Auditory envelope processing shifts from sensory cortices towards cognitive control systems with age

Julia Erb, Molly J. Henry, & Jonas Obleser

Max Planck Research Group "Auditory Cognition", Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany
jerb@cbs.mpg.de

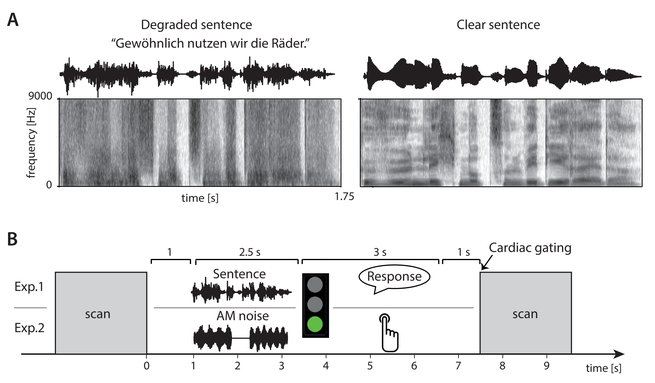
Introduction

- Speech envelope cues are necessary and almost sufficient for speech comprehension [1]. Although speech comprehension abilities decline with age and age-related hearing loss, the degree to which auditory envelope processing changes with age is unknown.
- The current functional MRI study examined the neural mechanisms of auditory speech and non-speech envelope processing in a group of older adults .
- Listeners heard and repeated back vocoded sentences in which the temporal envelope of the acoustic signal is preserved, while spectral information is substantially degraded. An additional fMRI experiment involved discriminating the amplitude modulation (AM) rate of two sounds.
- We hypothesized that older adults recruit cognitive-control-related brain regions [2, 3] to support sensory processing of auditory temporal envelope.

Methods

- **Participants** were a group of older adults (aged 56–77, n=15), with varying degrees of sensorineural hearing loss, and a cohort of young adults (aged 22–31, n=30, self-reported normal hearing [4]).
- **Degraded speech perception.** Stimuli were 100 low-predictable 4-band vocoded German SPIN sentences [5]; 24 clear-speech trials were included as baseline. Listeners verbally repeated back after each sentence what they had understood.
- **AM rate discrimination.** In a 2-AFC task, subjects listened to amplitude modulated white noises; standard stimulus was modulated at 4 Hz and the deviant at either a *discriminable AM rate* (range 2-6 Hz, linearly spaced, 6 levels with 16 trials each) or at the *identical AM rate* (4 Hz, 16 trials) [4].

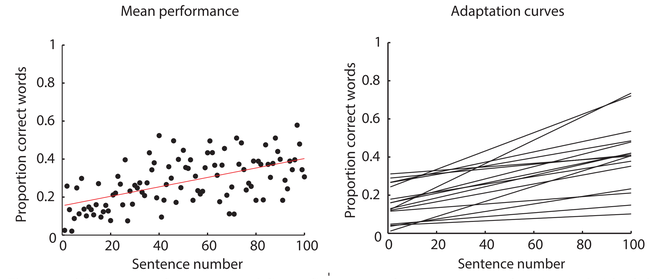
Stimuli and experimental design



- Functional MRI scans were collected on a 3T Siemens Verio scanner using an EPI sequence [TR ≈ 9000 ms (was variable due to cardiac gating), TA = 2000 ms, TE = 30 ms, voxel size = 3 x 3 x 3 mm]. Structural brain scans were acquired using an MPRAGE sequence. Data were preprocessed (realigned and unwarped, coregistered with the structural scan, segmented and normalized to MNI standard space, smoothed at 8 mm FWHM) and statistically analysed using a GLM in SPM8.

Results

1 A Degraded speech comprehension in older adults



1 B Group comparison

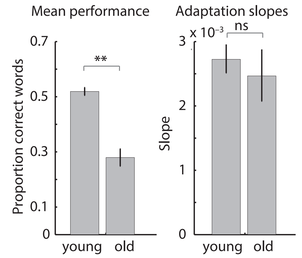
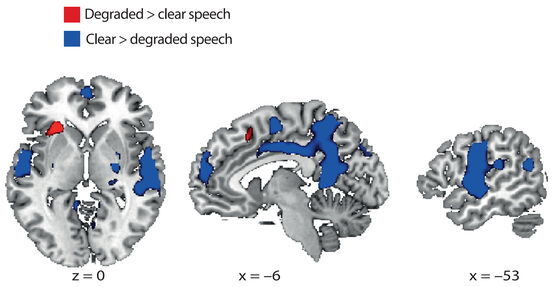


Figure 1. (**A**) Mean performance and linear fits to speech report scores, showing individual differences in adaptation to vocoded speech. The slope of the linear fit was taken as measure for perceptual adaptation to vocoded speech (adaptation slope). (**B**)Young and older adults differ in mean speech comprehension but not adaptation slopes (** $p < 0.01$, ns = non significant)

2 A Degraded speech processing in older adults



2 B AM discrimination in older adults

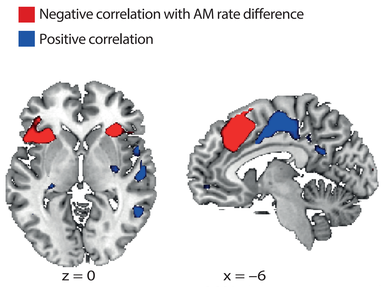
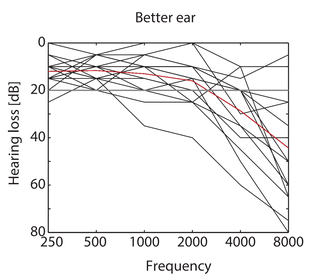


Figure 2. (**A**) For degraded speech perception, older adults activated the anterior insula. (**B**) For the AM-discrimination task, older adults exhibited a parametric modulation by discrimination difficulty in the anterior insula and ACC, with more difficult discriminations eliciting higher activation. Conversely, activity in the left supplementary motor area (SMA) increased as discriminations became easier.

3 A Audiograms



3 B Correlation with hearing loss in older adults

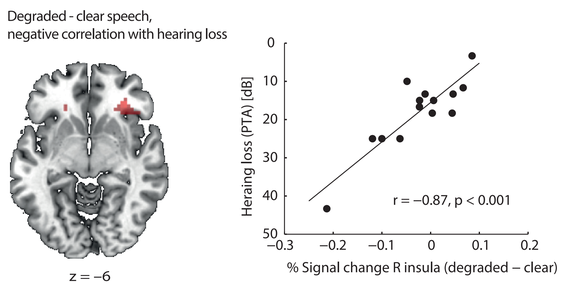
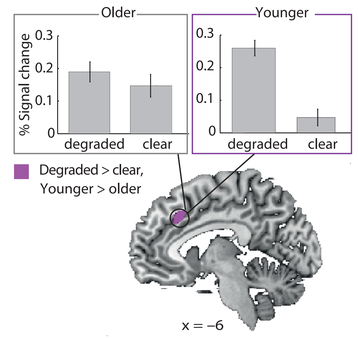
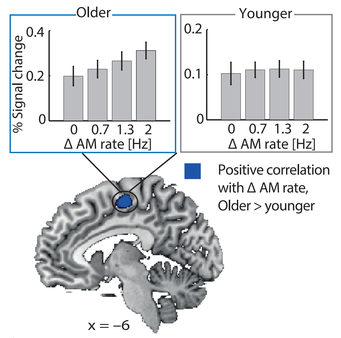


Figure 3. (**A**) Audiograms of older adults' better ear. (**B**) Pure-tone average (PTA) correlated negatively with the degraded > clear speech contrast in the right and left anterior insula. The plot of this correlation shows that older adults with better hearing acuity had an increased BOLD signal for degraded compared to clear speech in the right anterior insula, whereas more hearing-impaired listeners showed the inverse pattern. This correlation remained significant when partialling out age ($r = -0.79$, $p = 0.001$), and when removing the outlier participant with 43 dB HL.

4 A Group differences in degraded speech processing



4 B Group differences in AM discrimination



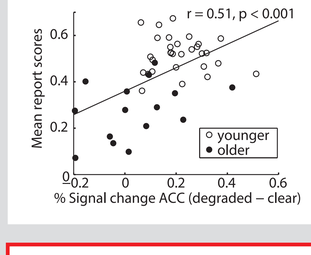


Figure 4. (A) Young adults recruited the anterior cingulate cortex (ACC) more than older adults for degraded speech processing. This condition-by-group interaction was driven by reduced dynamic range in older adults, who displayed high levels of ACC activation during perception of both clear and vocoded speech. ACC dynamic range correlated with mean performance. (**B**) Contrary to older adults, young listeners did not recruit the SMA for easier AM-rate discriminations, but rather relied on Heschl's gyrus [4].

Conclusions

- Although overall vocoded speech comprehension declined with age, older adults adapted to degraded speech at the same rate as young listeners.
- Neurally, more hearing-impaired older adults involved the anterior insula in even clear speech comprehension, which better hearing older and young adults recruited in degraded speech comprehension [6].
- Older adults had a reduced dynamic range in the ACC, displaying high levels of ACC activity in both the vocoded and clear speech condition, consistent with a persistent upregulation of a cognitive-control-related brain region [2,3,7].
- For the AM-discrimination task, older adults exhibited a parametric modulation by discrimination difficulty in the left SMA, whereas young listeners had the same parametric modulation in Heschl's gyrus [4]. This suggests the additional involvement of a nonsensory structure in a task for which younger listeners made use only of sensory cortices.
- Taken together, the results of the two experiments are suggestive of a compensatory mechanism, whereby with increasing age, higher-order brain structures must be recruited [3, 4], when solving even easy listening tasks [8].

References

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