Auditory, tactile, & vestibular systems

- Getting and using auditory information
  - sound and hearing review
  - information content
  - location and distance
- Problems of...
  - sound transmission & reception
  - speech
  - noise
- Tactile information
  - pressure
  - shape
- Proprioception & kinesthesia
- Vestibular senses

Sound

- What is sound?

- What are the 4 key characteristics of sound?

- How does the ear turn the vibration of air molecules into ‘sound’?
The auditory experience

- Psychophysical experience of loudness & pitch
  - see figs. 5.3 and 5.4, pp. 96-97

- Example: How loud does a sound at 100 Hz need to be to be perceived as equally loud as a 600 Hz sound at ~38 dB?

- Masking
  - minimum intensity difference to be heard above masking sound = 15dB
  - most often masked by sounds within a critical frequency band around the sound
  - lower pitch more often masks higher pitch

- Question: what are some uses and dangers of masking?

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The auditory experience

- Sound localization
  - direction determined by the phase shift and amplitude differences between sounds arriving at each ear (binaural differences)

  - distance determined mainly by amplitude and envelope (temporal characteristics)
    - close distance (<1m) cues also include interaural intensity differences and reverberation

- Uses ...

- Cocktail Party effect

- Sound envelope
  - changes in pitch and amplitude over time can convey specific information
  - Doppler effect
Alarms

• Advantages of auditory alarms
  • omnidirectional
  • attention-getting
  • immediate

• Potential disadvantages
  • can be masked by background noise
  • can induce startle response
  • can impede critical communication
  • limited ability to convey information
  • false alarms

Alarms

• ‘Nuts and bolts’
  • Alarm should be at least 15 dB above the background noise, preferably 30 dB to guarantee it will be heard.
  • Must not be above the noise level that can damage hearing.
  • Alarm should not be startling. Alarm should rise in intensity.
  • Should not interfere with critical speech communication.
  • Alarm should be informative.
  • Alarms should not be confusable. No more than 5-6 alarms that must be distinguished (absolute judgement).

• Example (from Report Of The President’s Commission On The Accident At Three Mile Island, http://stellar-one.com/nuclear/causes_of_the_accident.htm)

  “During the first few minutes of the accident, more than 100 alarms went off, and there was no system for suppressing the unimportant signals so that operators could concentrate on the significant alarms.”
Sound transmission (& sound reception)

- Speech transmission affected by:
  - Masking
  - S/N ratio (signal to noise or speech to noise)
  - Vowels versus consonants
  - Expectations, goals, assumptions of receiver
  - Hearing loss due to aging, exposure to noise, temporary threshold shift (TTS), or permanent threshold shift (PTS)
  - ‘live’ vs digital speech

Enhancing speech communication

- Face to face

- Choice of vocabulary

  - Use of phonetic alphabet (alpha, bravo, charlie …)
Noise

• Effects of noise in the environment
  • disrupting information transmission
  • stressor
  • hearing loss

• Noise remediation
  • enhance the signal
  • reduce the noise
    • at the source
    • in the environment
    • at the listener

• Benefits of noise
  • masking
  • alerting

Other senses: touch, space, & movement ...

• Without looking, find the number ___ on your calculator.

• Without looking, press the number 3 times. Think about how you know you have 3 ___s on your display.

• Place your book in front of you and slightly to your left (but still within reach.) Close your eyes. Now reach out and put your hand on your book.

• With eyes closed, move the book directly in front of you.

• Pair up. Use 1 pencil and 1 pen that are different in shape and size. One partner should close his/her eyes. The other should place the pencil and pen side by side in front of his/her partner without telling which is which. The partner with the eyes closed should now pick up the pen.
Tactile / haptic feedback

- Related to sensory receptors responding to pressure on the skin
- Helped you to:
  - find keys on your calculator
  - determine number of key presses
  - pick up the pen by its shape
- Information conveyed
  - Subtle changes in force applied
  - Surface texture
  - Shape
  - Temperature
- Design concerns:
  - Touchscreen & membrane keys
  - Gloves
  - Recognition of objects by shape
  - Virtual environments and remote manipulation

Proprioception and kinesthesis

- Accurate innate knowledge of joint angles (proprioception) and motion (kinesthesis)
- Helped you to:
  - find the correct number key
  - know when your hand had reached your book
  - know when the book was in front of you
- Information conveyed
  - position in space
  - motion through space
- Design concerns:
  - manipulator controls
  - control placement

Vestibular systems

- *Semicircular canals* and *vestibular sacs* in the inner ear convey information regarding angular and linear accelerations of the body
  - angular acceleration (semicircular canals) – turning, etc.
  - linear acceleration (vestibular sacs) – acceleration and braking, balance

Design concerns:

- Illusions of motion
  - caused when the body is placed in situations of sustained acceleration and nonvertical orientation for which it is not naturally adapted – pilots flying ‘in the clouds’
  - can also occur when vestibular and visual senses are decoupled – you are still but a nearby object (e.g., car) begins to move slowly parallel to you

- Motion sickness
  - vestibular and visual systems are decoupled and provide conflicting information – e.g., inside a moving vehicle with no view outside
  - can also occur in virtual environments – visual system says ‘moving’ but vestibular says not …

Signal Detection Theory (SDT)

(see pp. 82-87)

- A situation is described in terms of two states of the world:
  - a signal is present ("Signal")
  - a signal is absent ("Noise")

- You have two possible responses:
  - the signal is present ("Yes")
  - the signal is absent ("No")

<table>
<thead>
<tr>
<th>Response</th>
<th>Signal</th>
<th>Noise</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hit</td>
<td>False Alarm</td>
</tr>
<tr>
<td>Yes</td>
<td>P(H)</td>
<td>P(FA)</td>
</tr>
<tr>
<td>No</td>
<td>Miss</td>
<td>Correct Rejection</td>
</tr>
<tr>
<td></td>
<td>P(M)</td>
<td>P(CR)</td>
</tr>
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</table>
What does this mean?

- If you decide "Yes" and the true state of the world is "Signal," that's called a Hit.

- If you decide "Yes" and the true state of the world is a "Noise," that's called a False Alarm.

- If you decide "No" and the true state of the world is "Signal," that's called a Miss.

- If you decide "No" and the true state of the world is "Noise," that's called a Correct Rejection.

Theoretically ...

- The theory assumes that what you are doing is:
  - First, you collect sensory evidence concerning the presence or absence of the signal.
  - Next, you decide whether this evidence constitutes a signal. This means that you must have some criterion C that you use as a "cutoff": if the evidence is less than C, you decide "No"; if the evidence exceeds C, you decide "Yes".
Measures of performance in SDT: 1. Sensitivity (d’)

- A function of the keenness or sensitivity of the human's detection mechanisms and the relative strength of the signal in noise.
- This value may be calculated from the probabilities of a hit and a false alarm.
- Example: Radiologists evaluating a candidate MRI machine are given 1000 sample slides, 500 of which are from patients with a tumor. The results of the readings are as follows:

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<th>No tumor (&quot;noise&quot;)</th>
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<tr>
<td>Positive (&quot;yes&quot;)</td>
<td>400</td>
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</tr>
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Calculating d’

- \( P(FA) = \) ____________  \( z_{FA} = \) ____________
- \( P(M) = \) ____________  \( z_{M} = \) ____________

\[ d' = \] ________________
Measures of performance in SDT: 2. Response bias ($\beta$)

- Another way to describe performance is in terms of response bias: you may be prone to say "yes" (which is "risky") or you may be prone to say "no" (which is "conservative").

- Response bias the ratio of the heights of the two curves at the cutoff point and is measured by the quantity:

$$\beta = \frac{p(X_i | S)}{p(X_i | N)}$$

where $X_i$ = "evidence variable"
$S$ = signal
$N$ = noise

Going back to our example ...

- $P(FA) =$ __________  $Ord_{FA} =$ __________

- $P(M) =$ __________  $Ord_M =$ __________

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$$\beta = \_\_\_\_\_\_\_$$
Some important points ...

- Studies of human performance show that humans do change beta in response to changes in probabilities and payoffs -- but not as much as they should! This phenomenon is called *sluggish beta.*

- Note: the terms “risky” and “conservative” refer only to a person’s propensity to say “yes (signal)” or “no (noise).”

  - Examples:
    - radiologists reading x-rays for signs of tumors
    - radar operators on a battle ship looking for incoming enemy aircraft
    - scanning a parking lot for a parking space

Important points (cont.)

- The cutoff (C) for determining the presence of a signal is not the same as the response bias parameter (β). However, they are correlated. For example, if your strategy becomes more "risky" (in other words, your β goes down), then your cutoff also goes down. As you get more conservative, both your cutoff and your β go up.

- What is an “optimal setting” for β?

  Note that as terms in the denominator increase, β decreases and thus response becomes riskier. As terms in the numerator increase, β increases and thus responses become more conservative. Also, the first fraction shows the effect of signal likelihood and the second fraction shows the effect of payoffs.

  \[
  \beta_{opt} = \frac{P(\text{Noise}) \cdot \text{Value}(\text{CR}) + \text{Cost}(\text{FA})}{P(\text{Signal}) \cdot \text{Value}(\text{Hit}) + \text{Cost}(\text{Miss})}
  \]
The receiver Operating Characteristic (ROC) curve plots the probability of a hit against the probability of a false alarm. Each curve represents the same sensitivity at different levels of response bias.

- High sensitivity
- Neutral
- Conservative
- Risky
- Low sensitivity

\[ P(\text{hit}) \quad \text{P(false alarm)} \]