A Model Human Cochlea

Designing and Experiencing Audio-Tactile Displays

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ACHI 2010
Music in Film
Inclusive Design

- Deaf and hard of hearing viewers
  - No access to music
  - Unlike speech, music is often indicated as symbols
- Valuable information is lost
- Experience is degraded
- ASID attempts to address these problems
Crossmodal Displays

- Presenting information intended for one modality using the perceptual channel of another.
Sensory Substitution

- Translate, interpret, transform, or otherwise map characteristics of one sensory modality onto another.
Parameters

Form factor: Chair

Tactile Perception

Tactile devices
Mapping Modalities

- Audio perception: 20Hz – 20kHz
- Tactile perception: 10Hz – 1000Hz
- Can't alter original music without first understanding emotional content
- Need vibrotactile device that can handle music
- Piano music (orchestra): 27-4100Hz
- Music is not only pure tones: timbre, harmonics...
- Psychophysics focus on single-point contact
- Ambient experience not primary information comprehension
Issues

- Audio perception: 20Hz – 20kHz
- Tactile perception: 10Hz – 1000Hz
- Can't alter original music without first understanding emotional content
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- Piano music (orchestra) 27-4100Hz
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Voice Coils

**Pros:**

- Offer complete set of vibrations from the music
  - Speakers used in night clubs for deaf communities to provide musical vibrations for dancing
- Do not require alteration of audio signal to cause vibrations
- Low cost vibrotactile devices
- Presents entire audio signal

**Cons**

- Only most prominent frequencies can be detected
- May be fragile for prolonged use
- Little knowledge about vibrotactile properties
How do we model this sensory substitution?

Consider human hearing as a model

Found the following:
Human Cochlea Model

- **A**
  - cochlear duct
  - 20,000 Hz
  - 10,000 Hz
  - 7,000 Hz
  - 5,000 Hz
  - 2,000 Hz
  - 1,500 Hz
  - 600 Hz
  - 400 Hz
  - 200 Hz

- **B**
  - basilar membrane
  - base
  - apex
  - high-frequency waves (1,500–20,000 Hz)

- **C**
  - basilar membrane
  - base
  - apex
  - medium-frequency waves (600–1,500 Hz)

- **D**
  - basilar membrane
  - base
  - apex
  - low-frequency waves (200–600 Hz)
Model Human Cochlea (MHC)
Sensory Substitution Models

- Separating the audio signal into multiple vibrotactile devices

- Two models:
  - Track Model
  - Frequency Model
Track Model

- Requires source separation
  - Instruments represent individual signals
  - Intuitive approach

- MIDI
  - facilitates the separation of instruments into different tracks

- Problem: number of instruments do not always map onto number of speakers
  - Can't always access tracks from existing music
Frequency Model

- Separate audio signal into unique frequency bands
Approximate Frequency Ranges

Fundamental Frequencies  | Harmonics
---|---
30 Hz | 90 Hz | 160 Hz | 300 Hz | 500 Hz | 900 Hz | 1.6 kHz | 3 kHz | 5 kHz | 9 kHz | 16 kHz

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<tr>
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<tr>
<td>Female Voice</td>
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Prototype 0, 1
Prototype 2.0
Physical Considerations

**How the Deaf “Hear” Music**

A new chair allows the deaf to experience music through vibrations.

**Human Cochlea**
- The cochlea is the main organ that allows a hearing person to process different frequencies of sound.
- High-frequency waves: 1,500-35,000 Hz
- Medium-frequency waves: 600-1,500 Hz
- Low-frequency waves: 0-400 Hz

**Emoti-Chair**
- This research turns the human body into a cochlea by directing different frequency levels of sound to different parts of the back.
Tactile Music Perception

- **Mechanoreceptors:**
  - Sensors on the skin:
    - Most located in the non-hairy (glabrous) skin
    - Pacinian -> fast vibrations
    - Meissner -> texture changes
    - Merkel -> sustained touch
    - Ruffini -> tension
    - Hair cells (cochlea) -> air pressure waves
      - Most sensitive mechanoreceptor
Optimal Placement of Sound on Skin

- Higher frequencies require more sensitivity
- Fingertips, palms, feet, lips...and other glabrous skin most sensitive to vibrations
  - Locate highest frequencies where skin is most sensitive
  - Lowest frequencies do not need high sensitivity skin
Hands on session begins!