Mutual Information Analysis of Neural Representations of Speech in Noise in the Aging Midbrain

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Introduction

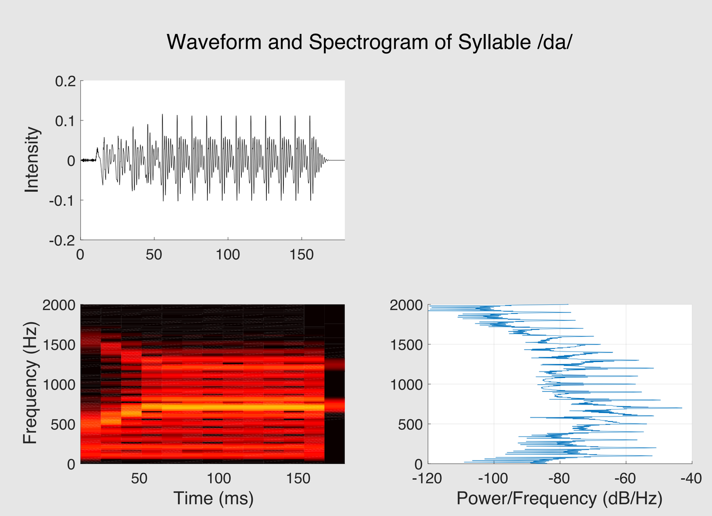
When two people talk at the same time, a young healthy listener does not have trouble attending to only one speaker. However, the ability to understand speech in challenging conditions deteriorates with aging, even for older adults with clinically normal audiograms. Deficits in the central auditory system, including midbrain, may underlie this difficulty.

- Neural processing measured with frequency following response (FFR)[1] recorded by electroencephalography (EEG)
- Brief speech stimuli (170-ms /da/) masked with continuous long-duration speech at 4 different SNRs (English and Dutch)
- 17 younger adults (age: 18-27) and 15 older adults (age: 61-73), native English speakers with clinically normal hearing
- Reanalysis of earlier experiment[2][3] using mutual information analysis

Methods

Sound stimulus

- The foreground sound stimulus is a 170-ms /da/, synthesized at a 20-kHz sampling rate[4], and is presented 2000 times in both polarities.
- For conditions with a noise background, the background is a story narrated by a female speaker in either English ("meaningful") or Dutch ("meaningless").



- The background speech segment is 1-min long and is repeated continuously.
- The background speech is mixed at SNR levels of 3 dB, 0 dB, -3 dB and -6 dB.
- The FFR is recorded with EEG at sampling frequency 16,384 Hz.

Mutual Information

- A 10-ms temporal response function centered at 0 ms with reference to the stimulus onset time estimated to remove feedthrough artifact[5]
- Consecutive opposite polarities averaged to get 1,000 trials for each condition
- Trials band-passed into frequency bands centered at harmonics of 100 Hz.
- Responses of each trial separated into transition region (15-64 ms) and steady-state region (64-170 ms).
- Mutual information between stimulus and response estimated by

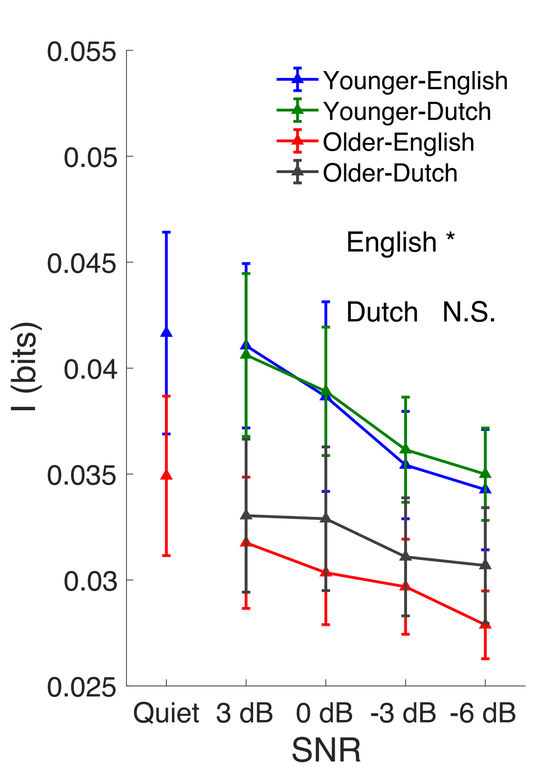
$$I(X;Y) = H(Y) - H(Y|X)$$

$$= -\sum_{i=1}^{N} p(Y=i)\log p(Y=i) + \frac{1}{T}\sum_{t=1}^{T}\sum_{i=1}^{N} p(Y=i|X=x_t)\log p(Y=i|X=x_t)$$

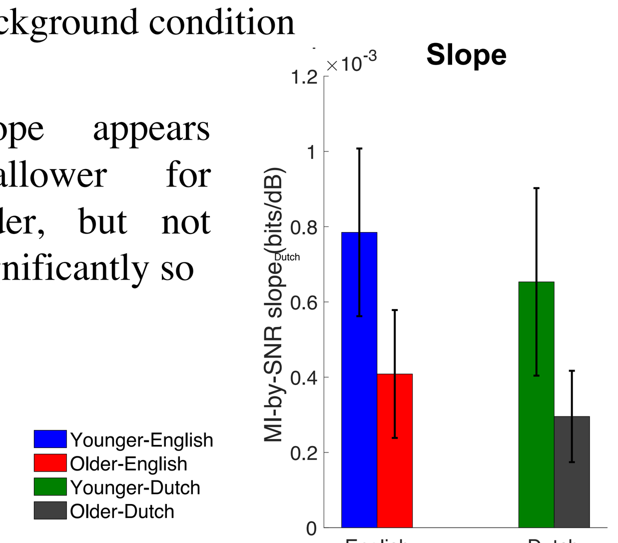
- X and Y: random variables denoting stimulus and response. Probability distribution of Y estimated by binning response samples from all trials; conditional probability of Y given X estimated by binning response from all trials at one single time point. Distribution of X assumed uniform

Results

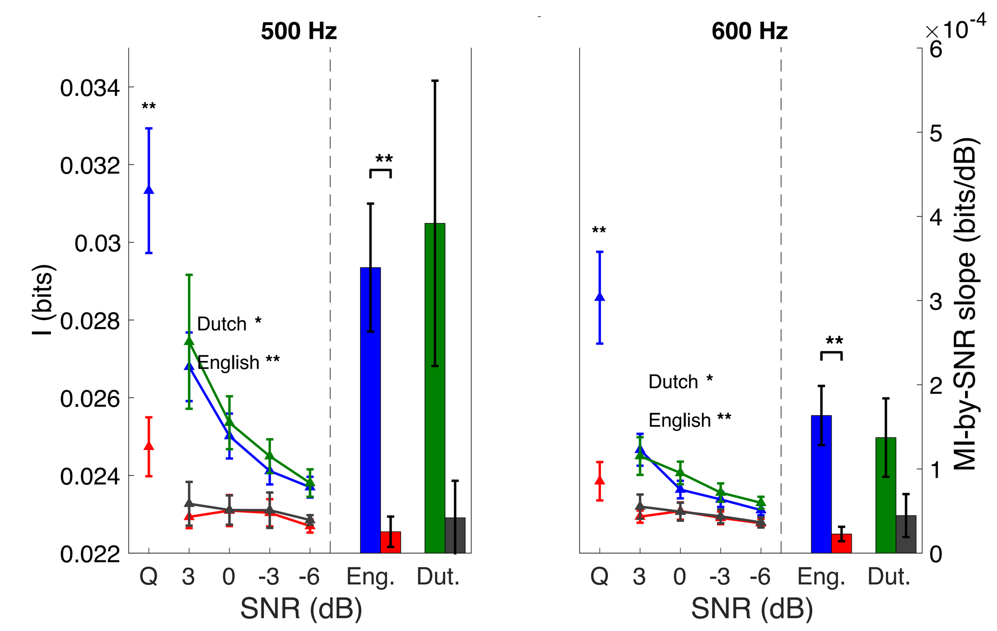
Information in FFR *amplitude* at 100 Hz by noise level



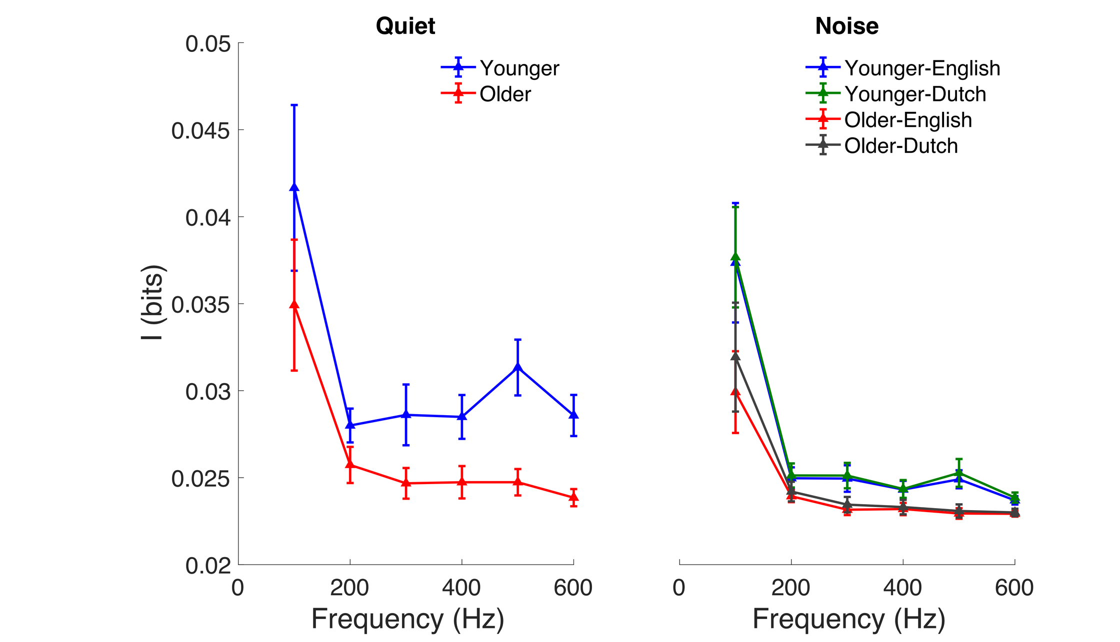
- Response in younger listeners conveys more *amplitude* information than for older listeners in the English background condition
- Slope appears shallower for older, but not significantly so



Information in FFR *amplitude* by noise level at harmonics

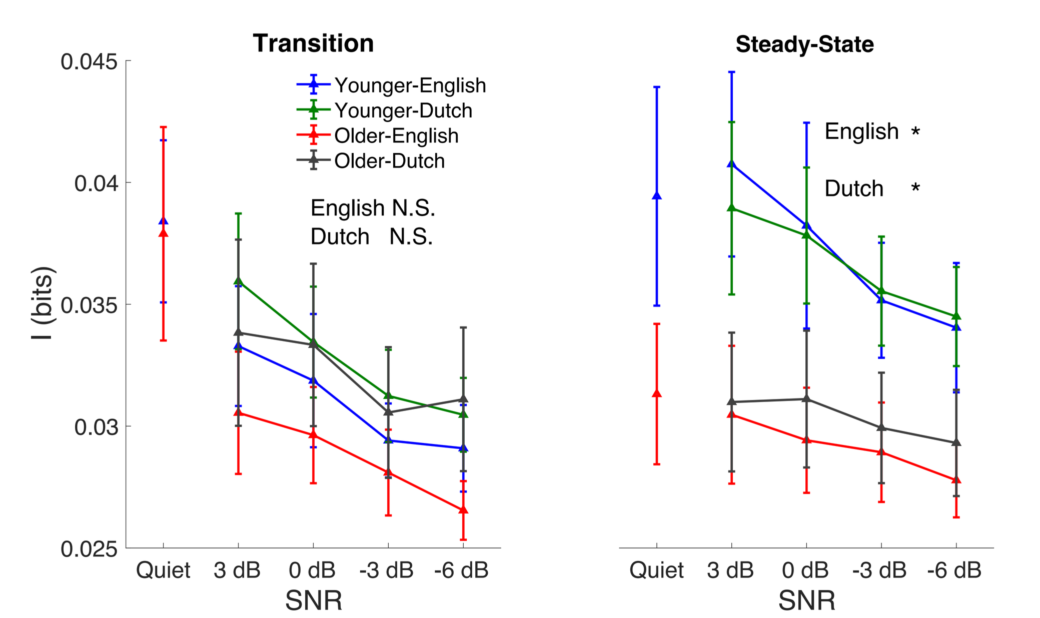


- Differences in slope become significant at harmonics
- Example harmonics 500 Hz and 600 Hz shown

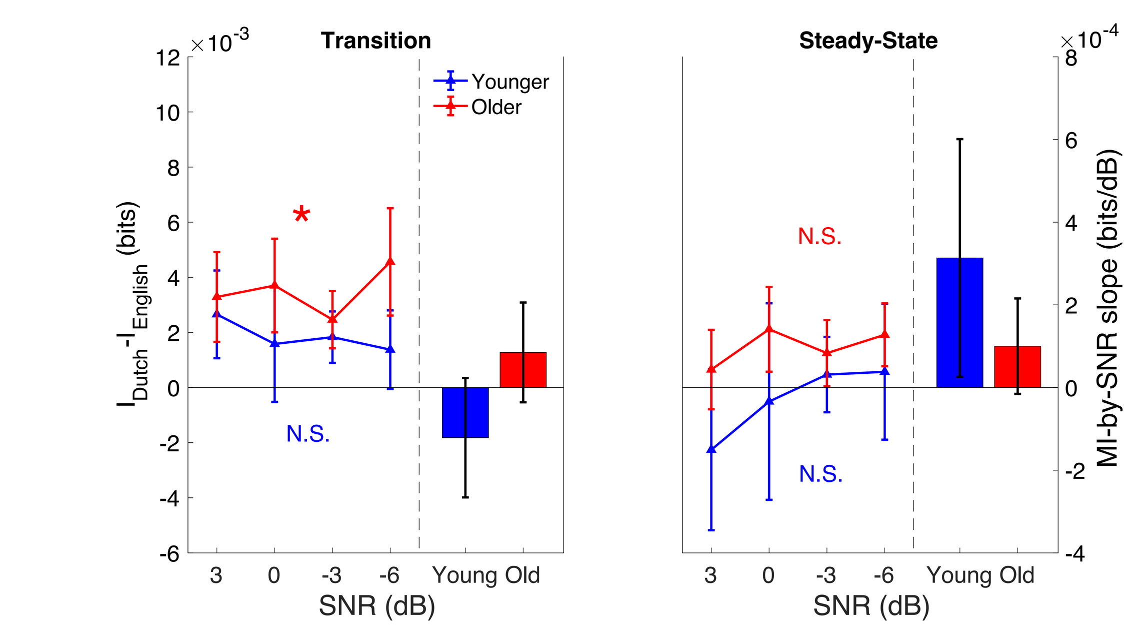


- The *amplitude* information limit for older listeners is ~300 Hz, lower than that for younger listeners.

Noise type influence during transition vs. steady-state

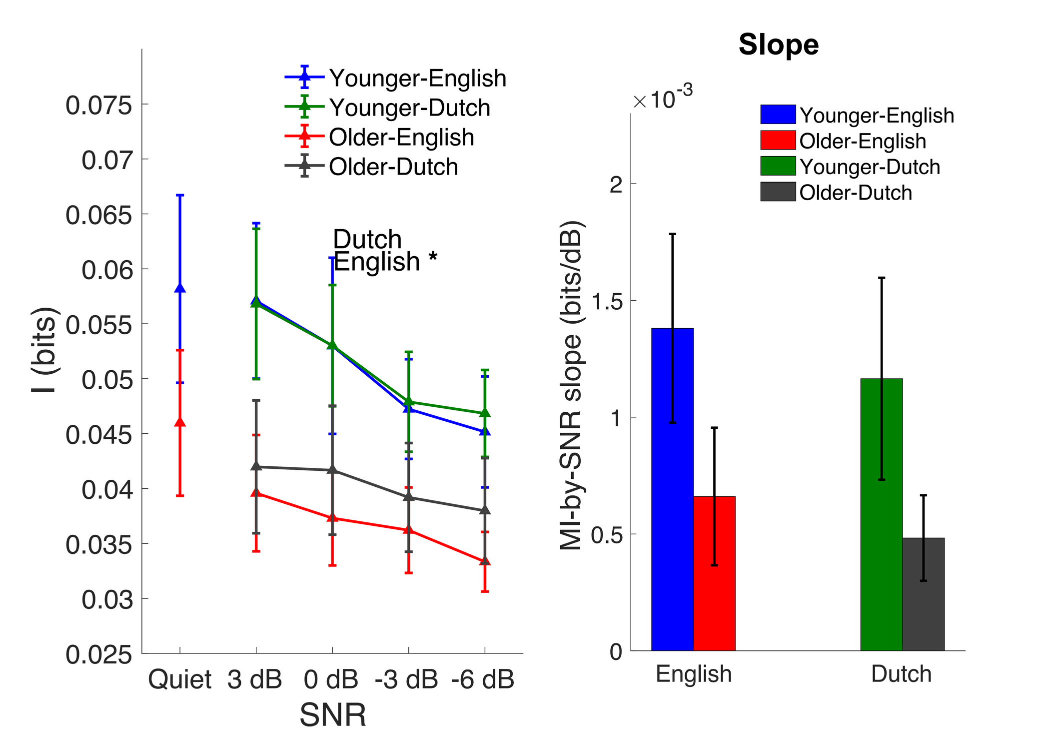


- Differences in *amplitude* information across age groups driven by Steady-State segment more than Transition



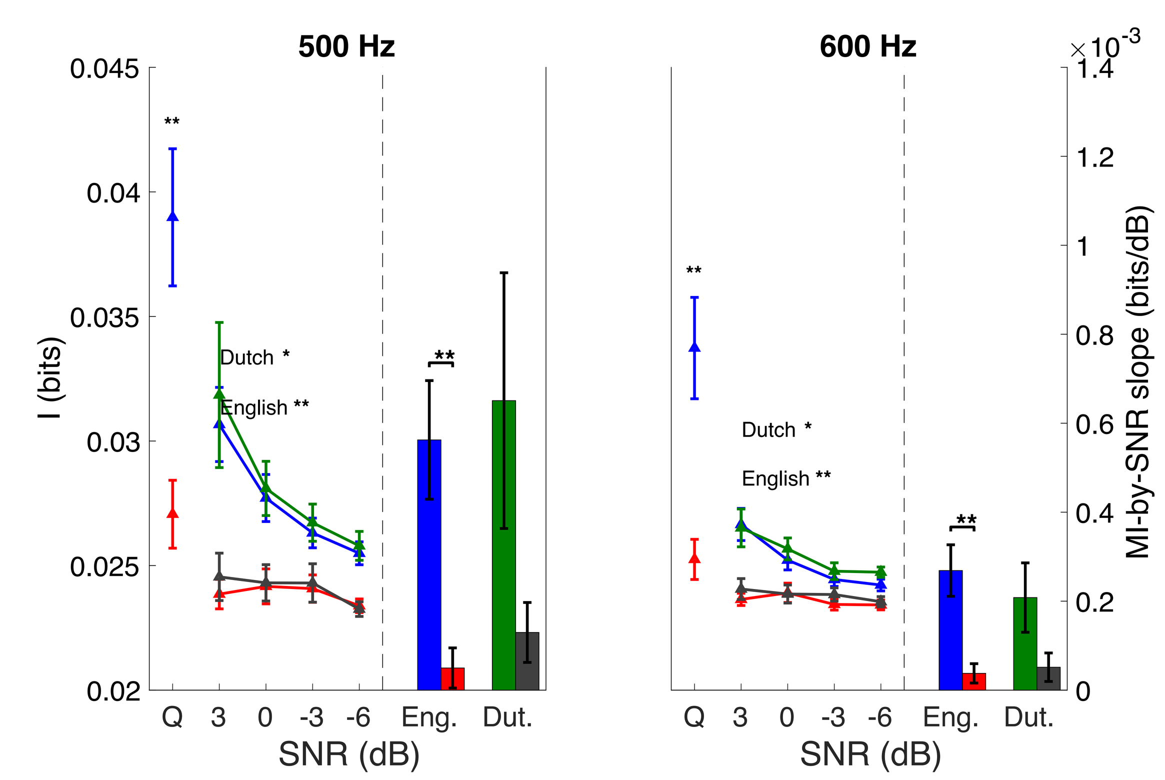
- Older listeners benefit in *amplitude* information from changing the background from English to Dutch in the transition stage
- Younger listeners do not show such a benefit

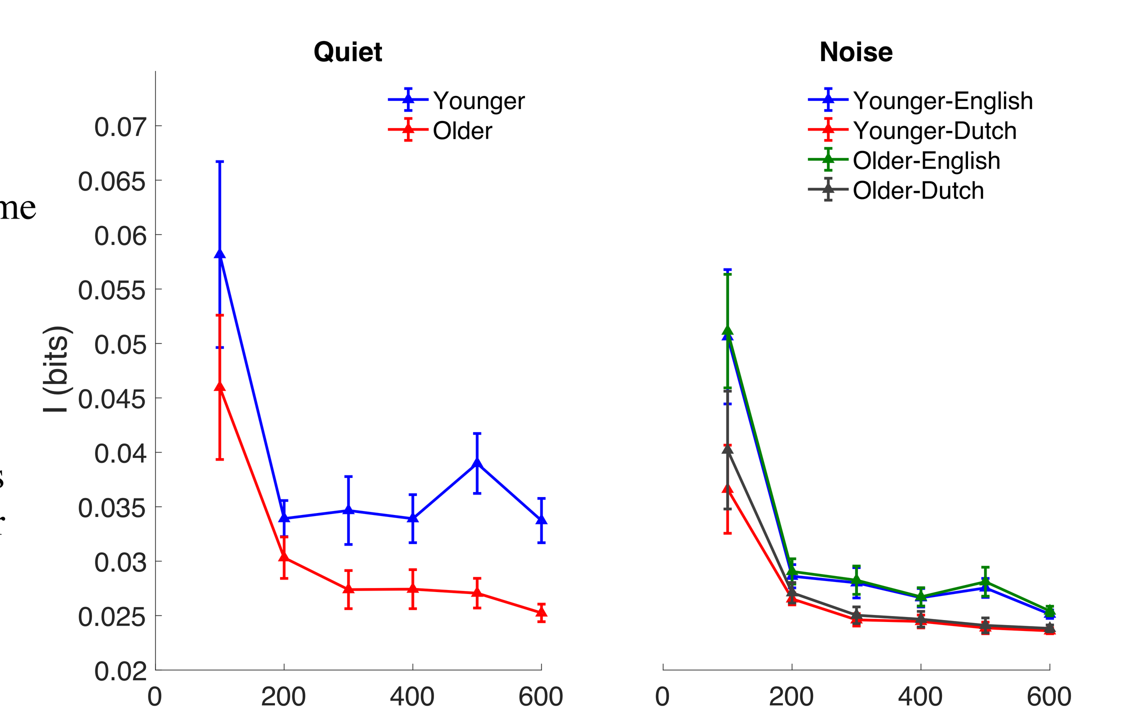
Information in FFR *phase* at 100 Hz by noise level



- Response in younger listeners processes more *phase* information than for older listeners in the English background condition
- Slope appears shallower for older, but not statistically significant

Information in FFR *phase* by noise level at harmonics

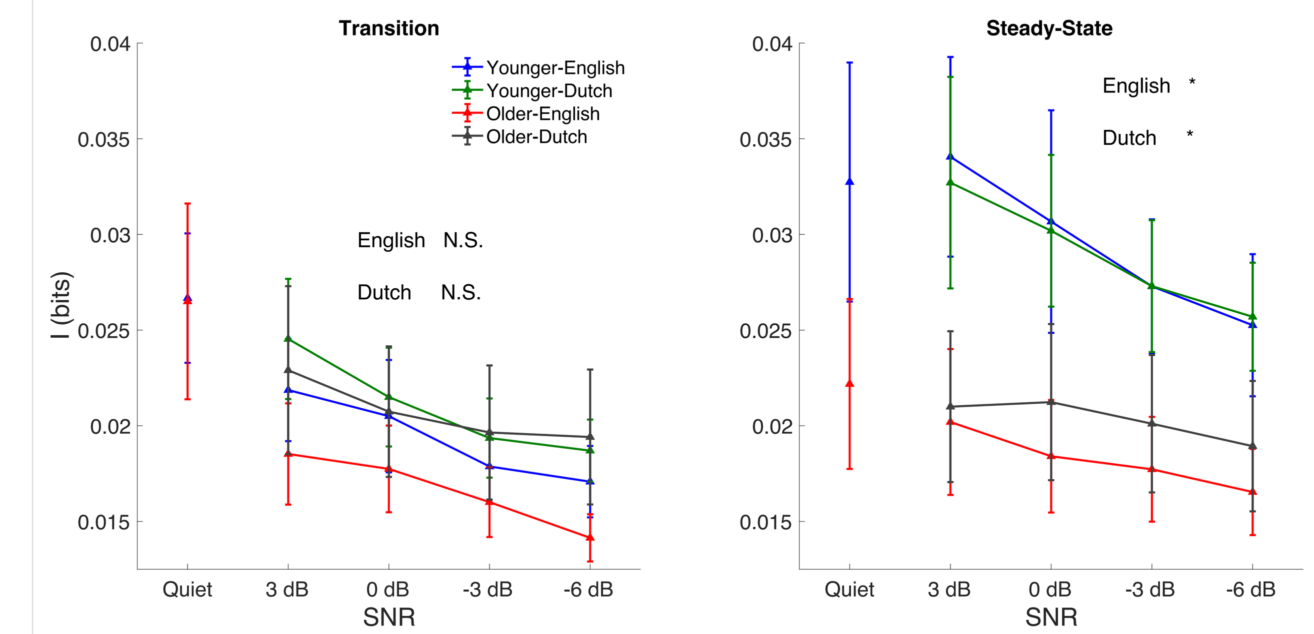




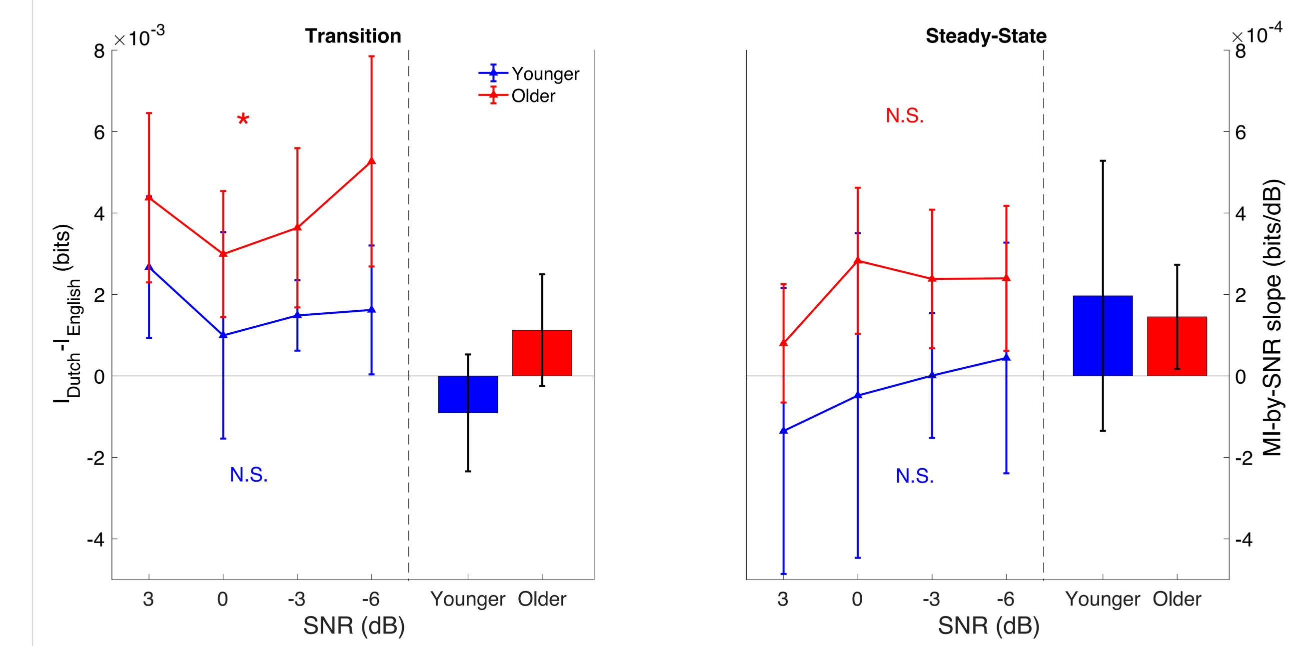
- Group differences in Dutch background become significant at harmonics
- Differences in slope become significant
- Example harmonics 500 Hz and 600 Hz shown

- The *phase* information limit for older listeners is ~300 Hz, lower than that for younger listeners.

Noise type influence on phase



- Differences in *phase* information across age groups driven by Steady-State segment more than Transition



- Older listeners benefit in *phase* information from changing the background from English to Dutch in the transition stage

Conclusions

- The older midbrain carries *less information in both amplitude and phase* of FFR, across all frequency bands in speech-in-noise conditions, than younger.
- The older midbrain benefits from *switching background noise from meaningful to meaningless* in *noise* conditions.
- Information carried by the younger midbrain *decreases faster than the older* as a function of decreasing SNR, especially in higher frequency bands. The older midbrain's ability to extract information decays more slowly with SNR.
- The FFR of both groups exhibits a low-pass character. The *older midbrain reaches its limit at a lower frequency*, retaining only a low-level information-extraction ability for higher frequencies.

Acknowledgments

This work was funded by the National Institutes of Health (grants R 01-DC014085 and P01-AG055365). We thank support for Peng Zan from the NSF funded COMBINE program.

References

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[2] Presacco A, Simon JZ, Anderson S (2016) ***Evidence of degraded representations of speech in noise, in the aging midbrain and cortex***, J Neurophysiol 116(5): 2346-2355.

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[5] Maddox R. K., Lee A.K.C (2018) ***Auditory Brainstem Responses to Continuous Natural Speech in Human Listeners***, eNeuro 5(1): ENEURO.0441-17.2018

For mutual information analysis of cortical response, see poster PS 245.

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