**Non-Visual Displays**

1. **Auditory** – Hearing
2. **Somatic** – includes Tactile (Touch), Haptic (Temperature, Pressure, Pain), and Kinesthetic (Motion, Force, Body and Limb Movement)
3. **Gustatory** – Taste
4. **Olfactory** – Smell

**1. Auditory Displays**
Auditory Displays

- Most often used to attract and direct a user's attention
- Auditory displays convey caution, warning, or danger information
- Examples:
  - Fire alarms
  - Burglar alarms
  - Ambulance/police/Fire sirens
- Auditory displays are sometimes preferred when they need not be in the field of view of the user
- Generally, sound should be accompanied with visual indicators such as flashing Red lights for redundant sensory coding

Typical Use of Auditory Displays

- **Warning** - A hazardous event *MAY occur* if circumstances prevail
- **Alert** - A hazardous event *is expected to occur* soon if nothing is changed
- **Alarm** - A hazardous event *is occurring* and requires *immediate* response

Aircraft Cockpits

<table>
<thead>
<tr>
<th>Aircraft Type</th>
<th>Number of Displays</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC8</td>
<td>172</td>
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<tr>
<td>DC10</td>
<td>481</td>
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<tr>
<td>Boeing 707</td>
<td>188</td>
</tr>
<tr>
<td>Boeing 747</td>
<td>455</td>
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Auditory Channel - Advantages

- Each sense modality can be thought of as a "channel" through which information is received and processed.
- Each channel has limited capacity or bandwidth in terms of the amount of information that can pass through it at one time.
- The human visual system has the greatest channel capacity/bandwidth and is heavily relied upon in display design.

Why Auditory Channels?

- Sound Surrounds - Sound is omni-directional
- Low Visibility Environments - Hearing does not depend on the presence of light
- Attention Getting - Sound can be very obtrusive, immediately demanding our attention
- Focused Attention - Our auditory system can filter sound, enabling us to locate and focus on specific sounds in a noisy or sound-filled background

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Disadvantages of Auditory Channels

- **Startle Response:**
  - Sound can be so obtrusive that it interrupts and disrupts task performance even to the extent of wiping out/erasing immediate memory.

- **Localization Difficulties:**
  - While sound surrounds us, it can be difficult to locate the source, depending upon the environment. Sound can be absorbed or reflected by barriers and objects.

Startle Response

- A sudden noise will cause an involuntary response and is characterized by:
  - vasoconstriction,
  - an increase in blood pressure,
  - dilation of pupils, and
  - muscle contractions

More Disadvantages

- **Limited Memory for Abstract Sounds:**
  - The human memory for abstract sounds, composed of pure tones, is very limited—typically from 5 to 8. It is recommended that no more than 6 be used in most circumstances.

- **Sounds Masked by Other Sounds:**
  - We may be able to attend to and hear the sound of a flute in an orchestra, but if more than one flute is playing we may not be able to determine "which" flute is playing "what" note.

- **Sound/Noise Habituation:**
  - We tend to become used to and not attend to continuous sound or noise unless it is pertinent to the task at hand ("Background" music is a common example)
Auditory Display - Pitfalls

- **Too Loud** - Causes startle response.
- **Too Frequent** - Causes auditory signals to be ignored.
- **Too Many** - Causes confusion.
- **Too Vague** - Causes uncertainty.

Sound Science

- Pressure variations in a media that the ear can detect.
- Radiates as wave oscillations from the source.

How we hear

The sound source vibrates and affects air particles, which strike the ear drum.
How do we HEAR ??!!??

Physiology of the Ear

Wave oscillations vibrate at the ear drum
Physiology of the Ear

1. **External ear**
   - The external ear amplifies sound by as much as 23 dB
   - The ear canal amplifies sound by as much as 12 dB

2. **Middle ear**
   - The middle ear is an air-filled chamber that vents to the throat through the Eustachian tube, it contains three small bones called the **Hammer, Anvil & Stirrup**

3. **Inner ear**
   - The main element of the inner ear is the cochlea, which is a fluid filled (20-30 mm long) coil that is divided into two chambers by thin tissue (Basilar Membrane)
Ch6: Auditory, Tactile, & Olfactory Displays

Damage to Hair Cells:

Principles of Sound

- Frequency (roughly, Pitch):
  - The number of sound waves/sec produced by a sound source (measured in cycles/sec or Hertz).
  - We hear frequencies between 20 Hz to 20K Hz.
  - We are more sensitive to certain frequencies than others (frequencies between 2,000 to 5,000 Hz).
### Principles of Sound

**Amplitude (Loudness):**
- The height of the wave and energy or strength of the sound.
- This can also be thought of as the power or pressure of the wave—the sound pressure level (SPL) which is measured in decibels (dB).
- \[ \text{SPL (dB)} = 20 \log \left( \frac{P}{P_0} \right) \]

### Sound Quality

**Defined as Timbre:** The humanly perceived difference between tones even though the tones are of the same pitch and loudness.
Human Auditory System

- Sound intensity (perceived as Loudness) is measured in units of Sound Pressure Level (SPL)
- To handle sound measurements and calculations over a range of 32 trillion units, a Logarithmic scale is used
- The units of this scale are decibels (dB)

dB Scales

- A scale measures what humans hear
- B scale used by phone company
- C scale measures all sound

dB

- dB are dimensionless ratios of a measured value of sound relative to some reference value
- 1 dB = 0.1 B
The Decibel Scale

Because decibels are on a log-scale:
- A 3 dB increase equates to twice as much sound (power)
- A 6 dB increase equates to 4 times as much
- A 10 dB increase equates to 10 ×’s as much
- A 60 dB increase is one-million × more power
- A 120 dB increase is one-million × one-million as much power
- Double the distance away from a sound source, you reduce the sound by ~6 dB

Some Examples of SPL (dB):
- 140 dB - Jet aircraft start
- 130 dB – Threshold of Pain
- 120 dB - Propeller aircraft start
- 110 db - Rock band (amplified)
- 100 dB - Power chain saw
- 90 dB - Disco
- 80 dB - Circular Saw
- 70 dB – Road traffic/factory floor (heavy industry)
- 60 dB - Normal conversation
- 50 dB - Office environment
- 40 dB - Living room
- 30 dB - Whisper
- 20 dB - Bedroom
- 15 dB - Threshold of hearing
- 10 db - Recording studio
- 0 dB - Acute threshold of hearing (weakest detectable sound)

For Correct Signal Identification

- Multiple encoding mechanisms for pure tone, auditory signals can be applied:
  - Frequency (Pitch)
  - Amplitude (Loudness)
  - Duration or phasing
Sound Properties

- Sound waves may have a single frequency or may be a combination of frequencies
- Frequency analysis instruments (Octave Band Analyzer) can sort complex sounds into a distribution of frequencies
- Octaves divide the entire audible range into smaller bandwidths
- Short duration noise pulses, which can occur once or be repetitive are called Impulse Noises

Sound Physics

- **Sound power** describes the energy radiated from a sound source and it is expressed in units of watts (W)
- **Sound pressure** refers to the pressure changes at some location
- **Sound intensity** is expressed in joules per square meter per second (J/m² s⁻¹)
- **Sound intensity level** L₁ in decibels is the sound intensity relative to 10⁻¹² W/m²

Sound Distribution

- In a free field sound moves from a source in a spherical pattern
- It may strike objects, panels, walls and ceilings
- It may be absorbed, it may travel through openings and around objects
### Sound Absorption

- Absorption can be predicted and is measured in **sabins**.
- One sabin is the absorption of 1 ft² of a perfectly absorptive surface.
- The noise reduction NR possible from absorption is:
  \[ NR = \log_{10} \left( \frac{\text{absorption before treatment}}{\text{absorption after treatment}} \right) \]

### Alarm/Alert Auditory Displays: Basic Principles

- Limit the number of alarms and alerts:
  - 6 immediate action signals and 2 precursor, attention signals
  - For 100% detectability, or for signals requiring rapid response, signals must be **15 dB** (min), and **25 dB** (max) above background noise.
  - Signals must differ in frequency from the frequencies of background noise.
  - Signals must differ sufficiently so that one signal doesn't mask another.

- Signals should be between 500 – 5,000 Hz, and composed of at least 4 prominent frequency components, each within 1,000 – 4,000 Hz.
- Signals should be composed of regular, harmonic, frequency components instead of inharmonic components (perceived tonal sequence vs. noise).
- Rapid (100 msec) glides in the signal's fundamental frequency command attention and convey urgency.
- Duration of signals have to be ≥500 ms.
### Alarm/Alert Auditory Displays: Basic Principles

- To gain attention, modulate the signal, using intermittent “beeps” or rise and fall in pitch (1 to 3 cycles/sec).
- Use temporal patterns to increase signal detectability and discriminability.
- Signals that must be heard from >1,000 ft away should be <1,000 Hz (because lower frequencies travel farther).
- Signals that must be heard through partitions or around obstacles should be <500 Hz (again, because lower frequencies can travel through barriers).
- Use redundant visual indicators.
- Always test in the operational environment to ensure effectiveness.

### Auditory displays are preferable to visual displays when:

- Origin of the signal is itself a sound (automobile horn)
- Message is simple and short (fire alarm)
- Message will not be referred to later (ambulance siren)
- Message deals with events in time (telephone ring)
- Message needs immediate action (smoke detector)
- Visual system is overburdened (air traffic control)
- Visual system is unavailable (alarm clock)
- Speech channels are fully employed, in which case auditory signal must be clearly distinguishable from speech (help desk)
- Illumination or dark adaptation limits use of vision (aircraft cockpit)
- Message receiver must move about in job performance (power plant)
2. Somatic (Tactile, Haptic, and Kinesthetic) Displays

The Somato-Sensory System

- The somato-sensory system provides us with information about our soma (Greek for body) contact with the outside world and our own movements and body position within it.

The Somato-Sensory System:

- **Tactile, Tactual, or Cutaneous:**
  - Touch, pressure, pain, vibration, shape, texture
  - Ex: Braille

- **Temperature:**
  - Perception at skin surface

- **Pain:**
  - Extreme temperature, intense pressure, burning chemicals.

- **Kinesthetic:**
  - Limb/joint movement and position and muscle contraction state
Haptic Displays

- Haptic refers to "Active Touch" to emphasize the importance of movement/kinesthetics when exploring an object by touch (to determine an object's size, shape, and texture).
- Most tactile and haptic displays are designed for the hand or fingers (areas of most numerous and sensitive touch receptors).

Tactile and Haptic Displays

- Tactual and Haptic displays receive and process mechanical energy (also kinesthetic).
- Tactual and Haptic displays are considered third after visual and auditory displays.

Tactile and Haptic Displays Example

- Computer keyboards have been designed to provide kinesthetic/ acoustic feedback, that a key has been successfully depressed for accurate and fast typing.
Tactile and Haptic Displays Examples

- "Rumble strips" on highways

Tactile and Haptic Displays Examples

- In aviation:
  - "Stick shakers" that alert the pilot of stalls have been in use since WWII.
  - Rudder pedals in larger, heavy modern aircraft are equipped with hydraulics to give appropriate force feedback to pilots.

Tactual/Haptic Displays - Example

- Anti-lock braking systems (ABS) provide tactual/haptic feedback to the driver when they are engaged.
More Examples

- NASA physicists can “Hold” and “feel” a rock from Mars

- NASA engineers can manipulate computational fluid dynamics of the shuttle

More Examples

- A robotic arm can replace a surgical assistant in holding and positioning the laparoscope more steadily than a human and is equipped with two video screens, enabling instant playback

More Examples

- Wrist bands that use tactile stimulation to alert pilots to status changes on automated flight decks.

- A vest provides spatial orientation and tactical information by tactile, cutaneous stimulation.
3. Gustatory Displays

Taste Displays
- Least used in information displays.
- Taste is generally considered inappropriate for information displays as substances must be placed in the mouth or on the tongue to activate this sense.
- This is a chemically reactive sense.
- Taste is based on contact with and processing of molecules in aqueous (water) solution.
- What we think of as our sense of "taste" is really comprised mostly of our sense of smell.
- Taste is limited to 5 primary elements:
  - sweet, sour, bitter, salty, and umami.

Example of Taste Display
- The use of Saccharine in Respiratory Fit Testing.
4. Olfactory Displays

- Also least used in information displays.
- This is a chemically reactive sense.
- Smell is based on the inhalation, binding, and processing of airborne odor molecules.
- Smell is a potent memory stimulus that can evoke strong emotional response.
- We can detect over 10,000 scents and can identify some odors in concentrations as small as 1 ppb.
- It has evolved as an important "survival" cue:
  - Warns us of the presence of fire
  - It also warns us of characteristics of food that could signal poisoning such as a strange or rotten odor
Olfactory Displays - Example

- Some computer control rooms and maintenance areas are equipped with CO₂ fire suppression systems. Since CO₂, a colorless, odorless gas that is hazardous to humans, some systems add the scent of wintergreen to the CO₂ to signal gas release.

More Olfactory Display Examples

- The addition of mercaptan, a sulfur compound, to natural gas (odorless) to warn of a gas leak
- The injection of mercaptan into mines as an evacuation signal. Sulfur compounds smell of “rotten eggs” and are easily detected and discerned by the human olfactory system.

More Examples

- Ancient China and Japan developed “incense clocks” by using the regular burning rate of incense to track the passage of time.
- Later, some clocks incorporated an “alarm” scent at the end of each hour to cue the striking of the temple bell to broadcast the time.
- Refinements led to the burning of a different incense for each hour of the day so you can tell the hour with a sniff.
Olfactory System - Advantages

- Airborne odor molecules can travel long distances. This, coupled with our capability to detect smells at very low concentrations, provides an effective, early warning system to changes in our environment.
- Olfaction works in background without conscious attention until a change in the environment occurs.
- Olfaction can be used when the visual and auditory systems are overburdened.
- We can make absolute identification of 15 to 32 common odors; with training some can identify up to 60.

- We can distinguish 3 to 4 levels of odor intensity.
- Odor memory does not degrade as rapidly as other sensory memory.
- Smell is a better memory cue than any of the other senses.
- Smell can enhance learning and recall.
- Odors can create a sense of "immersion" or "presence" in artificial environments.

Olfactory System - Disadvantages

- Individuals vary greatly in sensitivity to odors.
- At least 1% of population has some smell or taste disorder.
- Sensitivity declines with age.
- Sensitivity is Gender dependent—women have greater sensitivity at all ages.
- Sensitivity can be temporarily reduced due to a cold, the flu, or allergies.
- Humans adapt quickly to odors, even noxious, foul ones, so that an odor is no longer perceived a short time after exposure.
Olfactory System - Disadvantages

- We are better at relative judgments of odor than absolute identification.
- Odor dispersion is difficult to control
- Some odors cause allergic reactions, nausea, and headache in some people.
- Use of odors for individual messaging is not suitable for multi-person environments.
- Smell is a potent memory cue and may trigger unanticipated and unwanted emotional reactions in an individual.

Olfactory Uses

- A Virtual Reality simulation environment for paramedic training to incorporate olfactory/odorant stimuli to increase training realism.
- Computer and hourly scented clock