Virtual Reality and Sound Localization

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Abstract

Psychoacoustics is the scientific study of sound perception. Within this field, *virtual reality* is a technique that uses two synthesis speakers to simulate a sine tone coming from anywhere in open space. Using this method it is possible to independently control specific binaural cues in a free-field environment. This study analyzes listener responses to these controlled sine tones to investigate the relative importance of certain binaural cues at different frequencies.

Introduction

•**Psychoacoustics** is the scientific study of sound perception. The psychological as well as physiological responses to sound are studied.

•**Sound localization** is a listener's ability to identify direction and distance of a sound source.

•The **binaural auditory system** compares the intensity and timing between a listener's two ears to locate a sound source. These two comparisons are known as binaural cues [1].

•*Binaural Cues:*

- **Interaural Time Difference (ITD):** The difference in time between when the waveform reaches each ear.
- **Interaural Level Difference (ILD):** The ratio of the amplitudes between each ear expressed in decibels [2].

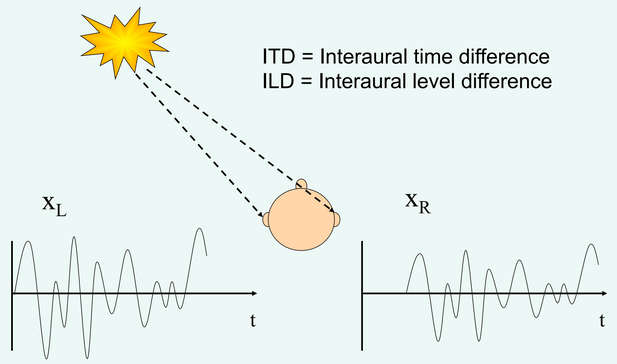


Figure 1. The yellow flash represents a sound headed toward a listener. X_L and X_R are the signals entering the left and right ears respectively. Due to the location of the sound, the signal in the right ear arrives earlier and has a larger amplitude compared to the signal entering the left ear.

•**Duplex Theory:**

- At low frequencies listeners use ITD to localize.
- At high frequencies the ILD is used to localize.
- Boundary between low and high frequencies ~1000 to 1500 Hz [3].

•ILD and ITD cues co-occur in nature.
•*Research question*: How do listeners combine the information that both provide?

Virtual Reality Method

- Two synthesis speakers and ear canal microphones.
- Simulate a sine tone coming from anywhere in space.
- ITD and ILD can be varied independently.

- *Can determine relative importance of interaural time and intensity differences at different frequencies in a real open space.*

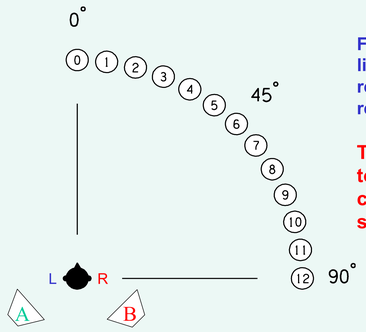


Figure 2. The position of the seated listener relative to the 90° array of 13 real speakers (0-12) and the virtual reality speakers (A and B).

The virtual reality speakers can work together to simulate a sine tone coming from any one of the real speakers in front of the listener [4].

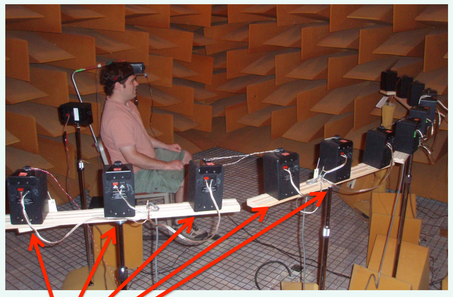
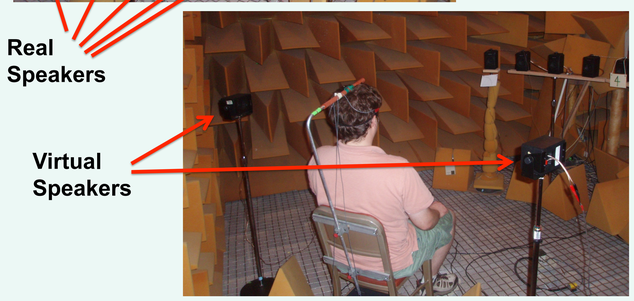


Figure 3. Listener seated in the anechoic room with 90° array of real speakers in front two meters away.

Figure 4. Virtual reality speakers are placed on the sides of the listener.



Physical Measurements

- Measurements taken in ear canals with probe microphones.
- Amplitudes and phases recorded to calculate ITD and ILD.

3 Types of Trials

- **Real Sources:** Sine tone played from one of the 13 real speakers.
- **Baseline Synthesis:** Virtual speakers produce sine tones identical to those present in real trials.
- **Adjusted Synthesis:** ITD or ILD controlled in some way.

Figure 5. Probe microphones are placed inside the listener's ear canals.

Results

•Results from baseline and adjusted trials of one listener at 500 Hz are shown.
•In adjusted trials the ITD is artificially held constant at 300 μs.

Low Frequency (500 Hz)

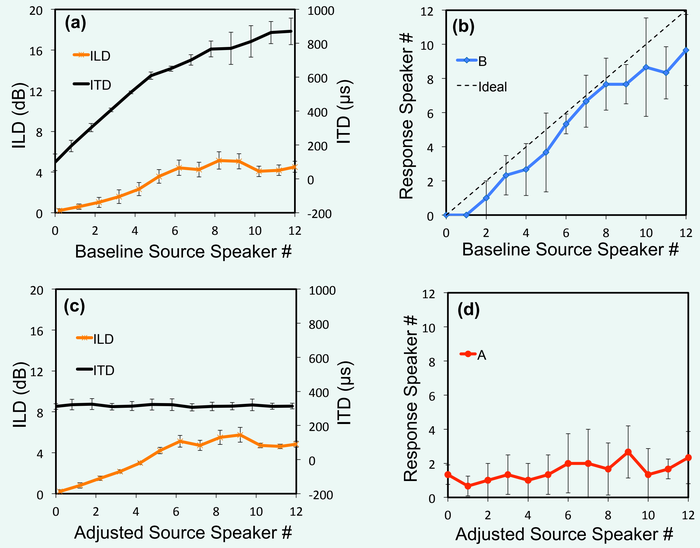


Figure 6. Listener responses and measurements of ITD and ILD at 500 Hz are averaged over three runs. (a) ILD and ITD measurements taken during baseline trials. (b) Listener's responses to baseline trials. Blacked dashed line represents ideal perfect responses. (c) ILD and ITD measurements taken during adjusted synthesis (d) Listener responses to adjusted synthesis.

Conclusion

•Results mostly agreed with Duplex Theory:

- Low frequency ➔ Listener used ITD to localize the sine tone.
- High frequency ➔ Listener used ILD to localize the sine tone.

•More data was collected at 500 Hz as well as at 2000 Hz.
•From this data there was evidence that the ILD has some effect on listener responses at low frequencies, which does not agree with the Duplex Theory.

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References

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[2] W. M. Hartmann, "How We Localize Sound," *Physics Today* (2010).
[3] Hartman, R. *Spatially Relocated Frequencies and Their Effect on the Localization of a Stereo Image*, Thesis for the Degree of Masters of Science University of Miami (2003), Chap 2.
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