The influence of aging on ITD-dependent human sound localization

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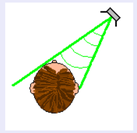
Introduction



Localization of sound relies upon central processing of external auditory cues influenced by the distance between the two ears and the shape of the pinnae

The central nervous system primarily utilizes inter-aural time differences (ITDs) for horizontal localization of frequencies below 2 kHz

Although past studies suggest age-related deterioration in auditory temporal processing, including ITDs, specific impairment of ITD-dependent sound localization under free-field conditions has not been reported in the elderly

The goal of this study was to investigate the influence of age and frequency range on ITD-dependent localization of free-field sound and its relationship to direct measures of ITD thresholds using headphones

Subjects and Methods

SUBJECTS

Young: N=8 (3 M, 5 F), 19-36 years; Middle-aged: N=7 (4M, 3 F), 50-65 years
Elderly: N=7 (3 M, 4 F), 71-86 years

All apparently free of neurological or sensory abnormalities. Audiometric thresholds < 20dB up to 2kHz), or at worst mild hearing loss in some elderly (thresholds < 40dB up to 2kHz)

FREE-FIELD SOUND LOCALIZATION

Test Chamber: dark, echo-attenuated room

Head Orientation: head fixed (bite-bar); subject facing center cylindrical screen

Target: 8 cm diameter speaker on robotic arm, hidden behind screen, 2 m distance

Stimuli:
150 ms bursts of 5 Hz repetition rate narrow noise bands; 40dB SL; 10 ms rise-fall time.
45 locations randomly distributed; subset of multi-sampled (3x) locations in 10° intervals
Bands: 250-500, 500-750, 750-1000, 1000-1250, 1250-1575, 1500-1890, 1750-2205 Hz

Paradigm: 2-axis cylindrical joystick used to point a laser LED at the perceived target location

Data analysis: targets in the range ± 40° H x ± 10° V for azimuthal sound localization

Azimuthal Sound Localization assessed by:

- Accuracy: the difference between each response and the target position
- Spatial Gain: regression slope of response vs.. target position
- Precision: average standard deviation of azimuthal accuracy in 10° bins

ITD DISCRIMINATION THRESHOLDS

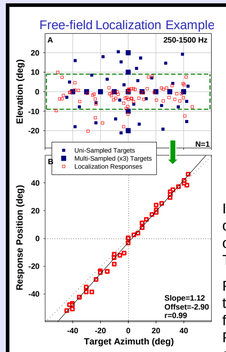
Test Chamber: dimly lit, echo-attenuated room

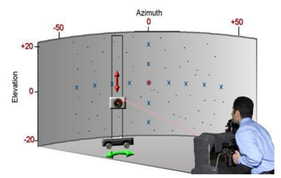
Head Orientation: head free under headphones (Sennheiser HD280 pro)

Stimuli: 150 ms bursts of narrow noise bands, same frequency ranges as the free field stimuli; 30dB SL against a 20dB SL notched noise floor; 10 ms rise-fall time

Paradigm: adaptive two-interval, three-alternative (Left, Right, Center) forced-choice
On each trial subjects heard two noise bursts. The first was a 'reference' burst (0 µs ITD), the second employed a non-zero ITD, led by either left or right ear
Subjects responded with a left, right, or center key-press to match the position of the perceived target burst relative to the initial reference burst
Trials were run adaptively: the stimulus ITD was lowered as the subject responded correctly and was raised as the subject responded incorrectly (3 Down, 1 Up)
For each subject, the ITD discrimination threshold was calculated as an average of 6 reversals

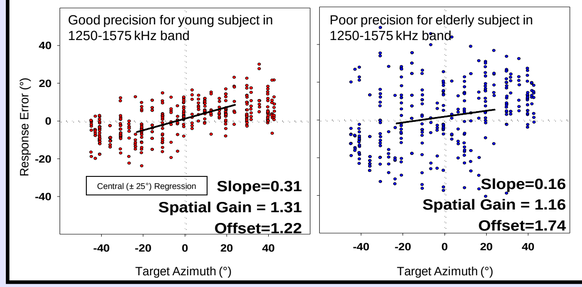
The frequency dependence of free-field localization precision changes with age

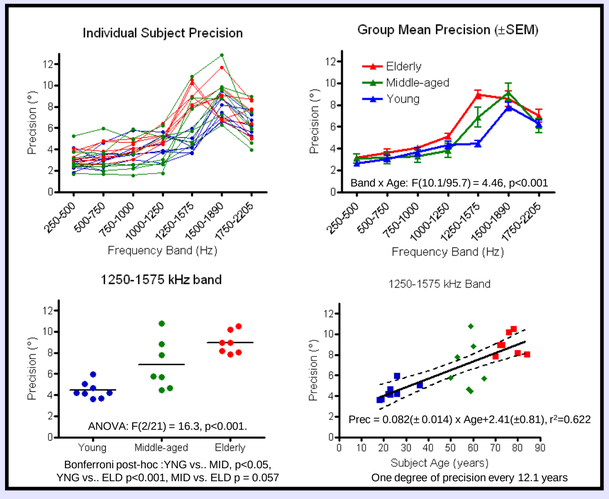




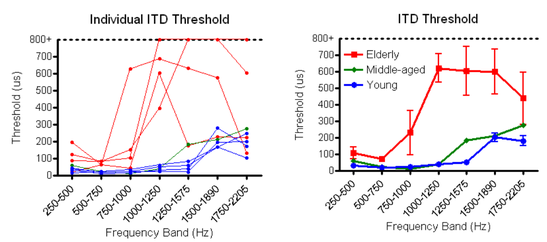
Ideal spatial gain is 1.0. Spatial gain shows a modest overshoot for low frequency bands, and a greater overshoot for higher frequency bands (not shown). There was no significant aging effect on spatial gain.

Precision is the azimuthal response error averaged across the spatial range. Precision is good (low) for lower frequency bands, and worse for the highest frequencies. Precision in the 1250-1575 Hz band is much worse for the elderly than the young.





ITD discrimination thresholds are much worse in the elderly for middle frequencies



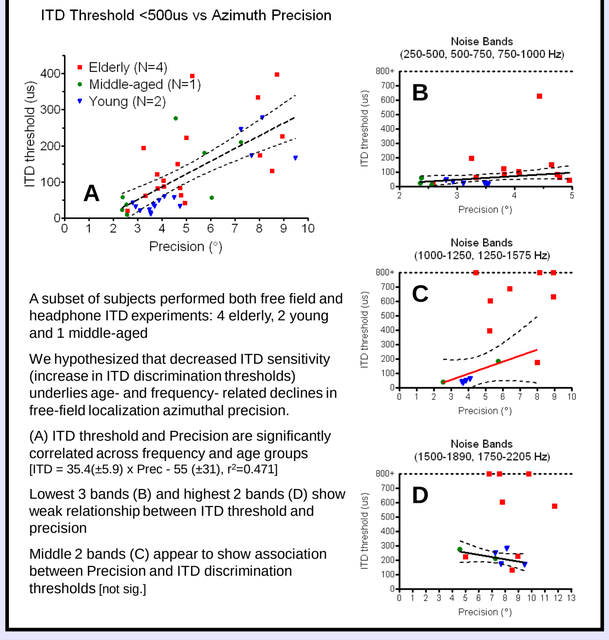
Young subjects have low ITD discrimination thresholds up to ~1500Hz
[ANOVA F(6/24) = 13.78, p<0.0001. Lowest 5 frequency average = 31µs, highest 2 frequency average = 184 µs]

The one middle-aged subject resembled the four young except for the 1250-1575 Hz band
[threshold 180 µs > young mean, t(4)=12.7, p=0.0002]

Elderly subjects displayed heterogeneous performance
Lowest ITD threshold was for the 500-750 Hz band [worse than young, t(7)=9.4, p<0.0001]
ITD thresholds deteriorate dramatically as frequency increased above ~1000 Hz

2 of the 4 elderly subjects performed as well as the young for the highest frequency band

ITD discrimination thresholds correlate with free-field localization precision



A subset of subjects performed both free field and headphone ITD experiments: 4 elderly, 2 young and 1 middle-aged

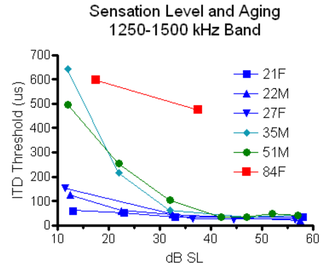
We hypothesized that decreased ITD sensitivity (increase in ITD discrimination thresholds) underlies age- and frequency- related declines in free-field localization azimuthal precision.

(A) ITD threshold and Precision are significantly correlated across frequency and age groups
[ITD = 35.4(±5.9) x Prec - 55 (±31), r^2=0.471]

Lowest 3 bands (B) and highest 2 bands (D) show weak relationship between ITD threshold and precision

Middle 2 bands (C) appear to show association between Precision and ITD discrimination thresholds [not sig.]

Sensation level dependence of ITD thresholds is strong in (young?) middle-age



We hypothesized that increasing presentation level would improve ITD discrimination thresholds

In the youngest subjects ITD threshold was insensitive to level [except near 10dB SL]

One elderly subject showed only modest change in threshold with level
[poor performance at low and high sensation levels]

The 35 and 51 year old subjects showed dramatic worsening of ITD discrimination thresholds at low and moderate sensation levels

Summary and Conclusions

Young subjects have excellent azimuthal precision in locating low-frequency free-field auditory targets. Performance deteriorates above ~1500 Hz, and this pattern is also seen for ITD discrimination thresholds

Elderly subjects have poorer localization precision compared with the young, but only the 1250-1575 Hz band shows a significant age effect, where precision also correlates with subject age

ITD discrimination thresholds are worse in the elderly than the young for every frequency band, modestly so up to ~750 Hz, but dramatically above this

Azimuthal precision and ITD discrimination thresholds are significantly correlated

Although preliminary, our data indicate that ITD discrimination thresholds are insensitive to sensation level in the young and elderly, but sound level may have a strong effect on ITD sensitivity for the middle-aged

These results demonstrate age- and frequency-dependent deterioration of auditory spatial processing, and suggest robust age-related degradation in the ability to utilize ITD cues for sound localization, even in early middle-age

We speculate that degradation in the temporal fidelity of binaural afferent information commences in young middle age. This especially disrupts binaural correlation for frequency channels near the phase-locking limit, and when this deficit is mild it may be corrected by increased sound level

Future experiments will examine whether free field localization precision is similarly affected by sound level in the middle-aged and elderly

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