Effect of Stimulus Type on Extended High Frequency Thresholds

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BACKGROUND

Extended high frequency (EHF) information (≥ 8 kHz) plays a significant role in speech understanding for both adults and children (e.g., Monson et al., 2019; Braza et al., 2021; Flaherty et al., 2021). However, measurement protocols at EHFs are not well established. Detection thresholds above 8 kHz can be highly variable (Plack et al., 2019). Some researchers suggest separate normative reference values for listeners above and below 18 years old (Hemmingson et al., 2021).

One factor that may influence variability and accuracy in EHF threshold measurement is the type of stimulus used for testing. For example, Lentz et al. (2017) found that FM tones elicit lower thresholds than pulsed and steady tones for test frequencies above 4 kHz. Those authors suggested this could be due to opportunities for off-frequency listening. Another factor could be increased perceptual salience of temporally variable EHF stimuli.

The purpose of this study was to further evaluate the effect of stimulus type—steady pure tones, pulsed pure tones, and FM tones—on detection thresholds at 8 and 16 kHz for adults and school-age children.

HYPOTHESES

1. Thresholds will be lower with FM tones than steady pure tones, due to opportunities for off-frequency listening.
2. Thresholds will be lower for pulsed tones than steady tones at 16 kHz, particularly for children. This was expected based on reduced familiarity of EHF stimuli and immature listening strategies in children.
3. Thresholds at 16 kHz will increase as a function of listener age due to normal aging.
4. Variability of threshold estimates will be larger for children than adults, and larger at 16 kHz than 8 kHz.

METHODS

Participants: Listeners were recruited at the University of North Carolina and Boys Town National Research Hospital. All listeners had normal hearing (≤ 20 dB HL from 250 – 8000 Hz) and healthy middle ear status. Data collection in both groups is ongoing.

- Children (5 – 13 years), n = 24
- Adults (19 – 45 years), n = 13

Procedure: Thresholds were measured at 8 and 16 kHz in one ear using steady pure tones, pulsed pure tones, and FM tones (Hughson-Westlake procedure; 5 dB step size). Left and right ears were counterbalanced across listeners. UNC used the GSI Audiostar Pro and Sennheiser HDA circumaural headphones. Boys Town used the Maden Astera 2 audiometer with Sennheiser HAD 300 headphones for adults and the GSI with Radioear DD450 for children.

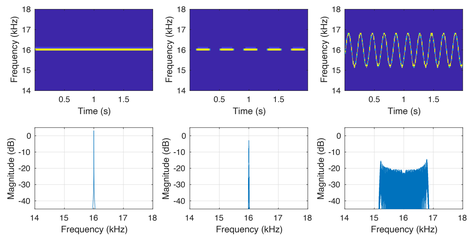


Figure 1. 16 kHz stimuli
Stimuli were recorded using a sound level meter and a 6 cc coupler. The top row of panels shows spectrograms, and the bottom row shows the long-term average power spectra.

RESULTS

Figure 2. Thresholds at 8 kHz
Thresholds are plotted in dB HL as a function of listener age. Values were clustered near 0 dB HL for both children and adults, and for all three stimuli.

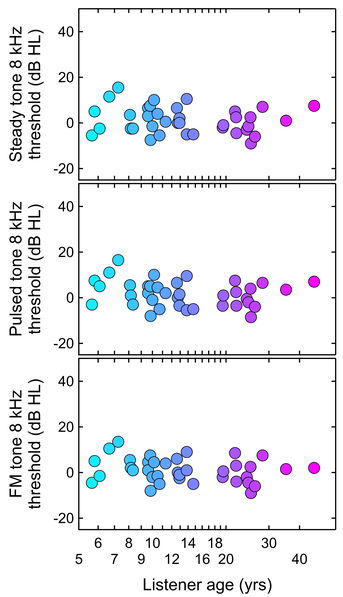


Figure 3. Threshold at 16 kHz
Plotting conventions follow Figure 2. Individual differences are greater than observed at 8 kHz, including evidence of age-related hearing loss. Children's thresholds tend to fall below 0 dB HL.

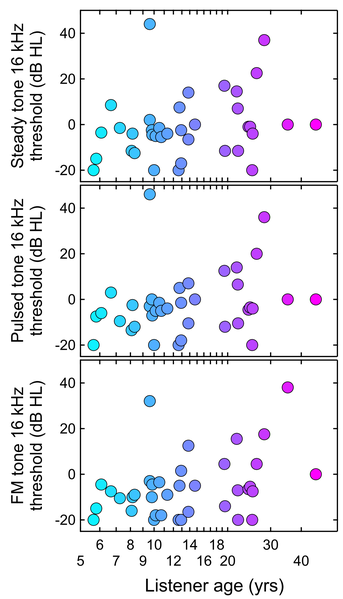
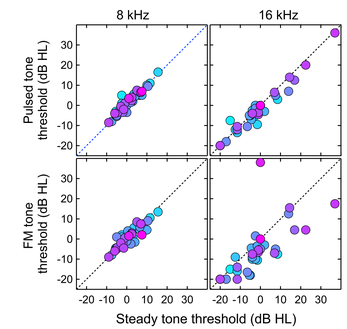


Figure 4a. Thresholds for variable stimuli by thresholds for steady tone stimuli.
Individual differences were more consistent across stimuli at 8 kHz than 16 kHz.



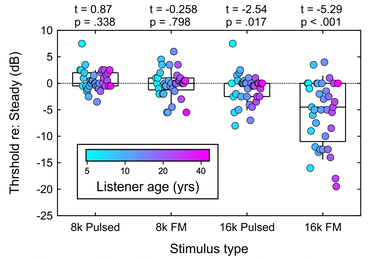


Figure 4b. Distribution of steady-variable differences
There was a significant advantage of using a variable stimulus at 16 kHz but not at 8 kHz.

DISCUSSION

With respect to our four hypotheses...

1. Thresholds were lower with FM tones than steady pure tones at 16 kHz, but not at 8 kHz.
2. Thresholds were lower for pulsed tones than steady tones at 16 kHz, and this was observed for both children and adults.
3. Consistent with previous literature, 16 kHz thresholds increased with listener age. One unexpected finding was the trend for thresholds < 0 dB HL at 16 kHz for children.
4. Contrary to predictions, there was no evidence of increased threshold variability for children relative to adults. Differences between 16 kHz steady and FM tones was larger than for other conditions, but this did not appear to be related to age.

CONCLUSIONS

1. Better thresholds for FM tones than steady pure tones at 16 kHz, may be due to off-frequency listening (see Lentz et al., 2017). This suggests that pulsed and steady pure tones may provide more accurate threshold estimates than FM tones.
2. There was a trend for pulsed tones to result in lower 16 kHz thresholds than steady tones in both age groups, but this effect was small – only 1 dB on average. This is not clinically significant.
3. Effects of ear canal size on EHF calibration will be considered in future studies.

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