Three methods for measuring perception

1. Magnitude estimation
2. Matching
3. Detection/discrimination

Magnitude estimation

Have subject rate (e.g., 1-10) some aspect of a stimulus (e.g., how bright it appears or how loud it sounds).

P = k S^n

P: perceived magnitude
S: stimulus intensity
k: constant

Steven's power law

In a matching experiment, the subject’s task is to adjust one of two stimuli so that they look/sound the same in some respect.

Example: brightness matching

Detection/discrimination

In a detection experiment, the subject’s task is to detect small differences in the stimuli.

Psychophysical procedures for detection experiments:
- Method of adjustment.
- Yes-No/method of constant stimuli.
- Simple forced choice.
- Two-alternative forced choice.
Method of adjustment

Ask observer to adjust the intensity of the light until they judge it to be just barely detectable

Example: you get fitted for a new eye glasses prescription. Typically the doctor drops in different lenses and asks you if this lens is better than that one.

Yes/no method of constant stimuli

Do these data indicate that Laurie's threshold is lower than Chris's threshold?

Forced choice

• Present signal on some trials, no signal on other trials (catch trials).

• Subject is forced to respond on every trial either "Yes the thing was presented" or "No it wasn't". If they're not sure then they must guess.

• Advantage: We have both types of trials so we can count both the number of hits and the number of false alarms to get an estimate of discriminability independent on the criterion.

• Versions: simple forced choice, 2AFC, 2IFC

Simple forced choice: four possible outcomes

<table>
<thead>
<tr>
<th>Tumor present</th>
<th>Doctor responds &quot;yes&quot;</th>
<th>Doctor responds &quot;no&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hit</td>
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<td>Miss</td>
</tr>
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<td>Correct reject</td>
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Tumor absent

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Information acquisition

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**Criterion shift**

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**Information and criterion**

Two components to the decision-making: **information** and **criterion**.

- **Information**: Acquiring more information is good. The effect of information is to increase the likelihood of getting either a hit or a correct rejection, while reducing the likelihood of an outcome in the two error boxes.

- **Criterion**: Different people may have different bias/criterion. Some may choose to err toward "yes" decisions. Others may choose to be more conservative and say "no" more often.

**Internal response: probability of occurrence curves**

- N: noise only (tumor absent)
- S+N: signal plus noise (tumor present)

Discriminability (d' or "d-prime") is the distance between the N and S+N curves.

**Discriminability (d')**

\[ d' = \frac{\text{separation}}{\text{spread}} \]

**Example applications of SDT**

- Vision
  - Detection (something vs. nothing)
  - Discrimination (lower vs greater level of: intensity, contrast, depth, slant, size, frequency, loudness, ...)
- Memory (internal response = trace strength = familiarity)
- Neurometric function/discrimination by neurons (internal response = spike count)

**Criterion**

Distribution of internal responses when no tumor

Distribution of internal responses when tumor present

Say "no"  Say "yes"
**Hits:** respond "yes" when tumor present

- **Correct rejects:** respond "no" when tumor absent

- **Misses:** respond "no" when present

- **False alarms:** respond "yes" when absent

**Criterion shift**

\[ d' = z[p(H)] + z[p(CR)] = z[p(H)] - z[p(FA)] \]

\[ c = z[p(CR)] \]

\[ \beta = \frac{p(x = c | S + N)}{p(x = c | N)} = e^{-d'^2/2} \]

**SDT: Gaussian case**

\[ G(x; \mu, \sigma) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \]
Receiver operating characteristic (ROC)

ROC: Gaussian case

ROC Criterion #1

ROC Criterion #2

ROC Criterion #3

ROC Criterion #4

ROC
**SDT review**

- Your ability to perform a detection/discrimination task is limited by **internal noise**.
- **Information** (e.g., signal strength) and **criterion** (bias) are the 2 components that affect your decisions, and they each have a different kind of effect.
- Because there are 2 components (information & criterion), we need to make 2 measurements to characterize the difficulty of the task. By measuring both **hits & false alarms** we get a measure of **discriminability (d')** that is independent of criterion.

**Measuring thresholds**

![High intensity](image)

- **Two-alternative forced choice**
  - Two options presented on each trial:
    - Two stimuli presented simultaneously at two different positions (e.g., one of which has higher contrast).
    - Two stimuli presented sequentially at the same position.
    - One stimulus presented with two possible choices (e.g., moving right or left).
  - Subject is forced to pick one of the two options. If they’re not sure then they must guess.
  - Feedback (correct/incorrect or $) provided after each trial.
  - **Advantage**: Two options with feedback balances criterion so we can measure proportion correct.

**Staircase**

![Staircase](image)
Absolute and relative thresholds

Weber’s law

Ernst Weber, c1850

Gustav Fechner, c1850

Weber’s law

Fechner’s analysis
**Weber's law: Fechner's derivation**

\[
R_1 = \log(x) \\
R_2 = \log(x + dx)
\]

\[
\sigma = \log(x + dx) - \log(x) = \log \left( \frac{x + dx}{x} \right) = \log \left( 1 + \frac{dx}{x} \right)
\]

At threshold:

\[
d' = 1 \\
\frac{R_2 - R_1}{\sigma} = \frac{dx}{x} = k
\]

**Weber's law: contrast ratio derivation**

Internal response = \( \frac{\text{intensity of test flash}}{\text{intensity of background}} \)

\[
R_1 = \frac{x}{x} \\
R_2 = \frac{x + dx}{x} \\
R_2 - R_1 = \frac{dx}{x} = \sigma
\]

At threshold:

\[
d' = 1 \\
\frac{R_2 - R_1}{\sigma} = \frac{dx}{x} = \sigma
\]

**Weber's law:** To perceive a difference between a background level \( x \) and the background plus some stimulation \( x + dx \) the size of the difference must be proportional to the background, that is, \( dx = k \cdot x \) where \( k \) is a constant.

**Fechner's interpretation:** The relationship between the stimulation level \( x \) and the perceived sensation \( s(x) \) is logarithmic, \( s(x) = \log(x) \).

Main difference: Fechner's is an interpretation of Weber's law, a hypothesis.

**Behavioral protocol**

Two-alternative forced choice

- Receptive field
- Pref target
- Fix Pt
- Null target
- Fixation Point
- Dots
- Targets
- 1 sec
Stimulus manipulation: motion coherence

Psychometric function

Motion coherence and MT neurons

Motion coherence and MT neurons

Neural responses are noisy

Perceptual decision

Decision rule: Monitor the responses of two neurons on each trial, the one being recorded and another selective for the opposite motion direction. Choose 'pref' if pref response > non-pref response.

\[
f_p(r) : \text{response PDF for pref direction}
\]

\[
f_n(r) : \text{response PDF for non-pref direction}
\]
**Probability correct**

\[ P(\text{correct}) = P(r_{p} > r_{n}) = \int_{0}^{r_{p}} f_{p}(r) \left[ \int_{r}^{\infty} f_{n}(r')dr' \right]dr \]

\[ \int_{0}^{r_{p}} f_{p}(r)dr = F_{p}(r) \]

**Neurometric function**

\[ P(\text{correct}) = \sum_{r} f_{p}(r)F_{n}(r) \]

Britten, Shadlen, Newsome & Movshon, 1992

**Neurometric vs. psychometric functions**

Britten, Shadlen, Newsome & Movshon, 1992

**Predicting the monkey's decisions**

Neurometric & psychometric functions: accuracy vs motion coherence

Response distributions for pref and non-pref decisions at a fixed motion coherence

Britten, Shadlen, Newsome & Movshon, 1992

Shadlen, Britten, Newsome & Movshon, 1996

**Predicting the monkey's decisions**

Choice probability: Accuracy with which one could predict monkey's decision from the response of the neuron given that you know the distributions.

\[ f_{p}(r) : \text{response PDF when monkey reports pref direction} \]

\[ f_{n}(r) : \text{response PDF when monkey reports non-pref direction} \]
**Choice probability**

![Example neuron](image1)

- 6.4% coherence
- 0% coherence
- -6.4% coherence

**Computation model**

- Noise is partially correlated across neurons.
- Responses are pooled non-optimally over large populations of neurons including those that are not the most selective.
- Additional noise is added after pooling.

![Diagram](image2)