Effect of informational content of noise on neural speech representations, with and without peripheral hearing loss

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Background

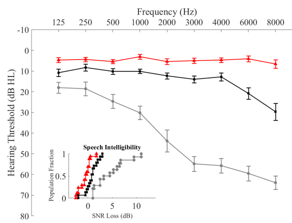
- Older adults report difficulty understanding speech in noisy environments [1,2], even when audibility is restored with hearing aids [3].
- Older adults may rely on cognitive resources to compensate for perceptual deficits to a greater degree than younger adults:
  - Speech-in-noise performance improves in the presence of a meaningless distractor (foreign language) compared to a meaningful distractor (native language) [4].
  - Activation of prefrontal cortical areas associated with attention and memory is increased in older adults during speech-in-noise perception tasks [5].
- Temporal processing deficits in the midbrain [6,7] and cortex [6,7] may account in part for the difficulties experienced by older adults in suppressing irrelevant information.
- Informational content of noise affects older adults' cortical, but not subcortical response [7].
- Peripheral hearing appears to alter subcortical [8] and cortical [9] responses.
- 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 adults (YNH) and in older adults with (OHI) and without (ONH) hearing impairment.

Method

Participants

- Participants with clinically normal hearing:
  - 17 normal hearing younger adults (YNH, 18 – 27 years old, mean ± SD, 22.23 ± 2.27 years)
  - 15 normal hearing older adults (ONH, 61 - 73 years old, mean ± SD, 65.06 ±3.3 years)
  - 14 hearing impaired older adults (OHI, 62 - 86 years old, mean ± SD, 71.28 ±6.2 years)
- All participants had IQs ≥ 85 on Wechsler Abbreviated Scale of Intelligence and the ONH and OHI groups were screened for dementia on the Montreal Cognitive Assessment
- All participants were native speakers of English with no understanding of the Dutch language and no history of neurological or middle ear disorders.
- Quick Speech-in-Noise test (QuickSIN) [12] used to measure sentence recognition in noise.

Audiogram and speech intelligibility score



- Normal hearing and hearing impaired older listeners has poorer speech intelligibility than the YNH group. Hearing loss exacerbates this difficulty.

Cognitive assessment

- 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

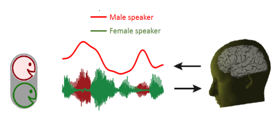
- 170 ms speech syllable /da/ presented diotically with alternating polarities at 75 dB SPL at a rate of 4 Hz through insert earphones (ER-1).
- FFRs from each subject obtained in 9 different conditions: /da/ presented in quiet and in one-talker babble: +3 dB, 0 dB, -3 dB, -6 dB SNR where noise was meaningful (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 Midbrain EEG Analysis

- Data averaged and filtered (70 - 2000 Hz; zero-phase; 4th order Butterworth).
- Grand averages of the 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 recordings

- Speech presented at 70 dB SPL (**adjusted when necessary to ensure audibility when testing OHI subjects**) and low-pass filtered at 4 kHz
- Participants asked to attend to one of two stories presented diotically while ignoring the other story
- 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.

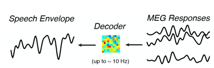


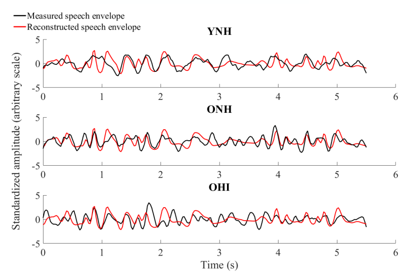
Graphical representation of the MEG task. Subjects instructed to attend to male speaker (red) while ignoring the female competing talker (green). The MEG response was used to reconstruct the speech stimulus envelope to which the participant was instructed to attend.

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 [6,7,10,11] 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





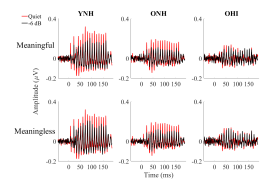
Data are representative samples recorded with -6 dB meaningful noise and are used for illustrative purpose, only.

Statistical analysis

- Paired t-tests were used to compare differences within subjects.
- One-way ANOVA applied to study differences across groups. Non-parametric Mann-Whitney U test used when Levene's test was not satisfied
- Repeated-Measures ANOVA used to study interactions across age groups. For the cortical analysis, the condition in quiet was used as a covariate.
- The false discovery rate (FDR) procedure (Benjamini et al. 1995) was applied to control for multiple comparisons where appropriate

Results - Midbrain

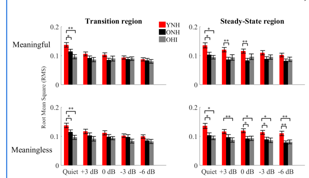
Grand averages



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

- **Noise reduces the amplitude of responses in both younger and older listeners**
- **Responses in all groups appear to be similarly affected by the two types of noise.**

Response amplitudes



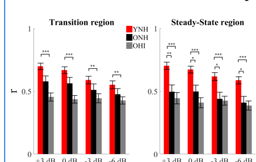
RMS amplitudes in the transition (18-68 ms) and steady-state region (68-170 ms) for meaningful and meaningless noise for all the conditions tested (Quiet, +3 dB, 0 dB, -3 dB and -6 dB).

- **Both types of noise reduce response amplitudes.**

  Normal hearing younger listeners had higher amplitudes than either group of older listeners in quiet and in both syllable regions.

  Normal hearing younger listeners had higher amplitudes than either group of older listeners (in meaningless noise) but only in the steady-state region.
- **No amplitude differences were seen between older adults with and without hearing loss.**

Correlation between the response in quiet and noise

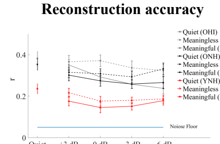


Quiet-to-noise correlations in the transition and steady-state regions for meaningful and meaningless noise for all the conditions tested (Quiet, +3 dB, 0 dB, -3 dB and -6 dB)

- **Lower SNRs produce greater degradation of responses for both types of noise.**
- **Normal hearing younger listeners had higher correlations than hearing impaired older listeners in both syllable regions, but their correlations were higher than the normal hearing older adults only in the steady-state region.**
- **No differences in response degradation were seen between older adults with and without hearing loss.**

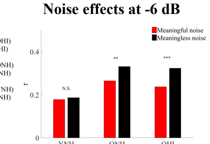
Results - Cortex

Reconstruction accuracy



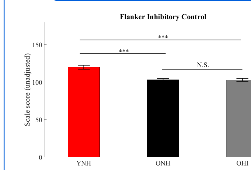
- **The reconstruction accuracy is reduced by the presence of the background talker at all the SNRs.**
- **Reconstruction accuracy not significantly different between normal hearing and hearing impaired older listeners.**
- **Reconstruction accuracy is higher in both groups of older listeners than in normal hearing younger listeners across all conditions.**

Noise effects at -6 dB



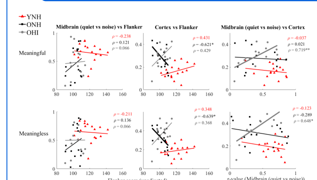
- **Differences between meaningful vs. meaningless noise are larger for both groups of older listeners than for normal hearing younger listeners for the most difficult condition (-6 SNR). *****p* **< 0.01, ******p* **< 0.001**

Results - Cognitive



- **Both groups of older listeners groups have reduced inhibitory control compared to normal hearing younger listeners**

Results – Correlation



- **Higher inhibitory control relates to lower reconstruction accuracy, but only for older normal hearing listeners.**
- **Greater resistance to noise degradation in midbrain relates to higher reconstruction accuracy, but only in older hearing impaired listeners.**

Discussion

Auditory midbrain

- The responses of normal hearing younger listeners were more resistant to the effects of background noise than those of either groups of older listeners
  - Increased temporal jitter associated with loss of auditory nerve fibers may result in decreased temporal precision, greater noise degradation in both groups of older adults

Auditory cortex

- Both normal hearing and hearing impaired older listeners 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 normal hearing older listeners 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 normal hearing and hearing impaired older listeners make use of favorable conditions and engage cognitive resources to enhance understanding of speech in noise.

Cognition

- Inhibitory control was decreased in both groups of older listeners compared to younger listeners.
- Reduced cognitive function limits this ability to compensate for speech perception difficulties.

Correlation

- Possible effect of peripheral hearing loss on the already deteriorated subcortical and cortical temporal processing and on cognitive processes?

Summary

- Altogether our results suggest that factors other than peripheral hearing loss, such as age-related temporal processing deficits in the midbrain and cortex, could explain communication problems experienced by older adults
- The fact that there are no differences in overrepresentation of cortical representation between listeners with and without hearing loss suggests that aging effects, in addition to sensory deficits, may significantly contribute to cortical encoding deficits
- Different results found by the correlation analysis in normal and hearing impaired older listeners suggests the possibility that peripheral hearing loss may cause lower interdependence between midbrain and cortex [13]
- The results of the correlation analysis emphasize the importance of studying auditory temporal processing at different levels of the auditory system, in order to better understand if and how the failure to properly encode sound at one level of the brain could affect the final representation of speech in the cortex

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Acknowledgements

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