Interacting effects of aging and context on neural temporal processing

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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 noise. These difficulties may arise from deficits in auditory temporal processing [1]. One important factor that affects the level of understanding of speech-in-noise in older adults is the type of background noise: low context noise is better filtered out by older adults than high context noise, while younger adults' performance does not vary significantly with noise context [2]. A loss of temporal precision may be a key factor underlying subcortical timing delays and decreases in response consistency and magnitude in older adults [3]. Temporal processing deficits at the midbrain and cortical level could also help explain the difficulties experienced by older adults in suppressing irrelevant information, as deficiencies to properly encode auditory stimuli might lead to a higher use of cognitive resources that will make the suppression of relevant stimuli more challenging to achieve. The frequency following response (FFR) is an efficacious measure at the midbrain level for predicting self-reported speech-in-noise perception difficulties in older adults [4]. Recent results using magnetoencephalography (MEG) [5,6] 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 [4,5,6], little is known about how the type (high vs low context) and the level of noise impacts cortical speech processing in younger vs. older adults.

Hypotheses

We compared the effects of noise in high and low context conditions and in different SNRs 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 that 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. We also hypothesized that high context noise and more challenging SNR values (i.e. -3 and -6 dB) will have a more deleterious effect on neural processing in older than in younger adults.

Participants

- Participants had clinically normal hearing:
  - 6 younger adults (23 – 27 years old, mean ± SD, 24.16 ± 1.6 years)
    - Normal IQ scores [[mean ± SD, 120.85 ± 13.38] on Wechsler Abbreviated Scale of Intelligence
  - 6 older adults (61 - 68 years old, mean ± SD, 65.66 ±2.58 years)
    - Normal IQ scores [mean ± SD, 117.88 ± 14.47] on WASI
- All participants were native speakers of English with no history of neurological or middle ear disorders.
- Older adults were also screened for dementia on the Montreal Cognitive Assessment (MOCA) [mean ± SD, 27.25 ± 2.25].

Behavioral data

Hearing thresholds (HT) were obtained from 0.125 to 8 kHz in each subject, while the Quick Speech-in-Noise test (QuickSIN) [7] 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.

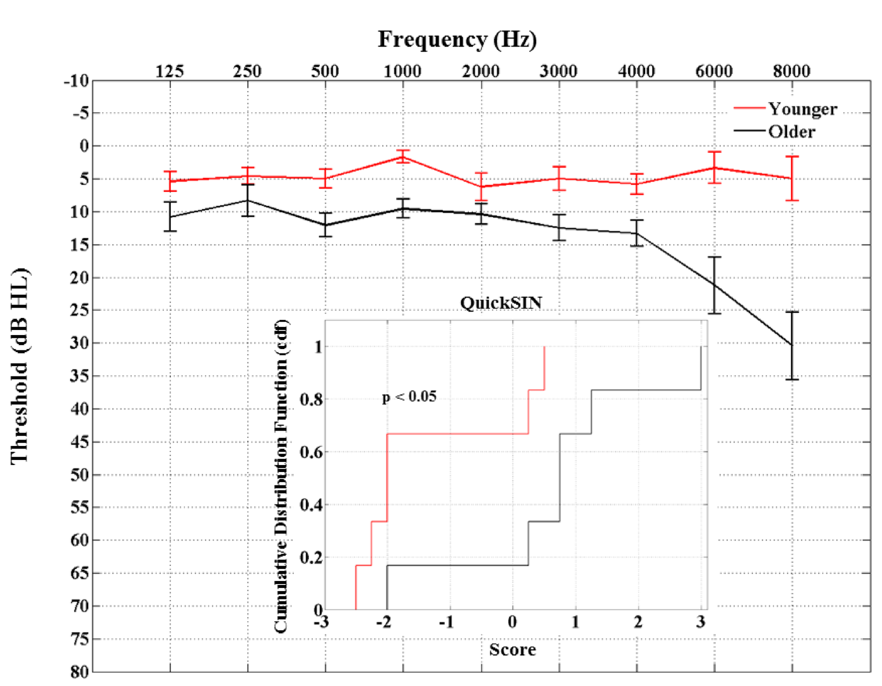

Fig. 1 Audiogram (mean ± 1SE) for younger (red) and older (black) adults. The inset shows the cumulative distribution function (cdf) of the results of the speech intelligibility test for younger and older adults (the lower the score, the better the understanding of speech in noise).

Auditory Midbrain EEG recordings

- A 170 ms speech syllable /da/ synthesized at 100 Hz with a Klatt-based synthesizer was presented diotically with alternating polarities at 80 dB SPL at a rate of 4 Hz through electromagnetically shielded insert earphones. The syllable /da/ was chosen because of its rapid change in the formant transition that poses an additional challenge to older adults.
- FFRs from each subject were obtained in 9 different conditions:

1) /da/ presented in quiet.
2) /da/ presented in one-talker babble: +3 dB, 0 dB, -3 dB, -6 dB SNR in high context (Female native English speaker) and in low context (Female Dutch Native English speaker)
3) 2000 sweeps per condition were recorded from the Cz electrode (Average ear lobes as reference and forehead as ground) using the Biosemi system with artifact 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 70 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.
- The target story was spoken by a male native speaker of English; competing speech was spoken by a female speaker
- There were two context conditions:
  - High context: the female speaker was a native speaker of English
  - Low context: the female speaker was a native speaker of Dutch
- Three trials (1 min/trial) were recorded for each condition:
  - Quiet, +3 dB, 0 dB, -3 dB, -6 dB SNR in low and high context scenarios.
- 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.

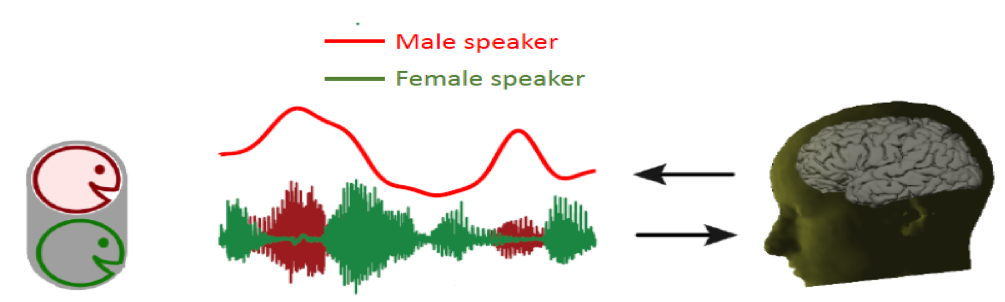

Fig. 2 Graphical representation of the MEG task. Subjects were instructed to attend to the male speaker (red) while trying to ignore the female competing talker (green). The MEG response was used to reconstruct the envelope of the speech stimulus to which the participant was instructed to attend.

Auditory Midbrain EEG Analysis

- Raw data were averaged and bandpass filtered between 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 9 conditions in quiet and noise
- Cross-correlations between responses in quiet and in high and low context noise were also calculated.

Auditory Cortex MEG analysis

- Data were de-noised using Time-shifted Principal Components Analysis (PCA).
- De-noised data were filtered between 2 – 8 Hz and separated into components via the Denoising Source Separation (DSS) algorithm.
- Only the first 6 DSS components were retained, and then filtered between 1 - 8 Hz.
- A linear model [5,6] 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.

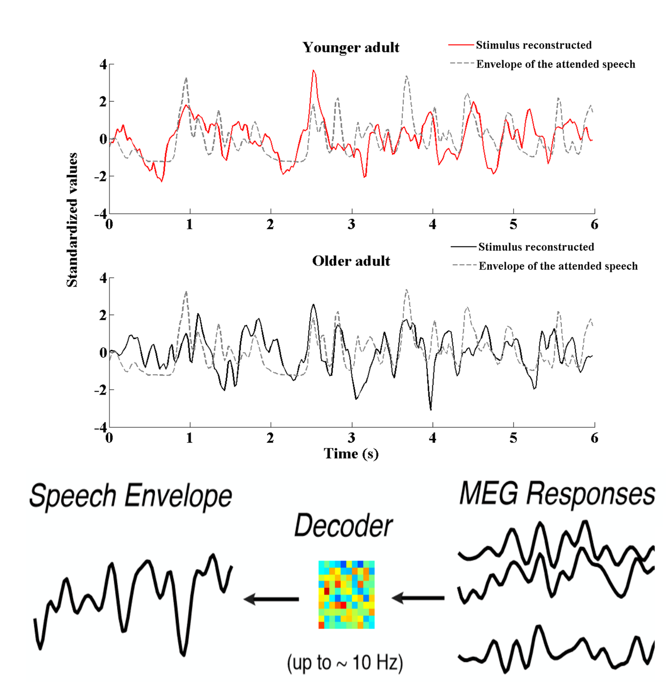

Fig. 3 *Top* Backward Model used to reconstruct the speech envelope from MEG response. *Bottom* Example of neural reconstruction of the speech envelope for two subjects, one per age group. Grey line represents the speech envelope of the attended stimulus, while black-dashed line represents the stimulus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

Statistical analysis

- A paired t-test was used to compare difference within subjects.
- One-way ANOVA was applied to study differences across groups.
- Whereas the Levene's test of equality was violated, the non-parametric Mann-Whitney U test was used in place of the One-way ANOVA.

Results

Auditory Midbrain (EEG)

Grand Average (Time domain)

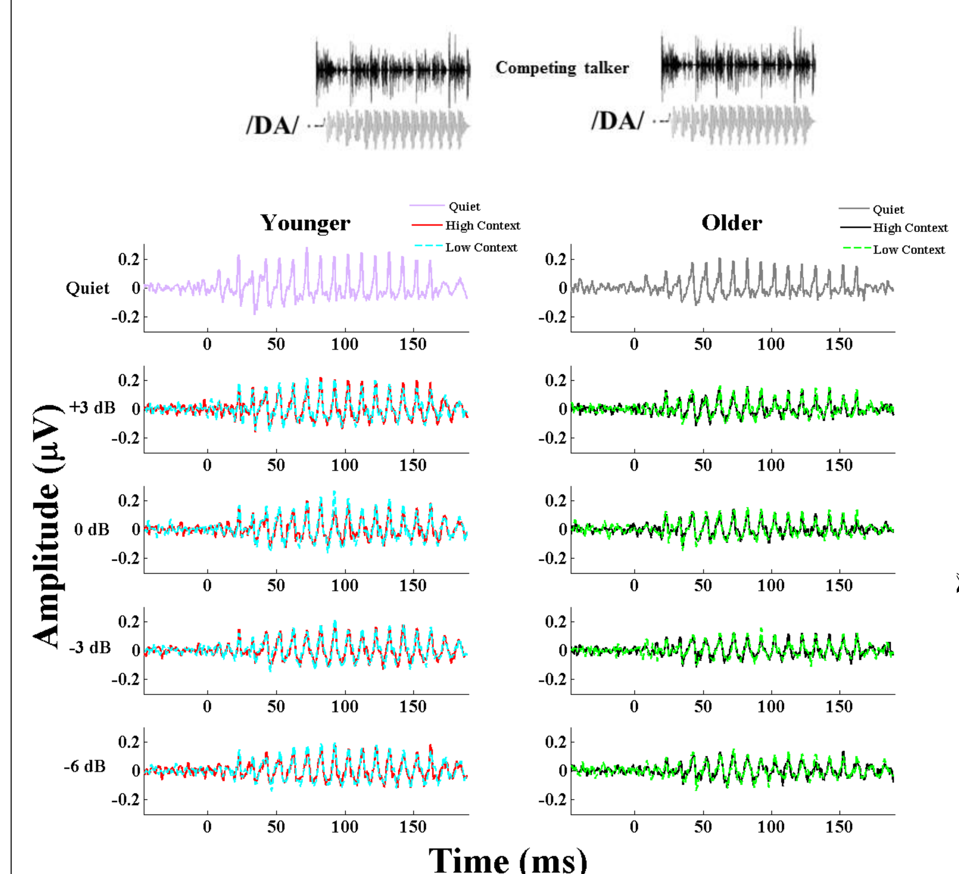

Fig.4 A) Time series of the speech syllable /da/ and example of a competing single talker. **B)** Grand average (n = 6) of the envelope for the 5 conditions of younger (left;) and older (right) adults. A paired t-test showed significant differences between high and low context RMS values in both younger ($p < 0.001$ and $p = 0.006$ in the transition and steady-state regions respectively) and older adults ($p < 0.001$ and $p = 0.006$ in the transition and steady-state regions respectively). A one-way ANOVA showed significant differences only in the steady-state region between younger and older adults both in high ($p < 0.001$) and in low ($p < 0.001$) context.

- **The degree that context affects the RMS value of the amplitude response in noise at the midbrain level does not significantly differ in the two age groups**

Grand Average (Frequency domain)

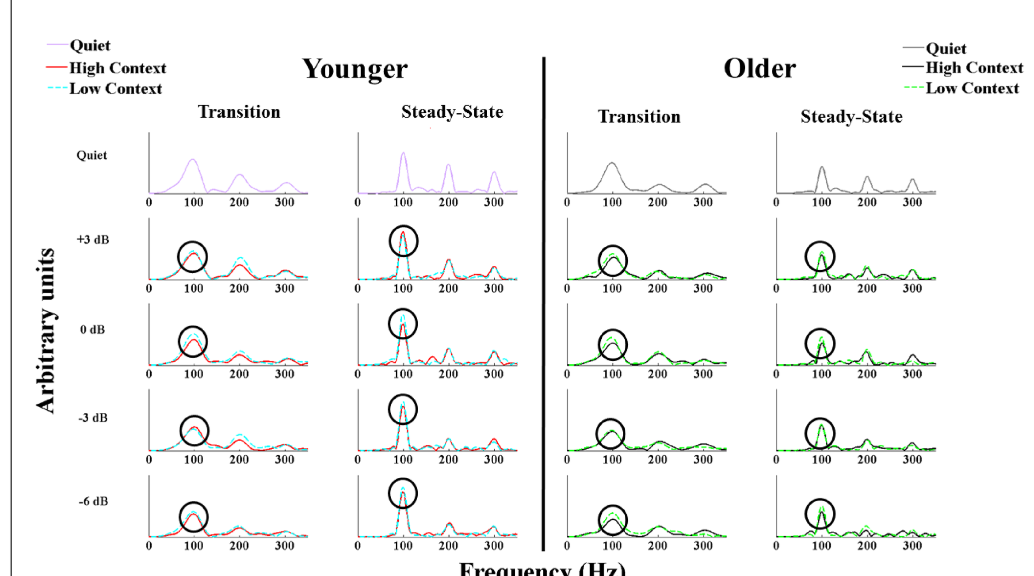

Fig.5 Frequency domain analysis of the grand average (n = 6) of the envelope for the 5 conditions of younger adults and older adults for the transition and the steady-state regions. A paired t-test showed significant differences in the transition between high and low context in the second harmonic (H2) in younger adults ($p = 0.021$) and in the fundamental frequency (F_0) in older adults ($p < 0.001$). In the Steady-State region, significant differences were observed only in older adults in F_0 ($p = 0.004$). A 3-level (F_0, H1 and H2) repeated measures ANOVA showed a correlation x group interaction ($p = 0.001$) in the steady-state region only.

- **The degree that context affects the fundamental frequency and the first two harmonics of the response in noise at the midbrain level differs in the two age groups. Frequency components are more attenuated in high context noise than in low context in older adults, whereas for younger adults significant differences were observed only in the transition region.**

Cross-Correlation response quiet vs noise

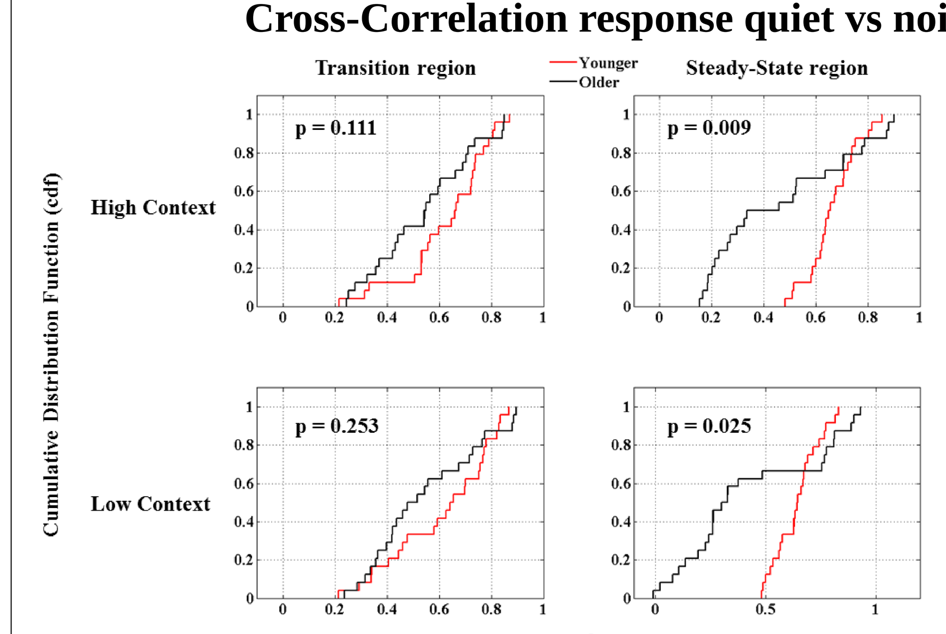

Fig.6 Cumulative Distribution Function (cdf) of the cross-correlation between quiet and noise in high (top row) and low (bottom row) context conditions for younger (red) and older (black) adults. Significant differences were found between younger and older adults in the steady-state region in both high ($p = 0.009$) a low context ($p = 0.025$). A 2-level repeated measures ANOVA showed a correlation x group interaction that approaches significant values ($p = 0.07$)

- **The degree that context affects the response in noise at the midbrain level differs in the two age groups. The FFR response appears to be degraded in high context more than low context noise in older adults.**

Auditory Cortex (MEG)

Neural enhancement in high and low context conditions

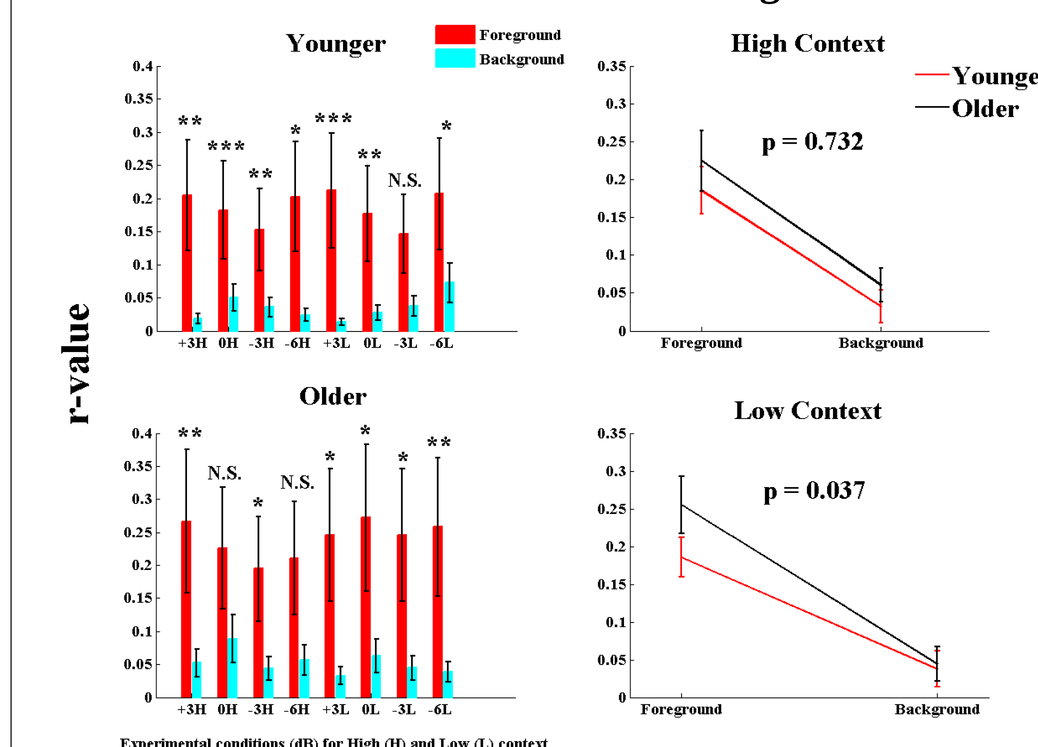

Fig.7 A) Significance values (paired t-test) for the contrast between foreground and background in high (H) and low (L) context situations for younger (top row) and older (bottom row) adults. Bars show the neural enhancement fir each single condition, **B)** ANOVA showed a significant interaction between group and foreground/background condition in low context ($p = 0.037$), but not in high context ($p = 0.732$). *$p < 0.05$, **$p < 0.01$, *** $p < 0.001$. N.S. = non-significant

- **The competing talker is suppressed equally efficiently by younger adults in low and high context conditions, while older adults' performance improves in low context.**

Neural advantage of reconstructing of foreground in low context vs high context

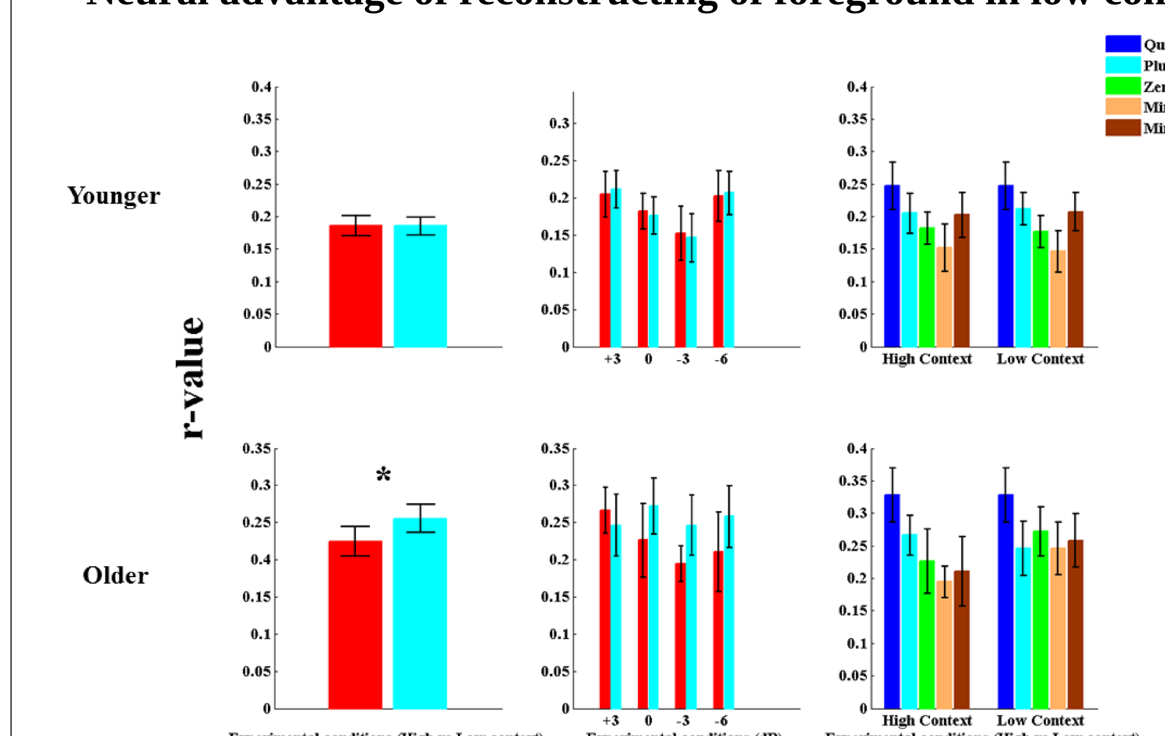

Fig.8 Foreground reconstruction accuracy for high and low context (*Left*). Significant differences were found between the two conditions only in older adults ($p = 0.029$). Foreground reconstruction accuracy for high and low context for each single condition (*Middle*). Comparison of the Foreground reconstruction accuracy between quiet and the noisy conditions tested (*Right*).

- **Older adults make use of low context to compensate for their problems in understanding speech in noise, while younger adults' performance is not affected by context.**
- **The higher baseline (r-value in quiet) in older adults suggests a higher level of cognitive resources are utilized to compensate for the higher listening efforts.**

- ***Auditory Midbrain***
  - The RMS value of the response in time domain is not significantly affected by the type of context: **RMS is not a good indicator of the effect of the context on older adults?**
  - A FFT x group interaction effect was found between age groups reflecting differences in F_0, H1 and H2 between quiet and noise conditions in older adults: **older adults' ability to encode speech information in the auditory midbrain is affected by the type of context.**
  - The cross-correlation between the response of younger adults in quiet and noise is significantly higher in younger adults in the steady-state region and is affected by the type of context, suggesting that **younger adults are more robust to noise and that the type of context could have some effects even at the midbrain level.**
- ***Auditory Cortex***
  - Older adults' ability to neurally reconstruct the target speech and filter out the competing talker is significantly affected by the type of context: **older adults make use of context to enhance their level of understanding of speech in noise.**
  - Younger adults' performance remains fairly stable across the different conditions.
  - Higher baseline found suggest **more attentional resources used to complete the task in older adults**.
  - Altogether our results show that the speech-in-noise difficulties reported by older adults are reflected by temporal processing deficits at the subcortical and cortical level. Our findings also suggest that the type of background noise (high vs low context) also affects the neural encoding of speech only in older adults. This is consistent with behavioral studies [2] that report a different performance of older adults in different contexts.

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