Effect of Meaningful vs. Meaningless Noise on Speech Representations in the Aging Midbrain and Cortex

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Background

- Older adults often report that they have difficulty understanding speech in noisy environments [1,2].
- Older adults may rely on cognitive resources to compensate for these perceptual deficits to a greater degree than do younger adults:
  - Speech-in-noise performance improves in the presence of a meaningless distractor (foreign language) compared to a meaningful distractor (native language) [3].
  - Activation of prefrontal cortical areas associated with attention and memory is increased in older adults during speech-in-noise perception tasks [4].
- 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.
- Integrity of the temporal processing in the midbrain may be evaluated using the frequency following response (FFR) [7], while in the cortex may be evaluated using phase-locked oscillations in the delta-theta range [8,9].
- We compared the effects of meaningful and meaningless noise (one-talker babble) in different signal-to-noise ratio (SNR) conditions on subcortical (FFR) and cortical responses (MEG) in normal hearing younger and older adults. We also recorded the same protocol in a subset of older adults with hearing loss.

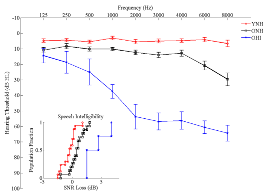
Hypotheses

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 with clinically normal hearing:
  - 17 younger adults (YNH, 18 – 27 years old, mean ± SD, 22.23 ± 2.27 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
- Participants with impaired hearing:
  - 4 older adults (OHI, 67 – 75 years old, mean ± SD, 70.25 ± 3.4 years)
    - Normal IQ scores [mean ± SD, 104.3 ± 13.91] on WASI
- All participants were native speakers of English without any understanding of the Dutch language and 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 for ONH and 27.25 ± 1.25 for OHI].
- 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 = 0.003.

Cognitive assessment

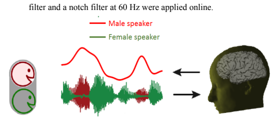
- Conners Continuous Auditory Test of Attention® (Conners CATA®) used to assess attention. Reaction times (ms), and a measure of inattentiveness were compared.
- Flanker Inhibitory Control and Attention Test of the National Institutes of Health Cognition Toolbox used to measure executive function (ability to inhibit visual attention to irrelevant tasks). 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 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 were noise was meaningful (Female native English speaker) or meaningless (Female Native Dutch 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 any 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, at 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.

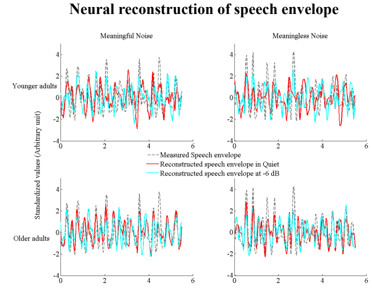
Auditory Midbrain EEG Analysis

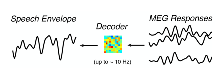
- Data averaged and filtered (70 - 2000 Hz; zero-phase; 4th order Butterworth).
- Grand-averages of the time series envelope of younger and older adults calculated for the 9 conditions in quiet and noise
- Correlations between responses in quiet and in high and low context noise were also calculated.

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.
- 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

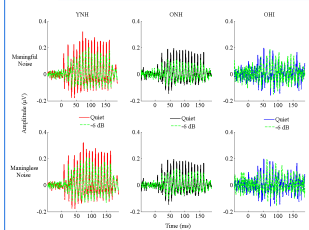




Statistical analysis

- Paired t-tests were used to compare differences within subjects.
- One-way ANOVA were applied to study differences across groups. Non-parametric Mann-Whitney U test used when Levene's test was not satisfied
- 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.

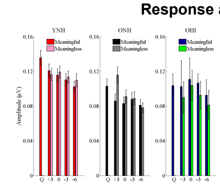
Results - Midbrain



- **Responses in all groups appear to be similarly affected by both types of noise.**

YNH, ONH and OHI responses in quiet and -6 SNR noise, with meaningful and meaningless noise.

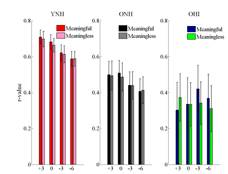
Response amplitudes



- **No significant differences between meaningful and meaningless conditions in both YNH and ONH**
- **YNH amplitudes > ONH and OHI amplitudes for all the conditions tested (all *p* values < 0. 01)**

RMS amplitudes in the steady-state region (68-170 ms) for meaningful and meaningless noise for all the conditions tested (Quiet, +3 dB, 0 dB, -3 dB and -6 dB)

Quiet-to-noise correlations

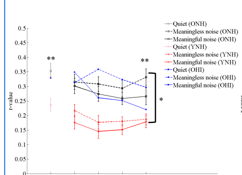


- **No significant differences between meaningful and meaningless conditions in either group**
- **YNH r-values > ONH and OHI r-values for all conditions (all *p* values < 0. 05)**

Quiet-to-noise correlations in the steady-state region for meaningful and meaningless noise for all the conditions tested (Quiet, +3 dB, 0 dB, -3 dB and -6 dB)

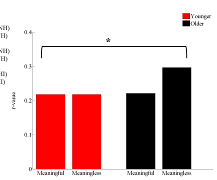
Results - Cortex

Reconstruction accuracy



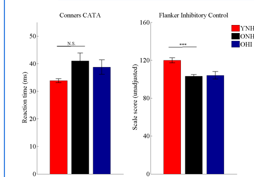
- **Reconstruction accuracy is higher in ONH and OHI than in YNH across all conditions.**

Age × correlation interaction at -6 dB



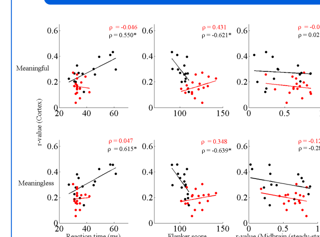
- **Group × condition interaction: differences between meaningful vs. meaningless noise are larger for the ONH than the YNH group for the most difficult condition (-6 SNR). ***p* = 0.003**

Results - Cognitive



- **ONH and OHI group have longer reaction times and reduced inhibitory control compared to YNH**

Results – Correlation



- **Mean Cortical reconstruction accuracy across all the SNR conditions is positively correlated with reaction time and negatively correlated with inhibitory control, but only in the ONH group and regardless of the type of noise.**
- **No correlation found between midbrain and cortex regardless of the noise type**

Discussion

Auditory midbrain

- YNH responses were more resistant to the effects of background noise than those of ONH and OHI
  - 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

- Both ONH and OHI had over-representation of the speech envelope 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 ONH in the correlations with performance on attention tests.
- The neural representation of the target speech stream is degraded by meaningful noise more than by meaningless noise at -6 dB:
  - Both ONH and OHI 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 both ONH and OHI compared to younger adults.
- Reduced cognitive function limits this ability to compensate for speech perception difficulties.

Correlation

- No correlation found between midbrain and cortex. Cortical plasticity might compensate for temporal processing deficits observed in the midbrain.

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.
- The fact that cortical encoding is enhanced with meaningless vs meaningless noise provides evidence for a neural mechanism underlying the perceptual improvement experienced in older adults when the background noise is meaningless [2].
- Absence of correlation between midbrain and cortex suggests the existence of a central neuroplasticity mechanism to compensate for temporal processing deficits observed in midbrain [11].

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Acknowledgements

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