3. The HRTF (c.1)

Gierlich Description of HRTF

- **Directional**
- **Indirectional**

### Directional

- \(0.1 - 2\) kHz: torso
- \(0.8 - 1.2\) kHz: shoulder reflection
- \(0.5 - 1.6\) kHz: head diffraction and reflection
- \(2 - 14\) kHz: pinnae, cavum conchae reflection

### Indirectional

- \(~3\) kHz: cavum conchae dominant resonance
- \(3 - 18\) kHz: ear canal and eardrum impedance

![Diagram of directional and indirectional HRTF](image)
3. The HRTF (c.2)
3. The HRTF (c.3)

Difference in spectral between two front-back locations on a cone of confusion: 60 and 120 degree azimuth, 0 degrees elevation.
3. The HRTF (c.4)

Changes in the HRTF spectrum are thought to be effective cues:

- Boosted bands
- Covert peaks
- Spectral troughs
- Notches

HRTF with azimuth

HRTF with elevation
3. The HRTF--Localization Judgements
(Oldfield and Parker (1984))

(a) Azimuth Error

(b) Elevation Error

Pinnae Folds Occluded
3. The HRTF-- Reversed Judgement

Reversed Judgement for speech stimuli

- Wenzel et al, 1993

Front-back reversals
Back-front reversals

Mean = 47%
Mean = 11%

Average angle of error (deg)

Individual Subjects
Means
Wightman and Kistler (1989b)
4. Implementation of HRTF

- **FIR Filters**
  - Truncation
  - Downsampling

- **Time-varying Filters**
### Products

<table>
<thead>
<tr>
<th>Years</th>
<th>Products</th>
<th>Systems</th>
<th>Processors</th>
<th>Audio</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRE</td>
<td>Convolvotron</td>
<td>2 PC Cards</td>
<td>128 16x16 Multipliers TMS320C25, IMSA100</td>
<td>4/1</td>
</tr>
<tr>
<td>1987</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CRE</td>
<td>Acousticron</td>
<td>Turn-Key System</td>
<td>PC, Convolvotron</td>
<td>16/4</td>
</tr>
<tr>
<td>1990</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CRE</td>
<td>Beachtron</td>
<td>1 PC Card</td>
<td>DSP56001</td>
<td>2</td>
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<tr>
<td>1993</td>
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<tr>
<td>CRE</td>
<td>Alphatron</td>
<td>1 PC Card</td>
<td>DSP56001</td>
<td>2</td>
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<tr>
<td>1994</td>
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</tr>
<tr>
<td>CRE</td>
<td>Acousticron II</td>
<td>Turn-Key System</td>
<td>486Dx33PC Convolvotron Beachtron</td>
<td>16/4</td>
</tr>
<tr>
<td>1994</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Focal</td>
<td>3D Focal Point</td>
<td>PC or Mac. Card</td>
<td>Motorola 56001, DSP</td>
<td>2</td>
</tr>
<tr>
<td>Point</td>
<td></td>
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</tr>
</tbody>
</table>

CRE: Crystal River Engineering; FP: Focal Point

表一：3D音訊產品
5. Distance Cues

- Reduction in intensity under anechoic and reverberant Conditions

- Sound velocity
  \[ c = 331.4 + 0.607T \]
  \( T \) is the temperature in degrees Celsius

- Live Speaker at 0 degree azimuth in anechoic chamber.
- Open circle = whispering; solid squares = low-level conversational speech; triangles = shouting.
6. Frequency-Dependent Attenuation at Large Distances

More relevant especially for high frequencies at large distance.

<table>
<thead>
<tr>
<th>Type of attenuation</th>
<th>500 Hz</th>
<th>1 kHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>wind profile:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(downwind)</td>
<td>minimal</td>
<td>minimal</td>
</tr>
<tr>
<td>(upwind)</td>
<td>up to 30 dB</td>
<td>up to 30 dB</td>
</tr>
<tr>
<td>ground cover:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>short grass</td>
<td>3 dB</td>
<td>3 dB</td>
</tr>
<tr>
<td>thick grass</td>
<td>5.4 dB</td>
<td>7.4 dB</td>
</tr>
<tr>
<td>trees</td>
<td>8 dB</td>
<td>10 dB</td>
</tr>
</tbody>
</table>
7. Reverberation

Refrlections
- Early reflection
  - 1-80 msec
- Late reflection
  - only the first 10-20 dB of decay will be heard

Features
- Reverberation time
- The ratio of reverberation-to-direct sound.
- Temporal and spatial patterns of early reflections.
8. Musical Quality

**Intimacy**
- A listener’s impression of the size of a room
- Determined by ITD.

**Fullness**
- Reverberation time
- The ratio of loudness of the reverberation sound to that of the direct sound.

**Liveness**
- Reverberation time for the middle and high frequencies (500 Hz to 2 kHz.)

**Warmth**
- The liveness of the bass
- Occurs when the reservation time for the low frequency tone is longer than that for the middle frequencies
8. Musical Quality (c.1)

Definition/ Clarity
- A function of room-surface pattern (intimacy), reverberation time (liveness), distance of the listener, and the room size.

Diffusion
- Spatial orientation of the reverberant sound.

Ensemble
- Ease of hearing among performer

Attack
- Immediacy of response.
9. Concluding Remarks

- Introduction
- Interaural Time and Intensity Cues
- Head-Related Transfer Function
- Implementation of HRTF
- Distance Cues
- Frequency-Dependent Attenuation
- Reverberation
- Musical Quality