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Human Factors Engineering

Audition

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Lecture 14

Massachusetts Institute of Technology

Overview

- Human ear anatomy and hearing
- Auditory perception
- Brainstorming about sounds
- Auditory vs. visual displays
- Considerations for design of auditory displays
- Auditory warning examples
  - Flight deck
  - Spectrograms
  - ATC

The Ear

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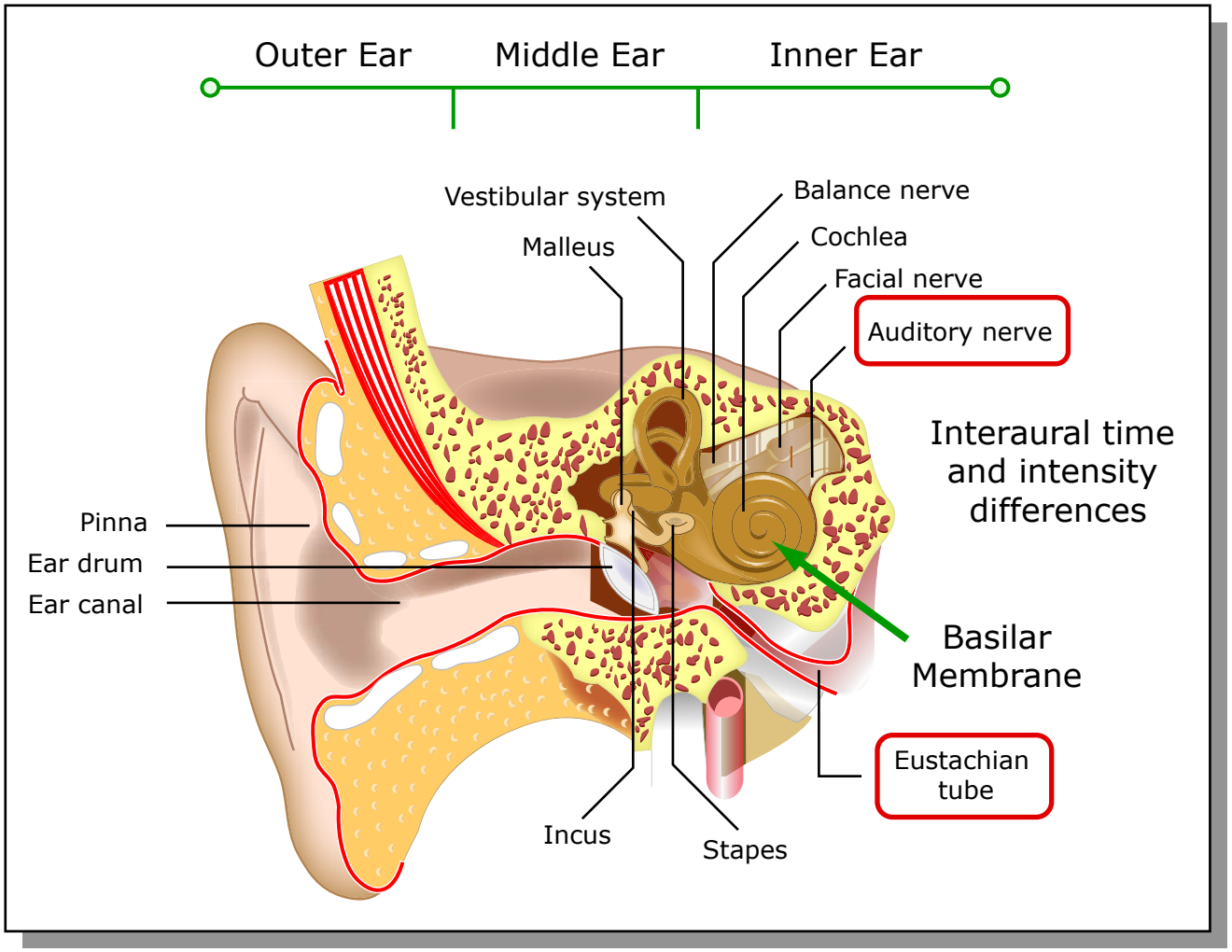

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The Cochlea

- Basilar Membrane Video on YouTube
- Organ of Corti (condensed video)

Preamble to Auditory Perception
Review of Stevens' Law

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From Psychophysical Scaling, PV Chapter 4

$$S = aI^n$$

S = reported sensory experience

a = a constant

I = physical intensity

n = exponent that varies for different sensory continuum

Example Exponents for Stevens' Law

Continuum Example	Physical Measure	Exponent
Apparent length	Length	1
Loudness	Sound pressure level	0.6
Brightness	Candela/Lumen	0.33
Heaviness	Weight	1.45
Electric Shock (Pain)	Current	3.5

- Perceived loudness varies based on both physical intensity and frequency
- Sone, one unit of (perceived) loudness
  - Defined as the loudness of a 1000 Hz stimulus at 40 dB intensity
  - 0 dB is at the sensory threshold for sound

Auditory Perception

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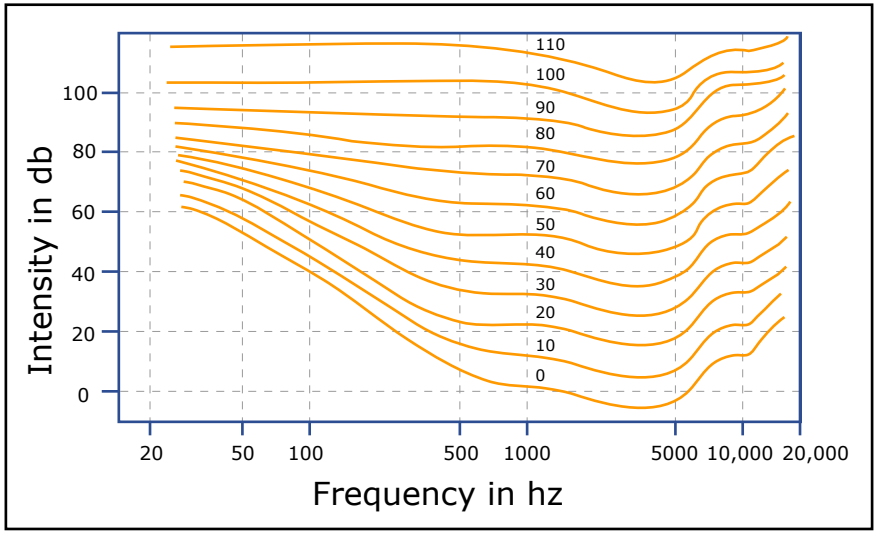
Source of Sound	Sound Pressure Level dB re 20 µPa	Loudness (Sone)
Threshold of pain	134	~ 676
Hearing damage during short-term effect	~ 120	~ 256
Jet, 100 m distant	110-140	~ 128-1024
Jack hammer, 1 m distant/club	~ 100	~ 64
Hearing damage during long-term effect	~ 90	~ 32
Major road at 10 m	80-90	~ 16-32
Passenger car at 10 m	60-80	~ 4-16
TV set at home, at 1 m	ca. 60	~ 4
Normal talking at 1 m	40-60	~ 1-4
Rustling of leaves/calm breathing	10	~ 0.02
Auditory threshold at 2 khz	0	0

Loudness & Frequencies



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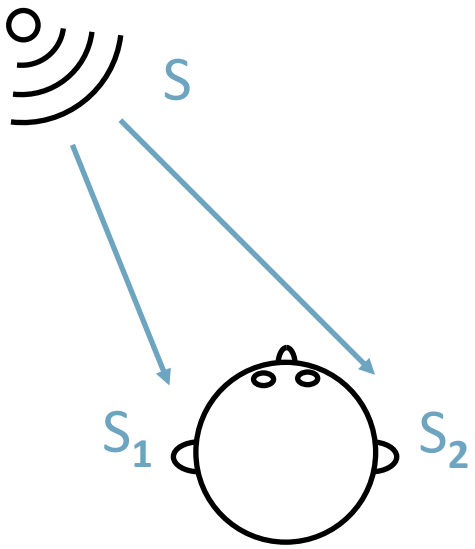
- **Equal loudness curves**: Fletcher-Munson curves – subjective!
- Max. sensitivity region for human hearing is 3-4 kHz, and low tones under 200 kHz are hard to detect
- **Temporal aspects of auditory perception**: longer tones sound louder; sense of loud diminishes over time

Localizing Sound

- **Binaural Cues**: subtle differences in the sounds reaching a listener's right and left ears (lateral translation)
  - Interaural Time Difference (ITD)
  - Interaural Level Difference (ILD)



- **Monaural Cues**: spectral transformations that occur to a sound along its path to a given ear (elevation, front/back orientation)

Ways to Describe Sound

- Amplitude (loudness)
- Frequency (pitch)
  - Fundamental and harmonics
- Sounds varying in time
  - Verbal vs. non-verbal
  - Horn, clacker, chime, beep, bursts…
  - Musical characteristics
    - rhythm, tempo, timbre
- Spectrogram

Brainstorming

- Describe some sounds that mean something to you
  - From a car?
  - From a computer?
  - From your home?
  - From a radio?
  - From your workplace? (e.g., lab)
- Did you have to “learn” these sounds?
- Do you take any action based on them?
- Are they annoying? Pleasant? Recognizable in different environments?

Audio vs. Visual Displays

	Auditory	Visual
Reception	Omnidirectional	Must be in field of view (Attention & selection)
Speed	Fastest	Slowest
Order	Difficult	Easy
Urgency	Easy	Difficult
Noise	Not affected by visual	Not affected by audio
Symbolism	Melodious, linguistic	Pictorial, linguistic
Mobility	Most flexible	Some flexibility
Suitability	Time-dependent info	Space-dependent info

When to Use Audio or Visual Displays

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Auditory	Visual
Message is simple/short	Message is complex/long
Message won't be referred to later	Message will be referred to later
Message deals with time	Message deals with space
Immediate action required	Immediate action not required
Visual channel overburdened	Auditory systems overburdened
Brightness/Darkness problems	Noisy environment
Person is moving	Person is static
Communications with many people at the same time	*Communication with one (or few) individuals, or when info has to be distributed at different times*
When multiple complex data sources are monitored compared	*When high resolution of variables is required or when absolute (instead of relative) values are required*
When 3D aspect can be represented(spatialized sound)	*When sound would interfere with the task (e.g., speech) or be masked by the environment*

Types of Auditory Displays

- Symbolic
  - Map sounds to meanings
    - Emergency preparedness signal, mail, 'bop'
- Non-speech
  - Tones, combinations of frequencies, patterns
  - Can vary in time
- Speech
  - Can be used in combination with non-verbal
  - Can convey more complex information, if the person is alert

Newer Auditory Displays

- Earcons
  - Patterns of a few musical notes (NBC)
  - Some training required
- Auditory icons
  - Represent actual features of objects/actions
  - Sounds are analogs
- Sonification
  - Non-speech audio that contain data (e.g., Geiger counter, auditory thermometer)
  - Best for relative, not exact data
  - Uses similes (analogs)
    - e.g., heart beat, filling bottles etc.
- Spatial auditory displays

Considerations for Design of Aural Warnings

- Goal: Accomplish intended function without disrupting user's ongoing tasks and information processing
- What's the intended function?
  - Attract attention (alert), convey information, or both?
    - Cue to perform an action or indication that a defined threshold has been reached
    - Additional context/explanation (urgency, nature of the problem)
    - Voice messages both alert and inform
    - Avoid startle response (onset rate)
  - Convey urgency
    - Warning, caution, advisory

More Considerations for Design of Aural Warnings

- Compliance
  - Intervention immediacy vs. intervention importance
- Effectiveness
  - Understandability +
- Learning time and retention
- Number of different warnings
  - More is less (potential for confusion)
  - Similar temporal patterns are confusable, as are single tones
  - Guess how many is too many? Does 6 sound familiar?

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Still More Considerations for Design of Aural Warnings

- Background noise & prominence
  - Match warning frequencies and amplitudes to environment
  - Auditory masking
  - Ensure audibility without disrupting subsequent speech
  - Cascading alarms & cacophony
- Standardization
  - User expectations and prior learning
- Testing for comprehension and usability

Urgency

- Too loud is ineffective
- Best way to increase urgency is to increase speed of warning
- Urgency categories and central warning design
- Speaker gender does not affect urgency (active research area)

Urgency Exponents for Auditory Warnings	Exponent
Speed	1.35
Number of repetitions	0.5
Frequency (pitch)	0.38

Level of Urgency	Meaning	Visual Cue	Auditory Cue
Warning	Immediate action required	Red	Nonverbal to get attention, backup verbal message for more information
Caution	Awareness	Yellow	Non verbal (optional verbal)
Non-alert	Information only	Green, white, cyan, etc.	None (Quiet/Dark)

Flight Deck Auditory Displays

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- Aural warnings test
- TCAS test
  - Without and with audio
- Spectrograms
  - Sonic Visualizer

What would you do if you only saw this?

Image of TCAS TVSI/RVSI removed due to copyright restrictions.

Auditory Issues in ATC

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Auditory Alarm Issues	Rank	
	ARTCC	TRACON
Too many alarms go off at the same time.	3	9
There are too many alarms for a person to learn the meaning of each alarm.	5	7
Alarms sound more urgent than they should or sound less urgent than they should.	11	11
Alarms are easily confused (because they sound alike).	1	2
Alarms can be masked (difficult to hear over the background noise).	4	3
Alarms are too loud.	7	9
Alarms are annoying.	10	11
Alarms disrupt thought.	12	15
Alarms startle the user.	15	6
Alarms interfere with voice communications.	8	13
Alarms go off too frequently, especially false alarms.	9	4
Alarms go off so infrequently that when they do go off, one doesn't know the meaning.	13	13
There are not audio alarms in some situations where there should be audio alarms.	6	1
It is difficult to locate the source of alarms.	14	5
Some alarms that are visual would be better auditory, or vice versa.	2	8

From Ahlstrom, 2003 DOT/FAA/CT-TN03/10

(ATC) Alarm Issues

- Some could not be silenced even when the user acknowledged the situation
- Specific alarms that sounded too similar
- False alarms on certain systems
- Alarms interfering with voice communications
- Alarms that were too loud
- Some systems that had no alarms that could benefit from auditory alarms.

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