an important part of the way they work and collaborate with each other or customers, the findings in this study emphasize the importance of equipping their workforce with industry-leading microphone voice pick-up technology, ensuring better conversations and call experiences.

At EPOS, we design audio solutions that put cognitive performance at the forefront. EPOS pioneering technologies, such as the microphone noise reduction evaluated in this study, are designed to support the brain, reduce cognitive load, and provide the most natural conversation experience. It's not just about making conversations possible; it's about making them better.

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