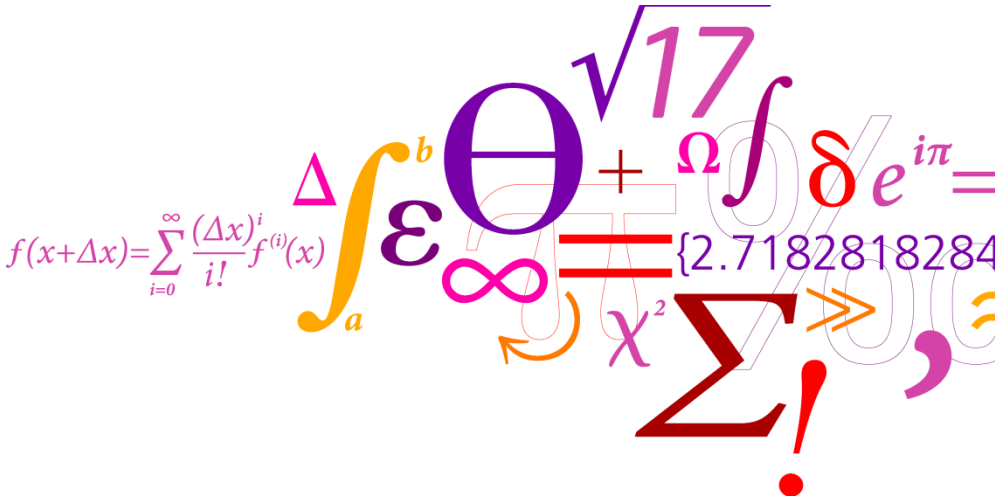
The role of binaural cues for the externalization of sound in reverberant environments

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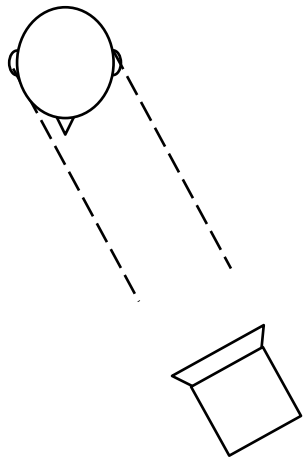
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DTU Electrical Engineering
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Introduction

- **Distant sound sources in our environment are naturally perceived as externalized**

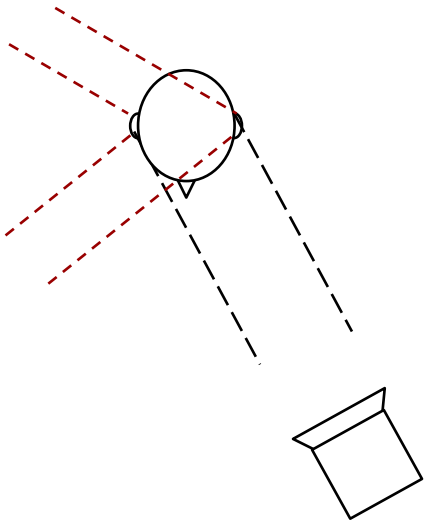


- Frequency shaping of binaural cues
  - Interaural level differences (ILDs)
  - Interaural time differences (ITDs)

- Externalization in anechoic rooms
  - Importance of binaural cues
    (Hartmann and Wittenberg 1996)
  - Spectral detail → no effect on externalization
    (Kulkarni and Colburn 1998)

Effects of reverberation

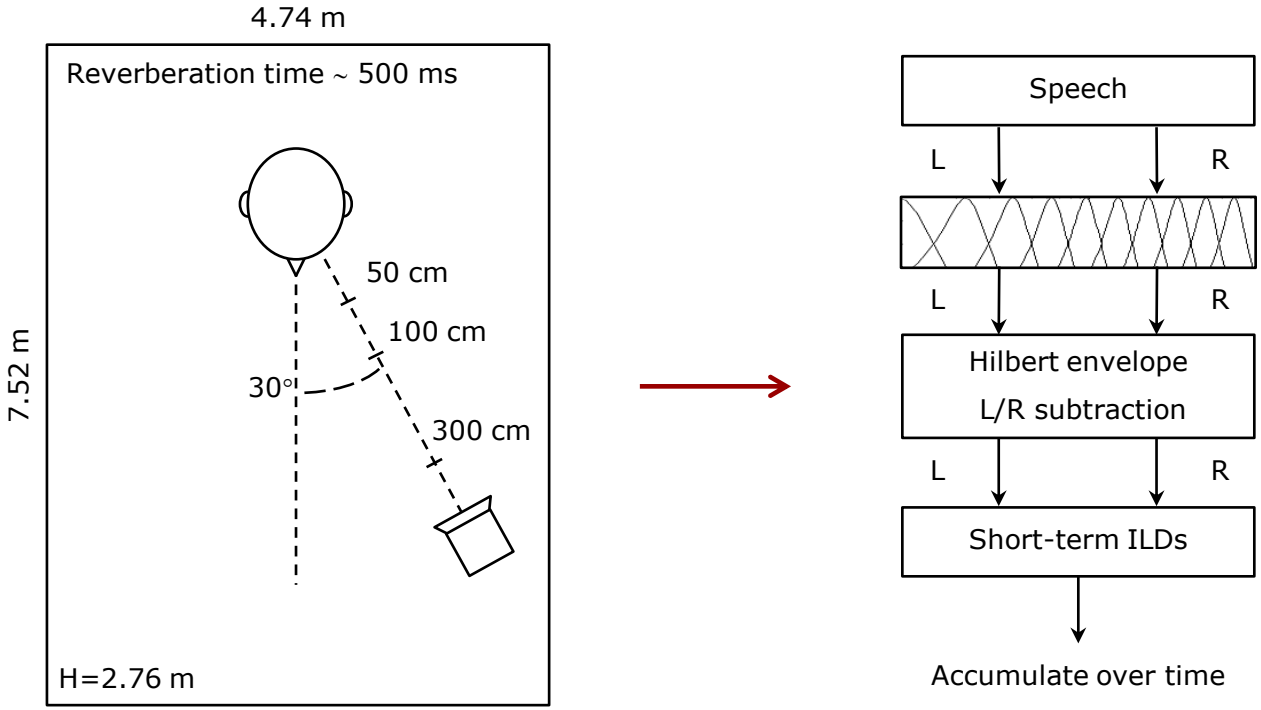
- **Aim of current project**
  - **Investigate the role of binaural cues for externalization in a reverberant room**



- Increased accuracy of distance judgments
- Enhances externalization
- Direct to reverberant ratio important cue to distance
- Modification of binaural cues

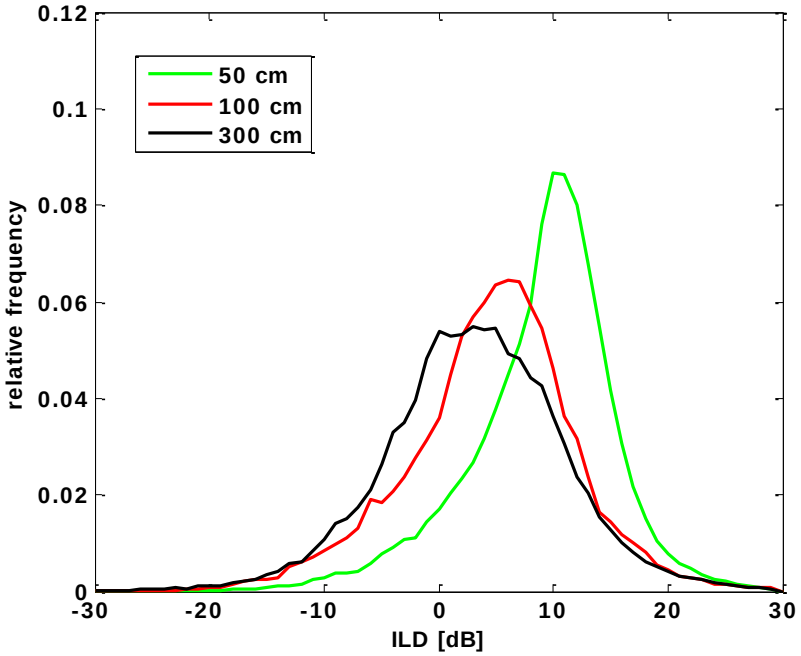
Behavior of ILDs for speech source in a standard listening room

- Speech recorded on a head and torso simulator (HATS)
- Analysis of short-term ILDs in logarithmically spaced filters



Behavior of ILDs for speech source in a standard listening room 2

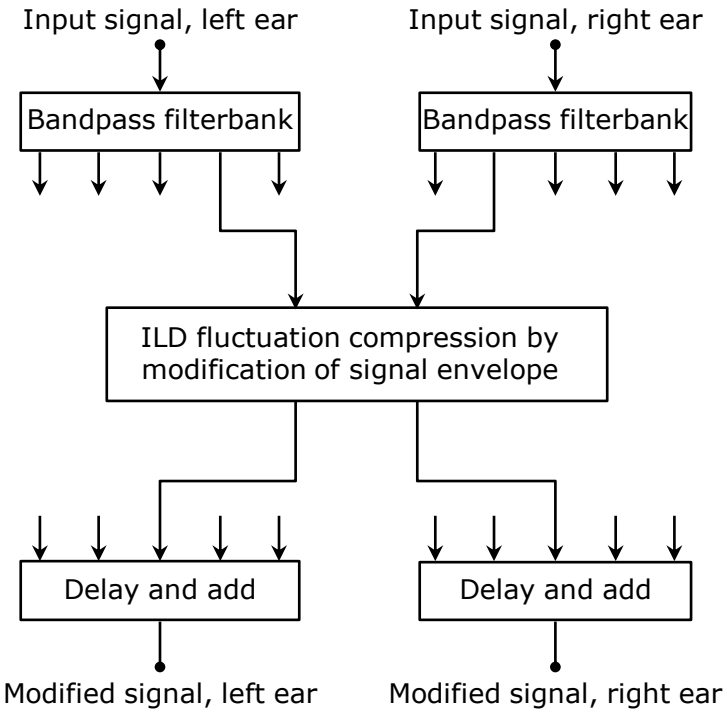
- **ILD distributions at different distances in a single frequency channel**

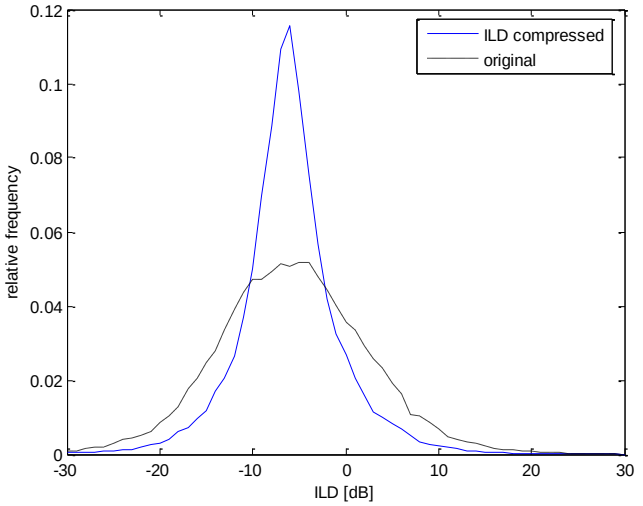


- As the distance to the sound source is increased
  - The ratio of direct sound to reverberant energy is decreasing
  - The width of ILD distributions is increasing
  - The magnitude of the ILDs is reduced

Modifying ILD distributions

- **Do ILD fluctuations have an effect on externalization?**
  - **Modification of ILDs to reduce the width of ILD distribution**

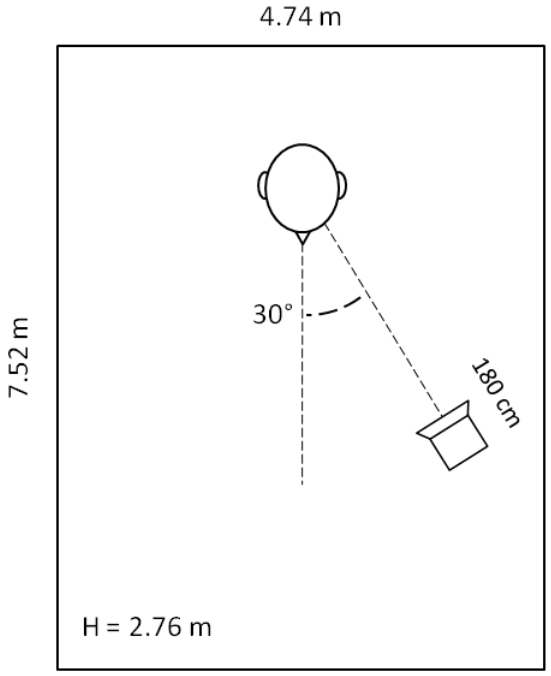




Amount of ILD fluctuation compression controlled by parameter α

Setup for psychoacoustic experiment

- **Simulating a distant sound source via headphones**
  - **Measurement of individual binaural room transfer functions (BRTF)**
  - **Individual equalization of headphone transfer functions**
  - **Miniature microphones inserted into the ear canals of test subject**



- Listening setup
  - Room reverberation time T30 ≈ 500 ms
  - Loudspeaker at 30 degrees and 1.8 m relative to listener
  - Speech source
- Virtual sound source externalized and coincident in location with real source

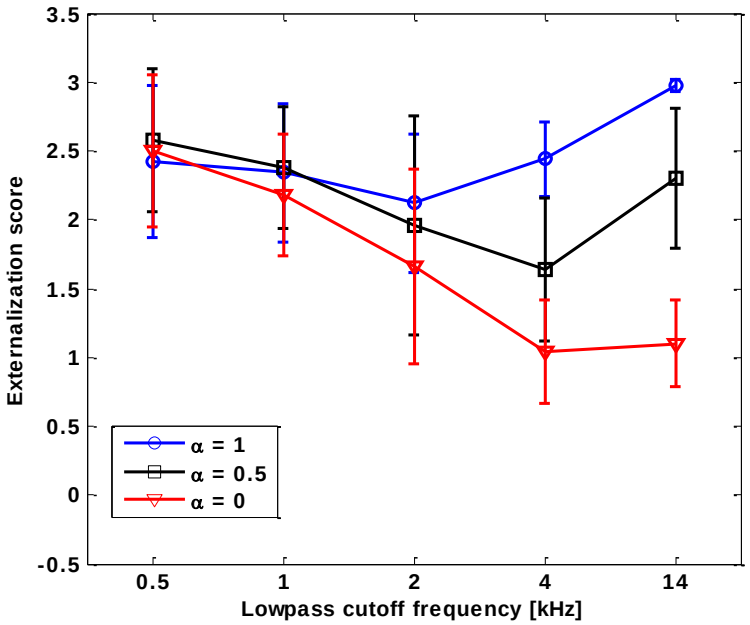
Experimental procedure

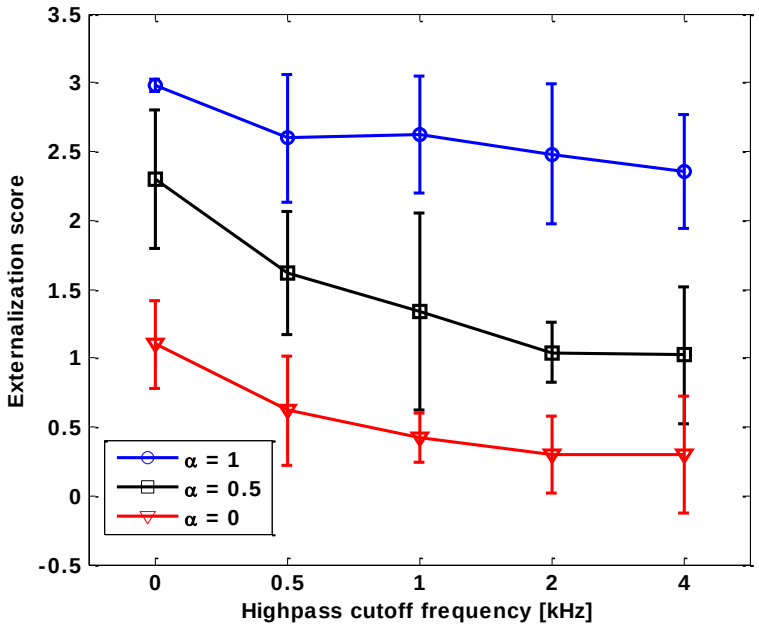
- 1 wideband, 4 lowpass, and 4 highpass conditions
- Frequency cutoff: 0.5, 1, 2, and 4 kHz
- 3 ILD compression factors
  - $\alpha = 0$ → full compression
  - $\alpha = 0.5$ → medium compression
  - $\alpha = 1$ → no compression
- 27 presentations in random order in each run

Listener externalization rating scale

0	The sound is in my head
1	The sound is closer to me
2	The sound is closer to the loudspeaker
3	The sound is at the loudspeaker

Results and Discussion 1





- The degree of externalization is slightly affected by signal bandwidth
- Decreasing the ILD fluctuations reduces the degree of externalization, particularly when the signal contains higher frequencies
- At low frequencies, the compression of ILD fluctuations has no effect

Results and Discussion 2

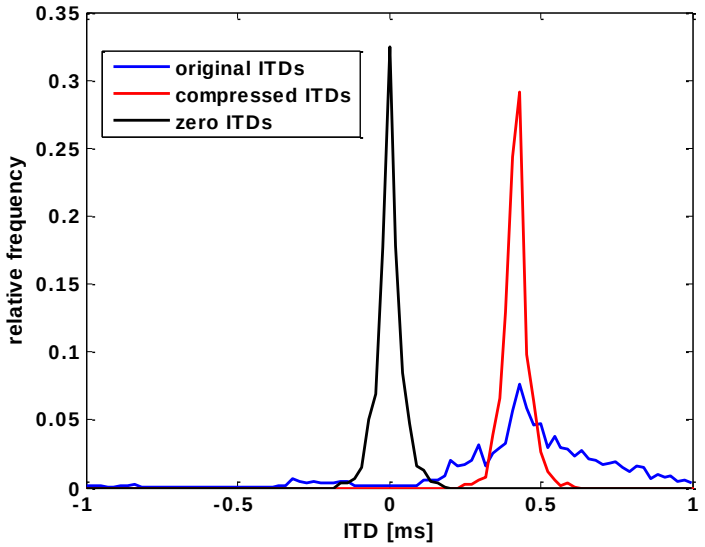
- Compression of ILD fluctuations is present at low frequencies, but it is not clearly perceived

- A previous study (Hartmann and Wittenberg 1996) used a similar listening setup in an anechoic room
  - ILDs were set to zero in order to completely remove ILD information
  - It was concluded that ILDs were important in all frequency regions

- Our follow-up experiment in the listening room with zero ILDs showed that
  - Externalization of lowpass stimuli was not affected
  - Broadband stimuli were completely inside the head

Effect of ITDs

- **What is the role of low frequency ITDs?**
  - **The signal phase was modified in order to manipulate low frequency ITDs**
  - **The width of the ITD distribution was reduced while the peak of the distribution was retained**



- Reducing the ITD distribution width does not affect externalization, if the overall ITD is retained
- This suggests that the ITD fluctuations may not be important for externalization
- It is important to retain the correct overall ITD → shifting the ITD distribution to zero results in lowpass stimuli inside the head

Discussion

- ITD and ILD fluctuations seem to have different effects
  - ITDs can be substituted with an ITD corresponding to the ITD of the direct sound without affecting externalization
  - Replacing ILDs with the direct sound ILD results in low externalization ratings
- Separating the direct sound and room related binaural cues
  - Direct to reverberant ratio as a monaural cue
  - Reverberation dependent change of binaural cues
- Monaural headphone presentation → no externalization

Summary

- If the ILD variability is restricted for a distant sound source, the source appears to be closer, i.e. less externalized
- Results suggest that the way in which the ILDs are shaped by the reverberation is important for proper externalization
- This study has focused on the shaping of ILDs as they are accumulated over time → future work will focus on timing information in ILDs
- Future work will also investigate whether ILD or ITD processing can make a sound source to appear more externalized
- The results may be relevant for hearing aid signal processing, as dynamic range compression and noise reduction algorithms can affect ILDs

Questions?