University of Huddersfield Repository

Lee, Hyunkook

Investigation on the Phantom Image Elevation Effect

Original Citation


This version is available at http://eprints.hud.ac.uk/26558/

The University Repository is a digital collection of the research output of the University, available on Open Access. Copyright and Moral Rights for the items on this site are retained by the individual author and/or other copyright owners. Users may access full items free of charge; copies of full text items generally can be reproduced, displayed or performed and given to third parties in any format or medium for personal research or study, educational or not-for-profit purposes without prior permission or charge, provided:

- The authors, title and full bibliographic details is credited in any copy;
- A hyperlink and/or URL is included for the original metadata page; and
- The content is not changed in any way.

For more information, including our policy and submission procedure, please contact the Repository Team at: E.mailbox@hud.ac.uk.

http://eprints.hud.ac.uk/
Investigation on Phantom Image Elevation

Hyunkook Lee

h.lee@hud.ac.uk

Applied Psychoacoustics Lab (APL)
University of Huddersfield, UK
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

• For **band-passed noise** signals, high frequency components (above 7kHz) are essential for accurate vertical localisation. (Roffler and Butler 1968b)

From Roffler and Butler (1968b)
- Low passed & high passed noise

- 4.8kHz tone
- 600Hz tone
- LPF noise < 2kHz
- HPF noise > 8k
- HPF noise > 2k
- Broadband
Pitch-Height Effect for “Real” Source

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

![Graph showing pitch-height effect for different frequencies and bandwidths.](image)
Pitch-Height Effect for “Phantom” Source

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

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

![Diagram showing pitch-height effect for octave bands](image-url)
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)
Previous studies reporting the elevation effect are limited in terms of sound sources or loudspeaker base angles tested.

<table>
<thead>
<tr>
<th>Source</th>
<th>Base angles</th>
</tr>
</thead>
<tbody>
<tr>
<td>de Boer (1947)</td>
<td>Not reported</td>
</tr>
<tr>
<td>Damaske and Mellert (1969/1970)</td>
<td>White noise 0.65 – 4.5kHz</td>
</tr>
<tr>
<td>Jo et al. (2010)</td>
<td>White noise 1 – 16kHz</td>
</tr>
<tr>
<td>Frank (2014)</td>
<td>Pink noise Broadband</td>
</tr>
<tr>
<td>Lee (2015)</td>
<td>Pink noise Broadband, octave bands</td>
</tr>
</tbody>
</table>
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

- GUI written in Max
  - Response method similar to Blauert (1968) but in a finer resolution
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.
• Responses for all sources
  – The general trend agrees with the suggestions from the past research.
Sound source dependency

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

![Graph of White noise](image)

![Graph of Rain](image)
Phantom Image Elevation

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

\[
\text{Perceived elevation angle} = \frac{\text{Loudspeaker base angle}}{2}
\]

[Graph showing perceived image region vs. loudspeaker base angle for transient white noise and rain sounds]
Phantom Image Elevation

• Sound source dependency
  – The elevation effect is weaker for sources with more low frequency energy. (no strong “aboveness”)

![Graphs showing Pink noise and Speech with frequency on the x-axis and intensity on the y-axis.](image)
• Sound source dependency
  – The elevation effect is weaker for sources with more low frequency energy. (no strong “aboveness”)

![Graph showing perceived image region vs. loudspeaker base angle for Continuous Pink noise and Speech.

- Continuous Pink noise: The elevation effect is weaker for sources with more low frequency energy. (no strong “aboveness”)
- Speech: The elevation effect is weaker for sources with more low frequency energy. (no strong “aboveness”)
Phantom Image Elevation

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

![Graphs showing elevation effects of Airplane and Thunder]
Phantom Image Elevation

• Sound source dependency
  – The elevation effect is weaker for sources with more low frequency energy. (no strong “aboveness”)

![Perceived image region](Airplane) ![Perceived image region](Thunder)
Phantom Image Elevation

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

- Spectral energy distribution of ear signal

  (a) 60 degrees

  Delta HRTF (60°–0°)

  8k 4k

  (b) 120 degrees

  (120°–0°)

  8k 4k

  (c) 180 degrees

  (180°–0°)

  8k

  (d) 240 degrees

  (240°–0°)

  8k 4k

  (e) 300 degrees

  (300°–0°)

  8k

  (f) 360 degrees

  (360°–0°)

  8k 4k

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

  (240°–0°) 8k

  (300°–0°) 8k

  (360°–0°) 8k
Theoretical explanations

• 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.
Theoretical explanations

- 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)
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).
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 a source right above).
Theoretical explanations

• 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

- 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

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


Free download links for useful tools

• HULTI-GEN  http://eprints.hud.ac.uk/24809

• HAART   http://eprints.hud.ac.uk/24579

• IAR      http://eprints.hud.ac.uk/25547

Please contact us for more information:

Hyunkook Lee
h.lee@hud.ac.uk