ITU-T Workshop on

"From Speech to Audio: bandwidth extension, binaural perception"

Lannion, France, 10-12 September 2008

High frequency sound for the hearing impaired

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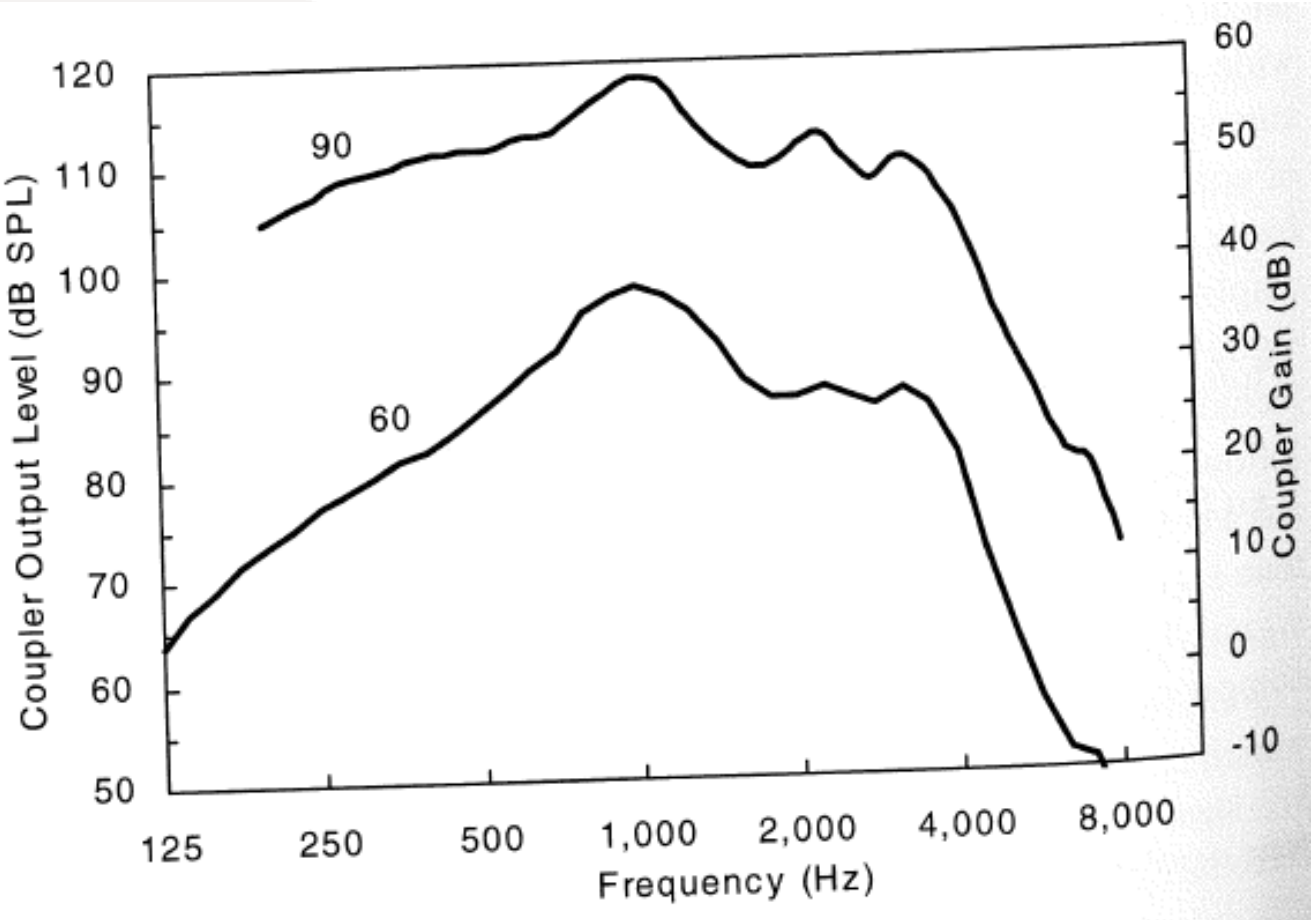
High-frequency cutoff of hearing aids



4-kHz typical,
6-kHz at best

From Dillon (2001)

Bandwidth of hearing aids

- Capability of extended bandwidths for at least 25 years (Killion & Tillman 1982)
- Incremental speech intelligibility benefit, at best, of extending bandwidth above 4 kHz (Hornsby & Ricketts, 2006)

Is it worth extending to high frequencies?

- Drawbacks
  - Power consumption, feedback
- Potential benefits
  - Language development in children, spatial hearing, listening effort, sound-source segregation, sound quality

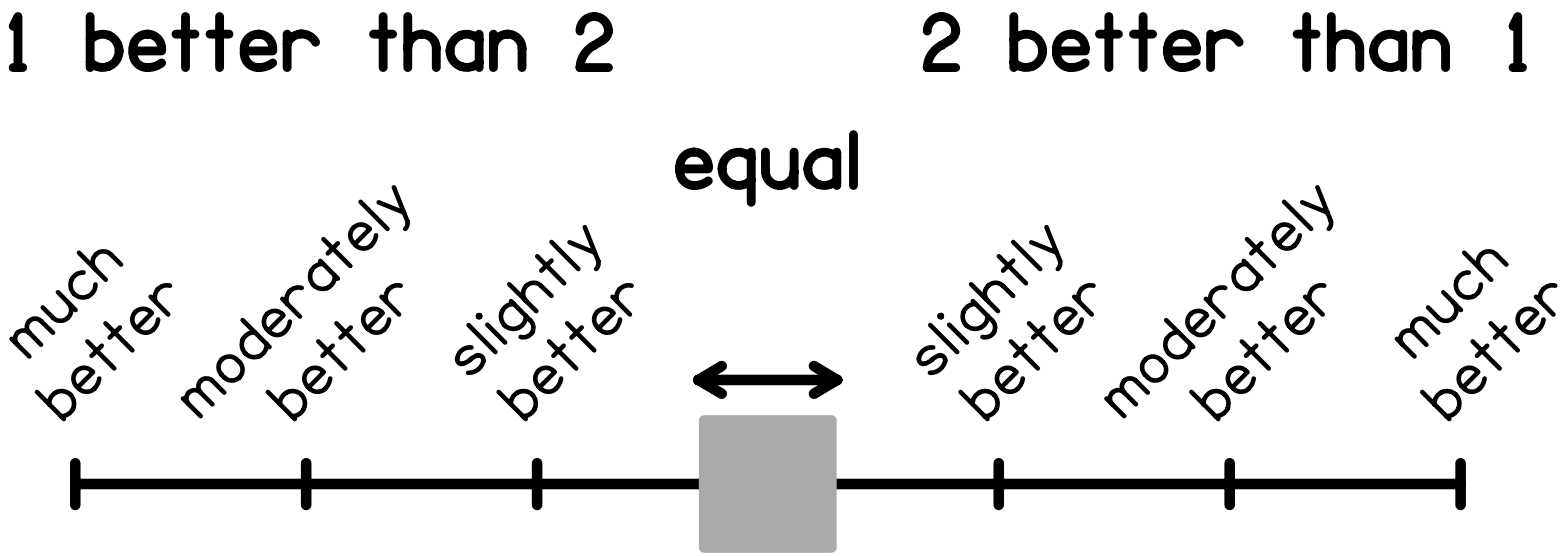
Is there a benefit of extending the bandwidth of amplification for sound quality?

Previous findings on sound quality

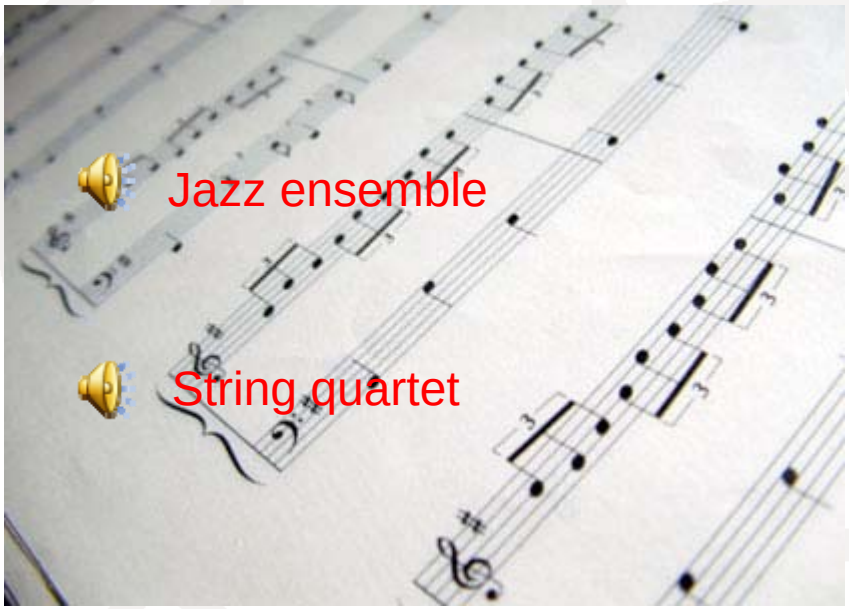
- Normal hearing
  - Preference for extended bandwidth up to 16 kHz (Moore & Tan, 2003; etc.)
- Impaired hearing
  - Inconsistent findings (Franks, 1982; Fullgrabe et al, 2007; Latzel et al, 2007; Ricketts et al, 2008)

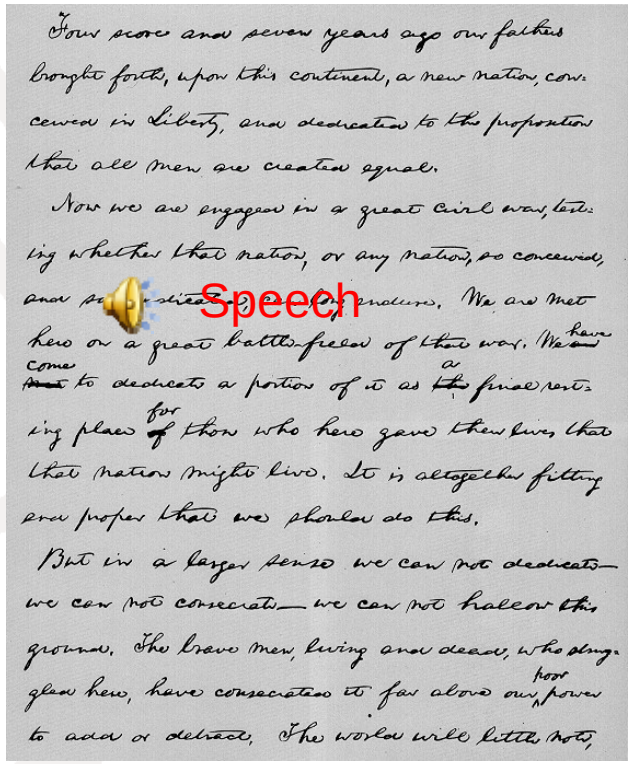
4, 6, 8, 10, and 12 kHz bandwidths

"… which of the pair do you prefer in terms of sound quality?"



Stimuli

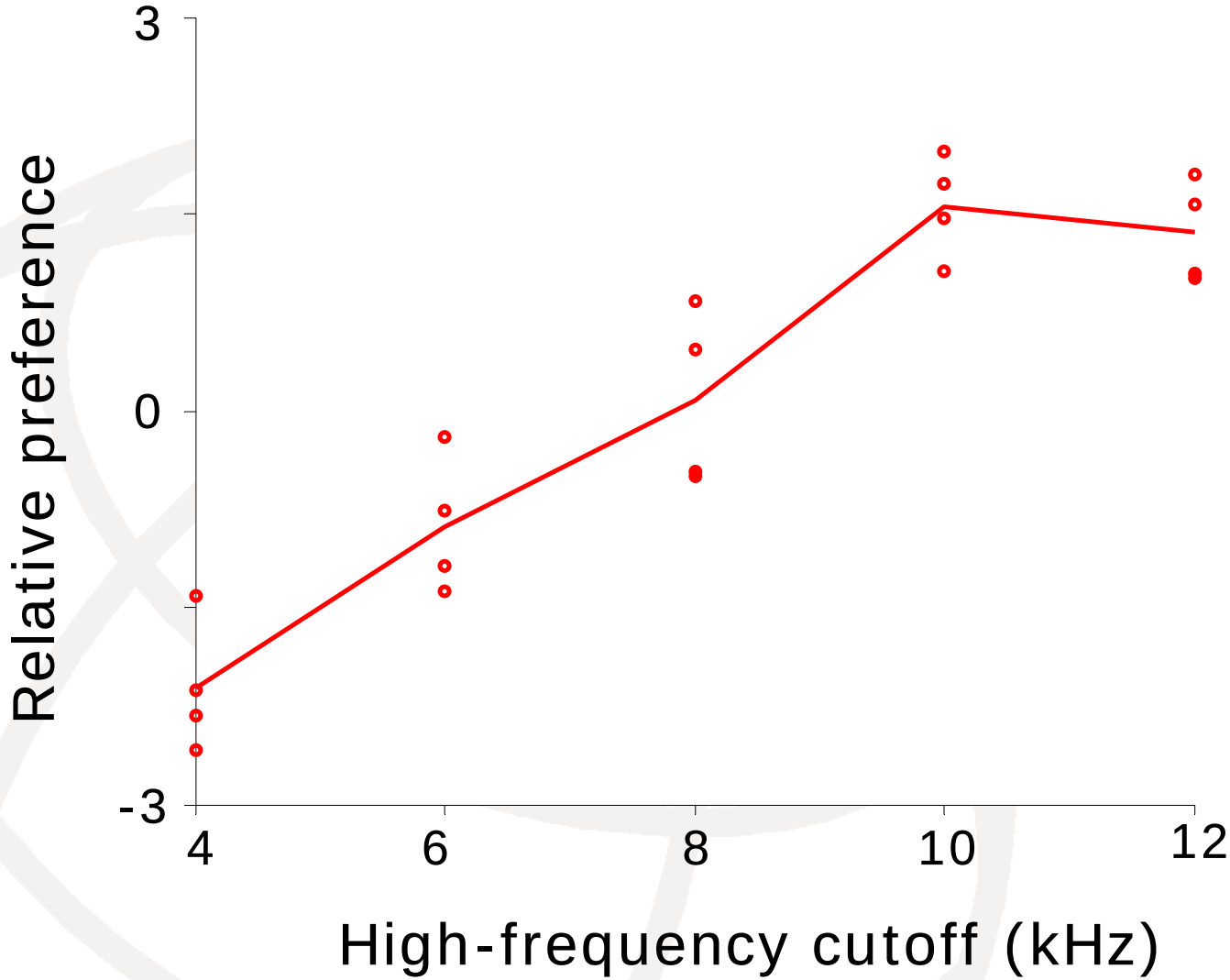




Four score and seven years ago our fathers brought forth, upon this continent, a new nation, conceived in Liberty, and dedicated to the proposition that all men are created equal.

Now we are engaged in a great civil war, testing whether that nation, or any nation, so conceived, and so dedicated, can long endure. We are met here on a great battle-field of that war. We have come to dedicate a portion of it as a final resting place for those who here gave their lives that that nation might live. It is altogether fitting and proper that we should do this.

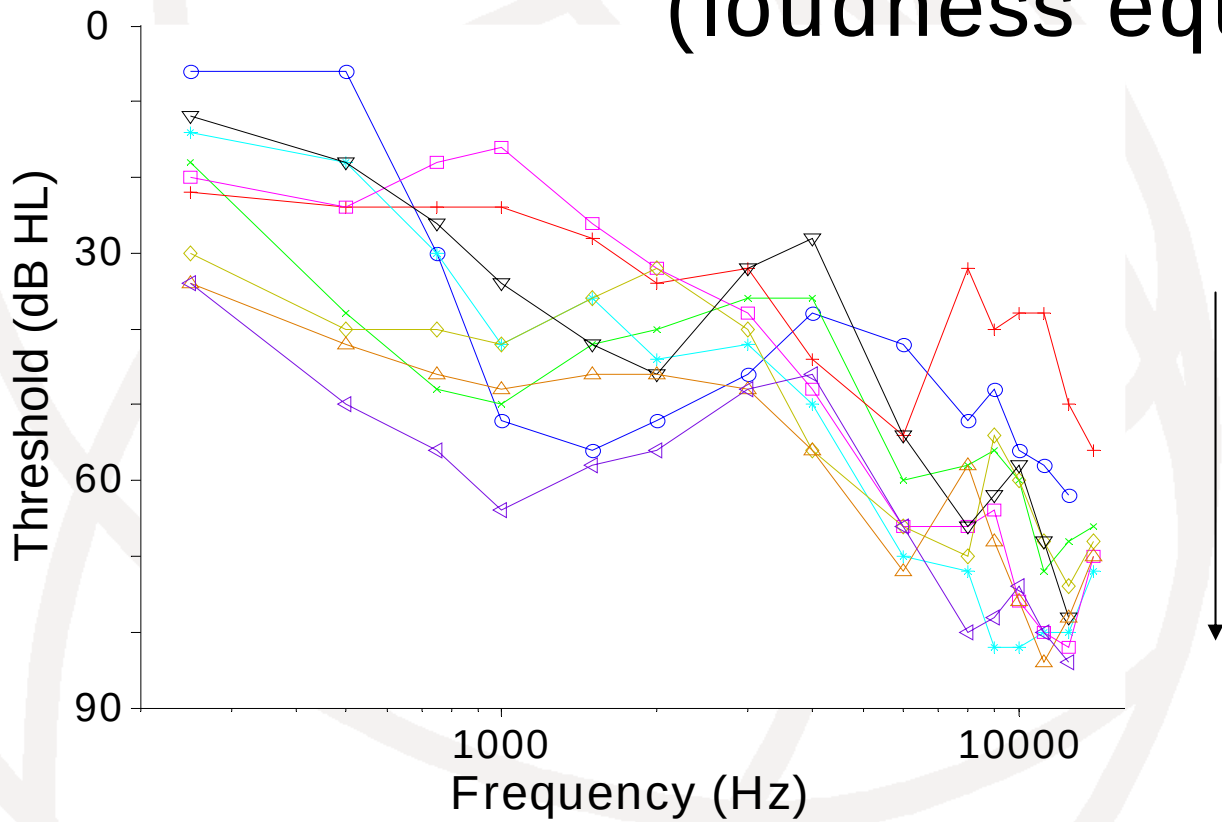
But in a larger sense we can not dedicate — we can not consecrate — we can not hallow this ground. The brave men, living and dead, who struggled here, have consecrated it far above our poor power to add or detract. The world will little note,



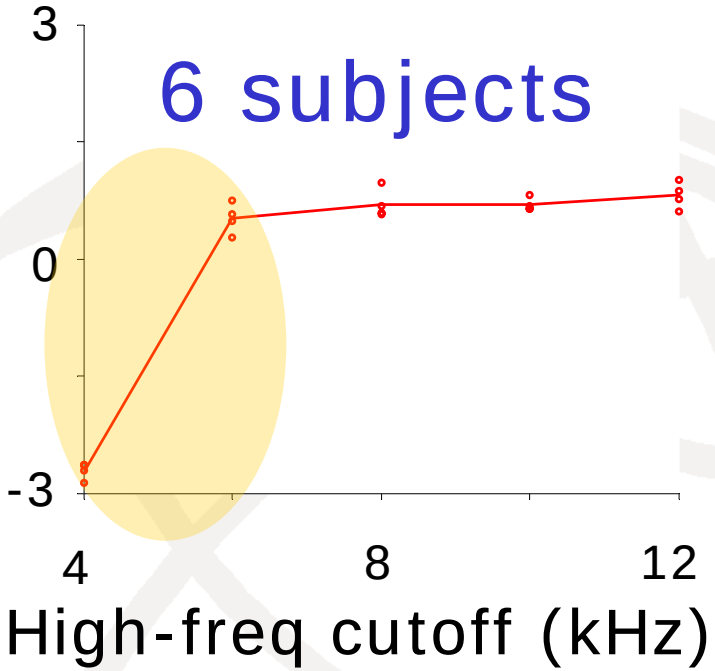
NH subject preferred higher bandwidths up to 10 kHz

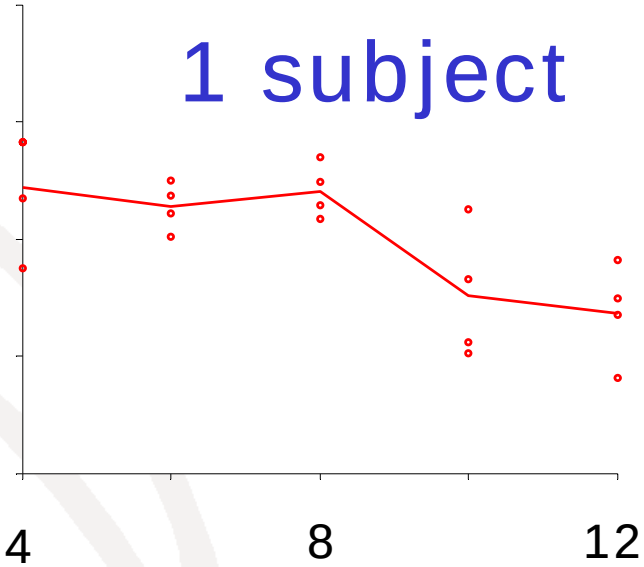
9 hearing-impaired subjects

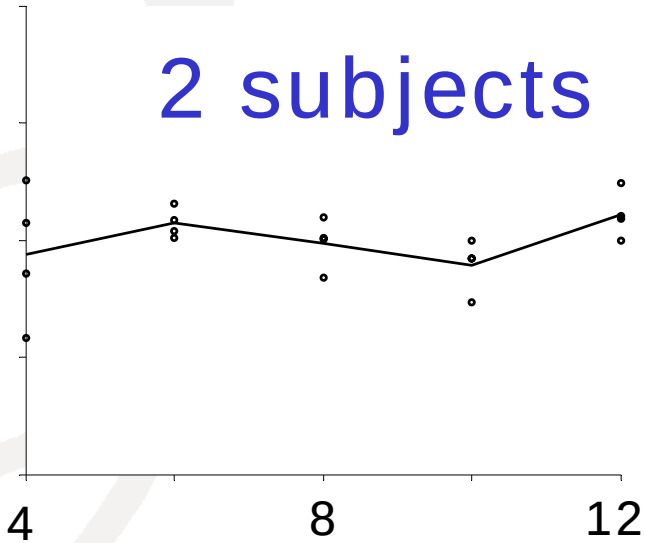
CAMEQ-HF amplification
(loudness equalization)



More hearing loss



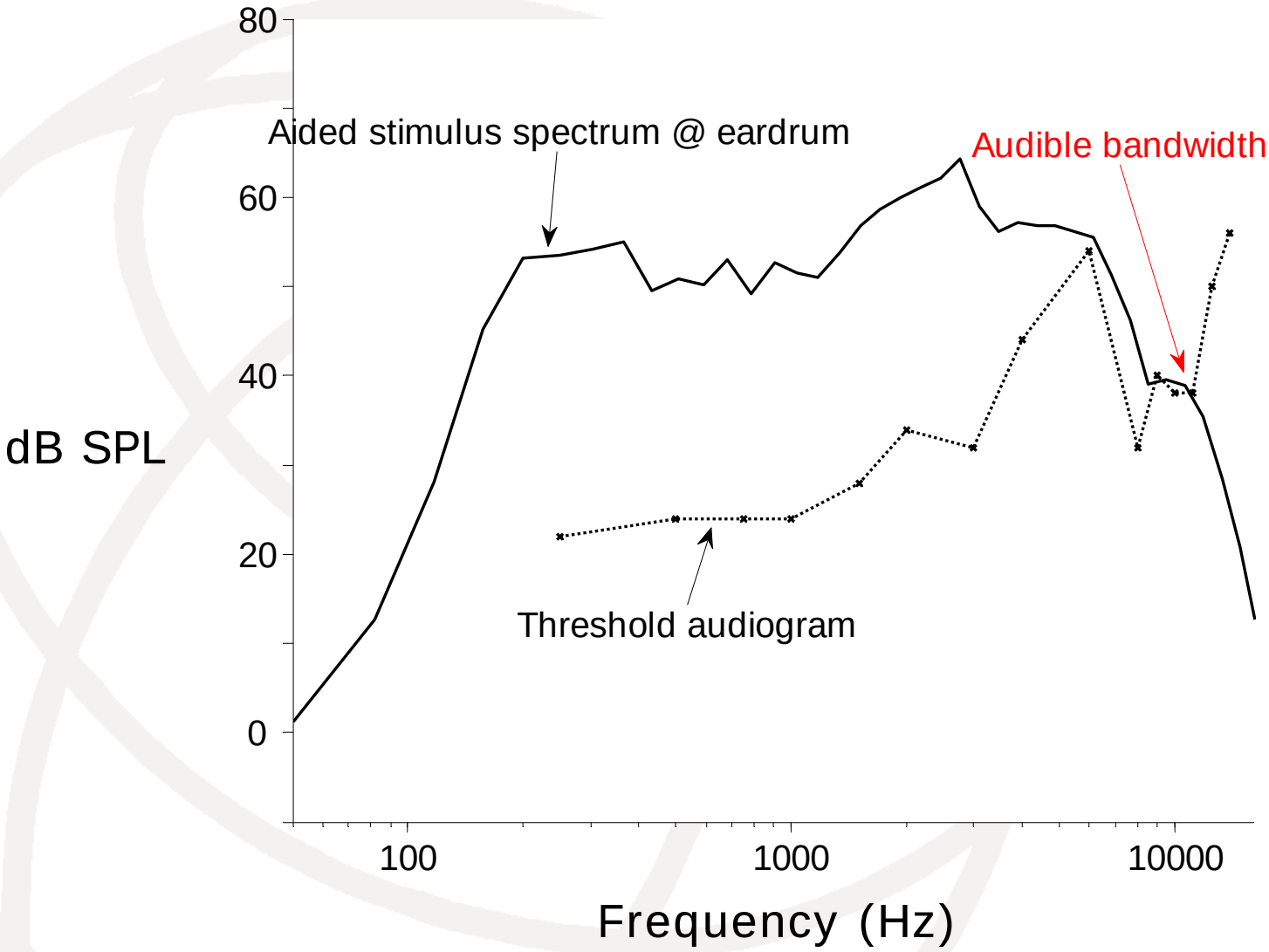




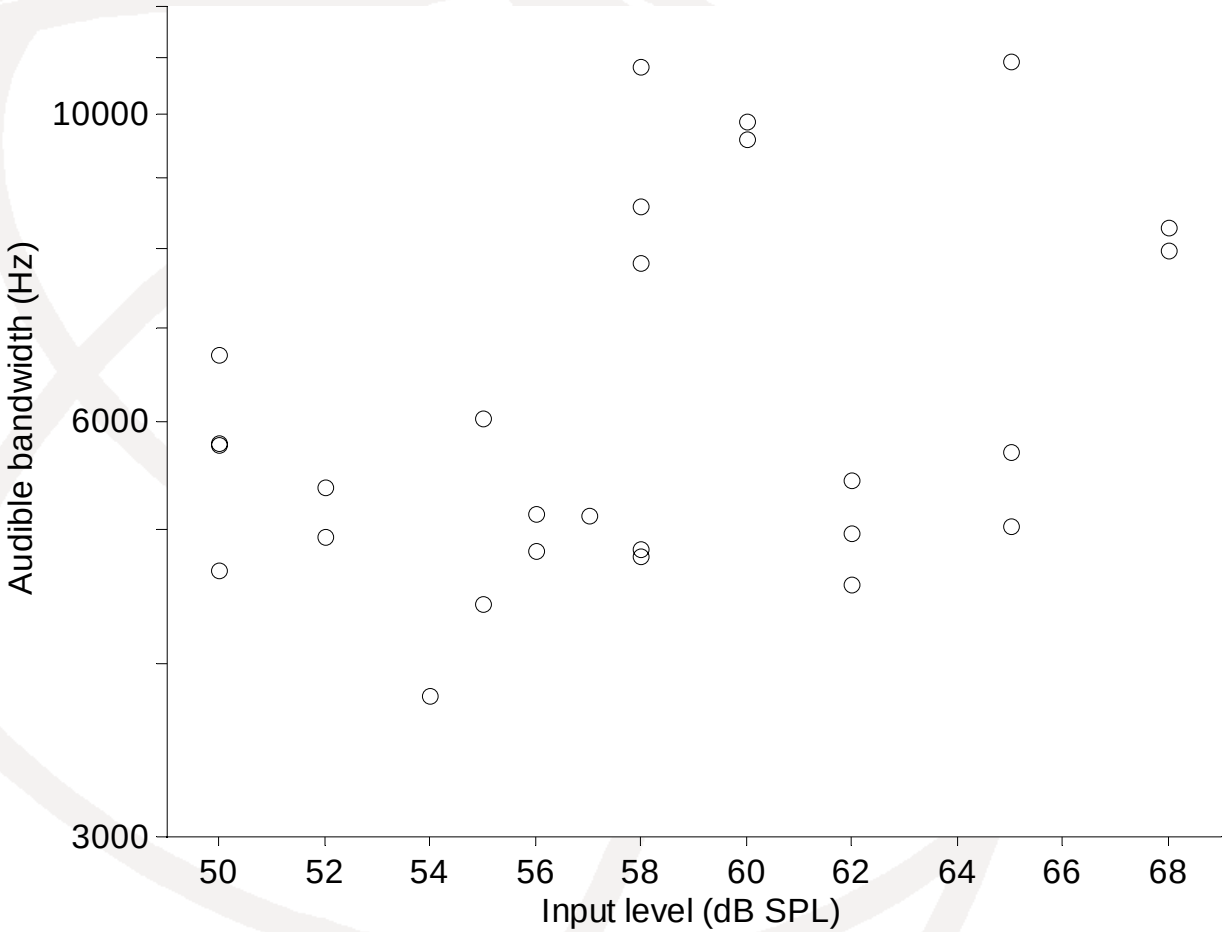
Benefit mainly for
4 kHz to 6 kHz

Why might benefit be limited to 6 kHz?

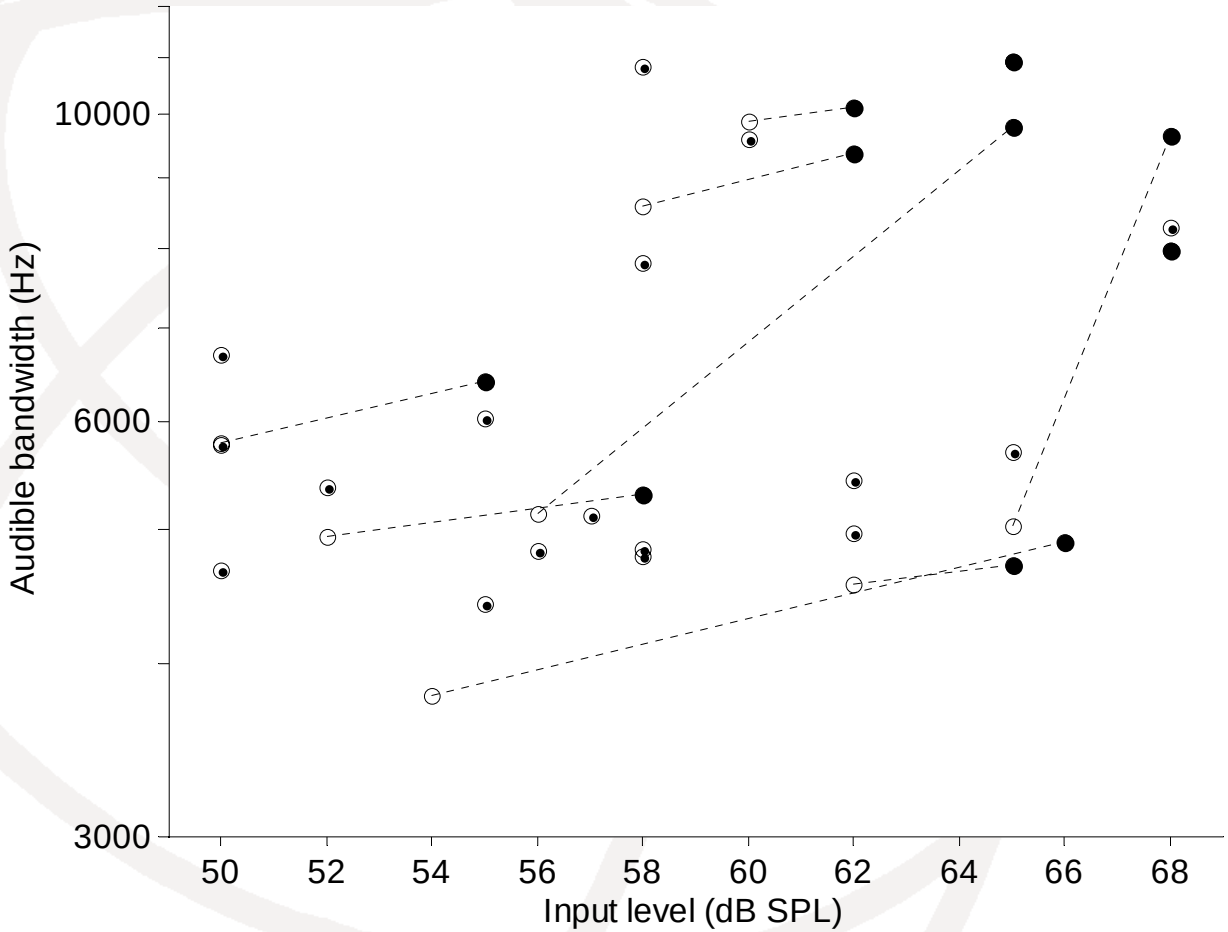
- Insufficient audibility at high frequencies


80
60
40
20
0
dB SPL
Aided stimulus spectrum @ eardrum
Audible bandwidth
Threshold audiogram
100
1000
10000
Frequency (Hz)

Audible bandwidth < 6000 Hz in large fraction of cases



Audible bandwidth < 6000 Hz in large fraction of cases



Why might benefit be limited to 6 kHz?

- Insufficient audibility at high frequencies
- Inefficient at utilizing information above 6 kHz

Summary of findings

- Extending bandwidth from 4 kHz to 6 kHz gave benefit for sound quality in most impaired listeners.
- Data are inconclusive about benefit of further bandwidth extension due to limited audibility above 6 kHz.

On overcoming limited audibility

- Acclimatization to extended-bandwidth amplification
- Gain prescriptions based on alternative rationales

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