Investigation on Phantom Image Elevation

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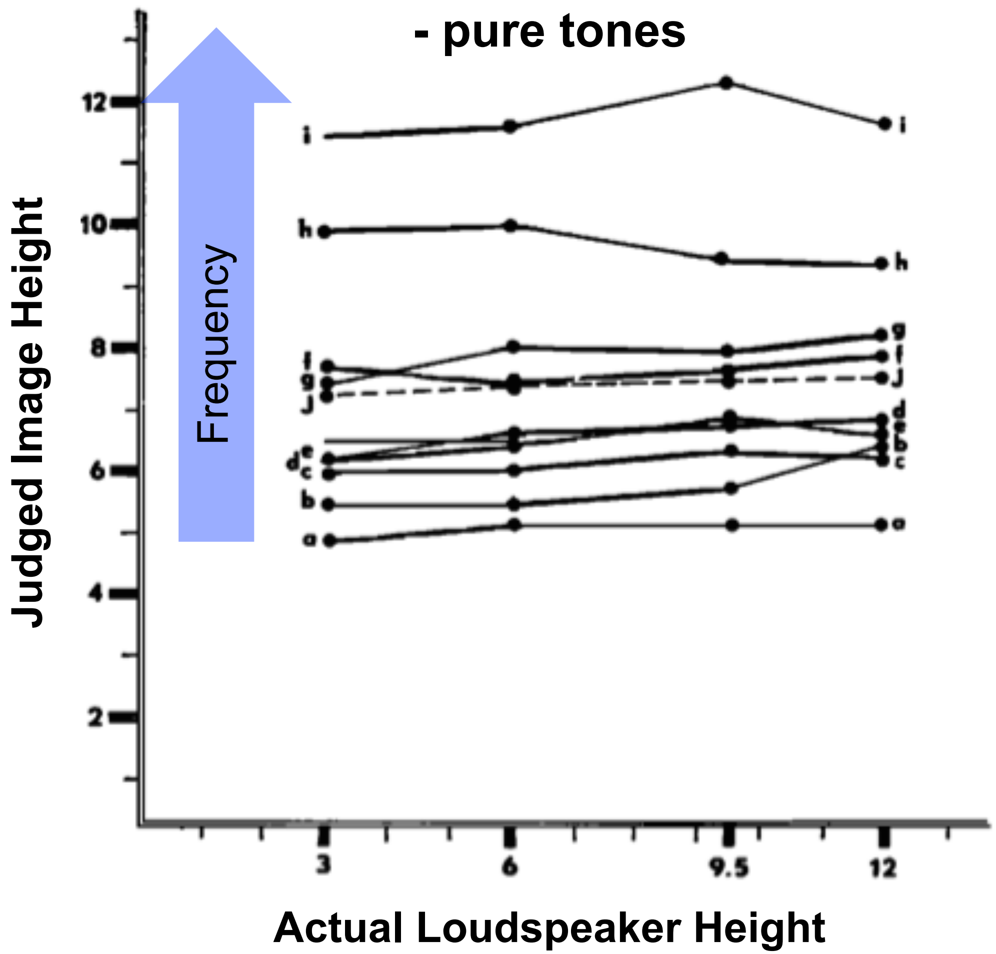
Contents

- Research background
- Experiment
- Summary

Pitch-Height Effect for "Real" Source

- The higher the frequency of a **pure tone** is, the higher the perceived image position is, **regardless of** the physical height of the loudspeaker. (Pratt 1930).
- Confirmed by Trimble (1934), Roffler and Butler (1968), etc.

From Roffler and Butler (1968a) - pure tones



Pitch-Height Effect for “Real” Source

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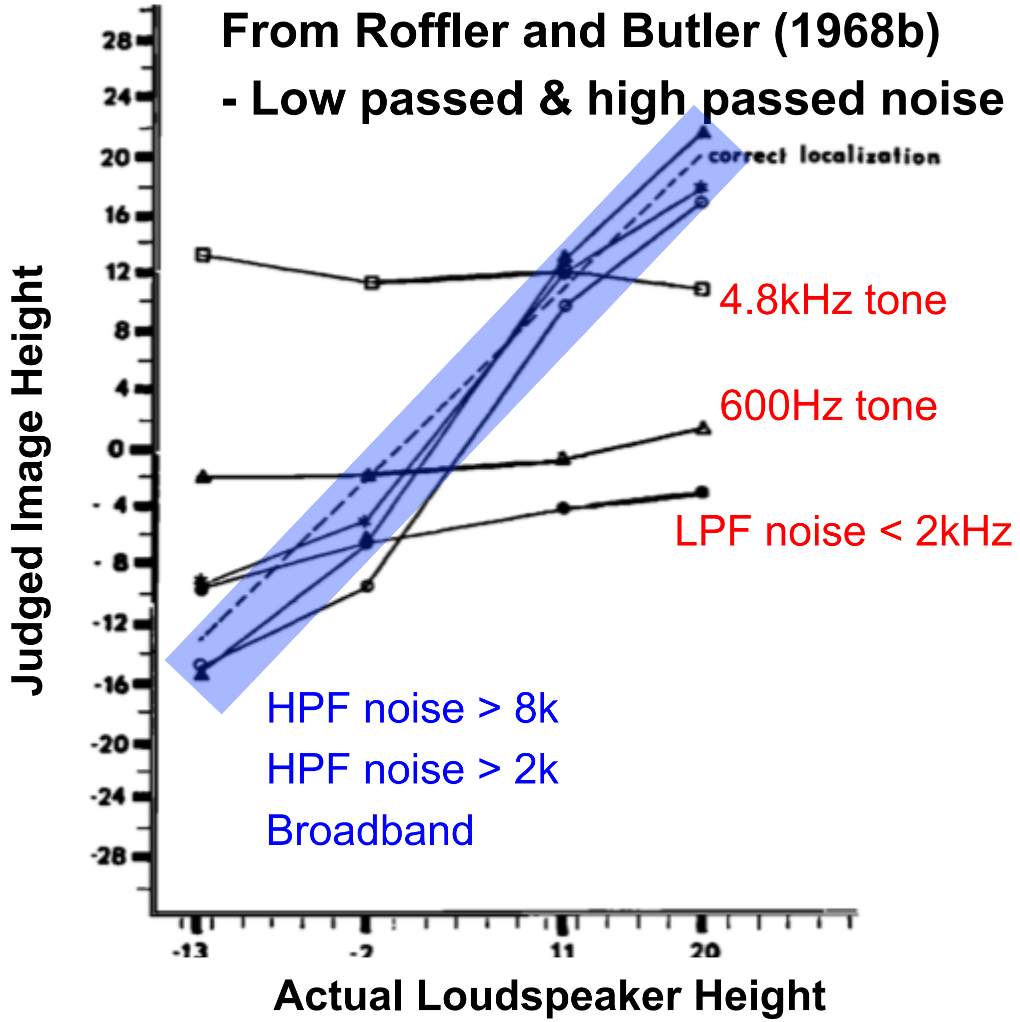
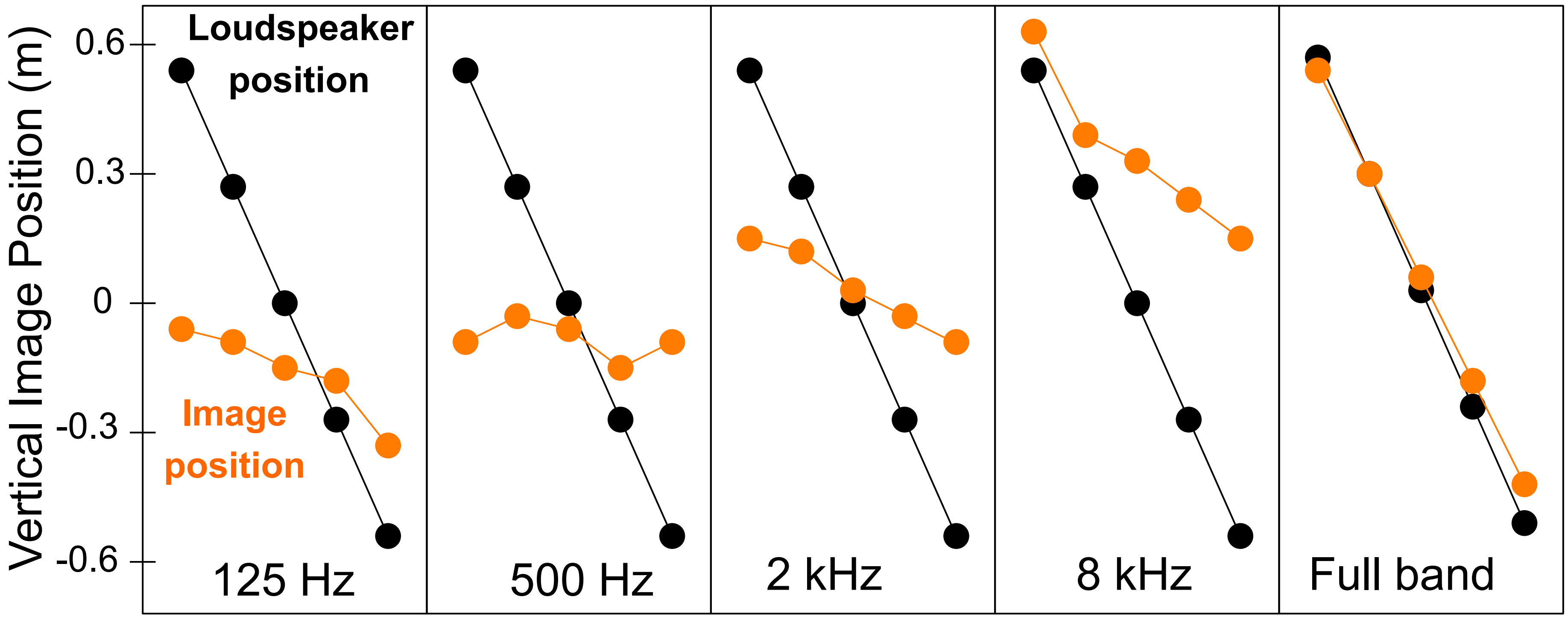
- For **band-passed noise** signals, high frequency components (above 7kHz) are essential for accurate vertical localisation.

(Roffler and Butler 1968b)



Pitch-Height Effect for “Real” Source

- Pitch height effect for **octave band pink noise**
  - Simplified from Cabrera and Tiley (2003); median plane results



Pitch-Height Effect for “Phantom” Source

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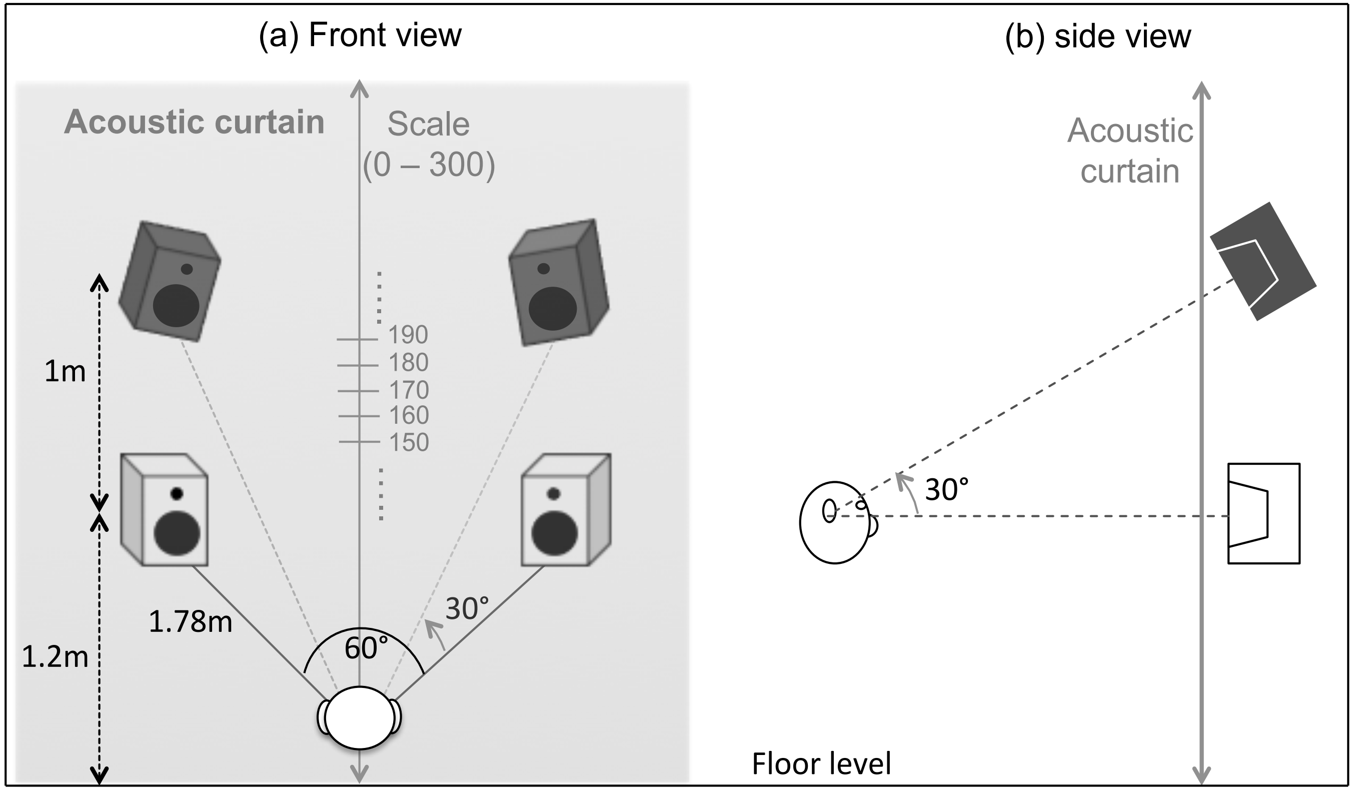
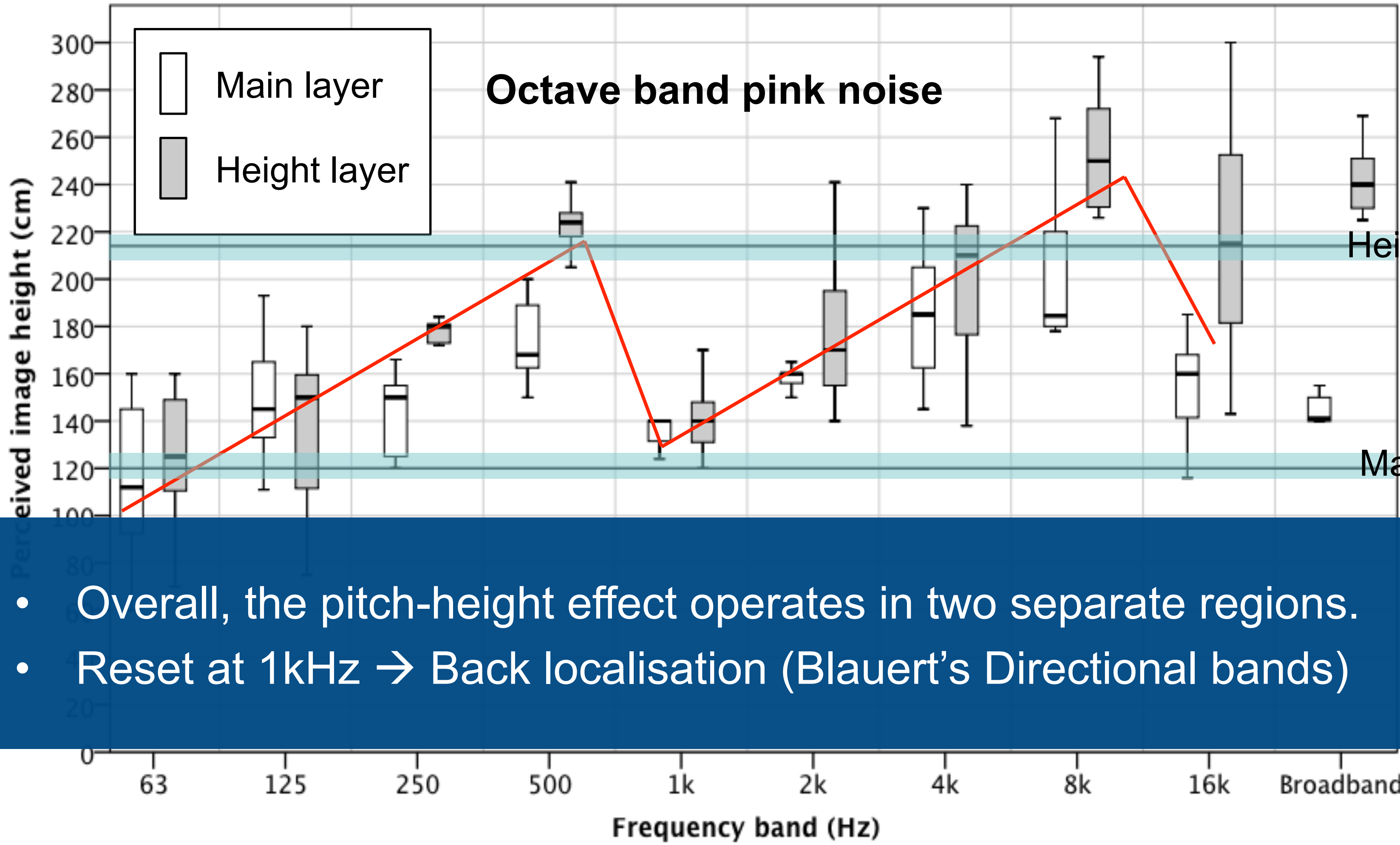
- Pitch-height effect for horizontal **phantom** images from main and height layers (Lee 2015)



Pitch-Height Effect for Phantom Source

- Pitch-height effect for horizontal **phantom** image (Lee 2015)



- Overall, the pitch-height effect operates in two separate regions.
- Reset at 1kHz → Back localisation (Blauert's Directional bands)

Directional bands

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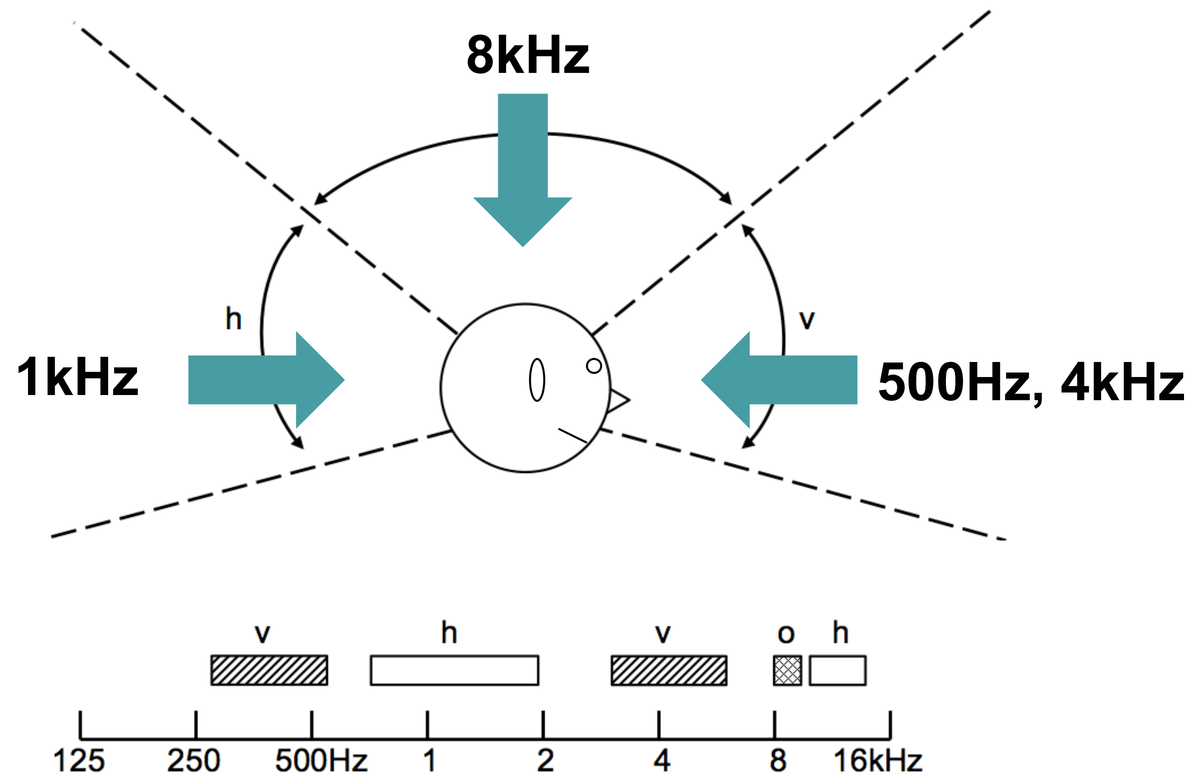
- Blauert (1968): physical mapping between frequency bands and their perceived positions in the median plane.



Pitch-Height Effect for Phantom Source

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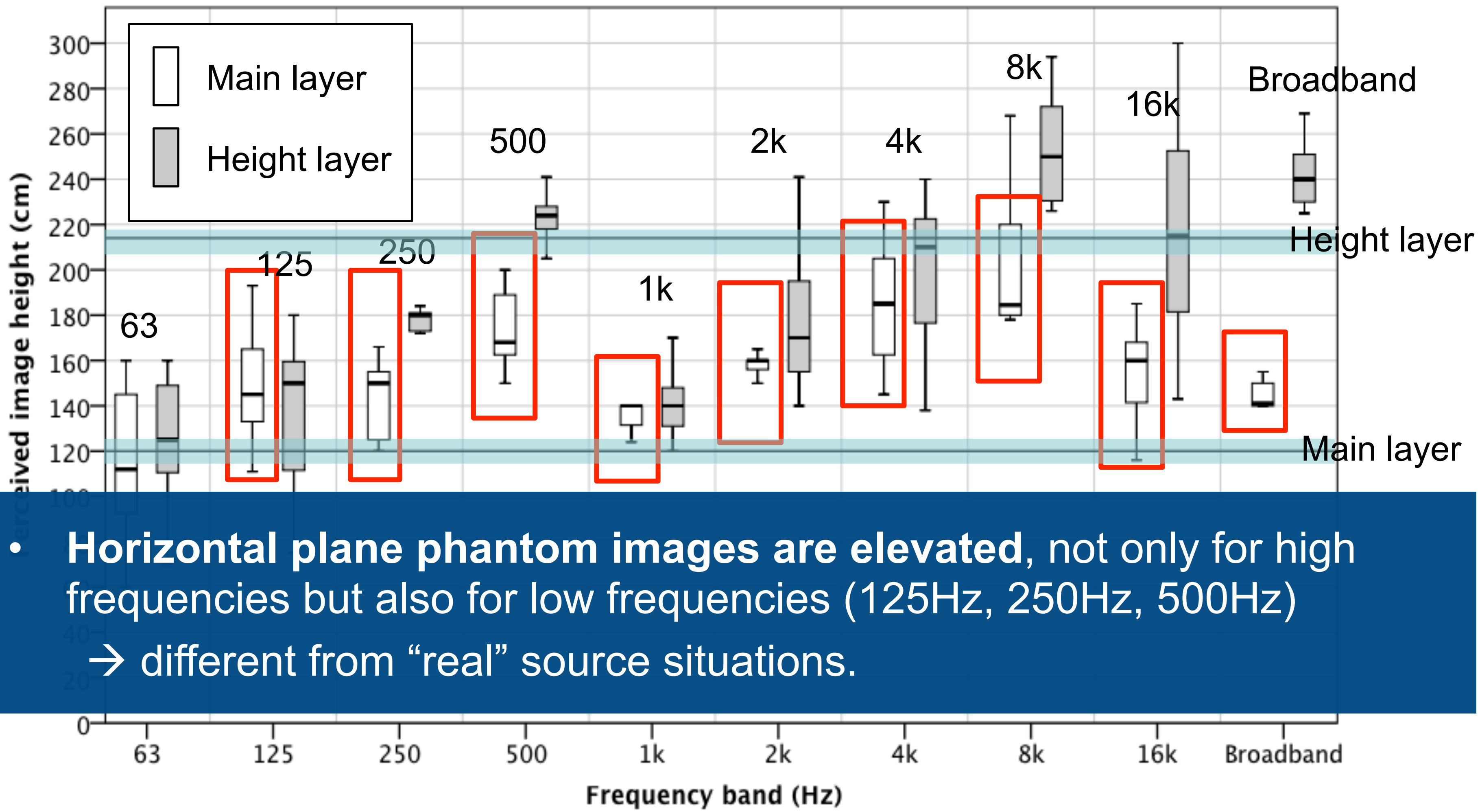
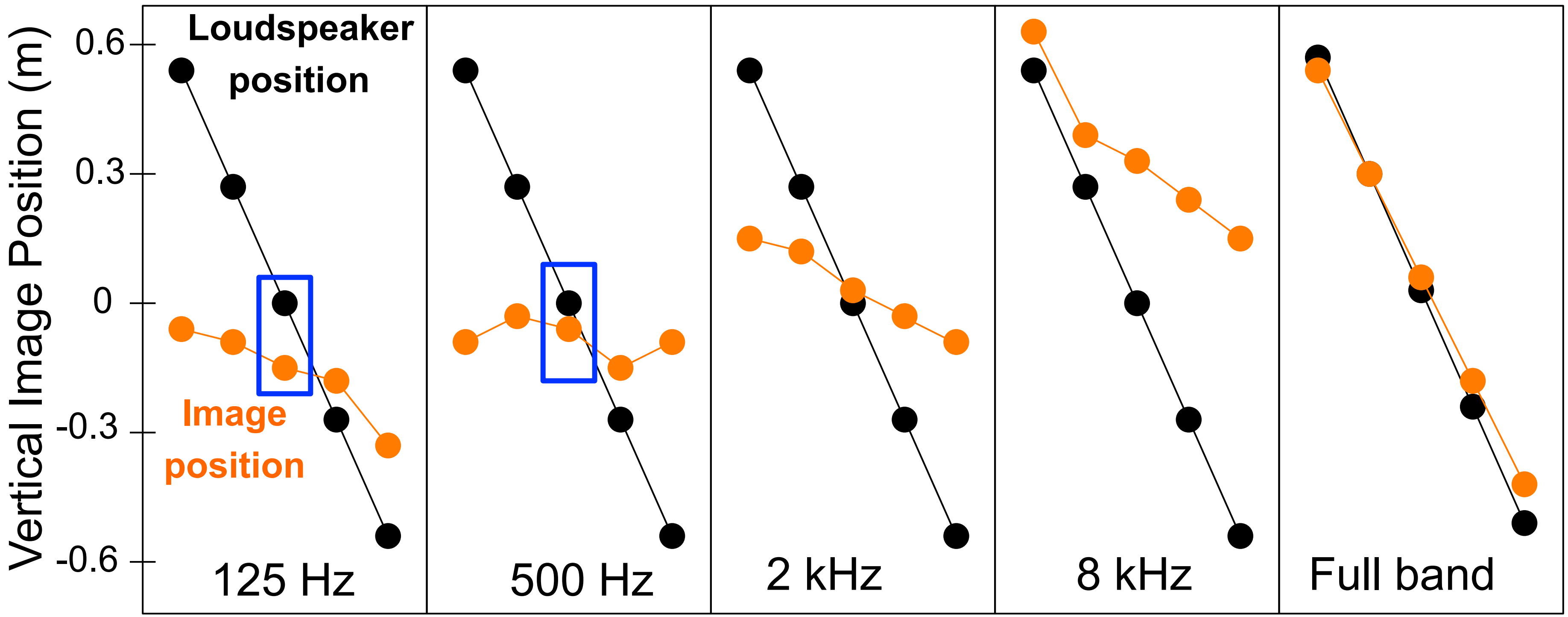


- **Horizontal plane phantom images are elevated**, not only for high frequencies but also for low frequencies (125Hz, 250Hz, 500Hz)

  → different from “real” source situations.

Pitch-Height Effect for Real Source

- Pitch height effect for octave bands
  - Simplified from Cabrera and Tiley (2003); median plane results



Horizontal Phantom Image Elevation
Vs.
Loudspeaker Base Angle & Sound Source

Previous studies

- de Boer (1947): Phantom centre image is perceived to be elevated, and the elevation angle increases as the loudspeaker base angle increases. (180° → overhead region)
- Confirmed by Damaske and Mellert (1969/1970).

Previous studies

- Previous studies reporting the elevation effect are limited in terms of sound sources or loudspeaker base angles tested.

	Source	Base angles
de Boer (1947)	Not reported	0° to 180°
Damaske and Mellert (1969/1970)	White noise 0.65 – 4.5kHz	0° to 360°
Jo et al. (2010)	White noise 1 – 16kHz	60°, 220°
Frank (2014)	Pink noise Broadband	40°
Lee (2015)	Pink noise Broadband, octave bands	60°

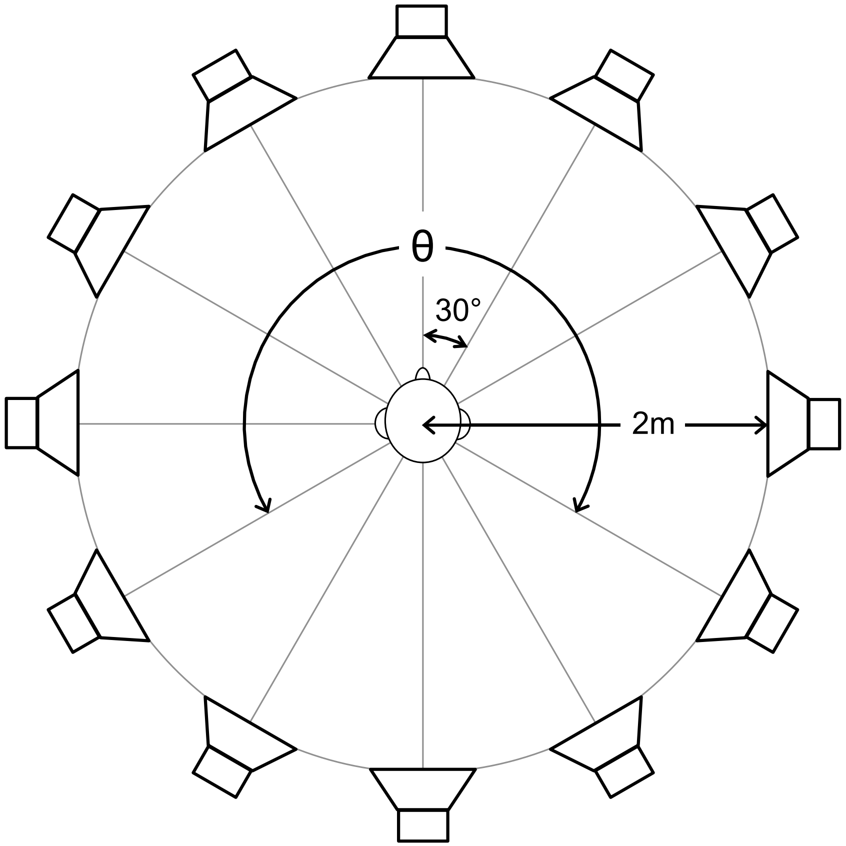
Aim of the Current Experiment

- To investigate the phantom image elevation effect for a wide range of sound sources, with base angles covering from 0° to 360°.

- Sound sources
  – Speech, Helicopter, Aeroplane, Thunder, Rain, Bird, Church Bell
  – Broadband pink noises (continuous and transient)
  – Broadband white noises (continuous and transient)

Test Method

- Loudspeaker arrangement
  - At the ear height in the horizontal plane, 0° to 360° at 30° interval.



Test Method


Critical listening room
at the University of Huddersfield
(ITU-R BS.1116-Compliant)

Test Method

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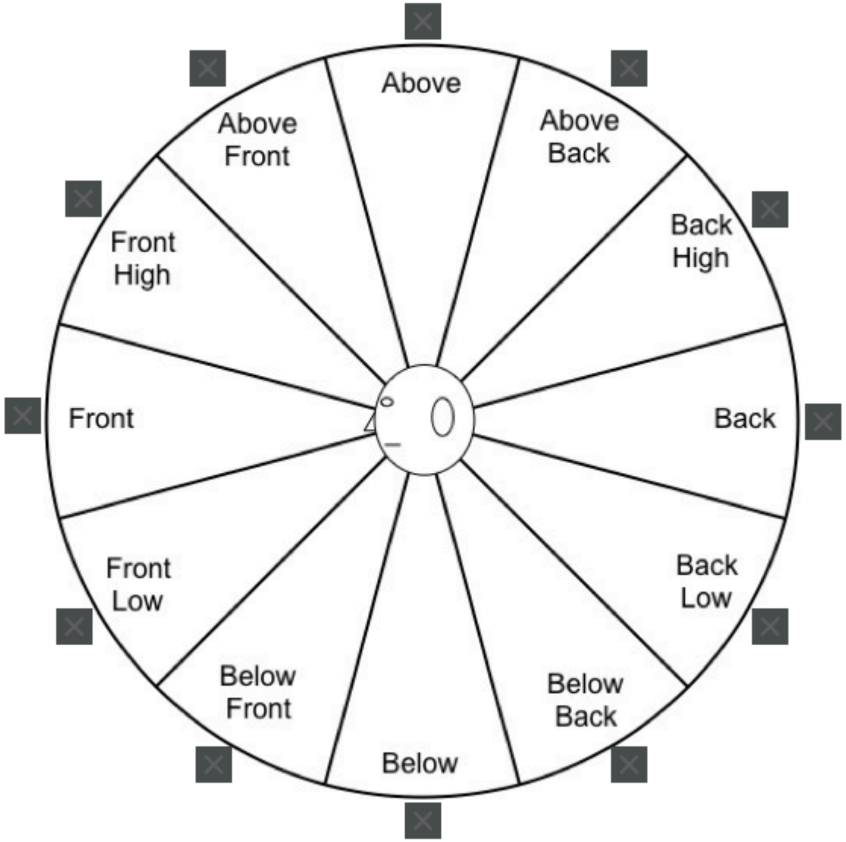
- GUI written in Max
  - Response method similar to Blauert (1968) but in a finer resolution



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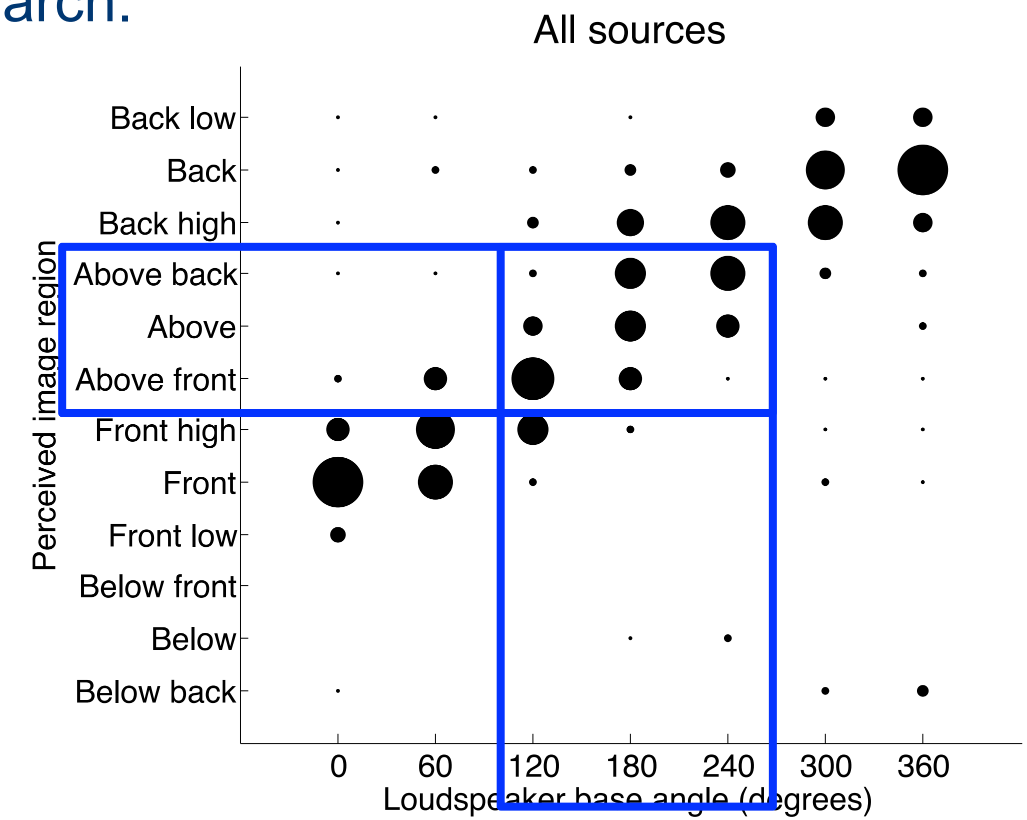
Test Method

- Subjects
  - 10 people comprising researchers and post-graduate students from the University of Huddersfield's music technology courses.
  - All were much experienced in spatial quality evaluation but not trained for the particular task of the experiment.

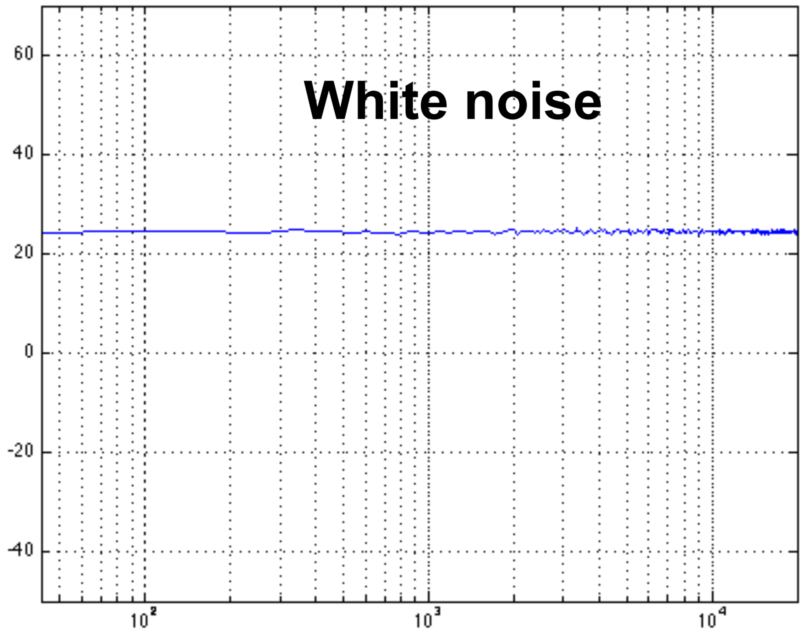
Results

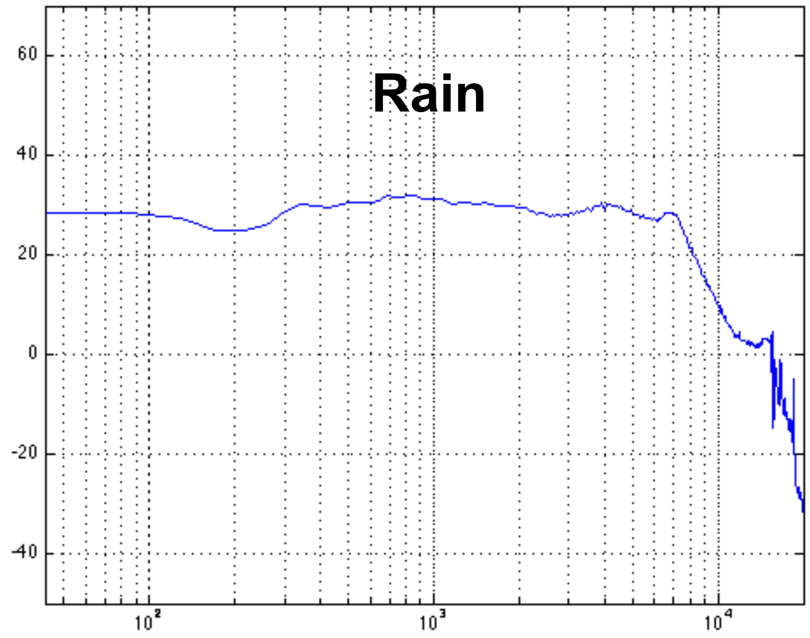
- Responses for all sources
  – The general trend agrees with the suggestions from the past research.



Phantom Image Elevation

- Sound source dependency
  - Responses are most linear and consistent for source with a broad and flat spectrum.





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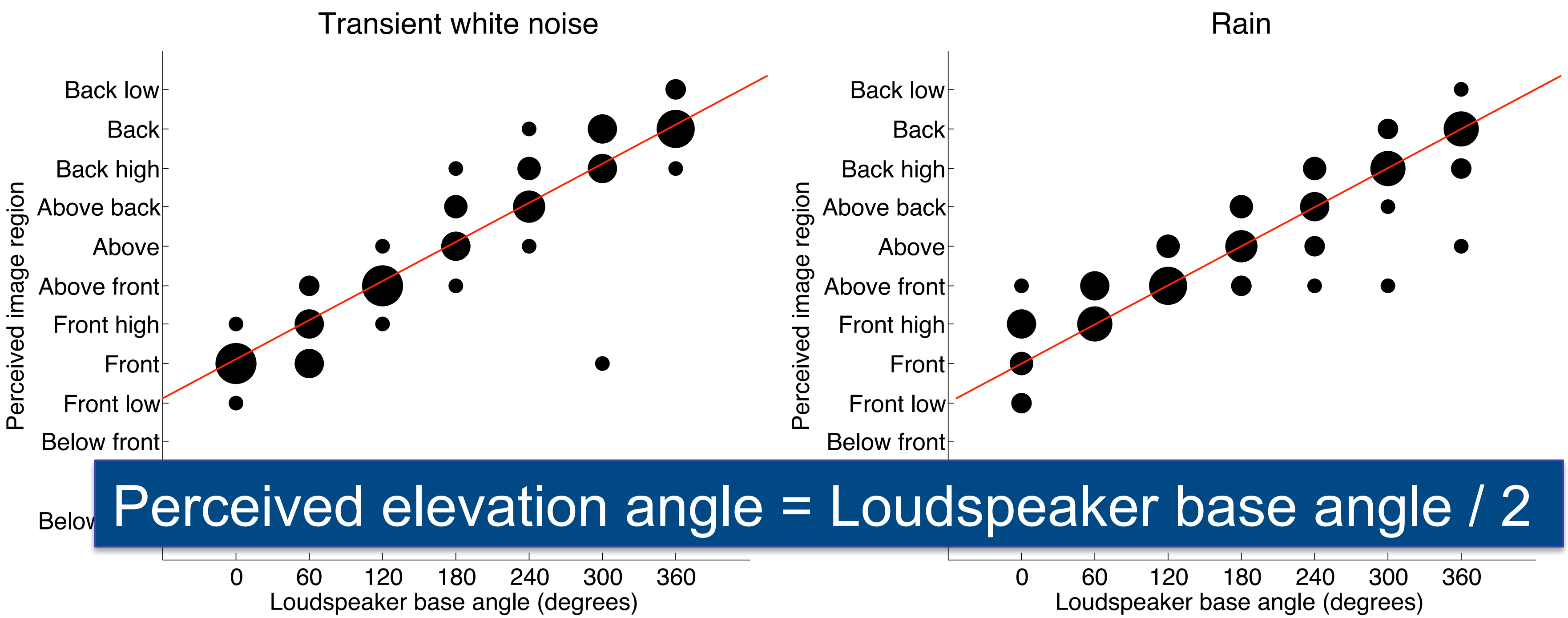
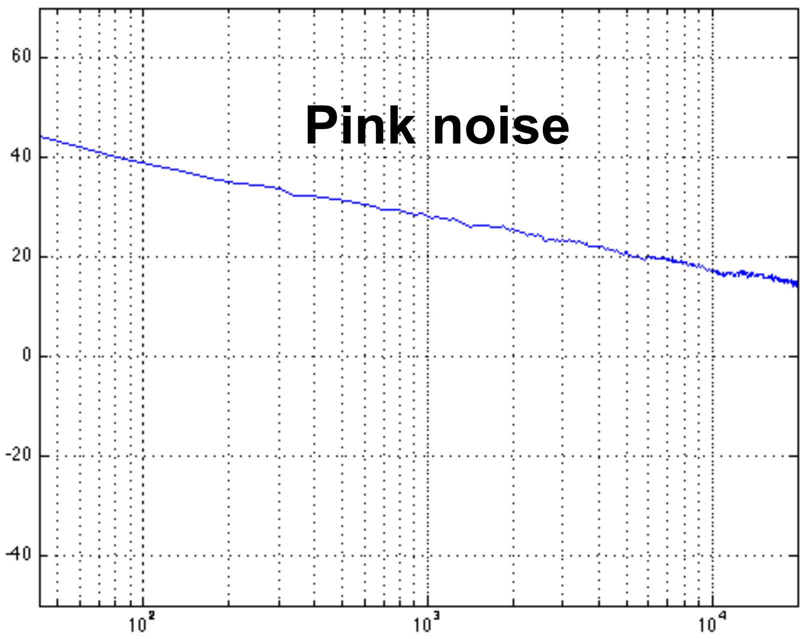
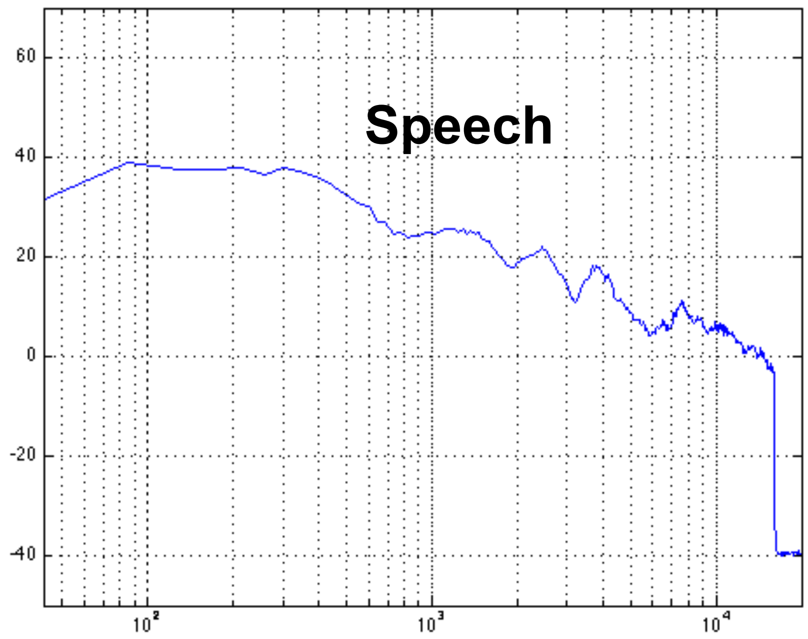


Perceived elevation angle = Loudspeaker base angle / 2

Phantom Image Elevation

- Sound source dependency
  - The elevation effect is weaker for sources with more low frequency energy. (no strong "aboveness")





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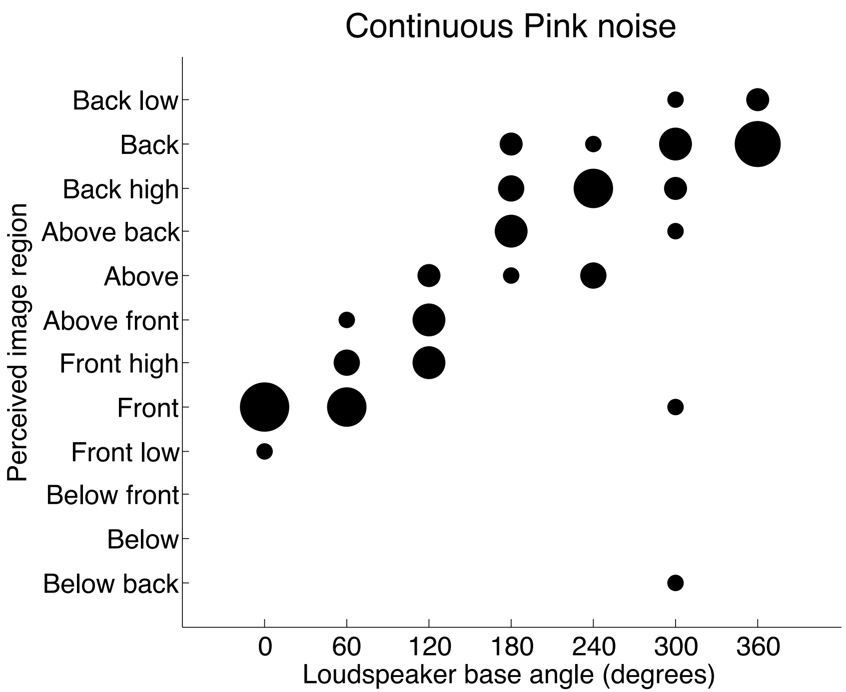

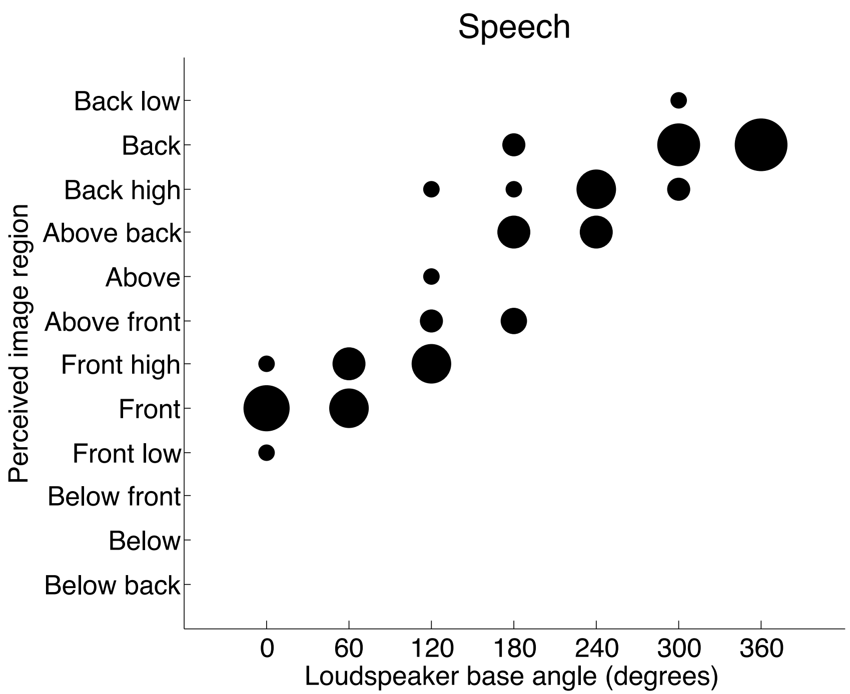

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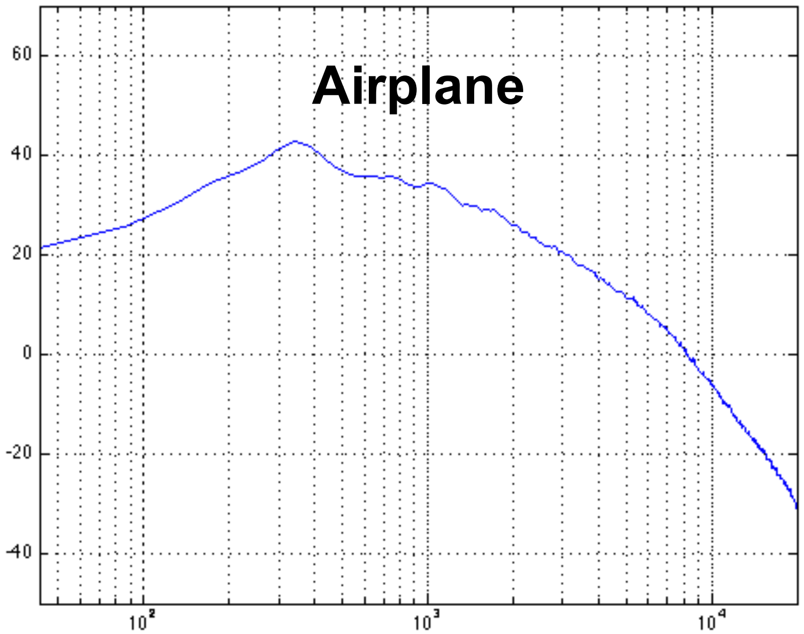

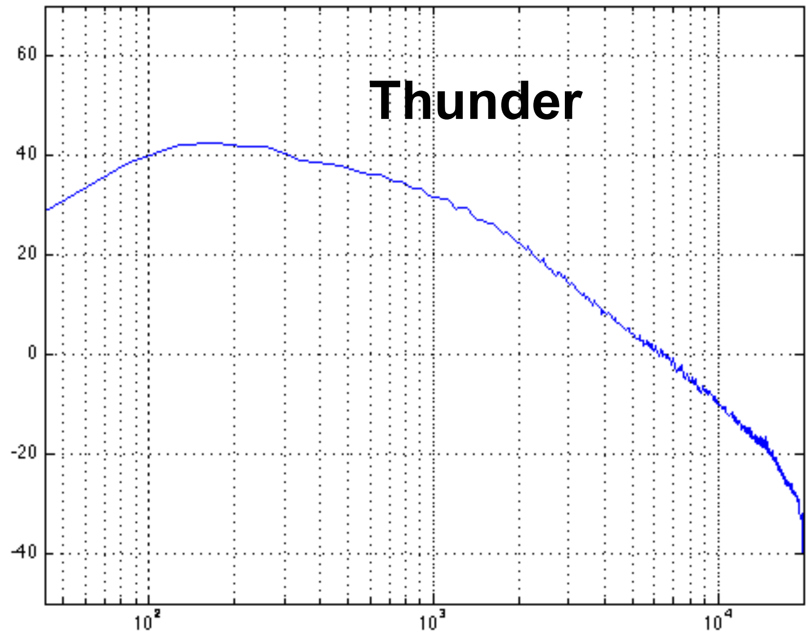

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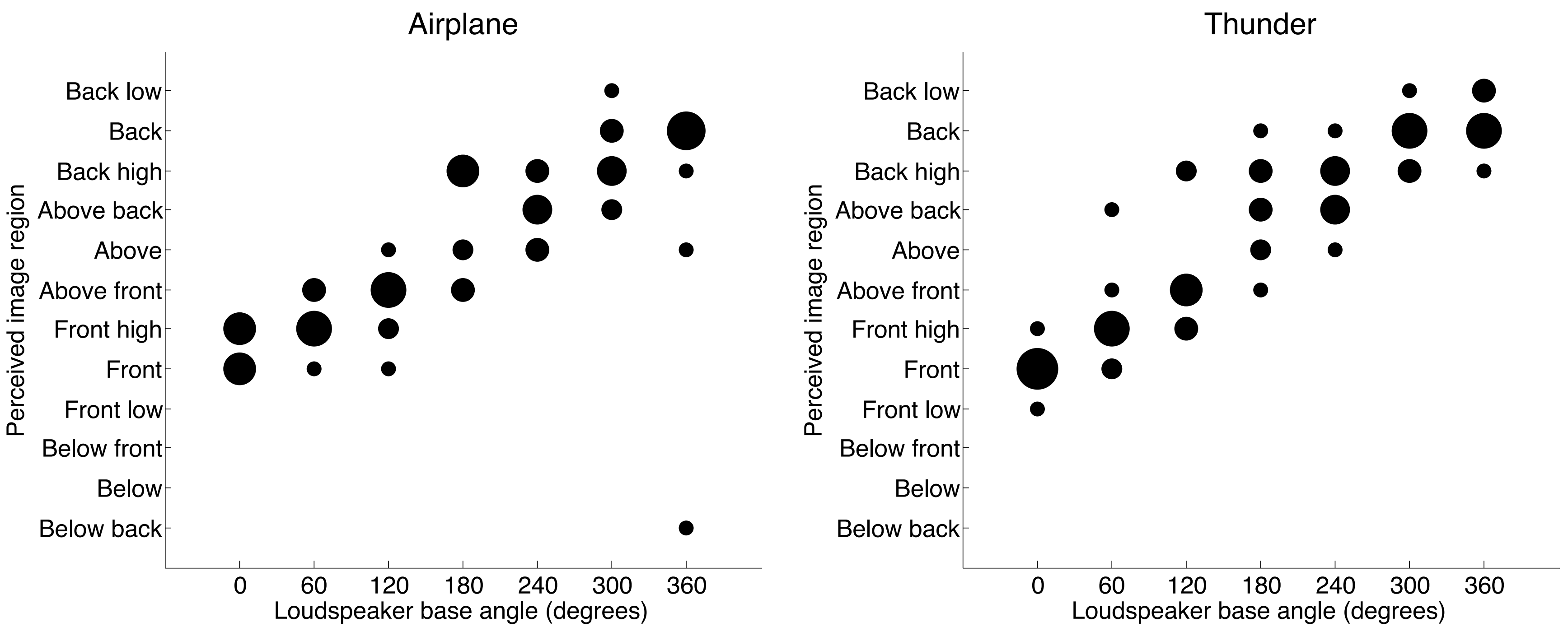
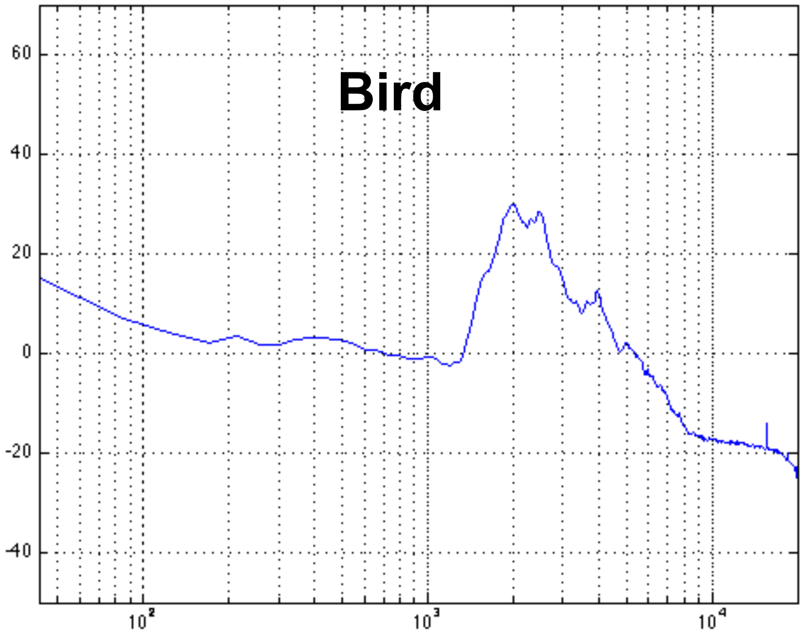
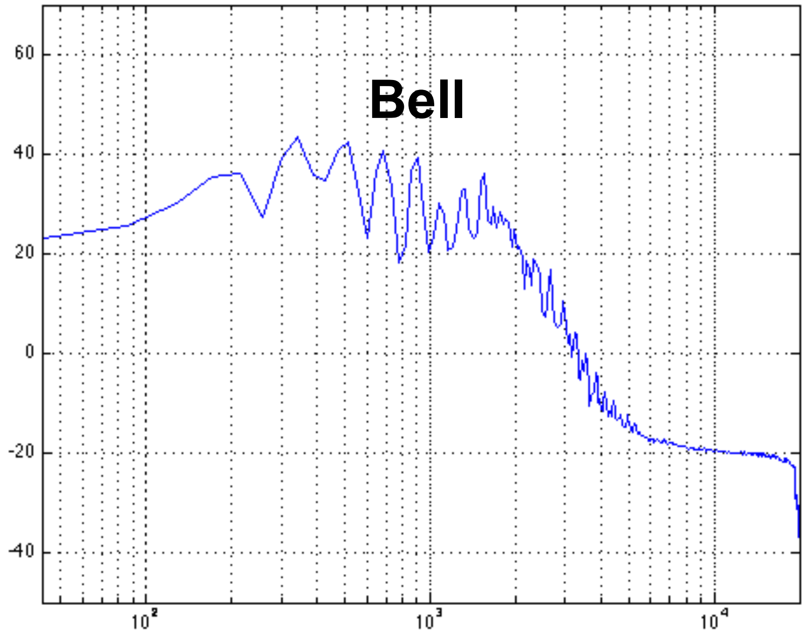


Phantom Image Elevation

- Sound source dependency
  - Responses are most inconsistent for sources with narrow spectrum or steady-state nature.





Phantom Image Elevation

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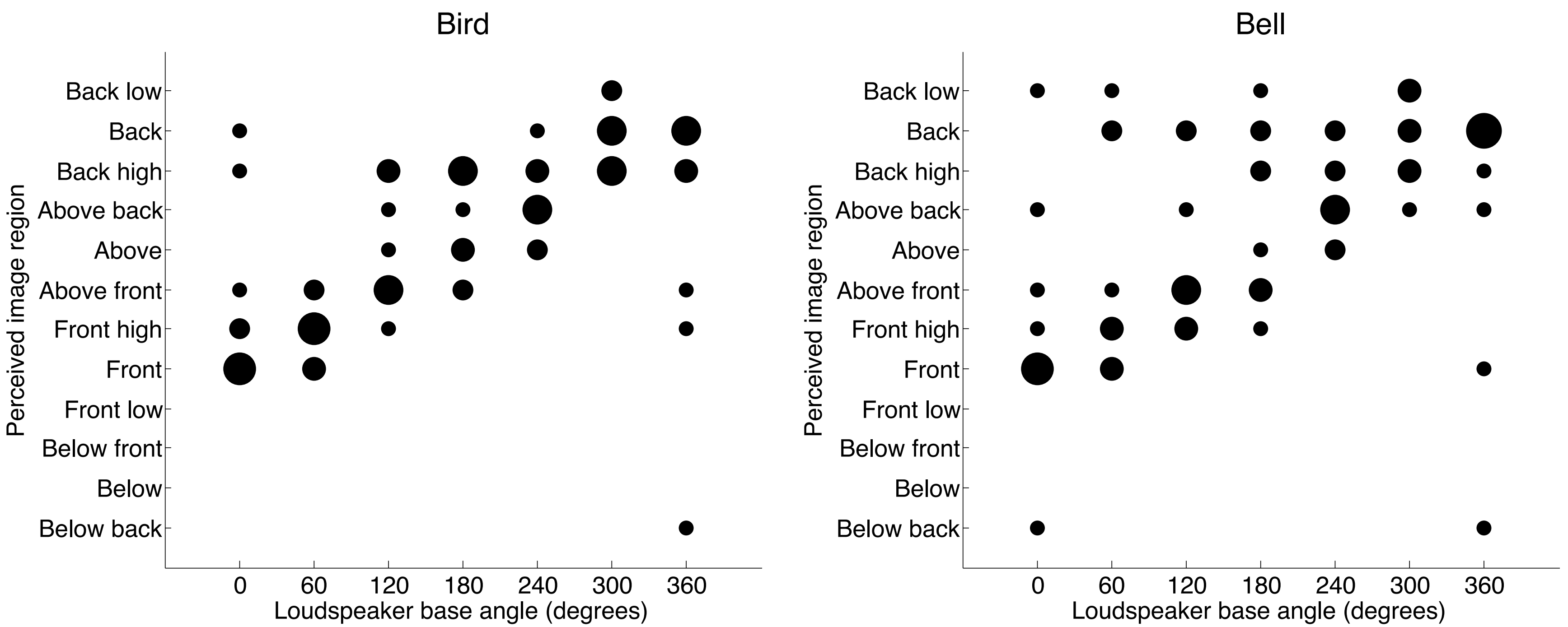
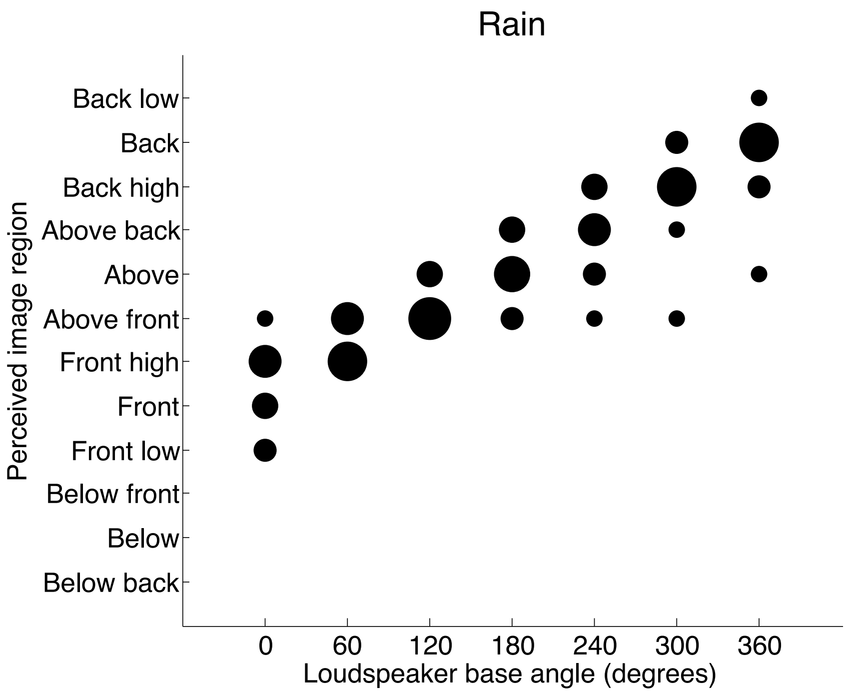
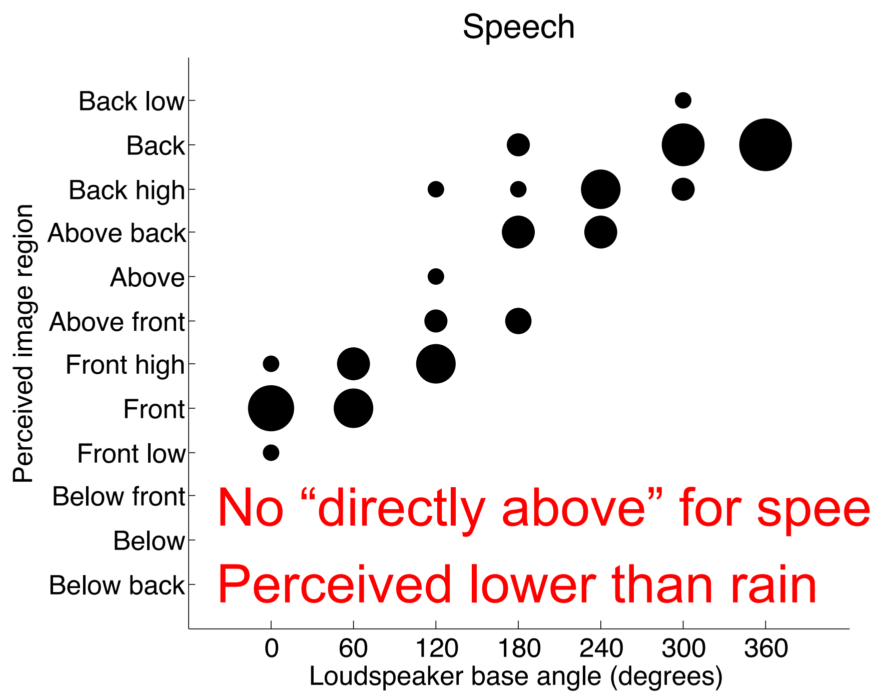


Phantom Image Elevation

- Expectancy bias
  - Subjective responses affected by the likely auditory or visual positions of the sound sources in real life.





No "directly above" for speech

Perceived lower than rain

Theoretical explanations

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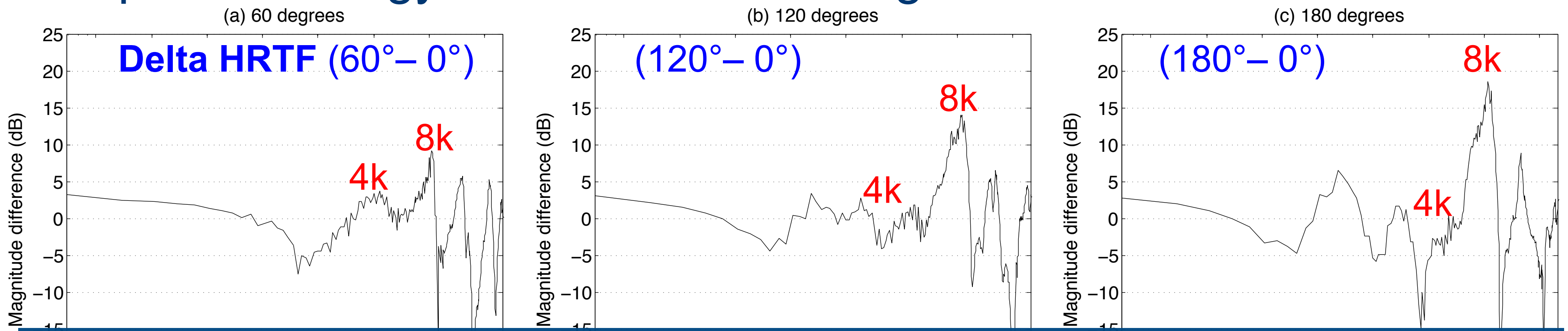
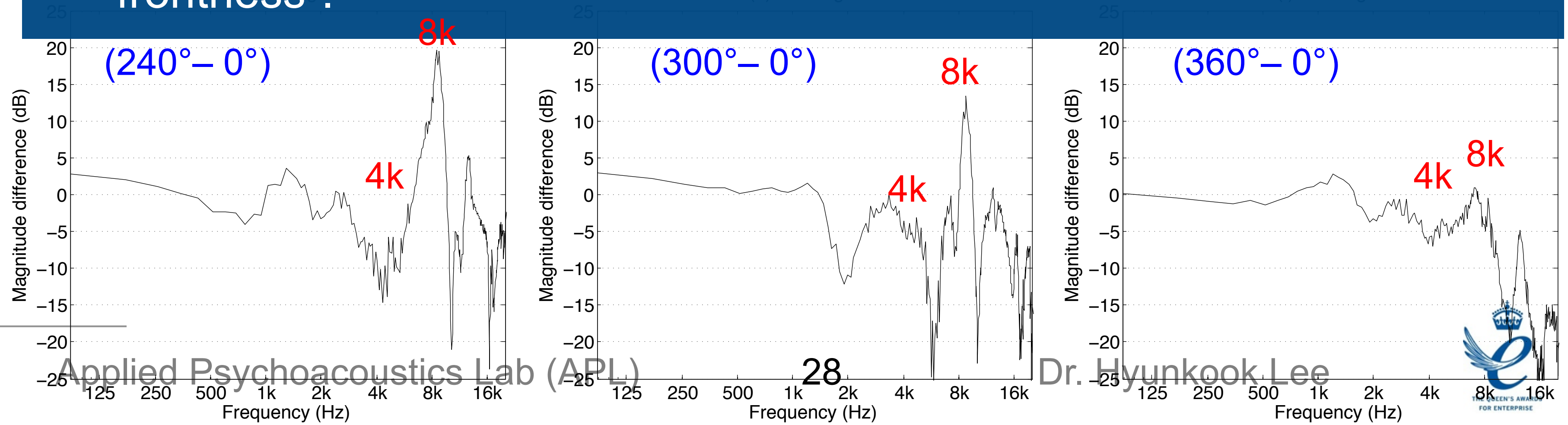
- Spectral energy distribution of ear signal



- As the base angle increases up to 240°, 8kHz energy increases while 4kHz energy decreases. → Increasing “aboveness” & decreasing “frontness”.



Theoretical explanations

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- However, spectral energy distribution does not explain the phantom image elevation for **low frequencies**.
  – Phantom image elevation is also perceived for low-frequency dominant sources and for octave-bands such 250Hz and 500Hz bands.

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Theoretical explanations

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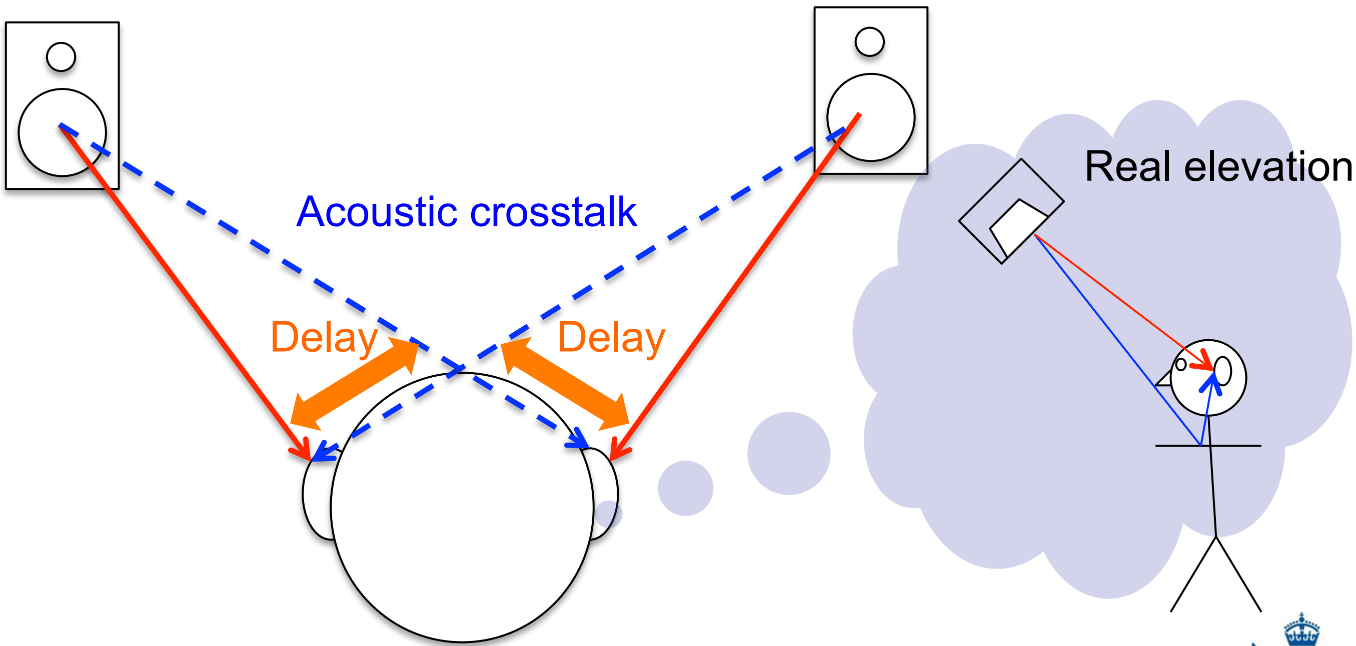
- A new hypothesis from a **cognitive** perspective
  - The brain interprets the acoustic crosstalk delay as a shoulder reflection delay for a real elevated source.
  - Shoulder reflection delay is the main cue for elevation perception for low frequencies in the median plane (Algazi et al. 2001)



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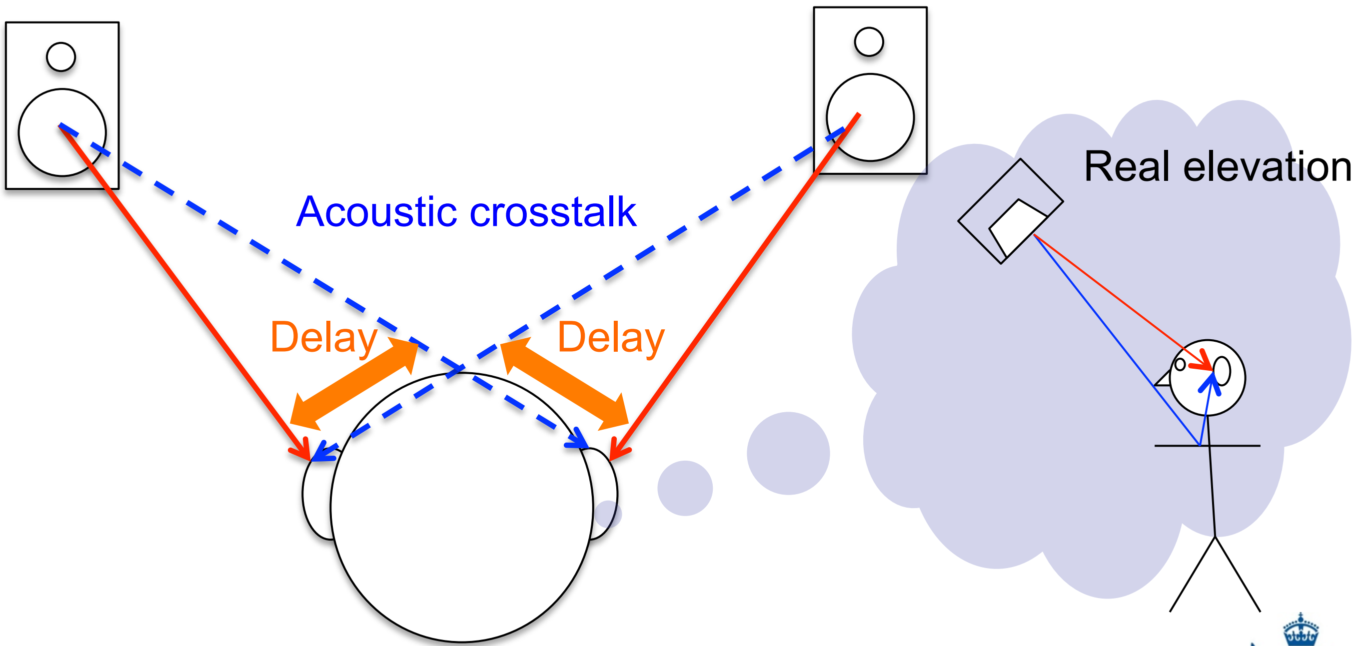
Theoretical explanations

- A new hypothesis from a **cognitive** perspective
  - As the loudspeaker base angle increases, acoustic crosstalk delay increases (max. around 0.7ms for 180°)
  - As the real source elevation angle increases, should reflection delay increases (max. around 0.7ms for right above).



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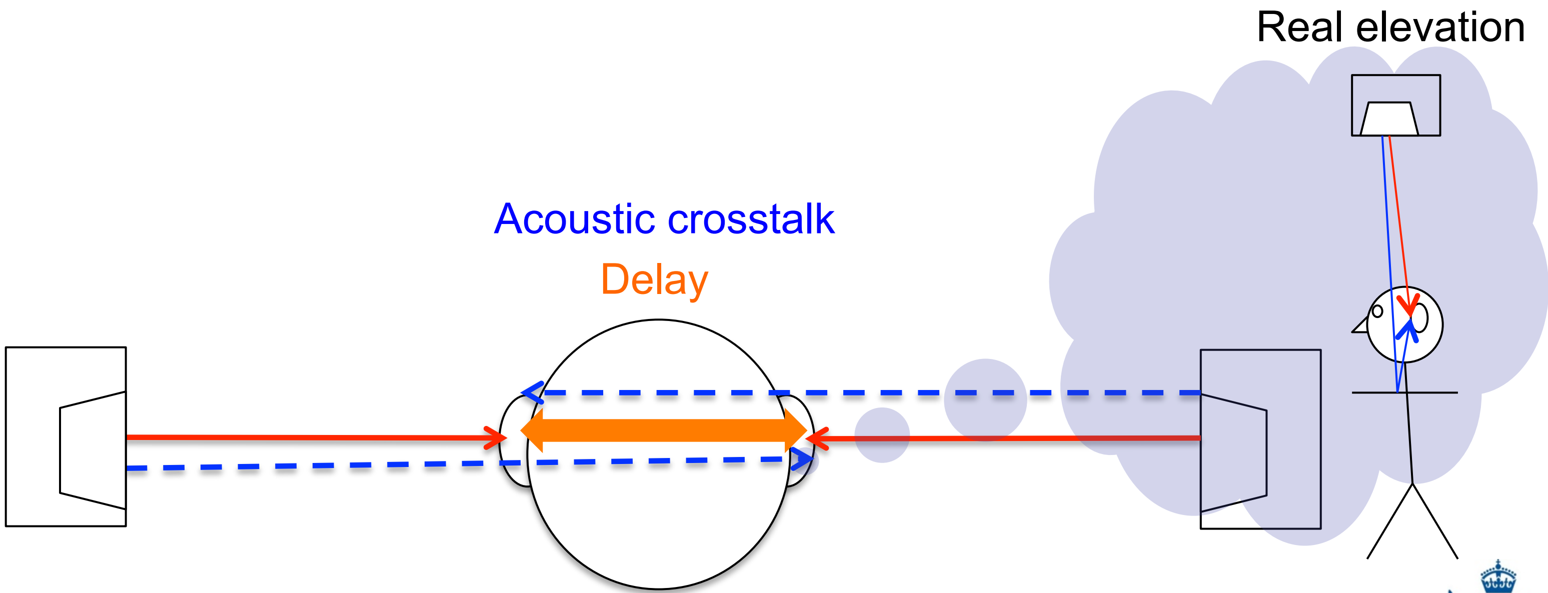

Theoretical explanations

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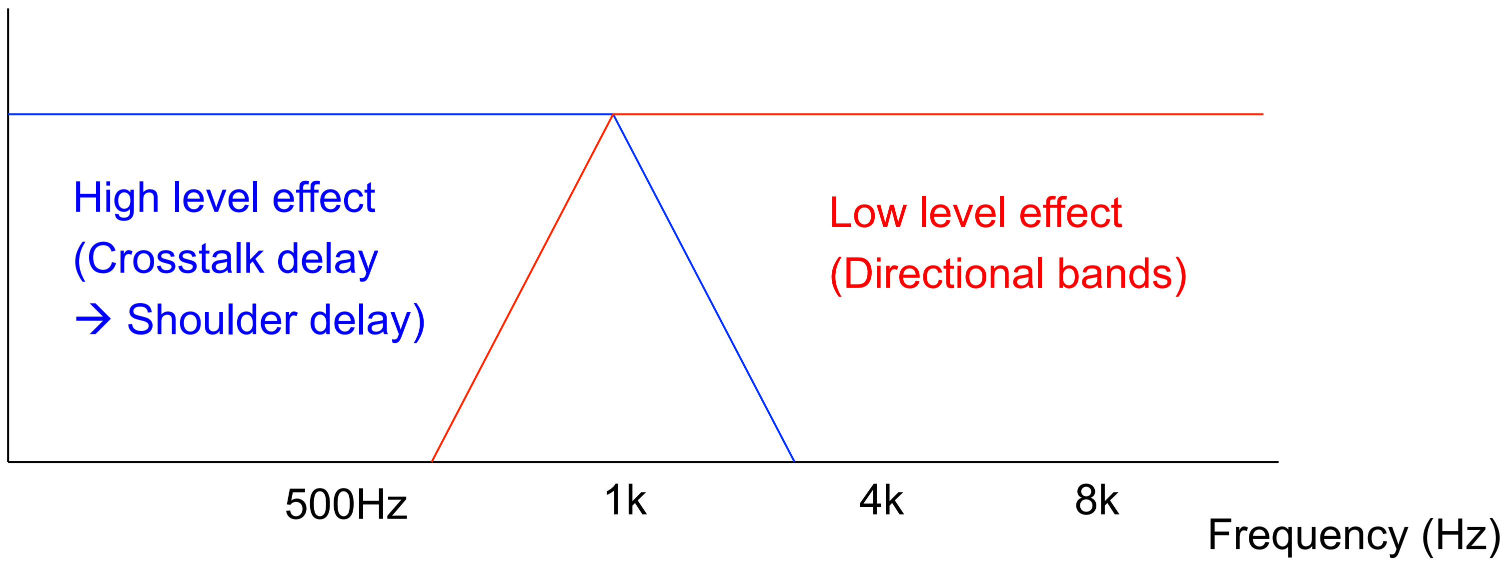
- A new hypothesis from a **cognitive** perspective
  - Low frequencies: Cognitive effect (crosstalk – shoulder delay)
  - High frequencies: Hard-wired effect (HRTF, directional bands, etc.)



Applications for 3D music production

- Simply routing overhead sources to the side or rear speaker pair in the conventional 5.1 or 7.1 format can create a virtual overhead image.
  - 3D mix without overhead speakers
  - 3D to 2D downmixing
  - 2D to 3D upmixing
  - Etc.

Conclusions

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- Phantom image elevation effect depends on the loudspeaker base angle and sound source characteristics.

- Base angles around 180° produces a virtual overhead image.
  → This is most effective for sound sources with a broad and flat frequency spectrum. (e.g. rain, white noise like sources)
  → Phantom image elevation is weaker for sources with low frequency dominance, narrow bandwidth or steady-state characteristics.

- Phantom image elevation can be explained by spectral energy distribution at HF, whereas it is more of a cognitive effect at LF.

Ongoing work

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- Relative weighting between different frequency bands in terms of phantom image elevation
- Verification of the cognitive hypothesis
- Virtual overhead panning method

References

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