Effect of meaningful and meaningless noise on speech processing in auditory cortex and midbrain in younger and older adults

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Background

- Older adults often report that they have difficulty understanding speech in noisy environments, with poorer performance on speech-in-noise perceptual tasks than that of younger adults [1,2].
- Older adults may rely on cognitive resources to compensate for these perceptual deficits to a greater degree than do younger adults. For example, their speech-in-noise performance improves in the presence of a meaningless distractor (foreign language) compared to a meaningful distractor (native language), but this same difference is not seen in younger adults [3]. Furthermore, activation of prefrontal cortical areas associated with attention and memory is increased in older adults during speech-in-noise perception tasks [4]. Overall, these studies suggest that reduced attentional control may be a factor in older adults' listening difficulties.
- Temporal processing deficits in the midbrain [5] and cortex [6] may account in part for the difficulties experienced by older adults in suppressing irrelevant information, as deficits in proper encoding of auditory stimuli may lead to higher use of cognitive resources and greater difficulty in suppressing competing stimuli.
- Temporal processing may be evaluated using the frequency following response (FFR), an efficacious measure at the midbrain level for predicting self-reported speech-in-noise perception difficulties in older adults [7], or magnetoencephalography (MEG), a measure that can be used to evaluate processing of attended and unattended speech streams in auditory cortex [8,9].
- We compared the effects of meaningful and meaningless noise in different signal-to-noise ratio (SNR) conditions on subcortical (FFR) and cortical responses (MEG) in normal hearing younger and older adults.

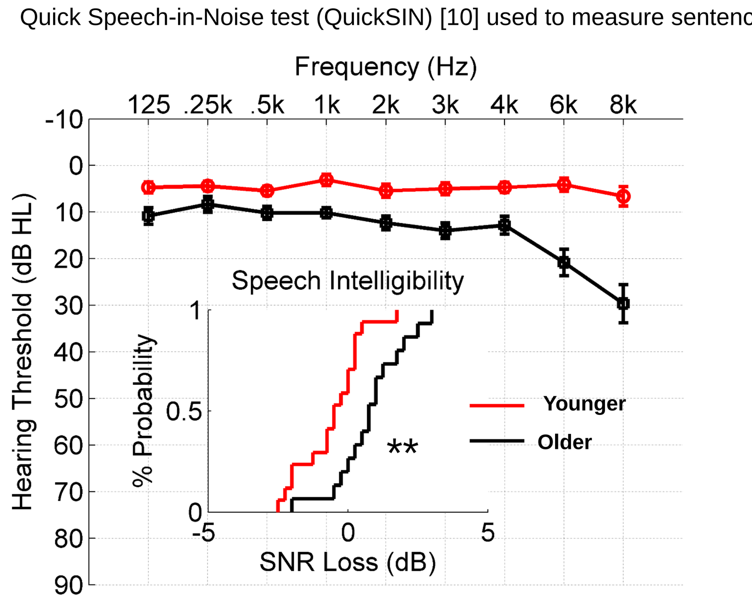
Hypotheses

Greater effects of noise will be observed for meaningful vs. meaningless competing speech on neural encoding in older but not younger adults. In addition, attentional ability plays a role in the strength of neural encoding in older adults.

Method

Participants

- Participants had clinically normal hearing:
  - 17 younger adults (YNH, 18 – 27 years old, mean ± SD, 22.35 ± 2.29 years)
    - Normal IQ scores [[mean ± SD, 111.88 ± 13.35] on Wechsler Abbreviated Scale of Intelligence
  - 15 older adults (ONH, 61 - 73 years old, mean ± SD, 65.06 ±3.3 years)
    - Normal IQ scores [mean ± SD, 116.26 ± 17.12] on WASI
- All participants were native speakers of English with no history of neurological or middle ear disorders.
- Older adults screened for dementia on the Montreal Cognitive Assessment (MOCA)
- [mean ± SD, 26.93 ± 2.71].
- Quick Speech-in-Noise test (QuickSIN) [10] used to measure sentence recognition in noise.



Despite clinically normal hearing, the ONH group has poorer speech intelligibility than the YNH group. ** p < 0.01.

Cognitive assessment

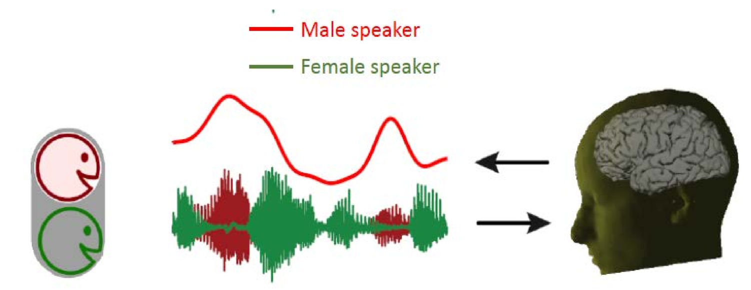
- The Conners Continuous Auditory Test of Attention® (Conners CATA®) used to assess attention. Reaction times (ms), and a measure of inattentiveness were compared.
- The Flanker Inhibitory Control and Attention Test of the National Institutes of Health Cognition Toolbox used to measure executive function (ability to inhibit visual attention to irrelevant stimuli). The unadjusted scale score used to compare age-related differences.

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 75 dB SPL at a rate of 4 Hz through electromagnetically shielded insert earphones (ER-1).
- FFRs from each subject 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 with meaningful noise (Female native English speaker) and with meaningless noise (Female Dutch Native English speaker)
- 2000 sweeps per condition 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
- Envelope extracted by summing the two polarities to reduce the stimulus artifact.

Auditory Cortex MEG recordings

- Speech presented at 70 dB SPL and low-pass filtered at 4 kHz.
- Participants asked to attend to one of two stories presented diotically while ignoring the other one.
- Target story spoken by a male native speaker of English and a competing story spoken by a female speaker in two conditions:
  1. Meaningful noise: the female speaker was a native speaker of English
  2. Meaningless noise: the female speaker was a native speaker of Dutch
- Three trials (1 min/trial) recorded for each of the following conditions:
  - Quiet, +3 dB, 0 dB, -3 dB, -6 dB SNR with meaningful and meaningless noise.
- Neuromagnetic signals 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.



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.

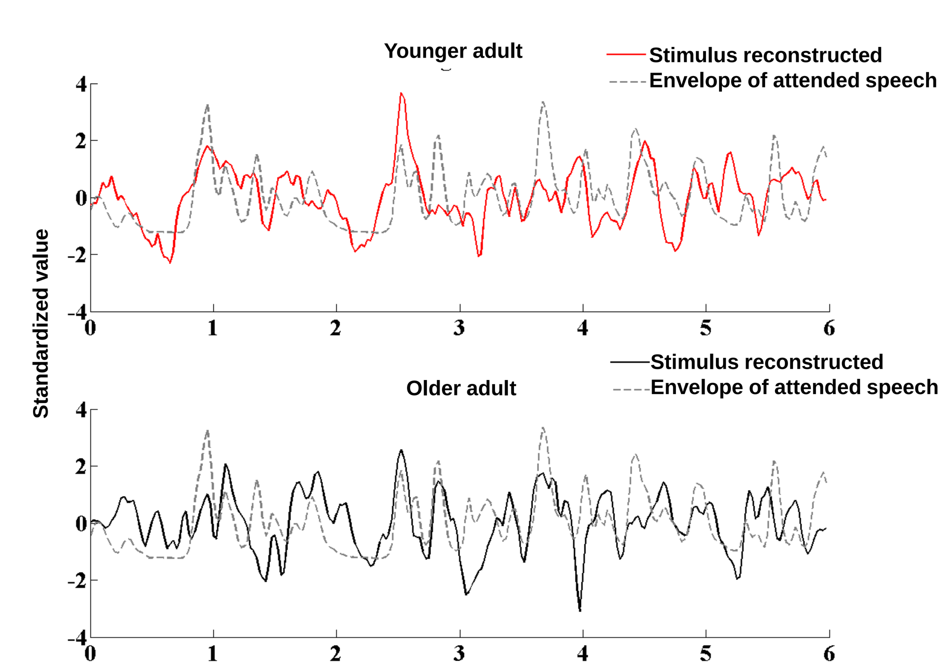
Auditory Midbrain EEG Analysis

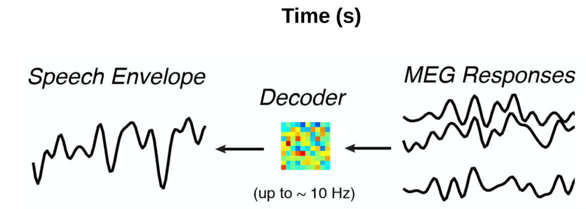
- Data averaged and filtered (70 - 2000 Hz; zero-phase; 4th order Butterworth).
- Grand-averages of the time series envelope of younger and older adults calculated for the 9 conditions in quiet and noise
- Correlations between responses in quiet and in high and low context noise were also calculated.

Auditory Cortex MEG analysis

- Data were de-noised using Time-shifted Principal Components Analysis (PCA).
- De-noised data filtered between 2 – 8 Hz and separated into components via the Denoising Source Separation (DSS) algorithm.
- Only the first 6 DSS components 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.

Neural reconstruction of speech envelope



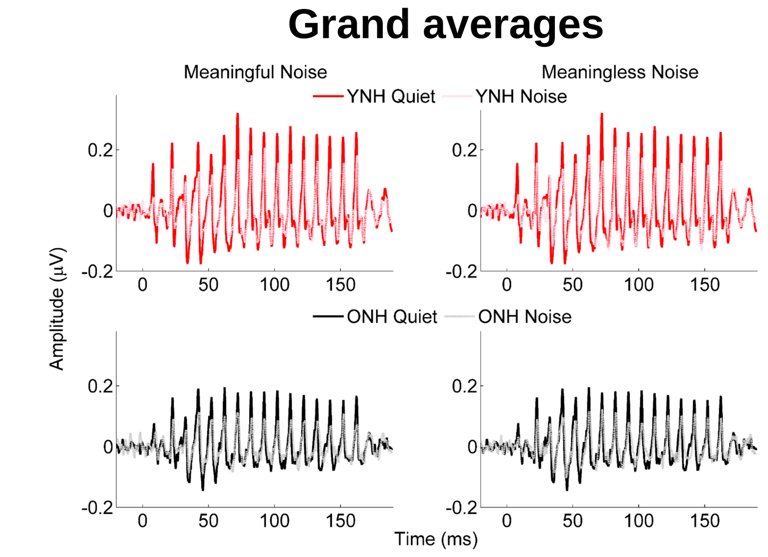


Statistical analysis

- Paired t-tests were used to compare differences within subjects.
- One-way ANOVA were applied to study differences across groups.
- Repeated-Measures ANOVA were used to study interactions between age groups. For the cortical analysis, the condition in quiet was used as a covariate.
- Familywise Error (Holm's method) to correct for multiple comparisons was applied as appropriate.

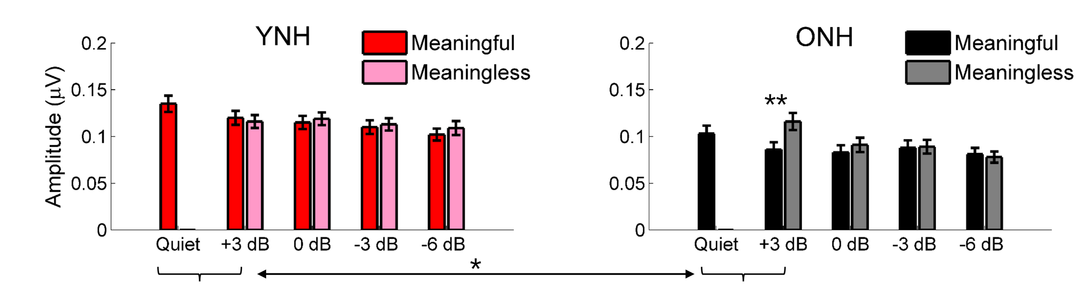
Results - Midbrain

Grand averages



- YNH and ONH responses in quiet and -6 SNR noise, with meaningful and meaningless noise.
- Responses in both groups appears to be similarly affected by both types of noise.

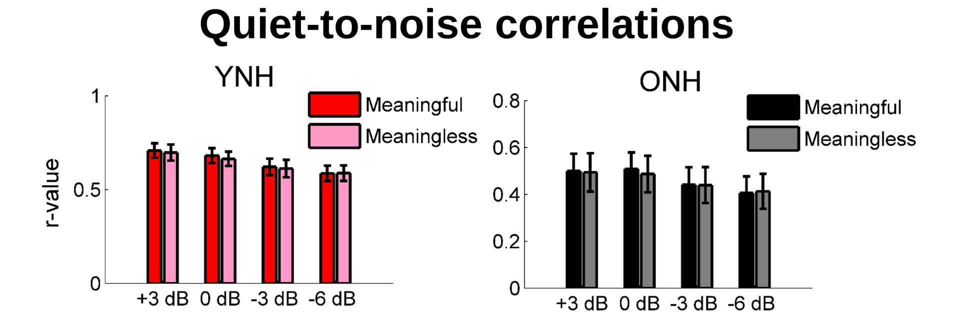
Response amplitudes



RMS amplitudes in the steady-state region (68-170 ms) for meaningful and meaningless noise for all presentation conditions:

- No significant differences between meaningful and meaningless conditions, except for the +3 dB condition in the ONH group (**p < 0.01)
- YNH amplitudes > ONH amplitudes for the quiet and +3 dB conditions (*p < 0.05)

Quiet-to-noise correlations

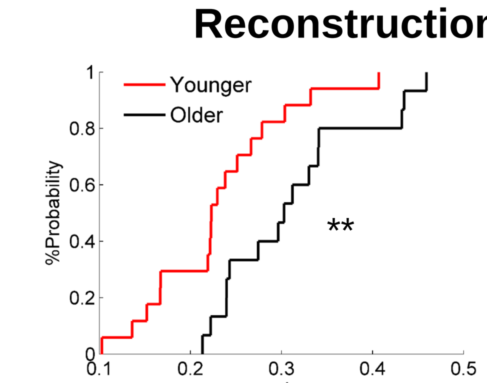


Quiet-to-noise correlations in the steady-state region for meaningful and meaningless noise for all presentation conditions:

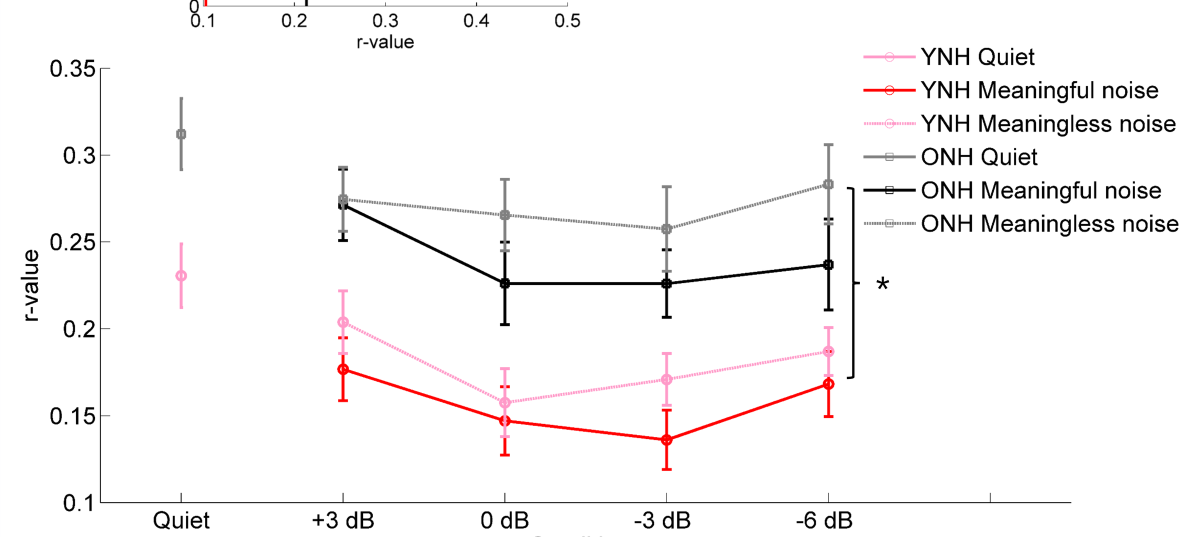
- No significant differences between meaningful and meaningless conditions in either group
- YNH r-values > ONH r-values for all conditions (all *p* values < 0. 05)

Results - Cortex

Reconstruction accuracy in quiet



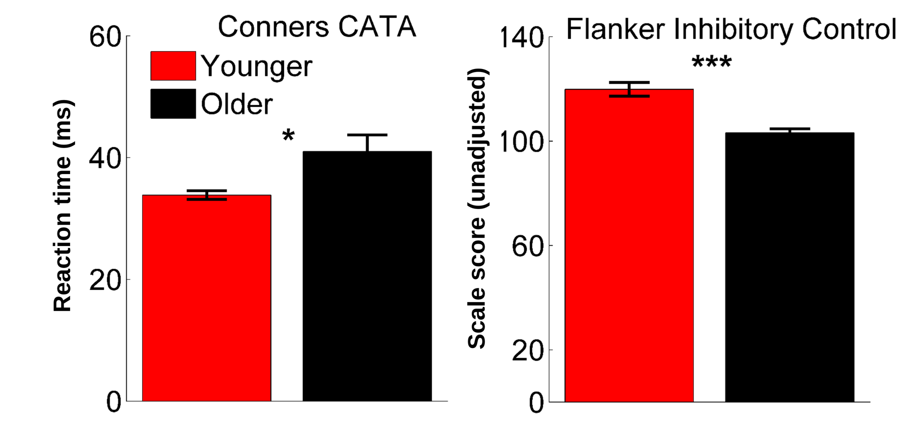
Cumulative distribution function: Higher reconstruction in ONH vs. YNH, indicating over-representation of speech envelope. **p 0.01



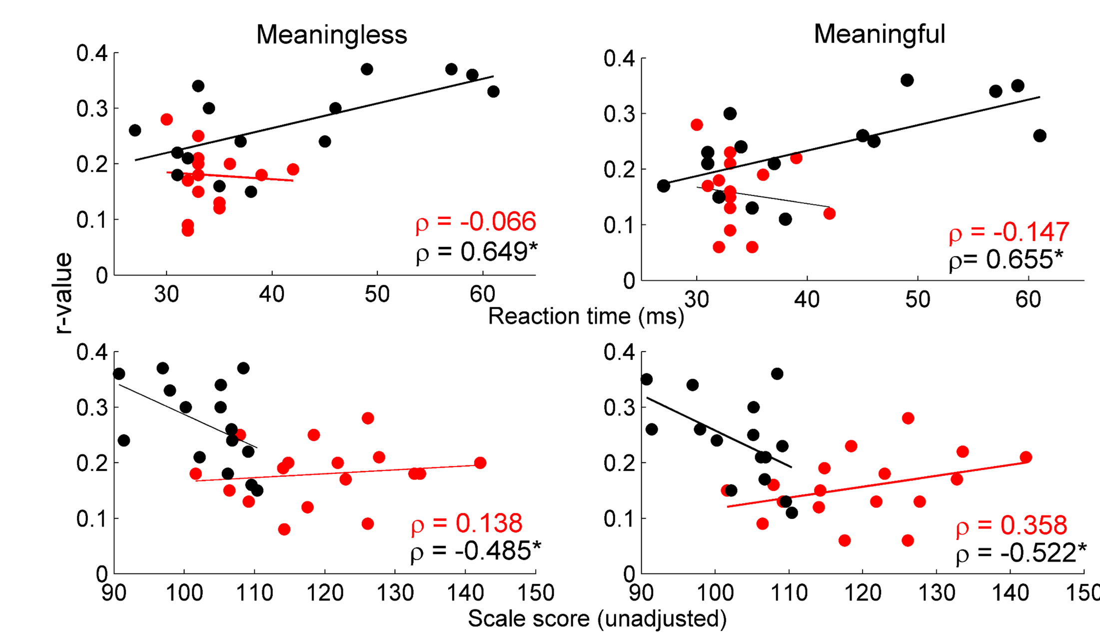
Reconstruction accuracy of target speech stream in the presence of meaningful vs. meaningless background:

- Group × condition interaction: differences between meaningful vs. meaningless noise are larger for the ONH than the YNH group for the most difficult condition (-6 SNR). *p < 0.05
- Reconstruction accuracy is higher in ONH than YNH across all conditions

Results - Cognitive



The ONH group has longer reaction times and reduced inhibitory control compared to younger adults



Cortical reconstruction accuracy is positively correlated with reaction time and negatively correlated with inhibitory control, but only in the ONH group.

Discussion

Auditory midbrain

- Younger adults' responses were more resistant to the effects of background noise than those of older adults
  - Increased temporal jitter associated with loss of auditory nerve fibers may result in decreased temporal precision, greater noise degradation in older adults
- Effects of type of background noise did not differ at the level of midbrain
  - The recording was passive and therefore did not engage top-down modulation of responses for different backgrounds

Auditory cortex

- Older adults had over-representation of the speech envelope for all conditions compared to young adults, suggesting:
  - Changes in the balance of excitatory and inhibitory neurotransmission, or
  - Increased neural resources (including cognitive functions) are engaged to encode the signal. This increase is especially evident in the correlations with performance on attention tests.
- The neural representation of the target speech stream is degraded by loud meaningful noise more than by loud meaningless noise:
  - Older adults make use of favorable conditions and engage cognitive resources to enhance understanding of speech in noise.

Cognition

- Reaction time was increased and response control inhibition was decreased in older adults compared to younger adults.
- Therefore, although older adults rely on cognitive resources to compensate for speech perception difficulties, reduced cognitive function limits this ability to compensate.

Summary

- Altogether our results suggest that the speech-in-noise difficulties reported by older adults may in part be explained by temporal processing deficits in the midbrain and cortex.
- Our finding that the type of background noise (meaningful vs. meaningless) may affect the cortical encoding of speech in older adults suggests a neural mechanism for behavioral studies that have found improved listening performance when the target speech signal is presented in meaningless vs. meaningful noise [2].

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Acknowledgements

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