Reducing listening effort in a realistic sound environment using directional microphones: Insights from behavioural, neurophysiological and self-reported data

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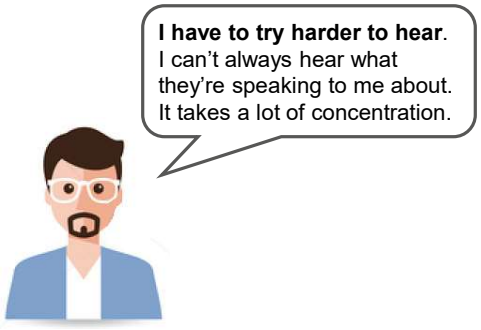
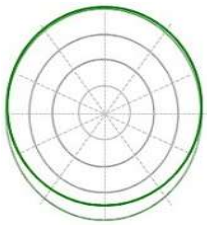
- Today I will present a study conducted at the National Acoustic Laboratories in Sydney (Australia) in collaboration with the Sonova group.
- In this study we investigated whether hearing aids directionality based on a binaural beamforming is effective in reducing listening effort.

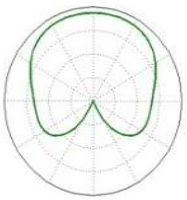
Motivation & hypothesis



Hearing aid microphones



[OD] Quasi Omnidirectional



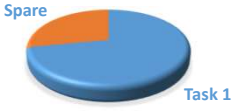
[BB] Binaural Beamforming

Dual-task

- Task 1. Speech-in-noise task
- Task 2. Behavioural task

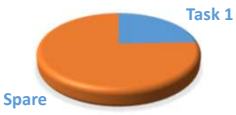
Reaction time

OD



Small amount of spare cognitive resources (long reaction time)

BB



Large amount of spare cognitive resources (short reaction time)

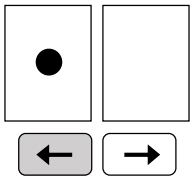
- It is very common that people with hearing loss often complain of the large amount of effort or concentration they need to dedicate to follow a conversation with their peers, particularly in noisy environments.
- For example, one participant reported "I have to try harder…"
- This study aimed to investigate if the directionality provided by a binaural beamformer reduced listening effort.
- For this, we used two different programs of the hearing aids microphones:
    1) A quasi-omnidirectional function that simulates the pinna effect
    2) A binaural beamformer that presents a very strong directionality
- The methodological approach we took to measure listening effort was based on a dual task.
- In dual tasks, participants are instructed to conduct two tasks simultaneously:
    - a primary task usually consists on repeating back a sentence presented in noise, and
    - a secondary task is usually a behavioural task where performance can be measured, for example via their reaction time

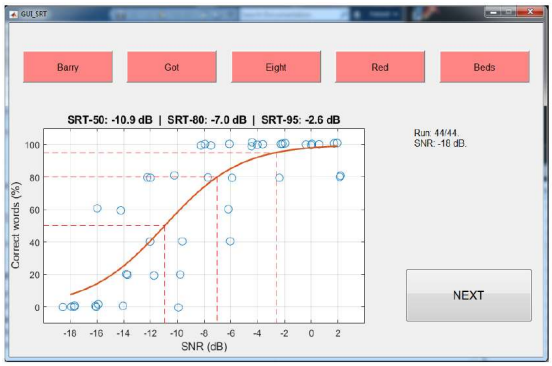
- The hypothesis of the study was that understanding a sentence in noise in the Quasi-Omnidirectional mode would require a large amount of cognitive resources, leaving less cognitive resources available to conduct the secondary task, which would lead to longer reaction times in that task.

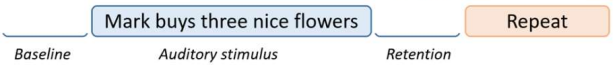
- However, the acoustic advantage provided by the stronger directionality in Binaural Beamforming would reduce the cognitive resources required to understand the sentence in noise, which would lead to shorter reaction times due to the extra spare cognitive capacity.

Dual-task methodology

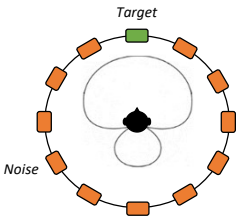
- PT: Repeat a sentence in noise
- ST: Auditory-visual task
  - Male name – pointing towards
  - Female name – pointing away







- Stimulus: Australian Matrix test
- Noise: Realistic cafeteria ±67° distractors at 70 dB SPL



Experimental conditions

- SRT-80: OD vs BB
- SRT-95: OD vs BB
  - *OD – Quasi Omnidirectional*
  - *BB – Binaural Beamforming*
- 4 runs per condition
- 20 sentences per run

- In the Primary task of the dual task that we developed to measure listening effort, participants were asked to repeat back a sentence from the Australian version of the Matrix test presented in realistic cafeteria background noise. The sentences from the Matrix test have the same structure: *name + verb + number + adjective + noun*; and there are ten words per category that can be combined to make a large number of meaningful sentences.

- The Secondary task consisted of an auditory-visual task where participants could see two rectangles in front of them. At the start of the sentence, a large black circle appeared randomly in one of the rectangles, and participants were instructed to press the arrow pointing towards the circle if the name was a male name, or the arrow pointing away the circle in case of a female name.

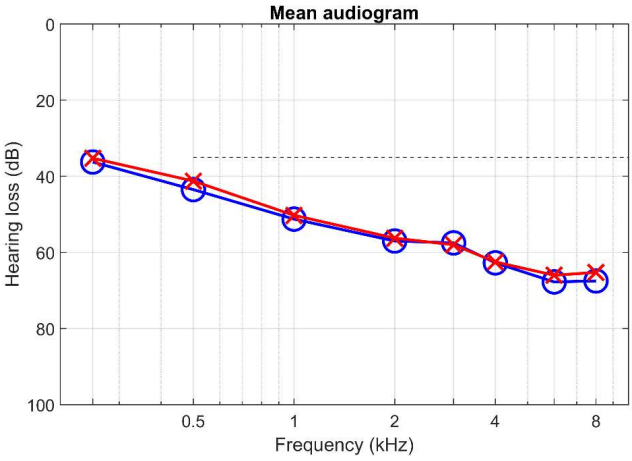
- This experiment was administered in the anechoic chamber of the Australian Hearing Hub in Sydney, Australia.

- We estimated the SNR corresponding to 80% and 95% intelligibility for each participant – we called these SNRs SRT-80 and SRT-95; and we tested our participants in those SNRs, both in Quasi-Omnidirectional (OD) and Binaural Beamforming (BB) conditions, obtaining 80 measures per condition in each participant.

- In addition, we also used self-reported measures of listening effort, and took neurophysiological measures via a 64-channels EEG setup.

Participants

- 20 participants (9 females)
- [19 - 81] years, mean = 65 years
- Native English speakers
- Experienced hearing aid users (>2 years)
- MoCA > 75%
- Bilateral downward-sloping hearing loss
  - >35 dB at 500 Hz and above
  - Symmetry differences <20 dB for 0.5-4 kHz

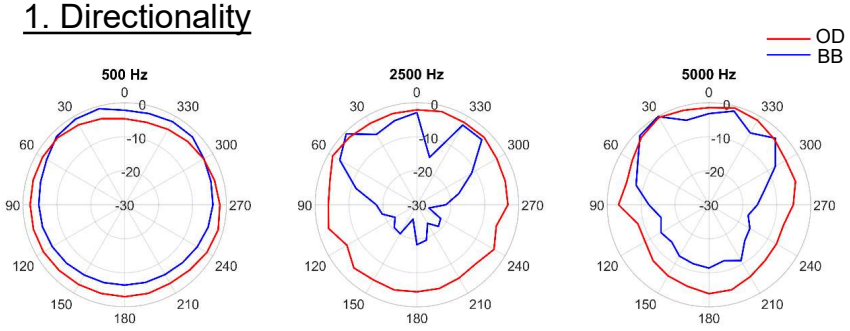


- Participant 0 for acoustic measures

- 20 adults (9 females) with hearing loss participated in the study.
- (Go over the headings)
- In addition, we also recruited our participant 0 (KEMAR) for acoustic measures.

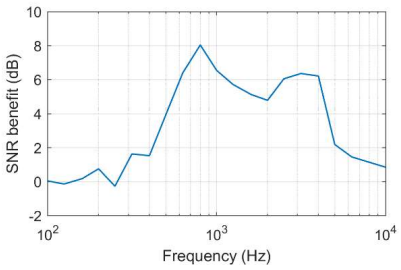
Acoustic measures

1. Directionality



Articulation index-weighted directivity index of BB relative to OD = +5.6 dB

2. SNR benefit

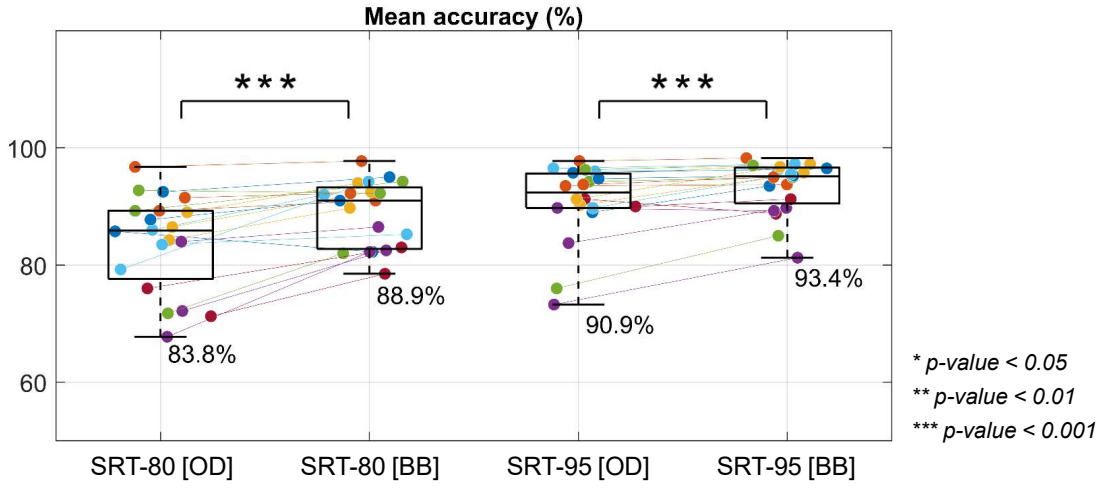


Articulation index SNR benefit of BB relative to OD = +4.8 dB

OD – Quasi Omnidirectional
BB – Binaural Beamforming

- As predicted, acoustic measures showed that Binaural-Beamforming (in blue in the polar plots) presented a much higher directionality than Quasi-Omnidirectional.
- We estimated that there was a difference of 5.6 dB in the articulation index-weighted directivity index between BB and OD – this is an interesting measure because this index weights the contributions at different frequencies according to their relevance in speech perception.
- Consistent with the previous result, the articulation-index SNR benefit was around 5 dB of BB advantage against OD.

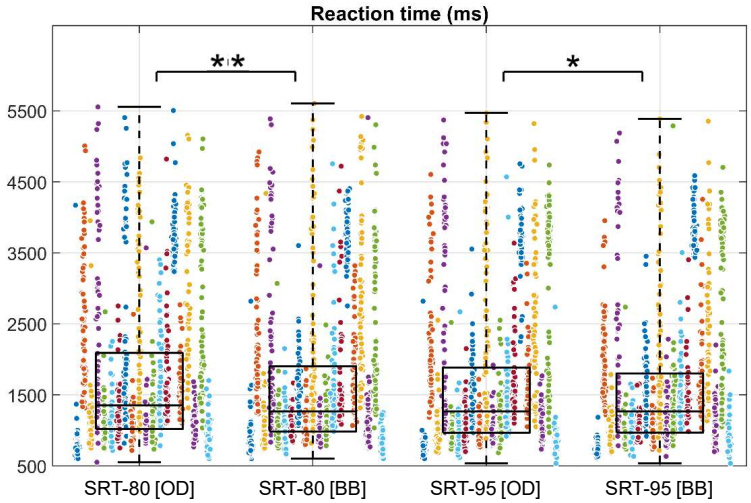
Intelligibility

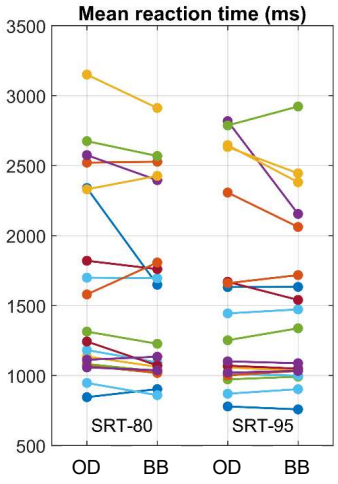


OD – Quasi Omnidirectional
BB – Binaural Beamforming

- Compared to OD, intelligibility improved with BB in the two SRTs.
- At SRT-80, intelligibility advanced from 83.8% to 88.9%, and this difference was statistically significant (with a p-value = $1 \cdot 10^{-14}$)
- At SRT-95, intelligibility improved from 90.9% to 93.4% (p-value = $2 \cdot 10^{-7}$) at SRT-95.
- Overall, the SNR improvement of BB relative to OD was +1.2 dB in the two SRTs.

Reaction time



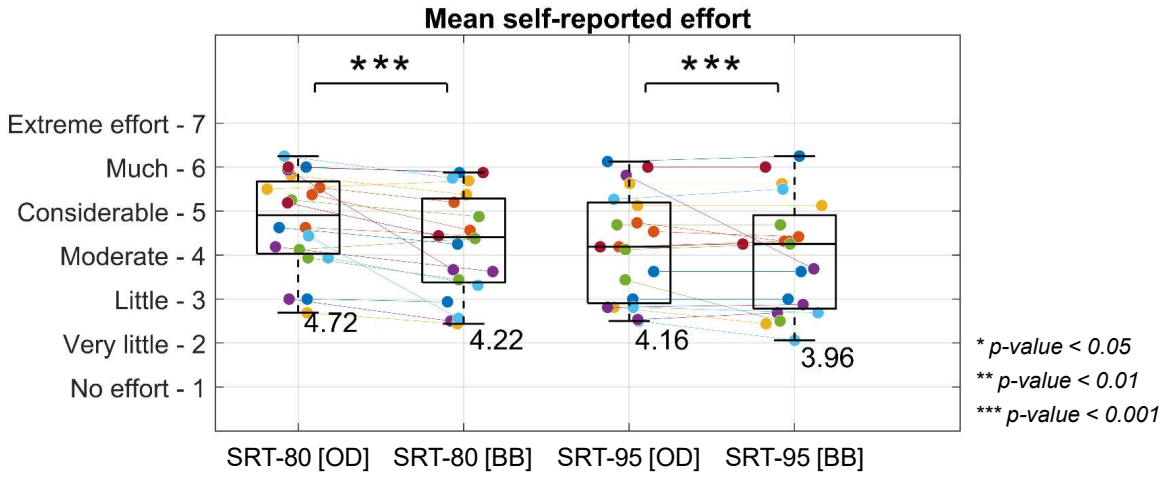


Reaction times decreased with BB in **75 ms** (p-value = 0.003) at SRT-80 and in **50 ms** (p-value = 0.02) at SRT-95.

The benefit was **not uniform** across participants

- The figure on the left shows the raw data of the reaction time per participant in each of the test conditions – each colour is a different participant; and the right figure shows the mean data per participant.
- These two figures show a large variability in the reaction time across participants.
- The figure on the right also shows that reaction times with BB were not always shorter in all participants.
- However, the statistical analysis showed that, on average, BB reduced reaction times in 75 ms at SRT-80 and in 50 ms at SRT-95 – a result that is consistent with our prediction.

Self-reported measures

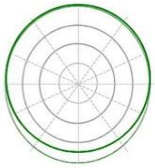


OD – Quasi Omnidirectional
BB – Binaural Beamforming

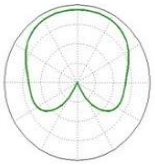
- When participants were asked to rate their self-perceived effort in a 7-point scale, results showed that their self-perceived effort decreased with BB in the two evaluated SRTs.
- Importantly, participants were blind with regards the hearing mode.
- Self-perceived effort decreased with BB from 4.72 to 4.22 at SRT-80 and from 4.16 to 3.96 at SRT-95.

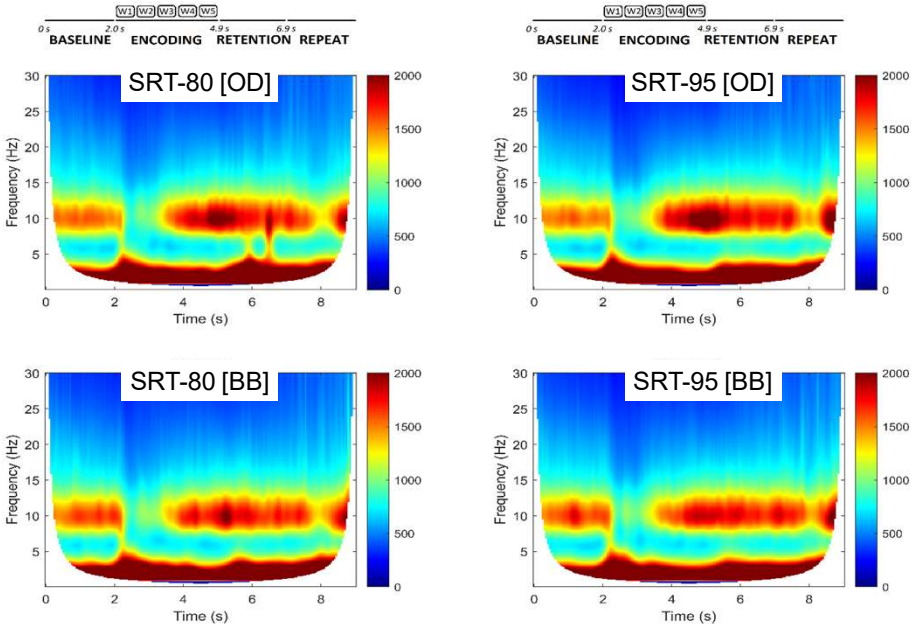
Neurophysiological measures

OD: Quasi Omnidirectional



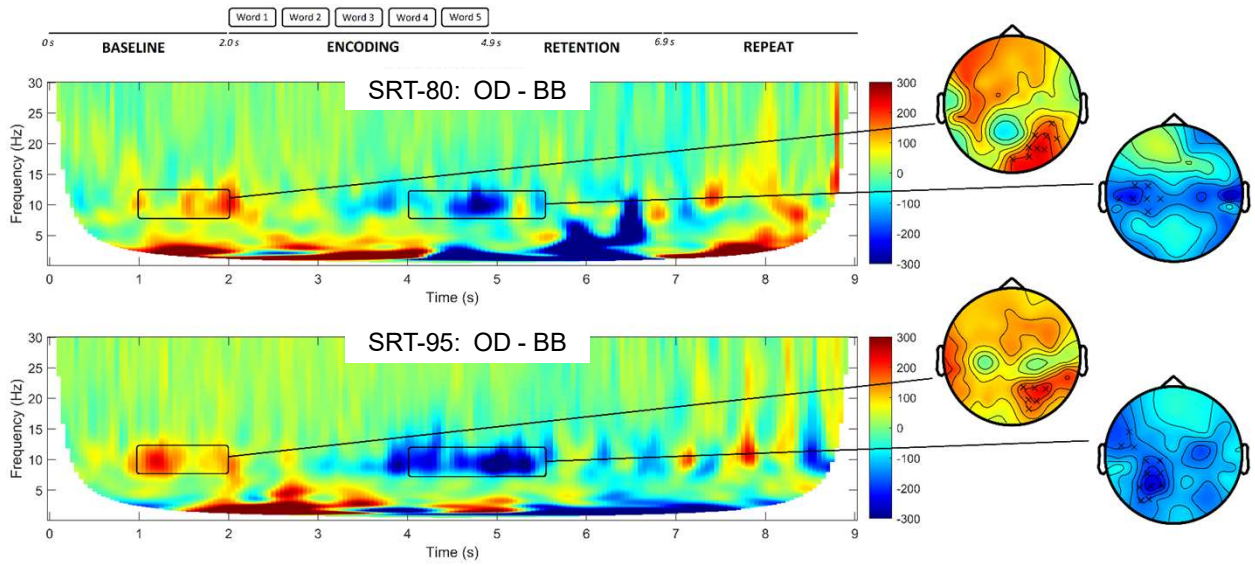
BB: Binaural Beamforming





- These figures show the grand-average spectrograms across participants and electrodes in the four experimental conditions.
- They show a consistent brain activity pattern in the energy in the alpha frequency band, i.e. between 8 and 12 Hz.
- In order to evaluate brain activity differences between OD and BB, a statistical analysis was conducted on the **DIFFERENCE** between the two modes in each SRT condition.

Neurophysiological measures



- This is shown in these two plots, that show the brain activity differences between OD and BB in SRT-80 at the top, and in SRT-95 in the bottom plot.

- The statistical analysis showed two important differences between OD and BB.
    1. increased pre-stimulus alpha in the OD condition in the right parietal section of the brain, and
    2. increased alpha in the encoding and retention part in BB in the left temporal side of the brain.

- These differences were consistent in the two SRT conditions (which increases the reliability of the findings); and are consistent with the two fundamental roles of alpha-band oscillations: inhibition and information processing.

Take-home & Acknowledgements

- The higher directionality of BB provides an AI-SNR benefit of +4.8 dB, which led to an **increase in intelligibility** in the two evaluated SRTs.
- Behavioural, neurophysiological and self-reported measures demonstrate that BB **reduces listening effort** relative to OD in a realistic cafeteria scenario.
- The effect size of the BB benefit may **assist clinicians** in providing evidence-based recommendations to their clients, and adequately manage their expectations.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- To take home… (read take-home messages)
- To conclude, I would like to acknowledge the contribution of the rest of the research team and other NAL colleagues who have made a significant contribution to the study.
- and thank the sponsors of this research: (1) the Sonova holding group, the Australian Government through the Department of Health and the Spanish ‘Ramón y Cajal’ fellowship, funded by the Ministry of Science, Innovation and Universities of the Spanish Government, the National Agency for Research and the European Social Fund Plus.
- Thank you for your attention. I am happy to take any question.