

# The Effect of Direct-to-Reverberant Energy Ratio on Front-Back Confusion in Binaural Reproduction

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# Background

- Problem: Front-Back (F/B) confusion in binaural reproduction.
- In the real world, we use head movement and visual cues to resolve F/B confusion.
- In binaural listening, head-tracking and individualized HRTF can be useful for avoiding the reversal error.
- However, non-head-tracked binaural audio with generalized HRTF is still widely used.

# Background

- Previous research on F/B confusion focused mainly on spectral cues.
- However, F/B confusion might be less in a reverberant room compared to an anechoic room.
- Direct-to-reverberation ratio (DRR) is an absolute cue for auditory distance perception (Zahorik 2002).
- Source-listener distance in a room has an effect on F/B confusion rate (Rychtáriková et al. 2015).

# Research Questions

1. What is the effect of DRR on F/B confusion in binaural reproduction?
2. What are the potential thresholds of DRR in terms of "front-to-back" confusion and "back-to-front" confusion?
3. Is there an optimal range of DRR to avoid strong F/B confusion?

# Experimental Stimuli

- Motivation: virtual loudspeaker monitoring in 3D audio production.
- Binaural room impulse responses (BRIRs) for  $0^\circ$  and  $180^\circ$  captured in an ITU-R BS.1116-3-compliant room at the APL.
  - $RT = 0.25s$ ,  $6.2m \times 5.2m \times 3.5m$
  - KU100 dummy head placed in the middle of the room, at 2m from each speaker (Genelec 8040A).



# Experimental Stimuli

- BRIR segmentation and DRR manipulation
  - The original BRIRs segmented into direct (up to 2.5ms) and reverberant (>2.5ms) parts.
  - DRRs ranging from -12 dB to 12 dB, with 4 dB intervals, by adjusting the levels of the reverberant part.
  - In addition, a pseudo-anechoic condition (no reverb).
- The manipulated BRIRs were convolved with a train of pink noise bursts (200ms-long, 500ms gap in between).
  - All resulting stimuli were RMS-normalized.

# Subjects and Test Protocol

- 5 subjects with self-reported normal hearing.
  - Experienced researchers in spatial audio.
  - Ages from 24 to 43.
- Forced choice method using HULTI-GEN v2 software.
  - Choose either “Front” or “Back” for each trial.
  - Each subject tested each stimulus 20 times in a random order.
  - All used K702 headphones with equalization.
- The test was conducted remotely at the subject’s home due to the pandemic.
  - In a quiet room, with eyes close while listening.

# Subjects and Test Protocol

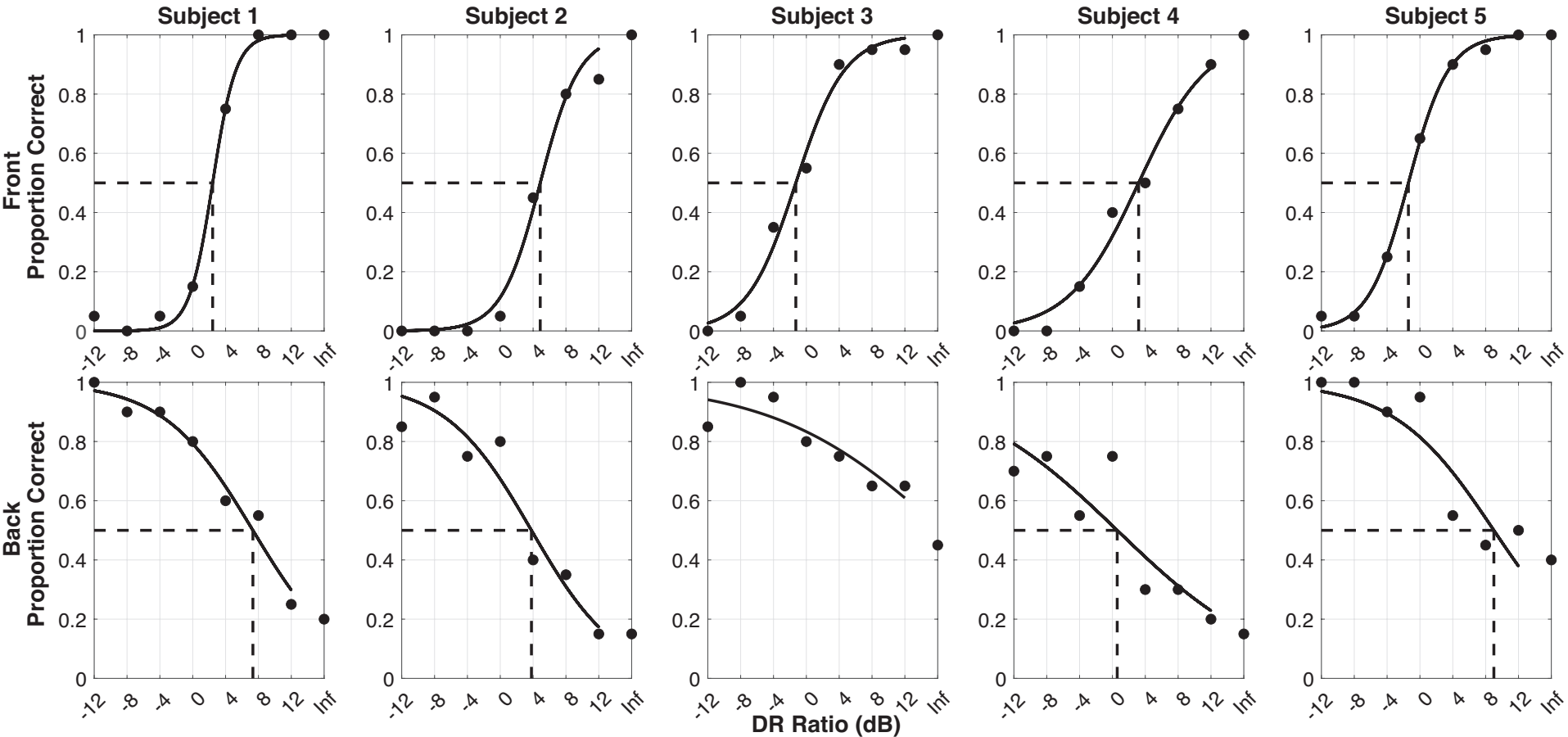
- A novel playback level calibration procedure.
    1. Hand-rubbing recording by the experimenter, convolved with HRIRs of  $0^\circ$  azi/elev.
    2. The experimenter set his audio interface output level to calibrate the stimuli to 68 dB LAeq, using an ear simulator.
    3. At the same interface level, the RMS level of the hand-rubbing recording was loudness-matched to actual hand-rubbing of the experimenter.
    4. Each subject first adjusted their audio interface output level so that the provided hand-rubbing matched their own hand-rubbing in terms of perceived loudness.
- This procedure was expected to make the playback level roughly around the target level of 68 dB LAeq (Formal hand-rubbing SPL measurements and loudness matching test under way).



# Results

- Proportions of correct responses (PC) and psychometric function (logistic) for each subject.
- The F/B confusion threshold was defined as the DRR corresponding to the PC of 0.5 of the psychometric function.

# Results

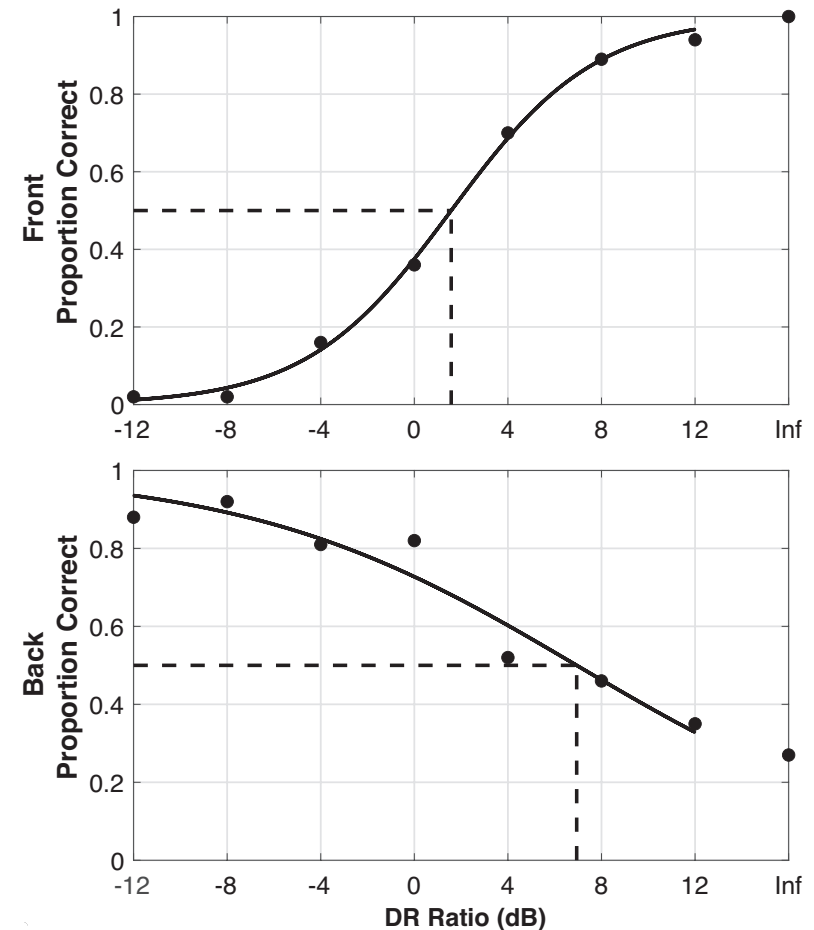


Lower DRR → More reverb. Inf = Pseudo anechoic

# Discussions

- As the DRR increases (**less reverb**), the subjects' responses tended to be biased to **Front**, regardless of the target source position.
- As the DRR decreases (**more reverb**), the subjects' responses tended to be biased to **Back**, regardless of the target source position.

## Global PCs

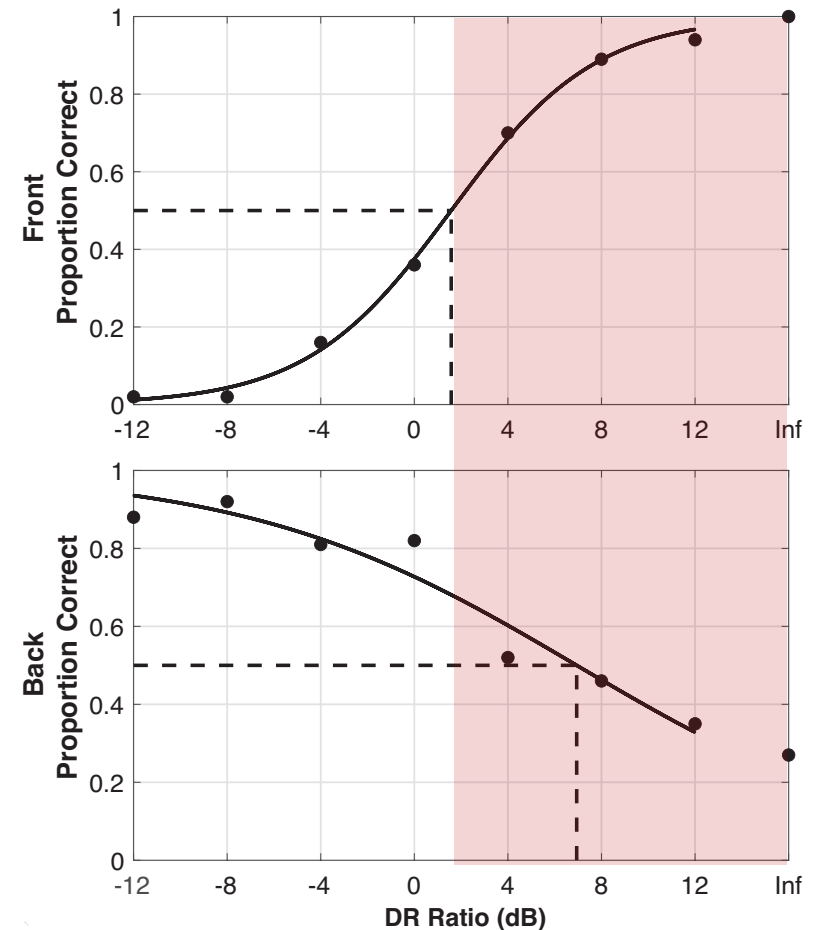


# Discussions

## Trade-off relationship

- At a higher DRR, localization accuracy for a source in front would be higher, but that for a source behind the listener would be lower (**Back-to-Front confusion**).

## Global PCs

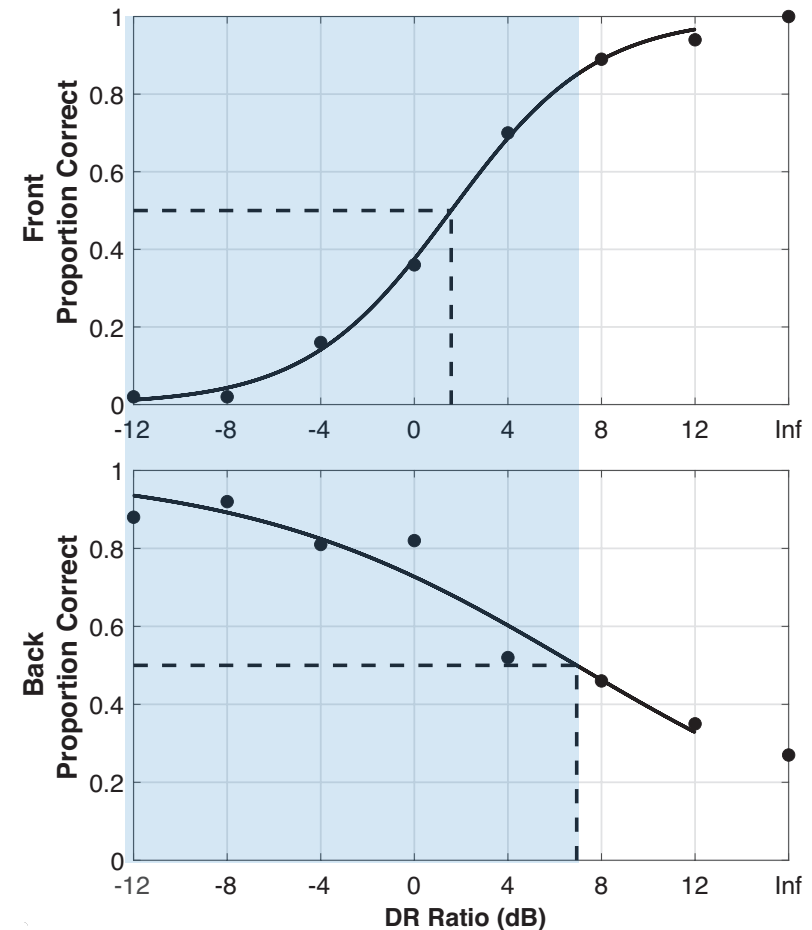


# Discussions

## Trade-off relationship

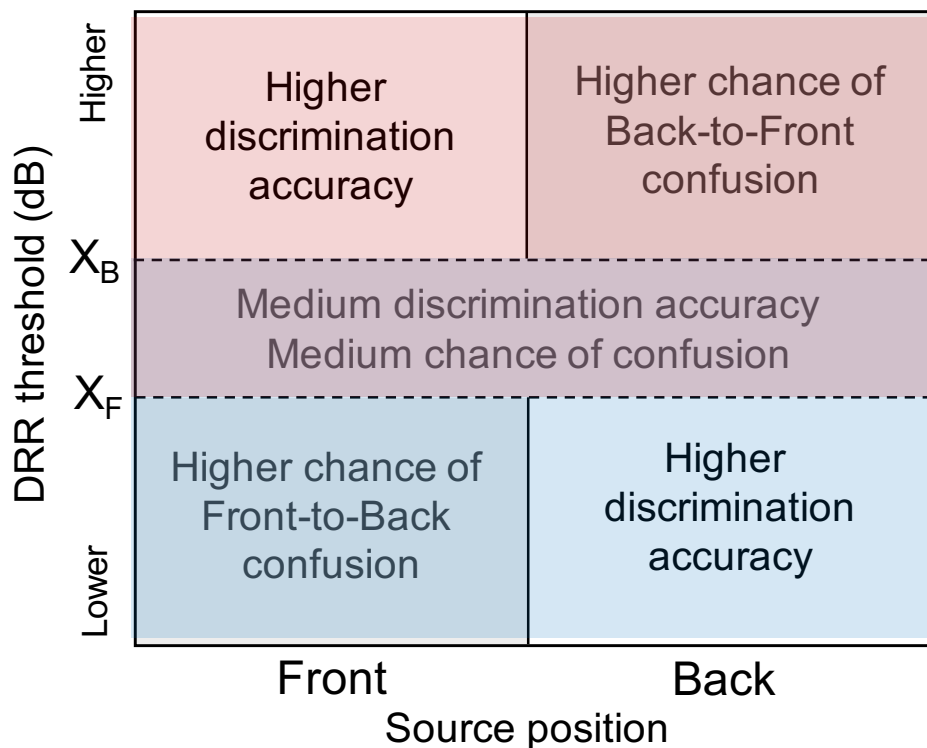
- At a lower DRR, localization accuracy for a source behind the listener would be higher, but that for a source in front would be lower (**Front-to-Back confusion**).

## Global PCs

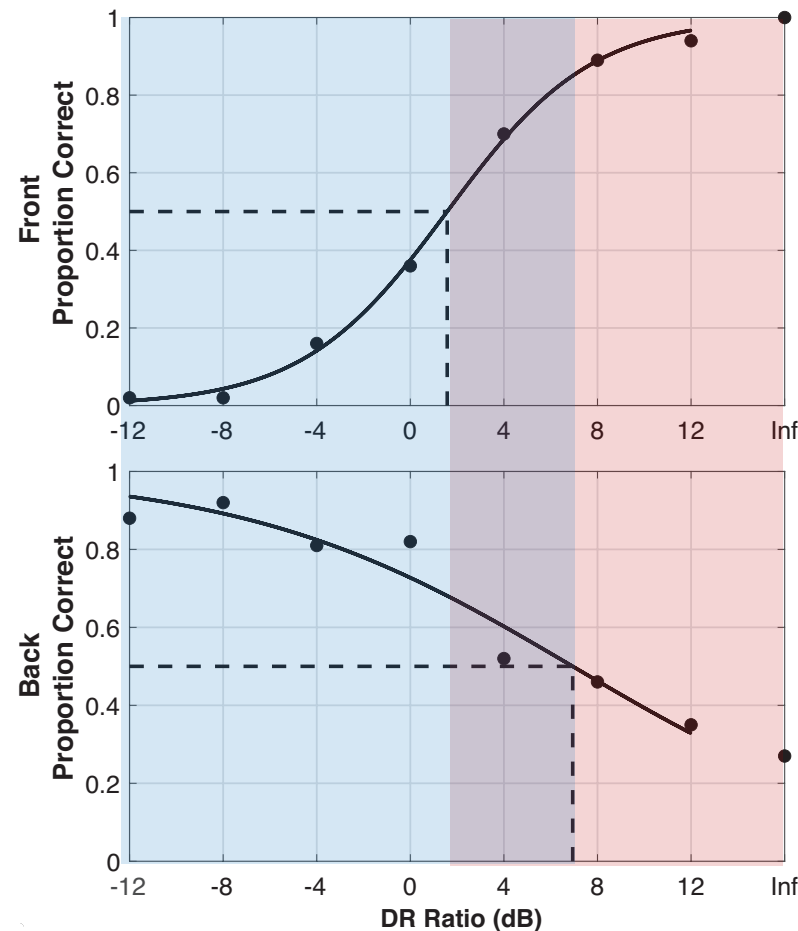


# Discussions

## Proposed model



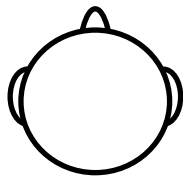
## Global PCs



# Discussions

Practical implication for binaural recording/mixing using BRIRs.

$$\text{DRR} > X_F$$



Good F/B discrimination

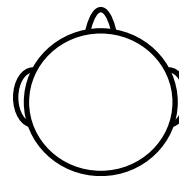
$$\text{DRR} < X_B$$



$$\text{DRR} < X_F$$



Strong F/B reversal



$$\text{DRR} > X_B$$



## Further work

- The study is still ongoing. A larger number of subjects will be tested to obtain a more reliable global psychometric function of DRR on F/B discrimination.
- Measurements of people's hand-rubbing SPLs and validation of the proposed remote playback level calibration method.





# Thanks for listening!

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