Neurophysiological biomarkers for tracking auditory selective attention

Joaquin T. Valderrama[1,2,3,4], Jorge Mejia[4,5], Jaime Undurraga[4,6]

[1] *Department of Signal Theory, Telematics and Communications, University of Granada, Spain*
[2] *Research Centre for Information and Communications Technologies, University of Granada, Spain*
[3] *National Acoustic Laboratories, Australia*
[4] *Department of Linguistics, Macquarie University, Australia*
[5] *School of Computing, Macquarie University, Australia*
[6] *Interacoustics Research Unit, Technical University of Denmark, Lyngby, Denmark*

jvalderrama@ugr.es

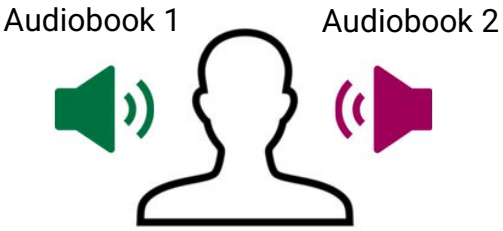
29th IERASG Biennial Symposium

Boulder (Colorado) | 14th – 18th June 2025

- Today, I will present preliminary results from a proof-of-concept study aimed at identifying a biomarker sensitive to auditory selective attention, which can be reliably measured at the individual level (not only at the group level).

Motivation

UNIVERSIDAD DE GRANADA



- Extended-high frequency audiometry.
- Working memory.
- Language proficiency.
- Selective auditory attention.[1]

[1] *Yeend et al. (2017). Hearing Research.*

- Understanding speech in noisy environments is a multifaceted and complex task that requires both adequate neural encoding of sounds in the peripheral auditory system and effective central processing involving cognitive mechanisms that enable the listener to comprehend speech degraded by one or more distracting sources.

- My team and I are particularly interested in characterising early signs of hearing deficits—those that arise before any change in hearing thresholds is observed—commonly referred to as *hidden hearing loss* (HHL).

- A previous study conducted by my colleagues at the National Acoustic Laboratories in Sydney (Australia) revealed that the most relevant factors explaining speech-in-noise difficulties reported by individuals with potential HHL were: (1) extended high frequencies, (2) working memory, (3) language proficiency, and (4) selective auditory attention.

- These findings motivated the search for an objective biomarker based on electroencephalography (EEG), sensitive to the person's ability to attend to one speech stream while ignoring another.

- To this end, we employed the *Dichotic Listening Task* paradigm, in which two speech streams are presented simultaneously to the two ears, and the listener is instructed

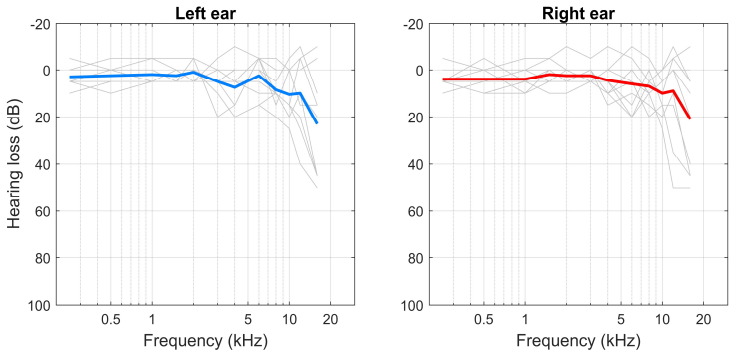
to focus on one of them and disregard the other.

- Ensuring that the biomarker is sensitive to selective auditory attention mechanisms at the individual level—not merely at the group level—was important to us, as it will subsequently serve to evaluate whether individuals with HHL present cognitive-level deficits in selective attention.

Participants

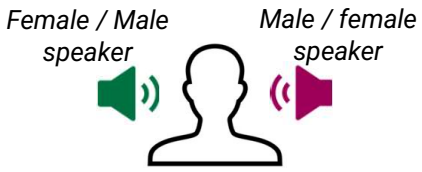
UNIVERSIDAD DE GRANADA

- 10 normal-hearing adults (4 females, 21.5—42.7 years, mean age: 32.0 years).
- **Otoscopy**: Clear ear canals and tympanic membranes.
- **Tympanometry**: Type A-normal middle-ear function.
- **Distortion product otoacoustic emissions (DPOAEs)**: Present from 0.5 to 10.0 kHz.
- **Air-conduction pure tone audiometry thresholds**: Clinically normal thresholds.



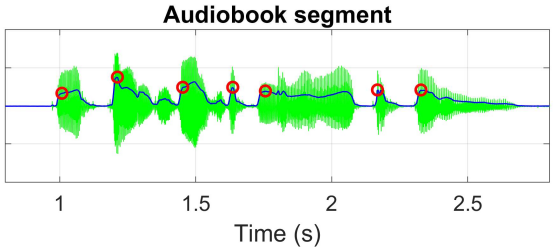
- We recruited ten adults with clinically normal hearing. Four of them were female, and their ages ranged from 21.5 to 42.7 years, with a mean age of 32.
- Otoscopy confirmed that all participants had clear ear canals and intact tympanic membranes, ensuring no visible obstruction or pathology.
- Tympanometric assessment yielded Type A curves in all cases, indicating normal middle-ear function.
- Distortion product otoacoustic emissions were present across a wide frequency range, from 0.5 to 10 kHz, confirming healthy outer hair cell function in the cochlea.
- Air-conduction pure-tone thresholds were within clinically normal limits across all standard audiometric frequencies.

Methods



Left ear	Right ear
Attended	-
-	Attended
Attended	Ignored
Ignored	Attended

- **Stimulus: 15-min audiobook**[2]
  - *Male speaker*: "The Jungle Book".
  - *Female speaker*: "The Adventures of Maya the Bee".
- **EEG recording**
  - BioSemi ActiveTwo system with ActiView software.
  - Cz electrode, referenced to Tp9/Tp10.
- **Word-onset CAEP**
  - Word-onset estimation (~2000 events/audiobook).[3]
  - EEG downsampled to 250 Hz, filtered 1–20 Hz.
  - CAEPs estimated via multi-response deconvolution.[4]



[2] https://librivox.org
[3] Gross et al. (2013). PLoS Biol.
[4] de la Torre et al. (2024). JASA.

- The auditory stimuli consisted of audiobooks freely available from the LibriVox database. For a male-speaking audiobook, we selected '*The Jungle Book*'; and for a female-speaking audiobook, '*The Adventures of Maya the Bee*'. Each chapter had a duration of 15 minutes, and the male or female audiobook was assigned to each ear at random.

- Each participant underwent four experimental conditions: (1) monaural stimulation on the left ear (attended); (2) monaural stimulation on the right ear (attended); (3) binaural stimulation, attending to the audiobook presented in the left ear; and (4) binaural stimulation, attending to the audiobook in the right ear.

- Attention was monitored by asking a few simple comprehension questions about both audiobooks at the end of each condition.

- EEG was recorded at the Cz electrode site, referenced to the combined mastoids, using a BioSemi ActiveTwo system.

- The biomarker under evaluation was the cortical response evoked by word onsets in each auditory stream. Word-onset trigger events were estimated from the audiobook signal following the methodology described by Gross et al. (2013). Briefly, this methodology involves estimating the speech envelope, detecting candidate word

onsets by applying a threshold (0.7 in our case), and validating the candidates based on the average amplitude before and after each onset, along with a minimum inter-onset interval of 100 ms.

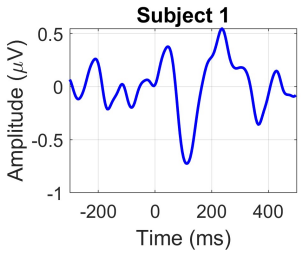
- The recorded EEG was downsampled to 250 Hz and digitally filtered within the 1–20 Hz frequency band.

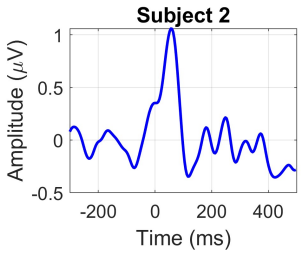
- Finally, word-onset CAEPs for each auditory stream were estimated using multi-response deconvolution—a technique that enables the simultaneous estimation of overlapping evoked potentials with different morphologies.

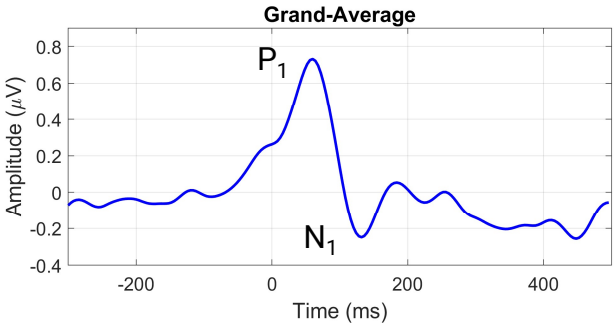
Word-onset CAEP in Quiet

UNIVERSIDAD DE GRANADA

Left ear	Right ear
Attended	-
-	**Attended**
Attended	Ignored
Ignored	Attended







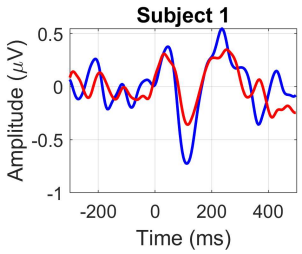
It is feasible to measure the cortical response to **word onsets in quiet** speech, both at the individual and group levels.

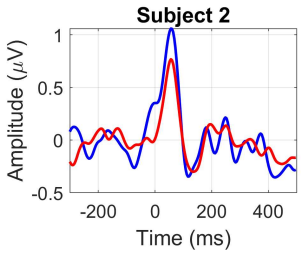
- The first objective was to determine whether the proposed methodology enabled a reliable recording of cortical responses to word onsets at the individual level.
- To assess this, we combined the two monaural stimulation conditions, in which only a single speech stream was presented.
- The grand-average response revealed a clear cortical evoked potential, with identifiable P1 and N1 components emerging above the background noise.
- At the individual level, these components were also identifiable in all participants.
- These results indicate that it is feasible to measure the cortical response to word onsets in quiet speech, both at the individual and group levels.

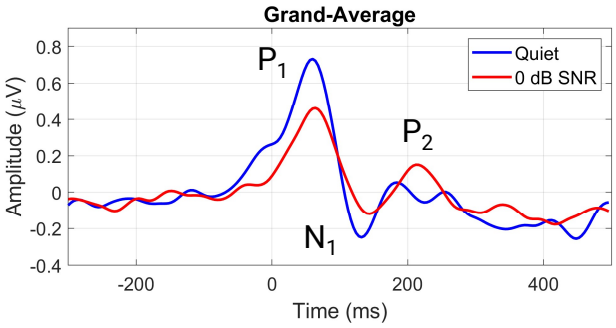
Word-onset CAEP in Noise

UNIVERSIDAD DE GRANADA

Left ear	Right ear
Attended	-
-	Attended
Attended	Ignored
Ignored	Attended







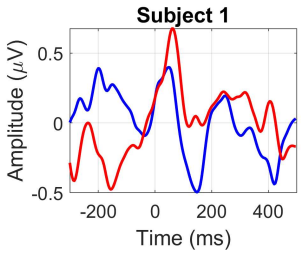
It is also feasible to measure cortical responses to **word onsets at 0 dB SNR**, both at the individual and group levels.

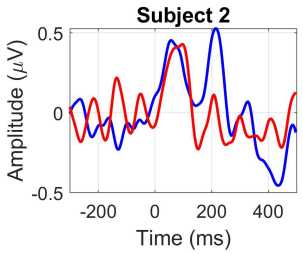
- The second objective was to assess whether a reliable cortical response could be obtained under conditions in which a secondary speech stream was presented at the target stream, i.e., at 0 dB SNR.
- In the grand-average figure, the blue trace corresponds to the cortical response in the monaural condition, as presented in the previous slide. The red trace represents the average of the cortical responses estimated from the binaural conditions, incorporating both the attended and ignored speech streams.
- Averaging the responses from both the attended and ignored conditions provides an estimate of the cortical response to speech in noise at 0 dB SNR.
- At the group level, the grand-average traces exhibit the expected reduction in response amplitude under noisy conditions. However, despite this reduction, a clear cortical response remains observable.
- At the individual level, the same pattern was observed across all participants.
- These findings show that it is feasible to measure cortical responses to word onsets at 0 dB SNR, both at the individual and group levels.

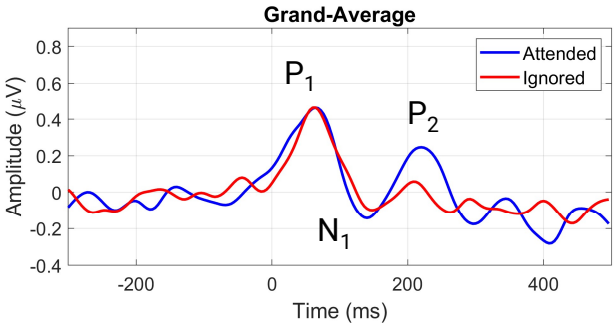
Attended vs Ignored

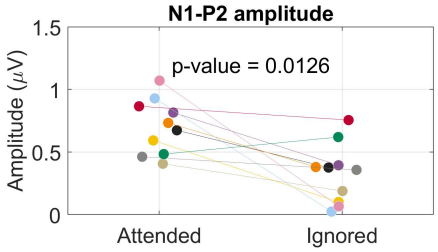
UNIVERSIDAD DE GRANADA

Left ear	Right ear
Attended	-
-	Attended
Attended	**Ignored**
Ignored	**Attended**









- Finally, we compared the morphology of the cortical response to word onsets from the *attended* and *ignored* speech streams.
- In the grand-average waveform, the blue trace represents the response to the attended audiobook, while the red trace corresponds to the ignored audiobook.
- At the group level, these waveforms exhibited similar morphology, with comparable latencies for the P1, N1 and P2 components. The P1-N1 amplitudes were also similar between the two conditions; however, the N1-P2 amplitude was notably greater for the attended compared to the ignored speech stream.
- At the individual level, the P1, N1 and P2 components were identifiable in all participants. Statistical analysis confirmed that N1-P2 amplitudes were significantly larger in the attended condition compared to the ignored one. This amplitude enhancement was observed across participants, with the exception of a single case.
- Latency values and P1-N1 amplitudes did not differ significantly between the two conditions. These findings support the interpretation that the P1-N1 complex reflects general sound detection mechanisms, as it was unaffected by attentional state, whereas the N1-P2 component appears to be sensitive to processes related to selective auditory attention.

Key takeaways

UNIVERSIDAD DE GRANADA

- The cortical response to word onsets can be reliably measured at the individual level using a dichotic listening task.
- The results support the N1-P2 amplitude as a candidate objective biomarker of selective auditory attention.
- Future work may explore the relationship of this biomarker and cognitive measures of selective auditory attention, as well as its association with speech-in-noise difficulties reported by individuals with clinically normal audiograms.

SLIDES & NOTES

Acknowledgements

- RYC2022-037875-I, funded by MCIU/AEI/10.13039/501100011033 and FSE+.
- CNS2024-154207, funded by MCIU/AEI/10.13039/501100011033.

MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES
Cofinanciado por la UNIÓN EUROPEA Fondo Social Europeo +
AGENCIA ESTATAL DE INVESTIGACIÓN
MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES
AGENCIA ESTATAL DE INVESTIGACIÓN

Australian Government
Department of Health and Aged Care