Evidence of Age-Related Temporal Processing Deficits in EEG and MEG Recordings

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Background

Older adults often report that during a conversation they can hear what is said, but cannot understand the meaning, particularly in a noisy environment. These difficulties may arise from deficits in auditory temporal processing [1]. A loss of temporal precision may be a key factor underlying subcortical timing delays and decreases in response consistency and magnitude in older adults [2]. The frequency following response (FFR) is an efficacious measure for predicting self-reported speech-in-noise perception difficulties in older adults [3]. Recent results using magnetoencephalography (MEG) [4,5] have shown the feasibility of reconstructing the envelope of speech in noisy conditions by using low frequency oscillations of the brain in younger adults. Although the effects of aging on neural speech processing has been investigated in quiet conditions [3,4,5], little is known about how noise impacts cortical speech processing in younger vs. older adults.

Hypotheses

We compared the effects of noise on subcortical and cortical responses in younger and older adults with normal hearing, hypothesizing that the neural response of younger adults will be more robust to noise than the one of older adults. Specifically, we hypothesized a higher correlation between midbrain encoding of speech in quiet and noise conditions and a better reconstruction (higher correlation values) of the envelope of the attended speech envelope at the cortical level in younger adults than in older adults.

Materials and Method

Participants

- Participants were native speakers of English: 15 young adults (20 – 28 years old, mean ± SD, 23.13 ± 2.58years) and 15 older adults (60 - 76 years old, mean ± SD, 64.46 ± 4.95 years).
- All participants had clinically normal hearing and no history of neurological or middle ear disorders.
- Participants had normal IQ scores [mean ± SD, 110.8 ± 9.87 for younger adults, and mean ± SD, 116.26 ± 15.2 in older adults on the Wechsler Abbreviated Scale of Intelligence].
- Older adults were also screened for dementia on the Montreal Cognitive Assessment (MOCA) [mean ± SD, 26.2 ± 2.04].
- All of the 30 participants participated in the auditory midbrain EEG study, while 16 participants (8 per age group), participated in the auditory cortex MEG experiment.

Behavioral data

Hearing thresholds (HT) were obtained from 0.125 to 8 kHz in each subject, while the Quick Speech-in-Noise test (QuickSIN) [6] was used to objectively measure the participant's sentence recognition in noise. Four lists were used for each participant and were averaged to produce a final score.

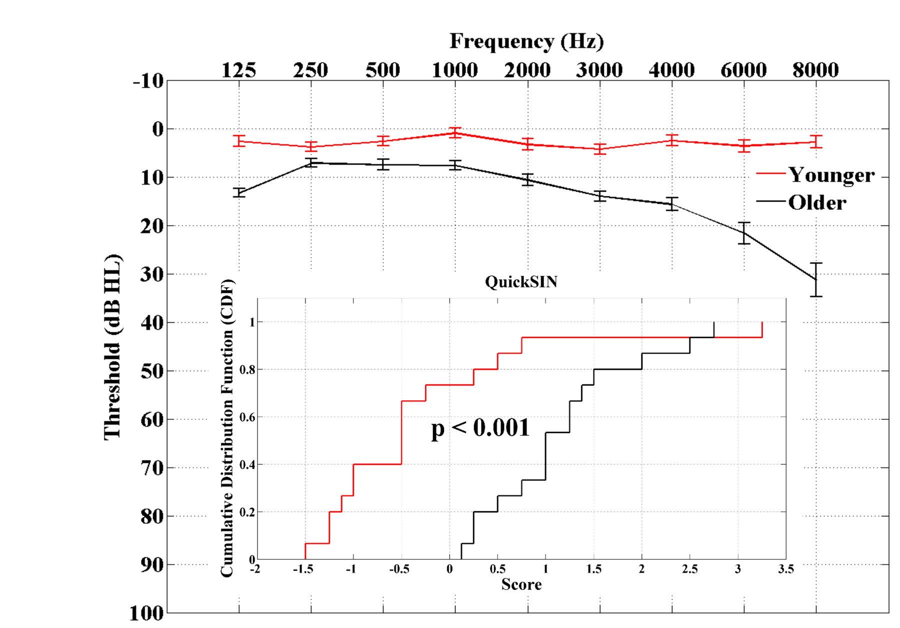


Fig. 1 Audiogram (mean ± 1SE) for younger (red) and older (black) adults. The inset shows the cumulative distribution function (cdf) of the results of the speech intelligibility test for younger and older adults (the lower the score, the better the understanding of speech in noise).

Auditory Midbrain EEG recordings

- A 170 ms speech syllable /da/ synthesized at 100 Hz with a Klatt-based synthesizer presented diotically with alternating polarities at 80 dB SPL at a rate of 4 Hz through electromagnetically shielded insert earphones.
- FFRs from each subject were obtained in two different conditions:

1) /da/ presented in quiet.
2) /da/ presented in one-talker babble (0 SNR)
3) 3000 sweeps per condition were recorded from the Cz electrode (Average ear lobes as reference and forehead as ground) using the Biosemi system with rtifact rejection set at ±30 μV
4) Envelope was extracted by summing the two polarities in order to reduce the stimulus-artifact.

Auditory Cortex MEG recordings

- Speech was presented at 62 dB SPL and low-pass filtered below 4 kHz.
- Participants were asked to attend to one of two stories presented diotically while ignoring the other one.
- One story was spoken by a male and the other by a female. Three trials, each one approximately 1 minute in duration were recorded.
- Neuromagnetic signals were recorded using a 157-signal whole head MEG system (Kanazawa Institute of Technology, Kanazawa, Japan) in a magnetically shielded room, with a 1 kHz sampling rate. A 200 Hz low-pass filter and a notch filter at 60 Hz were applied online.

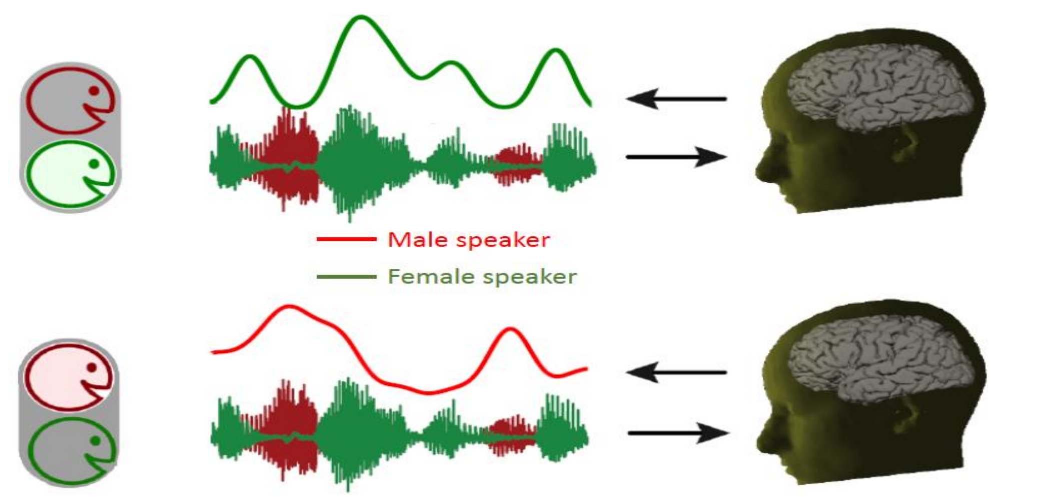


Fig. 2 Graphical representation of the MEG task. Subjects were instructed to attend to either the male speaker (red) or to the female speaker (green), while trying to ignore the competing talker. The MEG response was used to reconstruct the envelope of the speech stimulus to which the participant was instructed to attend.

Auditory Midbrain EEG Analysis

- Raw data were averaged and bandpass filtered from 70 - 2000 Hz using a zero-phase, 4th order Butterworth filter.
- Grand-averages of the time series envelope of younger and older adults were calculated for the two conditions (quiet and noise).
- Cross-correlation between responses in quiet and noise and auto-correlation values in quiet and in noise were also calculated.

Auditory Cortex MEG analysis

- Data were denoised using Time-shifted PCA .
- Denoised data were filtered between 2 – 8 Hz and separated into components via the DSS algorithm.
- Only the first 6 DSS components were retained, and then filtered between 1 - 8 Hz.
- A linear model [4,5] used these filtered responses to reconstruct the envelope of the foreground and background. Success in this prediction is measured by the linear correlation between the predicted and actual speech envelope.

Neural reconstruction of speech envelope

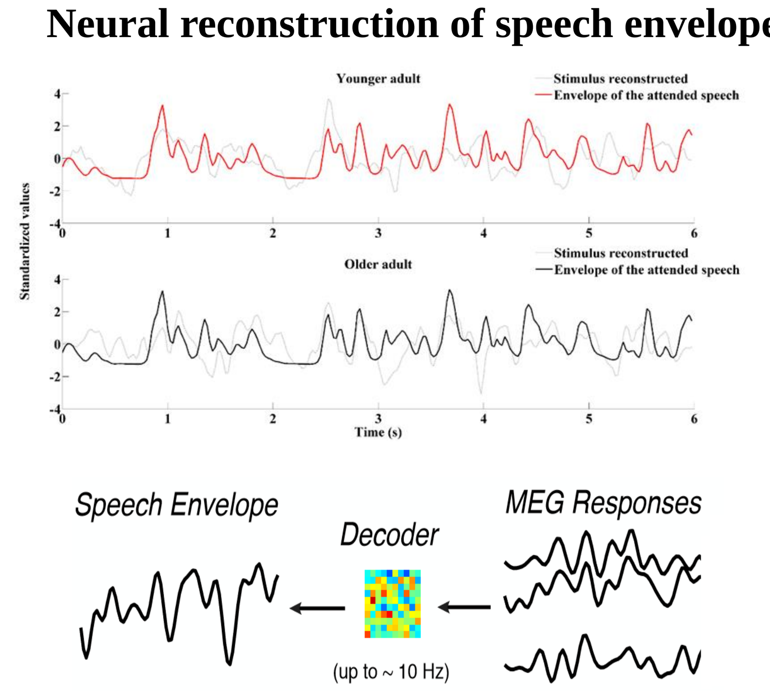


Fig. 3 *Top* Backward Model used to reconstruct the speech envelope from MEG response. *Bottom* Example of neural reconstruction of the speech envelope for two subjects, one per age group. Grey line represents the speech envelope of the attended stimulus, while black-dashed line represents the stimulus reconstructed with MEG.

Statistical analysis

- A paired t-test was used to compare difference within subjects, while 1-way ANOVA was applied to study differences across groups.
- The Spearman test (1-tailed) was used to calculate the correlation between peripheral hearing threshold , speech intelligibility score, auditory midbrain EEG and auditory cortex MEG variables.

Results

Auditory Midbrain EEG

A Grand Average

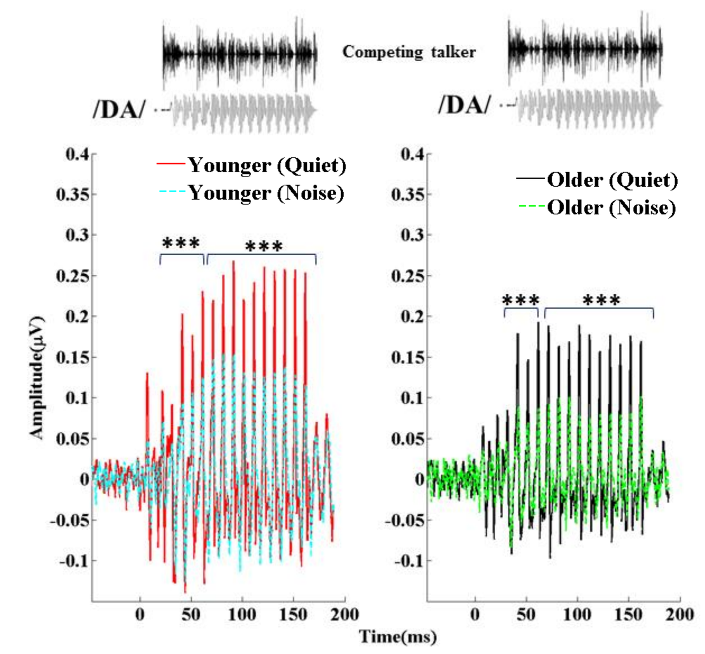
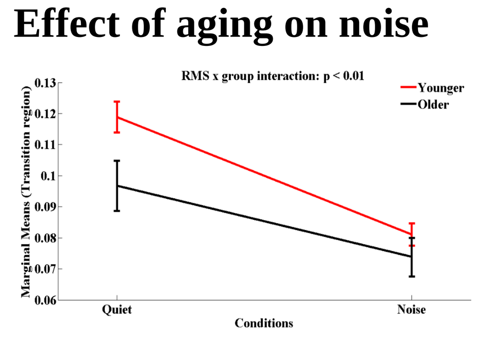


Fig.4 A) *Top.* Time series of the speech syllable /da/ and example of a competing single talker. *Bottom.* Grand average (n = 15) of the envelope for the two conditions of younger (left; quiet = red, noise = light blue) and older (Right; quiet = black, noise = green) adults. In the transition and steady-state regions, noise resulted in a significant decrease (p < 0.001) in the RMS amplitude in both younger and older adults. **B)** A 2-level repeated measures ANOVA showed RMS x group interaction effect in the transient region (*p < 0.01*), but not in the steady-state region (*p > 0.05*). **p < 0.05, **p < 0.01, ***p < 0.001*

B Effect of aging on noise



- **Adding noise to speech attenuates the neural response for both age groups.**
- **The effects of noise are reduced in older adults compared to younger adults, possibly because the responses of the older adults are already compromised in quiet.**

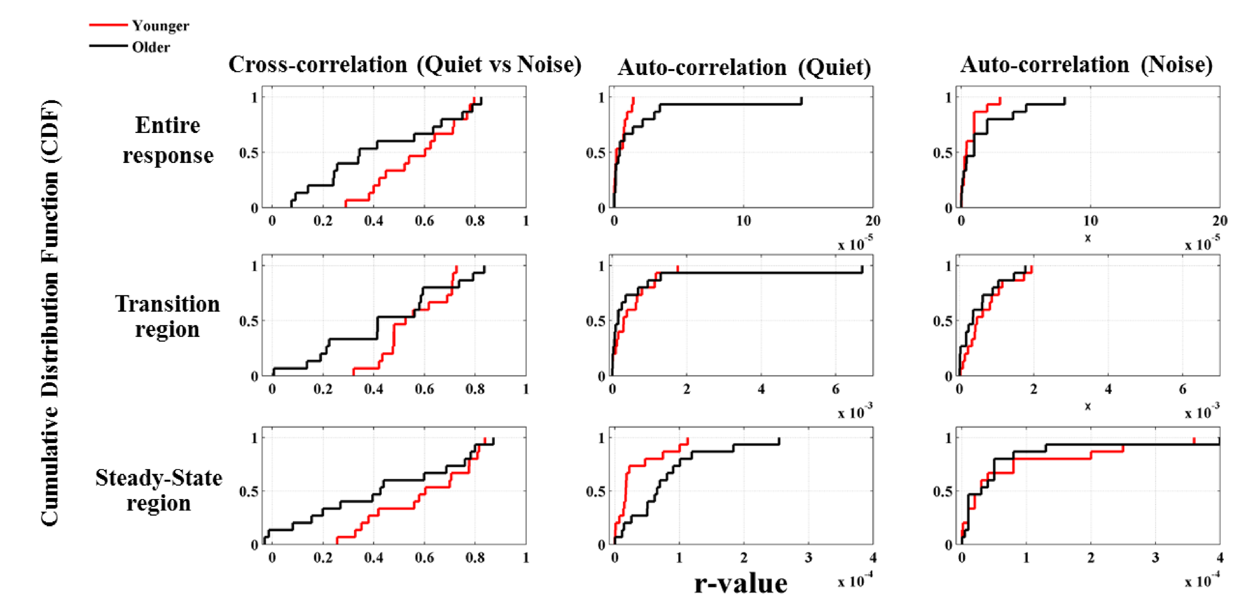


Fig.5 Cumulative Distribution Function (cdf) of the cross-correlation between quiet and noise and of the auto-correlation values in quiet and noise calculated for the entire response (*Top*), for the Transition region (*Middle*) and for the steady-state region (*Bottom*).

- **Overall, younger adults show stronger resistance to noise (higher cross-correlation values and lower auto-correlation values) than older adults.**

Auditory Cortex MEG

Reconstruction accuracy of the foreground speech envelope

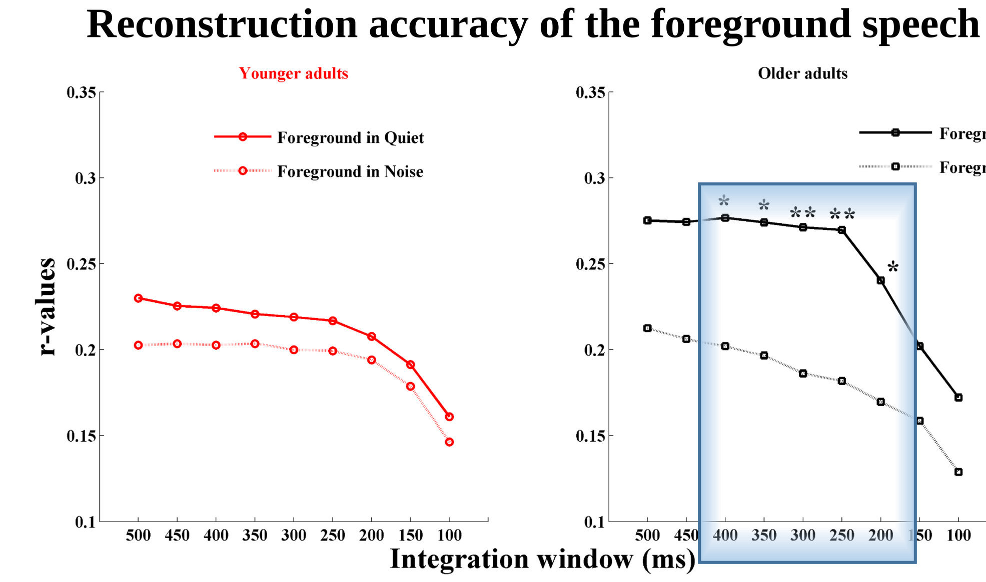


Fig. 6 Reconstruction accuracy of the target speech stimulus for younger (red) and older (black) adults in quiet (solid line) and in noise (dashed-line). The shadow area represents the region where the performance of older adults in quiet becomes significantly from noise *$p < 0.05$, **$p < 0.01$*

- **Noise minimally affects the performance of younger adults, while older adults' ability to track the envelope of the foreground is significantly reduced at most of the integration windows.**

Neural enhancement in younger and older adults

Integration window (ms)	500	450	400	350	300	250	200	150	100
Younger	*	*	**	**	**	**	**	*	N.S.
Older	*	*	*	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

Table 1 Significance values (paired t-test) for the contrast between foreground and background when the speech envelope was reconstructed using single trials. ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$; N.S. = Non significant

- **The competing talker is more efficiently suppressed by younger adults.**

Correlations between Hearing Threshold (HT), midbrain and cortex

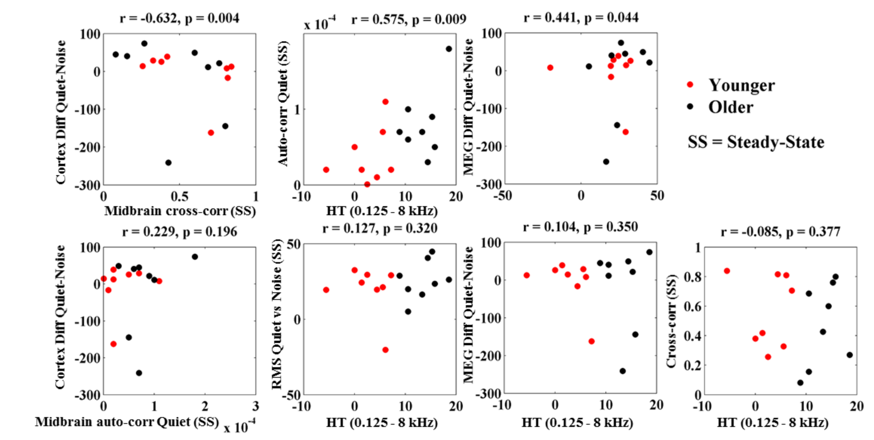


Fig.7 A) Correlations between HT (0.125 – 8 kHz) and auditory cortex MEG and auditory midbrain EEG variables. B) Correlations between auditory cortex MEG variable (Difference Foreground between Quiet and Noise at 500ms) and auditory midbrain EEG variables. **$p < 0.01$, *$p < 0.05$

- **Subcortical and cortical responses significantly correlated: midbrain temporal processing may strongly influence cortical speech encoding.**

Correlations between Speech Intelligibility, HT, midbrain and cortex

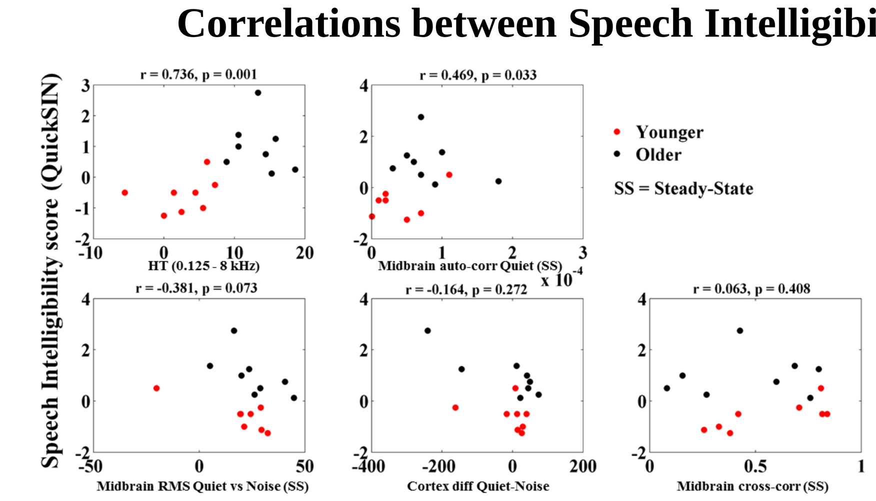


Fig.8 Correlations between speech intelligibility and the following variables: 1) HT (0.125 – 8 kHz), 2) Diff Foreground between Quiet and Noise at 500ms 3) Auto-correlation Quiet (Steady-State), 4) Cross-correlation Quiet vs Noise (Steady-State) and 5) Diff RMS Quiet vs Noise (Steady-State).

- **Significant correlation only between speech intelligibility and HT and subcortical activity: possible compensation of temporal processing problems at the cortical level.**

Can Neural Measures Account for Speech Intelligibility?

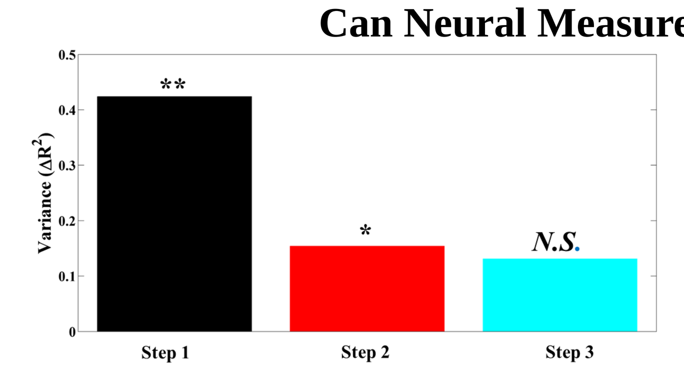


Fig.9 Results of a multiple linear regression analysis between speech intelligibility (dependent variable) and HT, auditory midbrain EEG and auditory cortex MEG parameters (independent variable). Each group represents a different set of independent variables used to predict the speech intelligibility score. Step 1 = HT, Step 2 = HT + Cortex parameters; Step 3 = HT + Cortex + Midbrain parameters. **$p < 0.01$, *$p < 0.05$; N.S. = Non significant

- **The audiogram significantly explains more than 42% of the variance.**
- **The addition of auditory cortex MEG and the auditory midbrain EEG parameters help explain an additional 28% of the remaining variance.**

Conclusions

- ***Auditory Midbrain***
  - A RMS x group interaction effect was found between age groups reflecting a smaller difference in amplitude between quiet and noise conditions in older adults: **older adults' ability to encode speech information in the auditory midbrain is already compromised in quiet.**
  - The cross-correlation between the response of younger adults in quiet and noise is higher in younger adults throughout the whole response, suggesting that **younger adults are more robust to noise**.
  - The auto-correlations in quiet in the steady-state region of the younger adults is significantly lower than the one of older adults, suggesting **a more stable and periodic response in younger adults**.
- ***Auditory Cortex***
  - Older adults were able to neurally reconstruct the target speech and filter out the competing talker as long as the integration window was long enough to allow them to process the speech, suggesting that **older adults need longer time to process information.**
- ***Midbrain-Cortex relationships***
  - A significant correlation was found between auditory midbrain EEG and auditory cortex MEG variables, suggesting the possibility that **temporal deficits at the subcortical level might partially affect encoding of speech at the cortical level.**
  - Significant correlations were found between speech intelligibility and auditory midbrain EEG parameters, but not between speech intelligibility and auditory cortex MEG parameters, suggesting **a possible compensation of temporal processing problems at the cortical level.**
  - A multiple linear regression analysis showed **auditory midbrain EEG and auditory cortex MEG parameters account for up to 28% of the variance of the speech intelligibility.**
  - Altogether our findings show a possible relationship between subcortical and cortical neural activity, suggesting that robustness of speech encoding in midbrain may affect processing in auditory cortex. Furthermore, our results show temporal processing deficits in older adults both at the subcortical and cortical level, which might lead to problems in understanding speech-in-noise, as highlighted by poor speech intelligibility scores.

References

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Acknowledgements

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