A quick and reliable estimate of extended high-frequency hearing

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Aim

- The clinical audiometric range stops at 8 kHz. But looking at hearing above this, in the extended high-frequency (EHF) range, has recently become more common in basic research studies [1].
- There is growing evidence that human hearing in the EHF range plays an important role in our auditory perception [2], and may be able to provide an insight into the health of the auditory system as a whole [3].
- There are methodological difficulties in acquiring thresholds in the EHF range;
  - It is not clear which specific frequencies should be tested in the EHF range, leading to inconsistency across studies.
  - As higher frequencies are tested the likelihood of a non-response increases.
  - It is not clear how an accurate pure tone average should be constructed if responses are missing at some frequencies.
  - At the upper EHF limit (16-20 kHz), very high SPL outputs, which are close to the maximum permissible output, are likely required. This leads to a risk of audible electrical noise or hardware artefact.
- The approach described here adapts an innovative method initially described by Rieke et al. [4] in which fixed-level frequency thresholds (FLFTs) are used to characterise EHF hearing.

Methods

Participants

30 listeners (16 male) were recruited, with a mean age of 27.3 years (S.D.=5.5 years). Participants were volunteers with no known hearing pathologies.

Standard pure tone audiometry

Pure tone audiometry was performed for the right ear at octave frequencies between 250 and 8000 Hz using a TDH-39 supra-aural transducer.

EHF audiometry was also performed in the right ear at 10, 12, 15 and 16 kHz using a Sennheiser HDA 300 circum-aural transducer.

A Kamplex KC50 clinical audiometer was used and recommended procedures followed [5].

Fixed-level frequency thresholds

A PC and external sound-card were coupled to HDA 200 circum-aural headphones.

A three-alternative forced-choice paradigm was used with a 2-down, 1-up staircase adaptively setting the stimulus frequency (shown schematically in Fig 1).

Two estimates of threshold were obtained. The stimulus level was fixed at 40 dB SPL (starting frequency of 8 kHz), and 70 dB SPL (starting frequency of 16 kHz), across different trials.

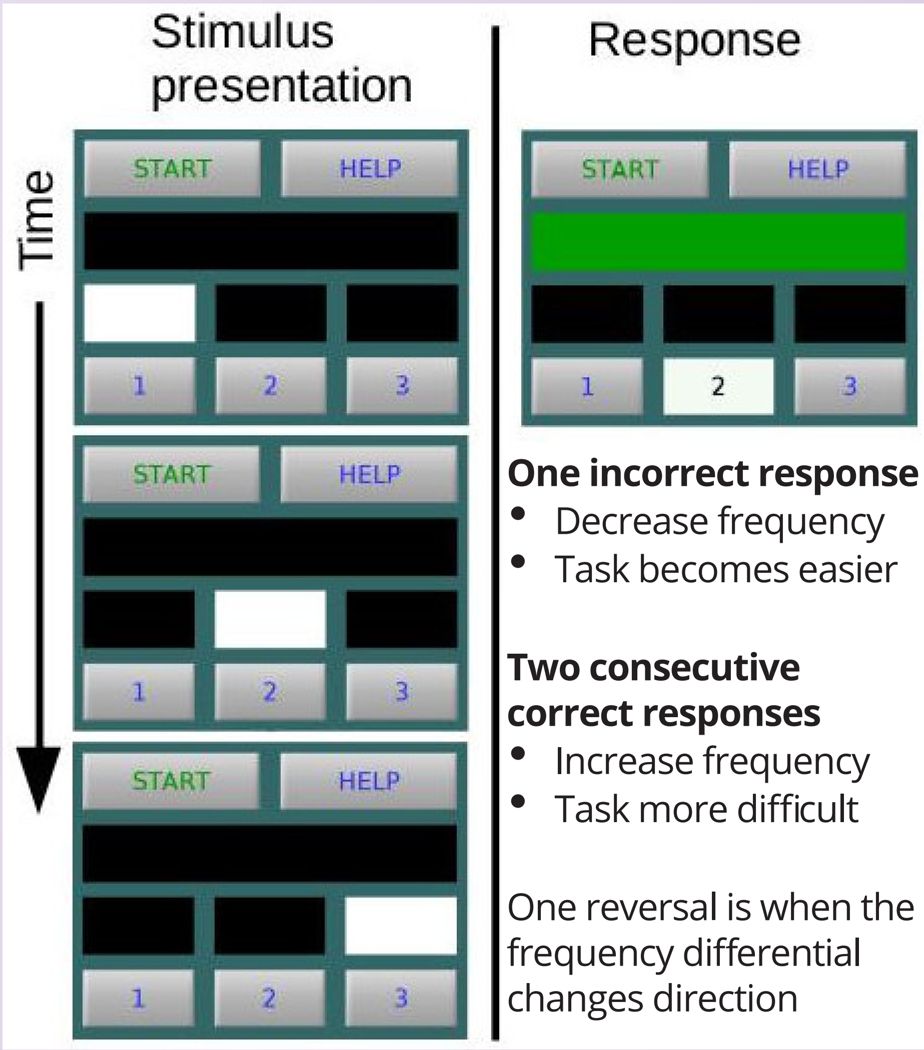

Fig 1. Schematic showing the structure of trial presentation and response. The left column shows three intervals (two of them silent) being visually cued over time. The right panel shows the feedback given for a correct response and summarises how the frequency for the next trial is determined.

The step size was 1000 Hz for the first 4 reversals and 250 Hz for the final 10. The FLFT was calculated as the average frequency of the final 10 reversals.

Each participant performed each FLFT level twice.

Analysis

The main analysis of interest was a correlation between FLFTs and EHF thresholds acquired using the standard PTA approach.

The Coefficient of Variation (CoV) is the ratio of the standard deviation to the mean and allows quantification of variability; a lower CoV indicates a more precise estimate.

Results

Fig 2. shows grand average thresholds for both methods. The average FLFT threshold at 40 dB SPL was 14.10 kHz and at 70 dB SPL was 16.35 kHz.

The time taken to acquire a single estimate of FLFT was ~ 2 minutes.

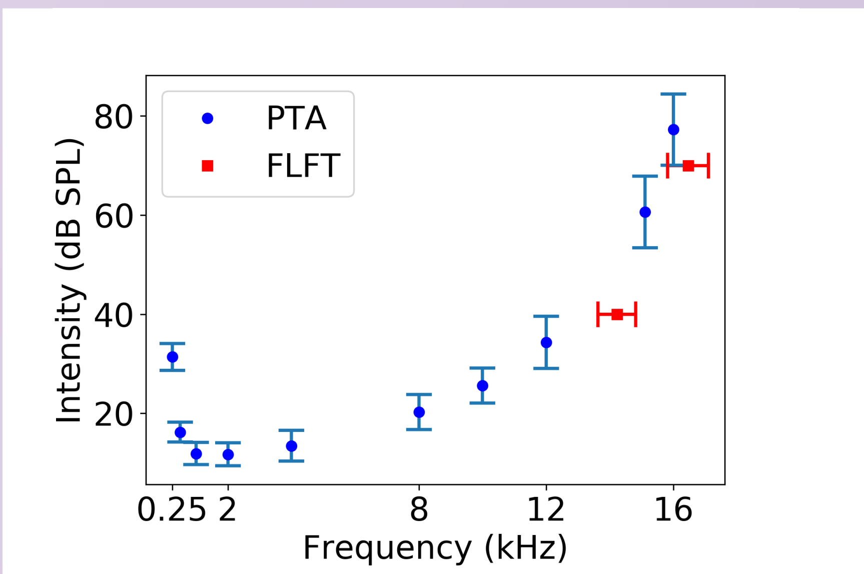

Fig 1. Average thresholds shown in dB SPL for each frequency tested using the standard PTA methodology (blue). Average FLFTs are shown in red for 40 and 70 dB SPL. Error bars show 95% CIs.

Correlations

There was a strong, statistically significant correlation between FLFTs and the highest pure tone frequencies assessed (15 and 16 kHz).

- These ranged from R = 0.68 to R=0.79 (all $p<0.001$).

To provide some context for these values, even neighbouring octave frequencies in the standard audiometric range correlate less strongly than the reported r-values.

The 4 EHFs tested using the standard approach also correlate poorly with each other in general, suggesting that the specific frequencies selected for testing would affect the estimate of auditory coding.

Coefficient of Variation

- Audiometric thresholds using the standard approach were converted from dB HL to dB SPL.
- The average CoV across all 6 clinical frequencies and the 4 EHFs was 43% and 32%, respectively. The lowest CoV was 22%, for the 250 Hz pure tone.
- The CoV for the FLFT method was 11% at both presentation levels.

Test-retest

The average difference between the two FLFT runs performed at 40 dB SPL was 284 Hz, which is 2.01% of the mean threshold.

At 70 dB SPL the average difference between an individuals' threshold across the 2 runs was 176 Hz, which represents 1.08% of the mean threshold.

Summary

FLFT is an alternative method of assessing hearing, in which the intensity of the sound is fixed and the frequency varied.

The summary metric produced represents the highest audible frequency at a given sound level. A single number characterises hearing across the entire EHF range.

The technique produces results which are related to standard pure tone estimates; those with good hearing at 15 and 16 kHz have high FLFTs.

FLFTs are therefore a rapid, reliable and accurate way in which EHF hearing can be characterised.

The approach avoids many of the pitfalls highlighted in the introduction

The use of this approach could help standardise the way in which EHFs are acquired and ensure that little additional resource is required to obtain them.

References

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[3] Vermiglio et al. (2012). J Am Acad Audiol. 23: 779-88.
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Acknowledgments

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