Agenda

- Review
- Auditory Sense: Hearing
- Other senses
- Multiple tasking
Factors affect visual performance

- Color
- Brightness
- Visual Angle
- Visual Acuity
- Contrast
- Visual Field
- Distance/Convergence

- Glare
- Individual differences
- Target movement
- Time available for seeing
- Etc.
The 50-year-old traveler, arriving in an unfamiliar city on a dark, rainy night, is picking up a rental car. The rental agency bus driver points to “the red sedan over there” and drives off, but in the dim light of the parking lot, our traveler cannot easily tell which car is red and which is brown. He climbs into the wrong car, realizes his mistake, and settles at last in the correct vehicle. He pulls out a city map to figure out the way to his destination, but in the dim illumination of the dome light, the printed street names on the map are just a haze of black. Giving up on the map, he remains confident that he will see the appropriate signage to Route 60 that will direct him toward his destination, so he starts the motor to pull out of the lot. The streaming rain forces him to search for the wiper switch, but the switch is hard to find because the dark printed labels cannot be read against the gray color of the interior. A little fumbling, however, and the wipers are on, and he emerges from the lot onto the highway. The rapid traffic closing behind him and bright glare of headlights in his rearview mirror force him to accelerate to an uncomfortably rapid speed. He cannot read the first sign to his right as he speeds by. Did that sign say Route 60 or Route 66? He drives on, assuming that the turnoff will be announced again; he peers ahead, watching for the sign. Suddenly, there it is on the left side of the highway, not the right where he had expected it, and he passes it before he can change lanes. Frustrated, he turns on the dome light to glance at the map again, but in the fraction of a second his head is down, the sound of gravel on the undercarriage signals that his car has slid off the highway. As he drives along the berm, waiting to pull back on the road, he fails to see the huge pothole that unkindly brings his car to an abrupt halt.
Assumptions

Expectation

Experience

Clear view: glasses / light

New place / Rental car

Rolling ball

Mood: frustrated / confident

"Assistance"

Plan: lack of knowledge.
The worker at the small manufacturing company was becoming increasingly frustrated by the noise level at her workplace. It was unpleasant and stressful, and she came home each day with a ringing in her ears and a headache. What concerned her in particular was an incident the day before when she could not hear the emergency alarm go off on her own equipment, a failure of hearing that nearly led to an injury. Asked by her husband why she did not wear earplugs to muffle the noise, she said, “They’re uncomfortable. I’d be even less likely to hear the alarm, and besides, it would be harder to talk with the worker on the next machine, and that’s one of the few pleasures I have on the job.” She was relieved that an inspector from Occupational Safety and Health Administration (OSHA) would be visiting the plant in the next few days to evaluate the complaints that she had raised.
Auditory Sense

- Ability to hear

- Unlike visual stimuli, auditory does not persist in time – stays a few seconds in memory then fades.

- Temporal nature of sound – time patterns of intensity, frequency
Auditory Sense

- Sensory organ: Ear

![Diagram of the auditory system](image_url)
Ear Anatomy: Outer Ear

- **Components**
  - Pinna
  - External auditory canal
  - Tympanic membrane (eardrum)

- **Functions**
  - Gather, resonate and attenuate signals based on frequency
  - Protects the ear (wax and hairs)
  - Converts sound pressure wave to mechanical vibration
Auditory ossicles – malleus, incus, and stapes
- Transmit vibration to inner ear: mechanical vibration → fluid-membrane wave
- Protect against loud and sudden noises by limiting movement of eardrum
Ear Anatomy: Middle Ear

- **Eustachian tube**
  - Connects middle ear with throat
  - Equalizes air pressure between middle ear and outside through the mouth
Ear Anatomy: Inner Ear - Cochlea

- **Cochlea**
  - Fluid filled tube
  - Basilar Membrane
    - Moves differently to sounds of different frequency
Ear Anatomy: Inner Ear - Corti

- **Organ of Corti**
  - Hair cells that convert vibration into nerve impulses
Ear Anatomy

sound energy
pinna
auditory canal
tympanic membrane
ossicles
oval window
cochlea
hair cells
auditory nerve
brain

mechanical energy

electrochemical energy

Diagram of ear anatomy with labels for each part, including:
- auricle
- malleus
- incus
- oval window
- scala vestibuli
- scala tympani
- organ of Corti
- hair cells
- cochlea

Legend:
- outer ear
- middle ear
- inner ear

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Sound

- Stimuli: Sound
  - Sensed variations in air pressure
    - Vibrating air molecules
  - Sound has frequency (pitch) and amplitude (loudness); usually a combination of frequencies
  - Frequency
    - Range of human hearing: 20 Hz to 20,000 Hz
    - Highest sensitivity: 1,000 Hz - 3,000 Hz
    - [https://www.youtube.com/watch?v=H-iCZEI8m0](https://www.youtube.com/watch?v=H-iCZEI8m0)
  - “Shape” of sound?
    - [https://www.youtube.com/watch?v=MwsGULCvMBk](https://www.youtube.com/watch?v=MwsGULCvMBk)
Sound Measurement

\[ p(t) \text{ (\( \mu \)bar)} \]

\[ p = \text{root mean square (RMS) sound pressure} \]

\[ = \sqrt{\frac{1}{T} \int_{0}^{T} (p(t) - \overline{p}_a)^2 \, dt} \]

- Range: \( p < 0.001 \mu \text{bar} \) (normal breathing)
  \( p > 1000 \mu \text{bar} \) (jet plane)
Sound Pressure Level (SPL)

\[ \text{SPL} = L_p = 20 \log_{10} \left( \frac{p}{p_r} \right) \]

\( p \) = RMS sound pressure of target sound
\( p_r \) = RMS sound pressure of reference sound
(e.g. 0.0002 \( \mu \text{bar} \))

SPL units: decibels (dB)
Range of Hearing
Psychophysical Scaling

- Loudness not directly proportional to intensity
- Psychophysical (perceived loudness) scales
  - Phons
    - Equal loudness contours
    - phons = dB @ 1000 Hz
  - Sones
    - Relative subjective loudness
    - 1 sone = 1000 Hz @ 40 dB
    - 2 sones = sound judged twice as loud as 1 sone sound
Psychophysical Scaling

**FIGURE 5.4**
Equal loudness contours showing the intensity of different variables as a function of frequency. All points lying on a single curve are perceived as equally loud. Thus, a 1,000-Hz tone of 40 dB sounds about the same loudness (40 phons) as an 8,000-Hz tone of around 60 dB. (Source: Kryter, K. D. Speech Communications, in Van Cott, H. P., & R. G. Kinkade, eds., 1972. Human Engineering Guide to System Design. Figures 4-6. Washington, DC: U.S. Government Printing Office.)
Factors Affecting Hearing

噪声

- **Common definition**: Unwanted sound
- **Information Theory definition**: Noise is the auditory stimulus or stimuli bearing no informational relationship to the presence or completion of the immediate task.
# Factors Affecting Hearing

<table>
<thead>
<tr>
<th>Source</th>
<th>SPL (dB)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jet engine at 30 metres</td>
<td>140</td>
<td>Ear damage</td>
</tr>
<tr>
<td>Pneumatic chipper</td>
<td>130</td>
<td>Onset of pain</td>
</tr>
<tr>
<td>Pneumatic rock drill</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td>Punch press</td>
<td>115</td>
<td></td>
</tr>
<tr>
<td>Hydraulic rock drill</td>
<td>115</td>
<td></td>
</tr>
<tr>
<td>Textile loom</td>
<td>105</td>
<td></td>
</tr>
<tr>
<td>Powered lawn mower</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Heavy traffic</td>
<td>95</td>
<td></td>
</tr>
<tr>
<td>Newspaper press</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>Milling machine</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>Diesel lorry</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td>Very noisy street corner</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Crowded room</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td>Vacuum cleaner</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>Passenger car (at 15 m)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conversation</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Air conditioning system Sound inside car at 50 km/h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Private office</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Quiet room</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>Library</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>Whisper 1 m from ear</td>
<td>20</td>
<td></td>
</tr>
</tbody>
</table>
Hearing Impairment

Hearing loss

- Acoustic Trauma - immediate, organic damage from an excessive, usually sudden, exposure, such as an explosion
  - loss may be in conductive chain, such as rupture of eardrum or dislodging of bones in middle ear
  - loss may be neural, such as damage to hair cells; this type is incurable, even with hearing aids
  - E.g., Explosion
  - Rapid pressure change
Hearing Impairment

- Hearing loss
  - Temporary Threshold Shift (TTS)
    - Usually measured two minutes following exposure to avoid recovery
    - Usually most pronounced at 4000Hz
      - Loss of birds singing
    - In intense noise, displacement of basilar membrane of maximum vibration is large, and hair cells are bent by considerable force
    - Overstimulation leads to temporary paralysis of hair cells
    - Recovers with time away from noise
Hearing Impairment

Hearing loss

- Permanent Threshold Shift (PTS)
  - Permanent reduction in hearing sensitivity
  - Usually results from repeated overexposures, wherein hair cells lose their ability to recover
  - TTS experienced repeatedly can lead to PTS
  - Auditory nerve may eventually degenerate
  - Can also result from acoustic trauma
Hearing Impairment

- Hearing loss is a type of cumulative strain.
- Hearing loss begins with exposure to noises over 67 dB.
- Factors include noise level, exposure duration, gender, age, and frequency.
## OSHA Standards: Continuous Noise

<table>
<thead>
<tr>
<th>Sound level, dBA</th>
<th>Permissible time, h</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>32</td>
</tr>
<tr>
<td>85</td>
<td>16</td>
</tr>
<tr>
<td>90</td>
<td>8</td>
</tr>
<tr>
<td>95</td>
<td>4</td>
</tr>
<tr>
<td>100</td>
<td>2</td>
</tr>
<tr>
<td>105</td>
<td>1</td>
</tr>
<tr>
<td>110</td>
<td>0.5</td>
</tr>
<tr>
<td>115</td>
<td>0.25</td>
</tr>
<tr>
<td>120*</td>
<td>0.125*</td>
</tr>
<tr>
<td>125*</td>
<td>0.063*</td>
</tr>
<tr>
<td>130*</td>
<td>0.031*</td>
</tr>
</tbody>
</table>

*Exposures above 115 dBA are not permitted regardless of duration; but should they exist, they are to be included in computation of the noise dose.

Source: OSHA, 1983
Noise Dosage

\[
\text{partial dose} (> 90 \text{ dBA}) = \frac{\text{time at sound level}}{\text{maximum time allowed at sound level}}
\]

• total (daily) dose = sum of partial doses
• Requirement: total dose \( \leq 1.00 \)
Example

Worker exposed to 90 dBA for 4 hours, 105 dBA for 30 minutes. Within dosage limits?

\[
\text{partial dose (}> 90 \text{ dBA}) = \frac{\text{time at sound level}}{\text{maximum time allowed at sound level}}
\]

### Permissible Noise Exposures According to OSHA

<table>
<thead>
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<th>Sound level, dBA</th>
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<td>4</td>
</tr>
<tr>
<td>100</td>
<td>2</td>
</tr>
<tr>
<td>105</td>
<td>1</td>
</tr>
<tr>
<td>110</td>
<td>0.5</td>
</tr>
<tr>
<td>115</td>
<td>0.26</td>
</tr>
<tr>
<td>120°</td>
<td>0.126°</td>
</tr>
<tr>
<td>125°</td>
<td>0.063°</td>
</tr>
<tr>
<td>130°</td>
<td>0.031°</td>
</tr>
</tbody>
</table>

*Exposures above 115 dBA are not permitted regardless of duration; but should they exist, they are to be included in computation of the noise dose*

*Source: OSHA, 1983*
Example

Worker exposed to 90 dBA for 4 hours, 105 dBA for 30 minutes. Within dosage limits?

\[
\begin{align*}
4 \text{ hr} @ 90 \text{ dBA} &= \frac{4}{8} = 0.5 \\
0.5 \text{ hr} @ 105 \text{ dBA} &= \frac{0.5}{1} = 0.5 \\
\text{Total dosage} &= 0.5 + 0.5 = 1.0
\end{align*}
\]

Since \(1.0 \leq 1.0\), dosage is OK
# Noise Control

<table>
<thead>
<tr>
<th>Source</th>
<th>Path</th>
<th>Receiver</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
<td>Barriers</td>
<td>Ear plugs</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Enclosures</td>
<td>Ear muffs</td>
</tr>
<tr>
<td>Mountings</td>
<td>Baffles</td>
<td></td>
</tr>
<tr>
<td>Mufflers</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
# Human Senses and the Energies That Stimulate Them


<table>
<thead>
<tr>
<th>Sensation</th>
<th>Sense Organ</th>
<th>Stimulation</th>
<th>Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sight (vision)</td>
<td>Eye</td>
<td>Some electromagnetic radiation</td>
<td>External</td>
</tr>
<tr>
<td>Hearing (audition)</td>
<td>Ear</td>
<td>Pressure variations</td>
<td>External</td>
</tr>
<tr>
<td>Rotation</td>
<td>Semicircular canals, Muscle receptors</td>
<td>Fluid movement in inner ear, Muscle stretching</td>
<td>Internal</td>
</tr>
<tr>
<td>Falling, rectilinear movement</td>
<td>Otoliths</td>
<td>Position change of otoliths in inner ear</td>
<td>Internal</td>
</tr>
<tr>
<td>Taste</td>
<td>Specialized cells in tongue &amp; mouth</td>
<td>Some chemical substances</td>
<td>External on contact</td>
</tr>
<tr>
<td>Smell</td>
<td>Specialized cells in nasal cavity</td>
<td>Some vaporized chemical substances</td>
<td>external</td>
</tr>
</tbody>
</table>
Human Senses and the Energies That Stimulate Them


<table>
<thead>
<tr>
<th>Sensation</th>
<th>Sense Organ</th>
<th>Stimulation</th>
<th>Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Touch</td>
<td>Skin</td>
<td>Surface deformation</td>
<td>On contact</td>
</tr>
<tr>
<td>Pressure</td>
<td>Skin &amp; underlying tissue</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>Skin &amp; underlying tissue</td>
<td>Temperature change, friction, chemicals</td>
<td>External on contact</td>
</tr>
<tr>
<td>Pain</td>
<td>Free nerve endings (?)</td>
<td>Pressure, heat, cold, shock, chemicals</td>
<td>Internal or external on contact</td>
</tr>
<tr>
<td>Position &amp; movement (kinesthesis)</td>
<td>Nerve endings in muscle, tendons, joints</td>
<td>Muscle stretching, contraction, joint movement</td>
<td>Internal</td>
</tr>
<tr>
<td>Mechanical vibration</td>
<td>No specific organ</td>
<td>Variations of skin pressure</td>
<td>External on contact</td>
</tr>
</tbody>
</table>
Multiple Tasking

- Use of multiple resources

Across Information Processing Stages
(perception/cognition vs. response)

Sensory Modalities
(only relevant for perception stage)

Output modality
(also, note that manual/spatial, vocal/verbal most compatible)

Input codes
(relevant in WM & processing)
## Multiple Tasking

- **Use of multiple resources**

<table>
<thead>
<tr>
<th>Codes</th>
<th>Spatial</th>
<th>Auditory (hearing)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual (vision)</td>
<td>Picture &amp; Map</td>
<td>Oral direction guide</td>
</tr>
<tr>
<td>Verbal (text)</td>
<td>Reading</td>
<td>Talking &amp; Reading aloud</td>
</tr>
</tbody>
</table>