Neural synchronization to speech in healthy aging : an investigation of the relationship between speech rhythm perception and brain oscillations

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1. State of art

Heathly aging and speech comprehension

- Healthy aging is associated with difficulties in spoken language comprehension (Wingfield et al., 2003; Kim & Ho, 2013).
- Difficulties are also influenced by the speaker's speech rate, with greater difficulties observed when the speech rate is faster (Wingfield et al., 2003).
- These comprehension difficulties are thought to be partly of cognitive origin (Dede et al., 2004; Criscuolo et al., 2025).
- These difficulties could be related to the processing of rhythmic information and perception in auditory stimuli (Criscuolo & al., 2025)

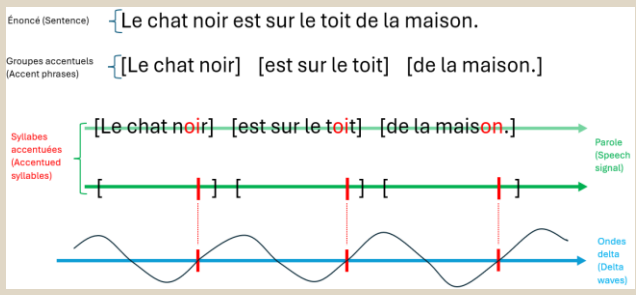
Rhythmic cues and speech chunking in french

- The segmentation of speech is necessary for its cognitive processing (short-term memory, Gilbert, 2012).
- Speech can be segmented into rhythmic units known as accent phrase (APs) (Martin, 2018).
- APs typically contain between 1 and 11 syllables and include a rhythmic cue : the final stressed syllable (Martin, 2018).
- The **perception of the final stressed syllable** is necessary to close **accentual phrases (APs)** as a chunk (Martin, 2018).

Rhythmic cues and brain waves

- Delta oscillations are involved in the cognitive processing of the speech envelope (Doelling et al., 2014).
- The duration of APs corresponds to the oscillation period of slow delta waves : 0.5 to 2 Hz or 1250ms to 250ms (Martin, 2018).
- Phrasal-level input units are processed at the oscillatory frequency of delta waves.
- For example :
  - Digit sequences occur at approximately 1.8 Hz (Rimmele & Poeppel, 2021).
  - Intonational units occur at around 1 to 1.5 Hz (Inbar et al., 2020, 2025; 25 languages studied).
- Each prosodic unit boundary is marked by a specific event-related potential (ERP), known as the **closure positive shift (CPS)** (Gilbert, 2012).

2. Focus on accent phrases and neural synchronisation



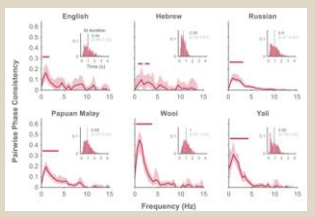
- Utterances are segmented into minimal rhythmic units known as **accent phrases (APs)**.
- Each rhythmic unit ends with a **stressed syllable** lasting approximately 250 ms (Duez, 1982; Martin, 2018).
- **In French**, the perception of this lengthened final syllable is thought to **trigger** synchronization with **delta oscillations**.

Phrasing : refers to the segmentation of an utterance into rhythmic units (APs) within the delta time window) and it is influenced by speech rate (Martin, 2023).

Synchronization between accentual groups and delta oscillations is maintained as long as phrasing and the length of the accent phrases allow it, within temporal constraints (i.e., the maximum number of syllables that an accent phrase can contain).

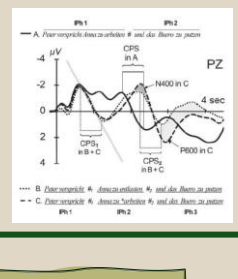
3. Hypothesis

Hypothesis 1: In older listeners, when listening to a sentence with an accelerated speech rate, a desynchronization occurs between perceived rhythmic cues in speech (the final accented syllable of accentual groups) and slow delta brain oscillations (0,5 – 2 Hz). As speech rate increases, older adults are expected to show a lower **Pairwise Phase Consistency (PPC)** index in the target frequency band (0,5 – 2 Hz; low delta).



Pairwise Phase Consistency (PPC):
A point-field phase coherence analysis used to investigate the synchronization between rhythmic cues (**accented syllables)** and **delta oscillations** (Vinck et al., 2010; Inbar et al., 2020).

Hypothesis 2: In older listeners, when listening to a sentence with an accelerated speech rate, difficulties in perceiving rhythmic cues in speech reduce the ability to segment the utterance at the phrasal level, thereby impairing working memory encoding. As speech rate increases, older adults are expected to show **fewer and less precise CPS responses**.



CPS analyses are used to identify the boundaries of rhythmic units (Steinhauer & Friederici, 2001; Gilbert, 2012).

4. Methodology and experimental task

4.1 Population

- Control group
- 20 to 30 years
- Heathly young people
- n = 60

- 3 exp. groups (by decades) 50-59; 60-69; 70-79 years
- Healthy elders
- n = 20 by groups

4.2 Control tasks

Audition control (Höra, 2026)

Working memory (Weschler, 2012)

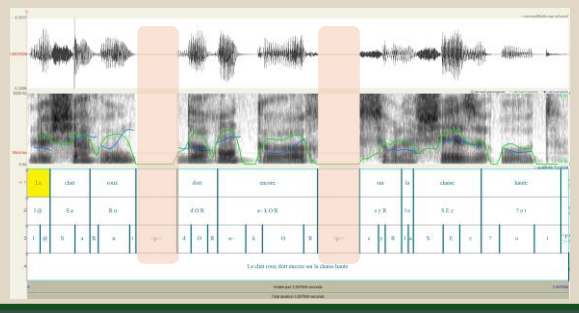
Rhythmic contour & metric (Peretz & al., 2013)

4.3 Stimuli

A total of **150 declarative sentences in French**.
→ 50 sentences presented in three speech-rate conditions :

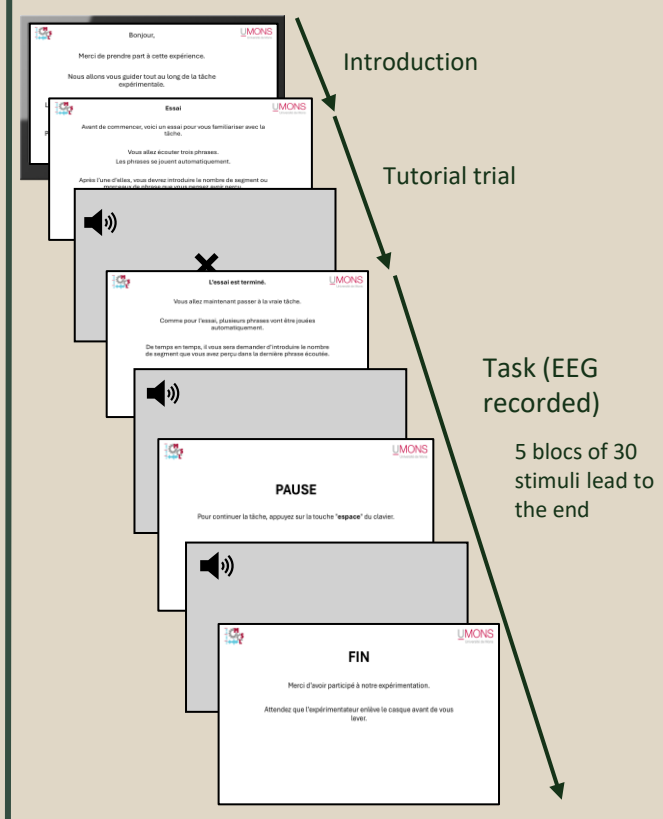
- **Neutral speech rate** (n = 50) (~4 syll/s)
- **Accelerated speech rate ×2** (n = 50)
- **Limit speech rate ×3** (n = 50)

All sentences are **emotionally neutral** and produced by a **male speaker**.
Each sentence contain **three accentual phrases** in the neutral speech-rate condition.
Inter-accentual-phrase pauses are normalized to 250 ms in the neutral speech-rate condition.
All modifications are made with Praat (Boersma & Paul, 2001)

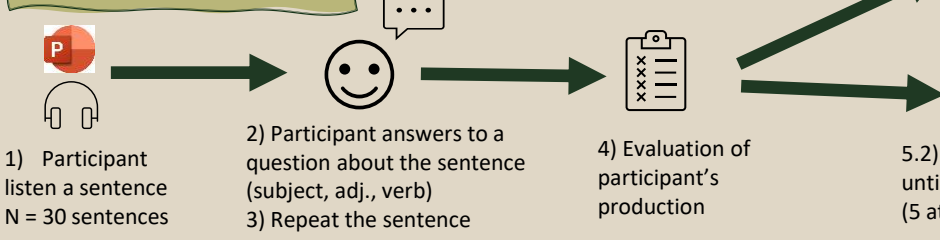


4.4 Exprimental task with EEG

- Stimuli were presented via **headphones**.
- EEG was recorded during listening (**Brain Products**, 64 electrodes).
- The task was automated in **PsychoPy (**Peirce & al., 2019) :
  - **Five blocks of 30 stimuli** presented in **pseudo-random order** (+ 1 tutorial trial)
  - One **break** between blocks
  - To maintain attention, participants completed a **perceptual/behavioral task** : after a pseudo-random sentence, they reported the **number of "chunks"** they perceived.



4.5 Comprehension & repetition tasks (post EEG)



5. EEG analyses (on going)

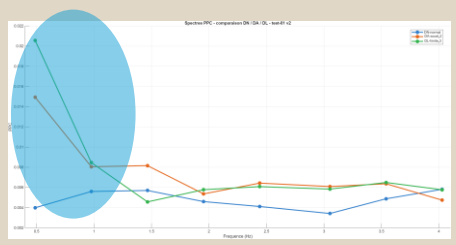
All analyses are made with **Fieldtrip toolbox** (20240620) (Oostenveld & al. , 2011) working on Matlab 2025b (The MathWorks Inc., 2025).

5.1 Basic controls & preproccessing pipeline

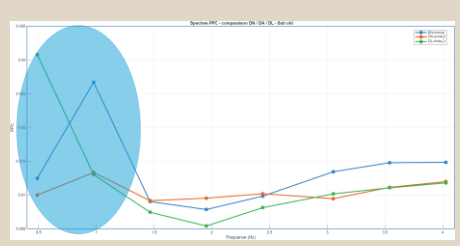
Triggers inspections → Read and rename channels (actiCap → Fieldtrip) → Low-pass (0,1Hz) and high-pass (40Hz) filteting → Re-referencing → ICA → Epoching & trials rejection → Interpolation

5.2 Pairwise Phase Consistancy

Analyses is on going at the time. Pictures are for illustration only, not the final results.



Control_group (20-30 y) PPC for each speech rate



Exp_group_2 (60-69 y) PPC for each speech rate

5.3 Closure positif shift

Analyses of the CPS will come later after the PPC

5.4 Statistics

Effects of Age X Speech Rate on sentences PPC
Effects of Age X Speech Rate on APs PPC
Effects of Age X Speech Rate on APs CPS

6. Results

In Progress …

The analyses will later be complemented by **question/responses task**, **sentence repetition task** and the **behavioral/perception task implemented during the experimental task**.

Bibliographie

- Criscuolo, A., Schwartze, M., Bonetti, L., & Kotz, S. A. (2025). Aging Impacts Basic Auditory and Timing Processes. European Journal Of Neuroscience, 61(5). https://doi.org/10.1111/ejn.70031
- DeDe, G., Caplan, D., Kemtes, K., & Waters, G. (2004). The Relationship Between Age, Verbal Working Memory, and Language Comprehension. Psychology And Aging, 19(4), 601-616. https://doi.org/10.1037/0882-7974.19.4.601
- Doelling, K. B., Arnal, L. H., Ghitza, O., & Poeppel, D. (2013). Acoustic landmarks drive delta–theta oscillations to enable speech comprehension by facilitating perceptual parsing. NeuroImage, 85, 761-768. https://doi.org/10.1016/j.neuroimage.2013.06.035
- Duez, D. (1982). Silent and Non-Silent Pauses in Three Speech Styles. *Language And Speech*, *25*(1), 11-28. https://doi.org/10.1177/002383098202500102
- Gilbert, A. (2012, 1 mars). Le découpage perceptif de la parole : sur la nature du groupement temporel et son effet sur la mémoire immédiate. https://umontreal.scholaris.ca/items/a6963a70-9b02-4fe9-81c3-a227e5fece4e
- Inbar, M., Grossman, E., & Landau, A. N. (2020). Sequences of Intonation Units form a ~ 1 Hz rhythm. Scientific Reports, 10(1). https://doi.org/10.1038/s41598-020-72739-4
- Inbar, M., Genzer, S., Perry, A., Grossman, E., & Landau, A. N. (2023). Intonation Units in spontaneous speech evoke a neural response. bioRxiv (Cold Spring Harbor Laboratory). https://doi.org/10.1101/2023.01.26.525707
- Kim, B. J., & Oh, S. (2013). Age-Related Changes in Cognition and Speech Perception. Korean Journal Of Audiology, 17(2), 54. https://doi.org/10.7874/kja.2013.17.2.54
- Martin, P. (2018). Intonation, structure prosodique et ondes cérébrales : introduction à l'analyse prosodique. ISTE Group.
- Martin, P. (2023). De la naissance du syntagme au groupe accentuel et à la structure prosodique. Travaux de Linguistique, n° 84-85(1), 73-89. https://doi.org/10.3917/tl.084.0073
- Rimmele, J. M., Poeppel, D., & Ghitza, O. (2021). Acoustically Driven Cortical δ Oscillations Underpin Prosodic découpage. eNeuro, 8(4), ENEURO.0562-20.2021. https://doi.org/10.1523/eneuro.0562-20.2021
- Steinhauer, K., & Friederici, A. D. (2001). Prosodic boundaries, comma rules, and brain responses : the closure positive shift in ERPs as a universal marker for prosodic phrasing in listeners and readers. Journal Of Psycholinguistic Research, 30(3), 267-295. https://doi.org/10.1023/a:1010443001646
- Vinck, M., Van Wingerden, M., Womelsdorf, T., Fries, P., & Pennartz, C. M. (2010). The pairwise phase consistency : A bias-free measure of rhythmic neuronal synchronization. NeuroImage, 51(1), 112-122. https://doi.org/10.1016/j.neuroimage.2010.01.073
- Wingfield, A., Peelle, J. E., & Grossman, M. (2003). Speech Rate and Syntactic Complexity as Multiplicative Factors in Speech Comprehension by Young and Older Adults. Aging Neuropsychology And Cognition, 10(4), 310-322. https://doi.org/10.1076/anec.10.4.310.28974