Introduction
Chapter 1 Introduction

• Thresholds and the Dawn of Psychophysics
• Sensory Neuroscience and the Biology of Perception
What do we mean by “Sensation & Perception?”

- **Sensation**: The ability to detect a stimulus (convert to nervous system activity)
- **Perception**: The act of giving meaning to a detected sensation. (Schieber say “integration” → “objects”)
- **Cognition**: The manipulation of perceptual objects (in the service of goals)

*Sensory processes are not available to consciousness but the products of perceptual processes are the objects of awareness*
Sensation and perception are central to mental life.

• Without them, how would we gain knowledge of the world?
Introduction

The study of sensation and perception is a scientific pursuit and requires scientific methods.

• **Thresholds**: Finding the limits of what can be perceived.

• **Scaling**: Measuring private experience.

• **Signal detection theory**: Measuring difficult decisions.

• **Sensory neuroscience**: The biology of sensation and perception.

• **Neuroimaging**: An image of the mind.
Psychophysical
Thresholds
First, some formal definitions:

- **Just noticeable difference (JND):** The smallest detectable difference between two stimuli, or the minimum change in a stimulus that can be correctly judged as different from a reference stimulus; also known as difference threshold.
- **Absolute threshold:** Minimum amount of stimulation necessary for a person to detect a stimulus 50% of the time.
The Concept of Absolute Threshold

Ideal Absolute Threshold

(a)

```
<table>
<thead>
<tr>
<th>Percentage of times reported present</th>
</tr>
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<tbody>
<tr>
<td>100</td>
</tr>
<tr>
<td>75</td>
</tr>
<tr>
<td>50</td>
</tr>
<tr>
<td>25</td>
</tr>
<tr>
<td>0</td>
</tr>
</tbody>
</table>
```

```
<table>
<thead>
<tr>
<th>Stimulus level (arbitrary units)</th>
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<tbody>
<tr>
<td>7</td>
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<td>8</td>
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<tr>
<td>9</td>
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<tr>
<td>10</td>
</tr>
<tr>
<td>11</td>
</tr>
<tr>
<td>12</td>
</tr>
</tbody>
</table>
```

"I don’t hear it."

"I hear it."

SENSATION & PERCEPTION 4e, Figure 1.6 (Part 1)
But…. early experimental psychologists like Fechner discovered that humans were not ideal observers.

Instead, behavior at the boundary of sensory sensitivity appeared to reflect probabilistic processes rather than ideal detection.
The Concept of Absolute Threshold

Psychophysical function demonstrating the probabilistic (statistical) nature of the threshold
Ernst Weber (1795-1878) was an experimental philosopher whose work eventually fostered the establishment of what would become known as scientific psychology.
Ernst Weber discovered that the smallest change in a stimulus that can be detected is a constant proportion of the stimulus level. i.e. human sensory sensitivity is **relative** rather than **absolute** in nature.

This relationship has been formalized as **Weber’s Law** (see next slide).
Scientific psychology’s first law (Weber’s Law)

\[
\Delta I = kI
\]

algebraically rephrased as

\[
\frac{\Delta I}{I} = k
\]

where

\[
I = \text{stimulus intensity}
\]
\[
\Delta I = \text{just noticeable difference}
\]
\[
k = \text{numerical constant}
\]
Thresholds and the Dawn of Psychophysics

If we know the value of “k” and “I”, we can use Weber’s Law to determine how much a stimulus needs to change in order for the average person to detect that change.

For example:

If the Weber fraction (k) for judging weight = 0.02 then the JND (delta I) for a 10 ounce weight would be (10 ounce x k) = (10 x 0.02) = 0.2 ounces

Hence, an 10.1 ounce weight would be indistinguishable from a 10 ounce weight…but a 10.2 ounce weight would appear heavier than the same 10 ounce weight (i.e., >= JND).
How many ounces would you need to add to a 100 ounce weight before you could tell the difference?

What about a 1 ounce weight?

How about a 0.01 ounce weight?

(This one is a “trick question”)
Some common Weber Fractions (k)

<table>
<thead>
<tr>
<th>Sensory Modality</th>
<th>Weber Fraction (k)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric shock</td>
<td>0.01</td>
</tr>
<tr>
<td>Lifted weight</td>
<td>0.02</td>
</tr>
<tr>
<td>Sound intensity</td>
<td>0.04</td>
</tr>
<tr>
<td>Light intensity</td>
<td>0.08</td>
</tr>
<tr>
<td>Taste (salty)</td>
<td>0.08</td>
</tr>
</tbody>
</table>

Source: From Teghtsoonian (1971).
Building upon the work of Weber:

**Gustav Fechner** (1801–1887) invented “psychophysiology” and is often considered to be the true founder of experimental psychology.
Fechner attempted to describe the relationship between the mind and body using the language of mathematics.

- **Psychophysics**: The science of defining quantitative relationships between physical and psychological (subjective) events.
Fechner mathematically extended Weber’s law to make it more universal.

- **Fechner’s law**: A principle describing the relationship between stimulus magnitude and resulting sensation magnitude such that the magnitude of subjective sensation increases proportionally to the logarithm of the stimulus intensity.

\[
\text{Sensation} = \log(\text{Stimulus Intensity})
\]

\[
S = k \log(I)
\]
Fechner’s **major assumptions** were that:

(1) The basic unit of analysis for modeling psychological processes was the **JND** ("just noticeable difference")

(2) Mathematical functions capturing such processes could be “anchored” using the **absolute threshold** (a “relative” zero point)
Fechner’s Law: Measure and plot sequential JND values

1. Plot sequential JNDs (1 thru 6 here)
2. Find a mathematical “model” that fits the data:
\[ S = k \log(I) \] (i.e. Fechner’s Law)

The strength of sensory experience grows at a slower rate than the physical stimulus.

Sensory compression

\[ S = k \log R \] (textbook)
Classical Psychophysical Methods
Psychophysical methods

- **Method of constant stimuli**: Many stimuli, ranging from rarely to almost always perceivable, are presented one at a time.

- **Method of limits**: The magnitude of a single stimulus or the difference between two stimuli is varied incrementally until the participant responds differently.
Psychophysical methods (continued)

- **Method of adjustment**: Similar to the method of limits, but the participant controls the stimulus directly.

- **Magnitude estimation**: The participant assigns values according to perceived magnitudes of the *suprathreshold* stimuli.

All methods except Magnitude Estimation were developed by Fechner
# Method of Constant Stimuli Design Matrix / Data Matrix

<table>
<thead>
<tr>
<th>Intensity (arbitrary units)</th>
<th>Randomized Trials</th>
<th>Randomized Trials</th>
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</thead>
<tbody>
<tr>
<td>20</td>
<td>Y   Y   Y   Y   Y</td>
<td>1.0</td>
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<tr>
<td>19</td>
<td>Y   Y   Y   Y   Y</td>
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<tr>
<td>18</td>
<td>Y   Y   Y   Y   Y</td>
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<td>17</td>
<td>Y   Y   Y   Y   Y</td>
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<td>16</td>
<td>Y   Y   Y   Y   Y</td>
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<td>15</td>
<td>Y   Y   Y   Y   Y</td>
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<tr>
<td>14</td>
<td>Y   Y   Y   Y   Y</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Y   Y   Y   Y   Y</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Y   Y   Y   Y   Y</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Y   Y   Y   Y   Y</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Y   Y   Y   Y   Y</td>
<td></td>
</tr>
</tbody>
</table>

\[ p(Yes) \]
MCS: Psychophysical Function with Interpolated 50% Threshold
Figure 1.7  The method of limits

<table>
<thead>
<tr>
<th>Trial series</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
<tr>
<td>20</td>
</tr>
<tr>
<td>19</td>
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<td>18</td>
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<td>10</td>
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</table>

<table>
<thead>
<tr>
<th>Intensity (arbitrary units)</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.5</td>
</tr>
</tbody>
</table>

Crossover values (average = 13.5)
Suprathreshold magnitude estimates are well described by **Stevens’ power law**

\[ S = k(I)^n \]

where

\[ S = \text{sensation magnitude} \]
\[ I = \text{stimulus intensity} \]
\[ k = \text{proportionality factor} \]
\[ n = \text{exponent (power)} \]

\[ S = aI^b \] (textbook formula)
Magnitude Estimation Functions ("Direct Sensory Scaling")

- Electric shock (3.5)
- Apparent length (1.0)
- Sweetness (0.8)
- Brightness (0.3)
Exponent parameter = “slope” when plotted in log-log space.
Cross-modality matching: The participant matches the intensity of a sensation in one sensory modality with the intensity of a sensation in another.

- Useful method for allowing people to classify how dull or intense a flavor is (or other sensation)
- Provides *prima facie* support for the validity of direct reports of the strength of sensory experience
Some sample Power Law Exponents

Loudness (SP @ 3kHz) 0.67
Brightness (point source) 1.0
Visual area 0.7
Visual Length 1.0
Smell (heptane) 0.6
Taste (sucrose) 1.3
Vibration (finger @ 60Hz) 0.9
Electric shock (pain) 3.5
Lecture Ends Here
Signal detection theory: A psychophysical theory that quantifies the response of an observer to the presentation of a signal in the presence of noise.
Four possible stimulus/response situations in signal detection theory:

- **Hit**: Stimulus is present and observer responds “Yes.”
- **Miss**: Stimulus is present and observer responds “No.”
- **False alarm**: Stimulus is not present and observer responds “Yes.”
- **Correct rejection**: Stimulus is not present and observer responds “No.”
Many real-world problems can be conceptualized as a search for a signal amidst noise.
FIGURE 1.10 Mammograms, X-rays of the breast, are used to screen women for breast cancer
Signal detection theory makes a distinction between an observers’ ability to perceive a signal and their willingness to report it. These are two separate concepts:

• Sensitivity
• Criterion
Thresholds and the Dawn of Psychophysics

• Sensitivity: A value that defines the ease with which an observer can tell the difference between the presence and absence of a stimulus or the difference between stimulus 1 and stimulus 2.

• Criterion: An internal threshold that is set by the observer.
  - If the internal response is above criterion, the observer gives one response.
  - Below criterion, the observer gives another response.
Figure 1.11 Detecting a stimulus using signal detection theory (SDT) (Part 1)

(a) Number of instances

Less ← Your perception ← More

(b) Number of instances

Less ← Sounds like phone ← More

(c) NO Criterion YES

Number of instances

Less ← Sounds like phone ← More

- Red: Shower “noise” alone
- Blue: Ring + noise
Figure 1.11 Detecting a stimulus using signal detection theory (SDT) (Part 2)

(d) Correct rejection

(e) Hit

(f) False alarm

(g) Miss

<table>
<thead>
<tr>
<th>NO</th>
<th>Criterion</th>
<th>YES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less</td>
<td>Sounds like phone</td>
<td>More</td>
</tr>
<tr>
<td>Less</td>
<td>Sounds like phone</td>
<td>More</td>
</tr>
</tbody>
</table>

Number of instances

- NO
- Criterion
- YES

- Less
- More

**Legend:**
- Red: Shower “noise” alone
- Cyan: Ring + noise
Your sensitivity to a stimulus is illustrated by the separation between the distributions of your response to noise alone and to signal plus noise.

(a) No sensitivity

(b) Moderate sensitivity

(c) High sensitivity

Shower "noise" alone

Ring + noise
Figure 1.13 For a fixed $d'$, all you can do is change the pattern of your errors by shifting the response criterion.

(a) "Gotta get that call!"

(b) "Is that the phone?"

(c) "That’s not a phone."

- Red: Shower "noise" alone
- Blue: Ring + noise
Receiver operating characteristic (ROC): In studies of signal detection, the graphical plot of the hit rate as a function of the false alarm rate.

• Chance performance will fall along the diagonal.

• Good performance (high sensitivity) “bows out” towards the upper left corner.
Plotting the ROC curve allows one to predict the proportion of hits for a given proportion of false alarms, and vice-versa.

- Changes in criteria move performance along a curve but do not change the shape of the curve.
Figure 1.14 Theoretical receiver operating characteristic (ROC) curves for different values of $d'$.