Introduction to Cognitive Neuroscience

Lecture 03 Psychophysics

Mohammad-Reza A. Dehaqani

dehaqani@ut.ac.ir

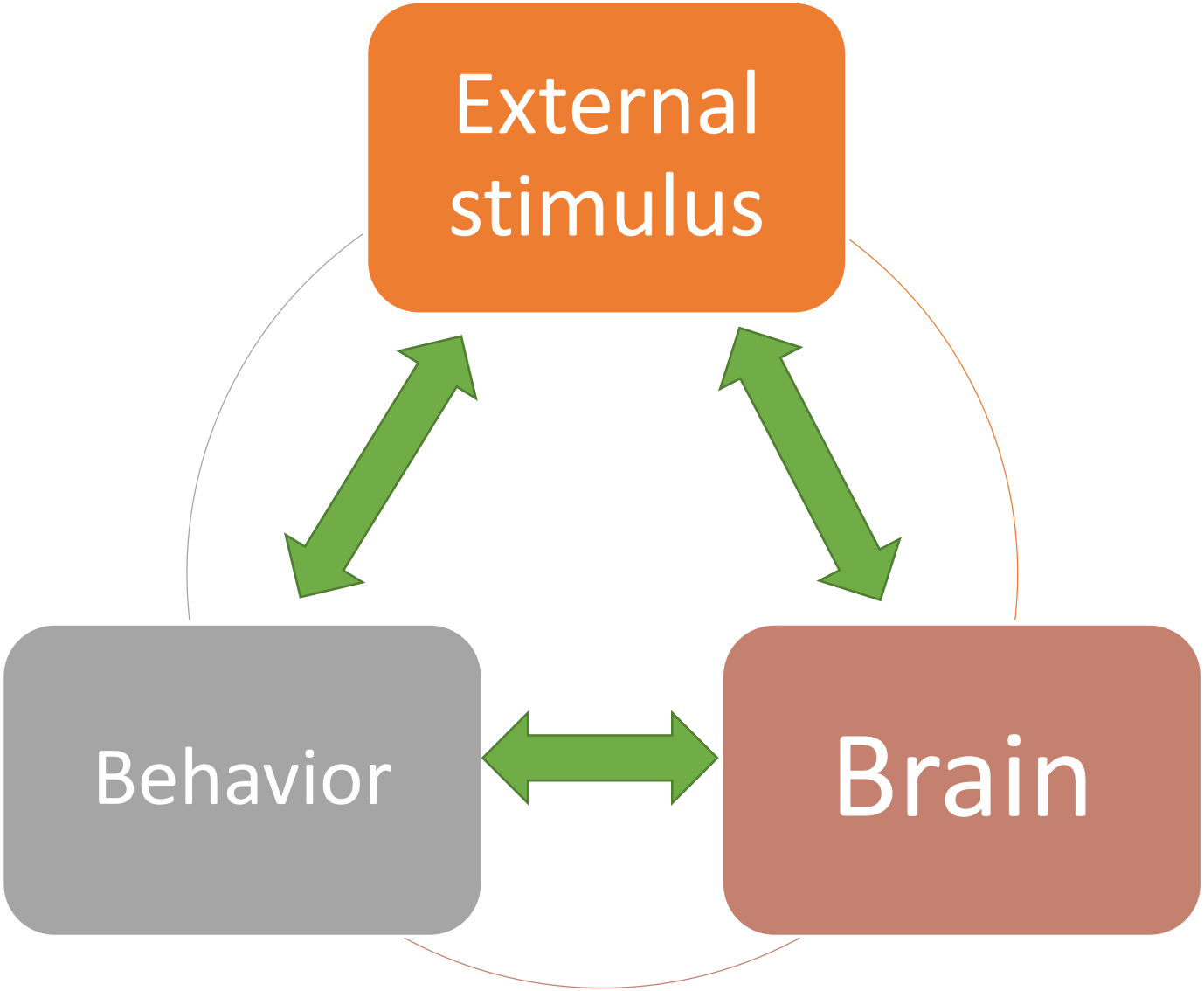
What is Psychophysics?
Definition

Methodology for investigating relationships between sensations in the psychological domain and stimuli in the physical domain

Perception:

The goal (task) of perception is to acquire accurate and reliable (precise) information about the environment.

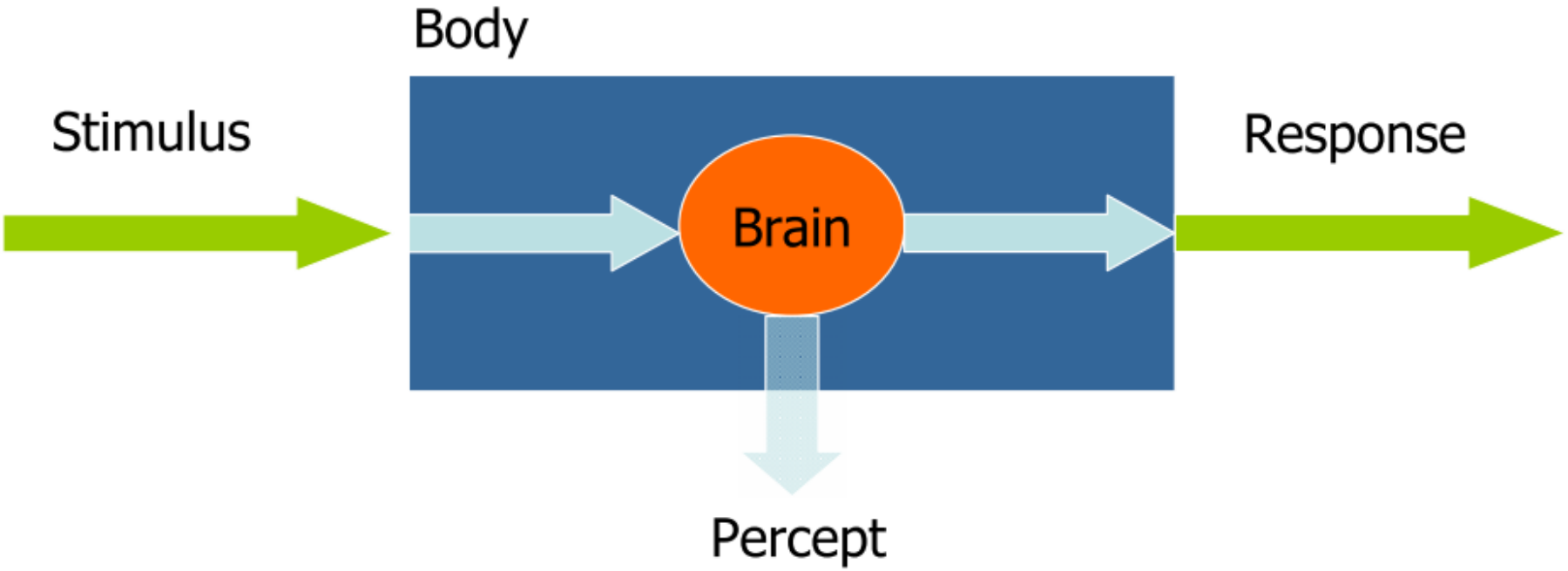
System neuroscience



The power of psychophysics

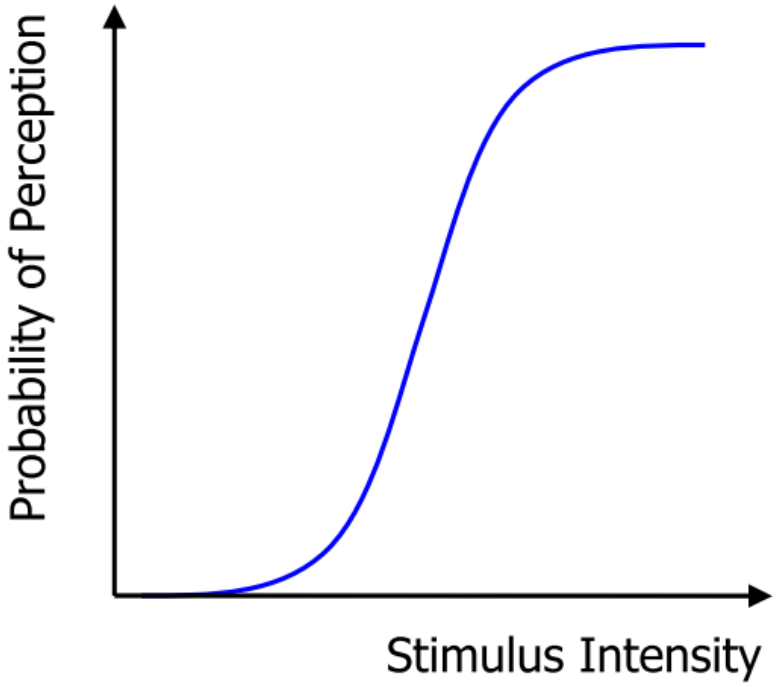
- Quantitative - objective scale of measurement
- Does not suffer from subjectivity of introspection
- Can be used to study "pure" mental phenomena - e.g. attention
- Valid inter-subject, inter-species, and inter-method comparisons
  - E.g. color perception in humans and bees
  - Sensitivity of neurons vs. sensitivity of brains (humans)
- Can identify (possibly subconscious) response bias
- It is easy to setup

Central to experimental psychology



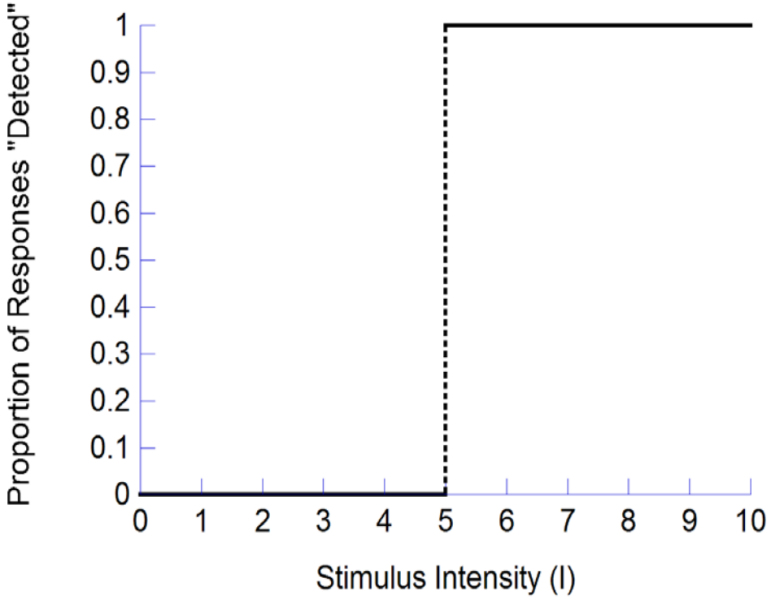
Psychometric Function

- A function from stimulus intensity to probability to perceive the stimulus
- Usually a S-shaped (cumulative normal distribution)



Concept of threshold

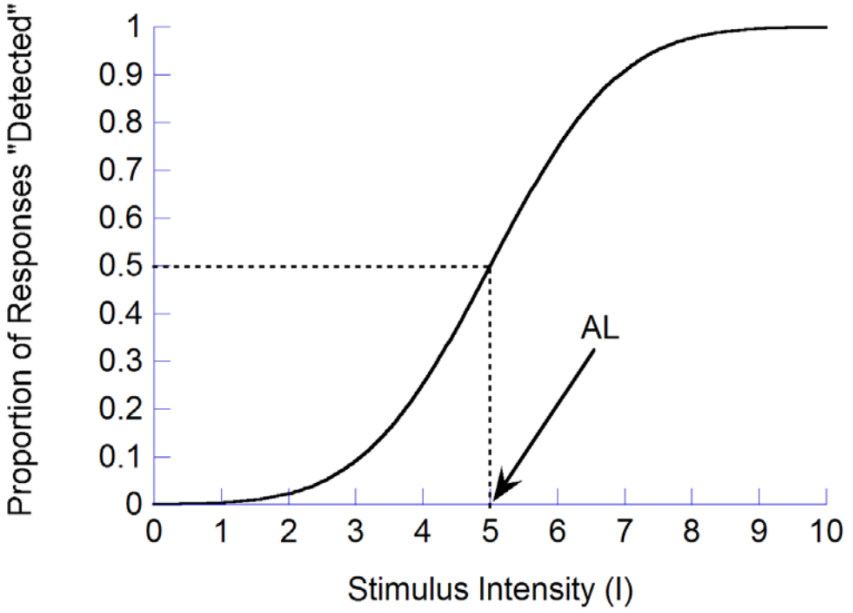
- Absolute threshold is the smallest amount of stimulus energy that can be reliably detected
- Often called AL (absolute limen) or RL (Reizen Limen)



Classical Threshold Theory

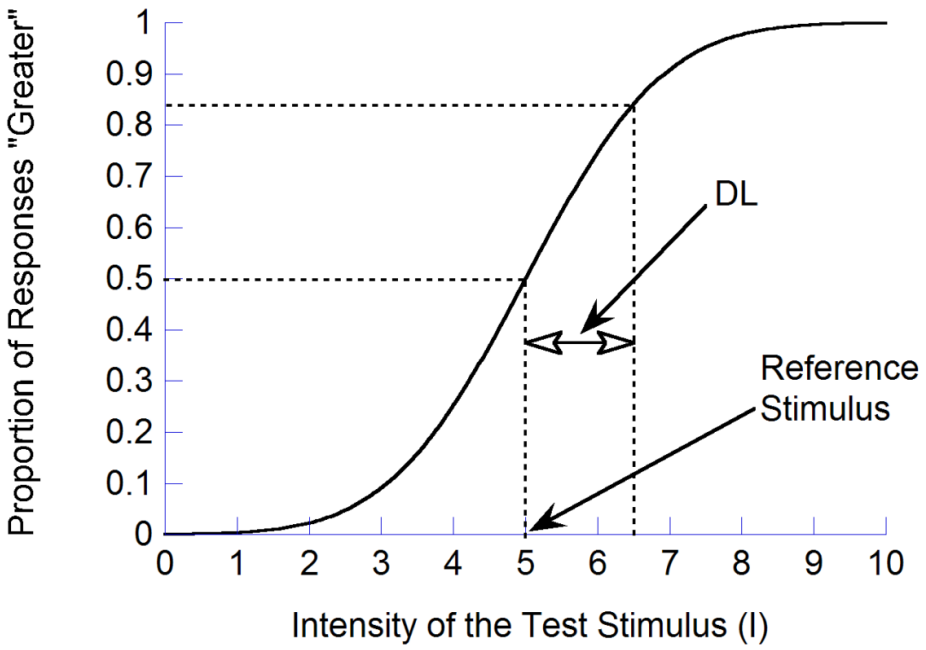
Actual shape is not a step-function

- **Perceptual representation** of a stimulus is not constant; it involves an additive random error.
- **Threshold is defined as the 50th percentile point**



Difference threshold

- Difference threshold (DL: difference limen): is the smallest difference between **two stimuli** that can be **reliably detected**



Weber's Law

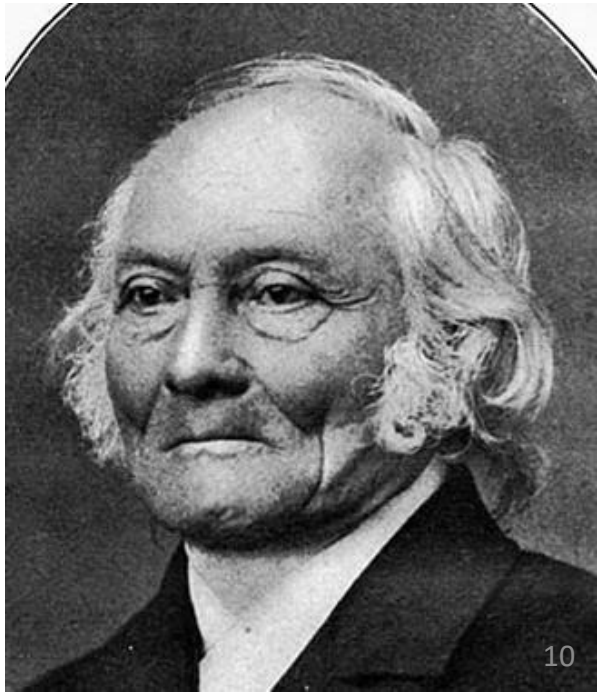
- Difference threshold is proportional to the magnitude (intensity) of the stimulus:

$$DL = w \cdot I$$

- ***W*** is called the Weber fraction:

$$w = DL / I$$

- ***DL*** grows linearly with ***I***



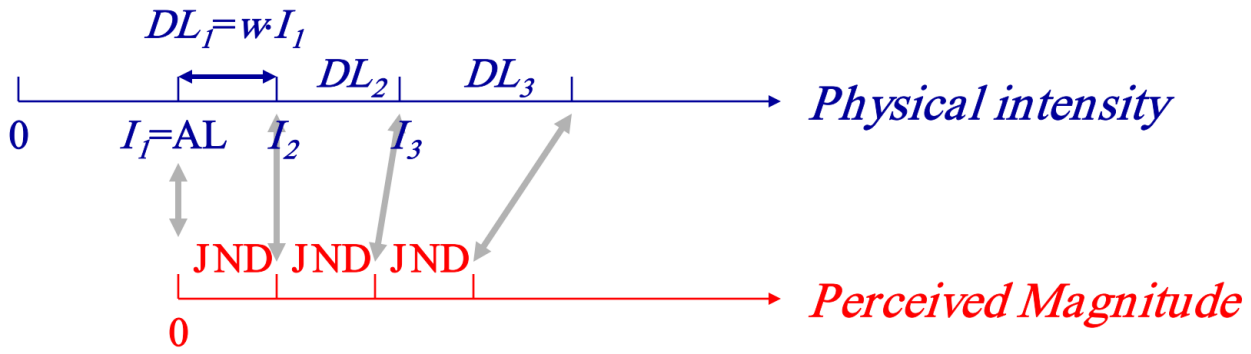
Perceived Magnitude and JND

- Fechner 's Law:

$$dP = c \cdot dI/I \longrightarrow P = c' \cdot \log(I/I_0)$$

- JND: just noticeable difference

$$w = DL/I = constant$$

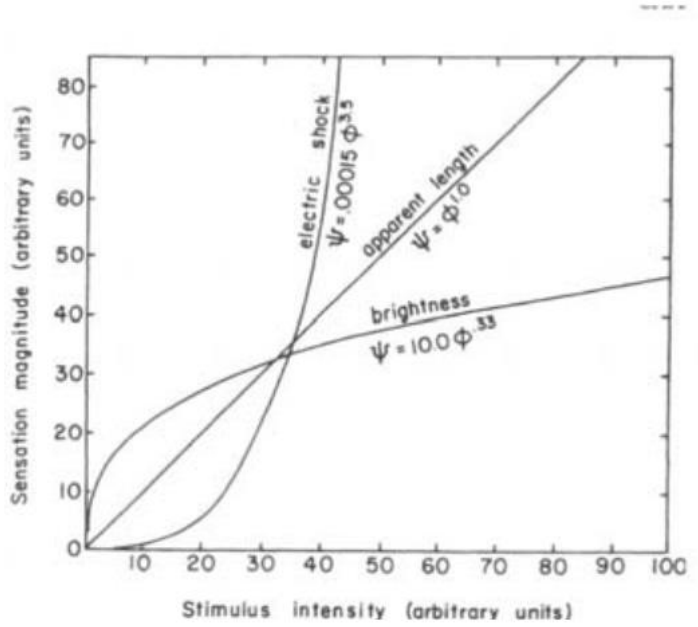


Stevens's (power) Law:

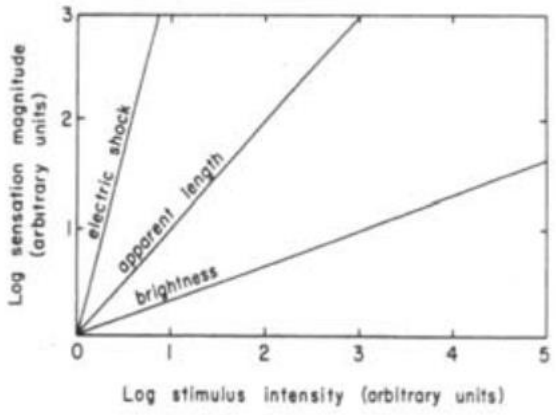
$$dP/P = c \cdot dI/I \longrightarrow P = c' \cdot I^n$$

- One of the best established **empirical** laws in psychology

Linear vs. Linear



Log vs. Log



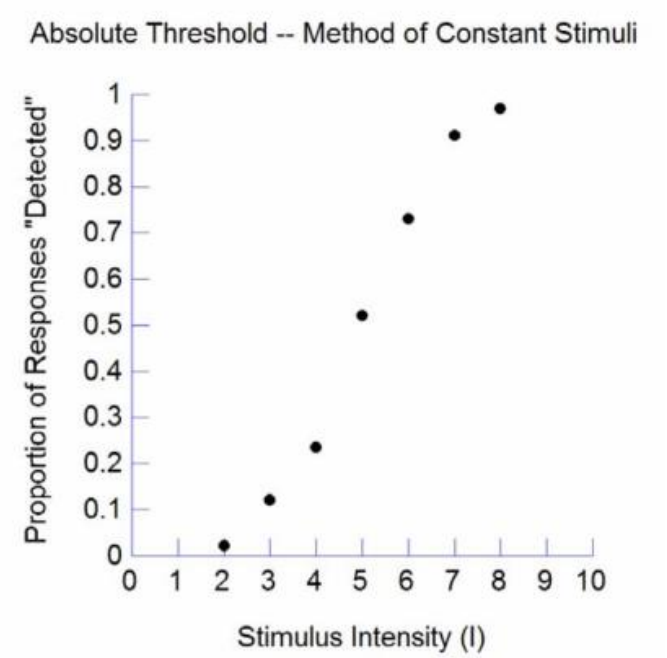
Classical Psychophysical Methods

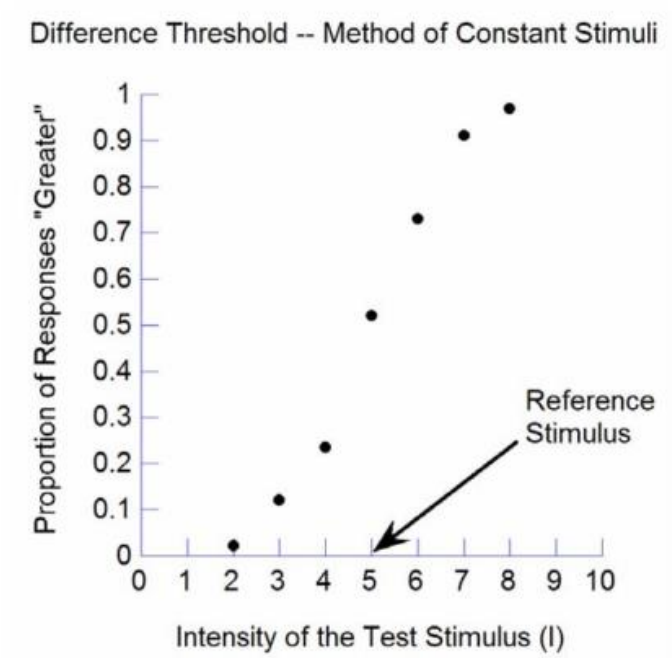
Method of Constant Stimuli

The Recipe

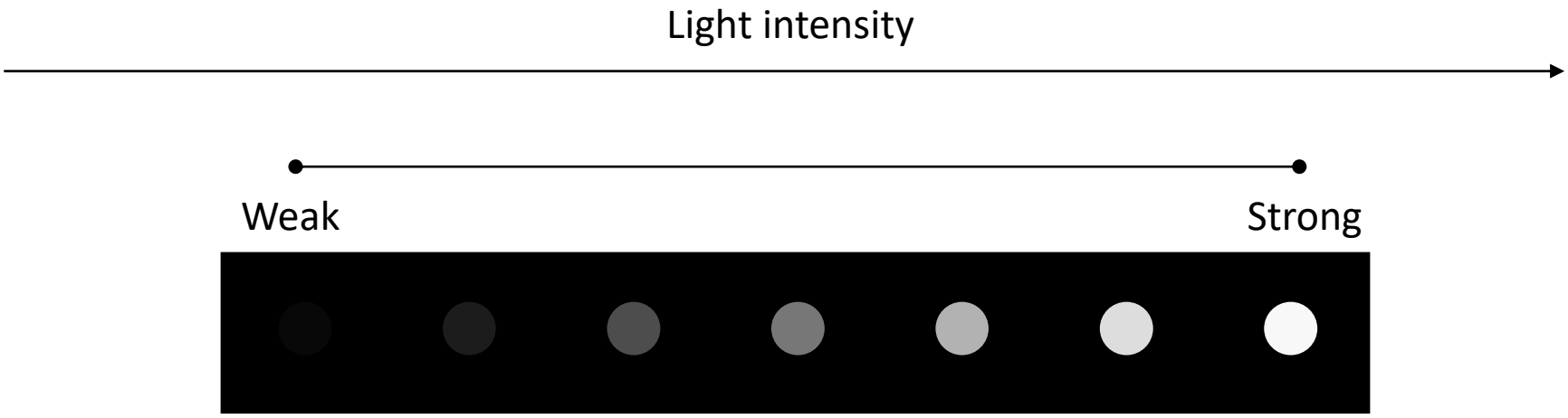
- A set of equally spaced levels of the stimulus intensities is chosen (usually 5-9).
- Each level is repeated large number of times in a given session (e.g. 100).
- The **order** of presentations is **randomized**.
- The subject is asked to report whether the presented stimulus can be detected (when AL is measured), or whether the intensity of the presented test stimulus is greater than that of the **reference** stimulus (when DL is measured).

- The **proportion of responses (YES)** for each level of stimulus intensities is recorded and plotted against the stimulus intensity.



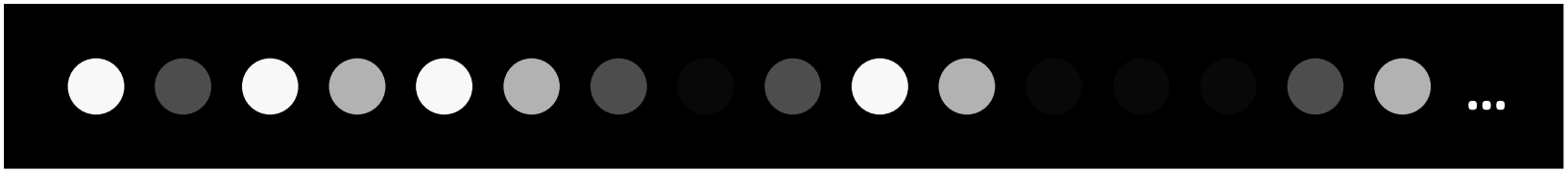


Step By Step Example

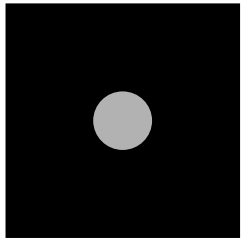


1. Select a range of light intensities from certainly invisible to certainly visible
2. Pick a few (4-7) points uniformly in this intensity range; this will be the constant stimulus set

3. Test each stimulus many times (20-25) in random order



Each trial is:

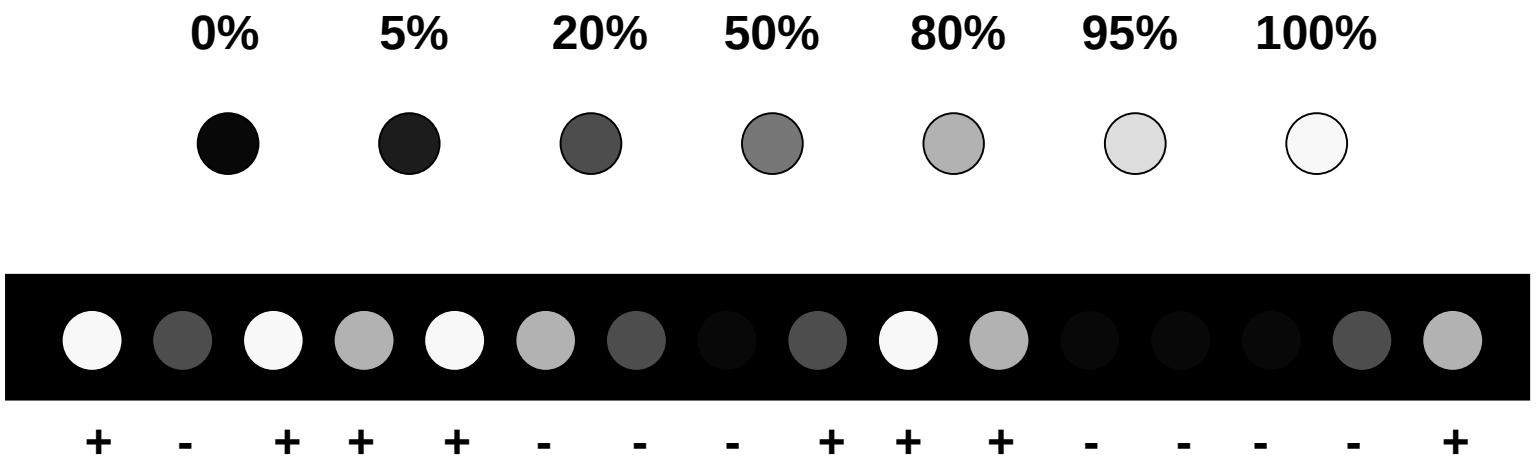


Visible?

YES NO

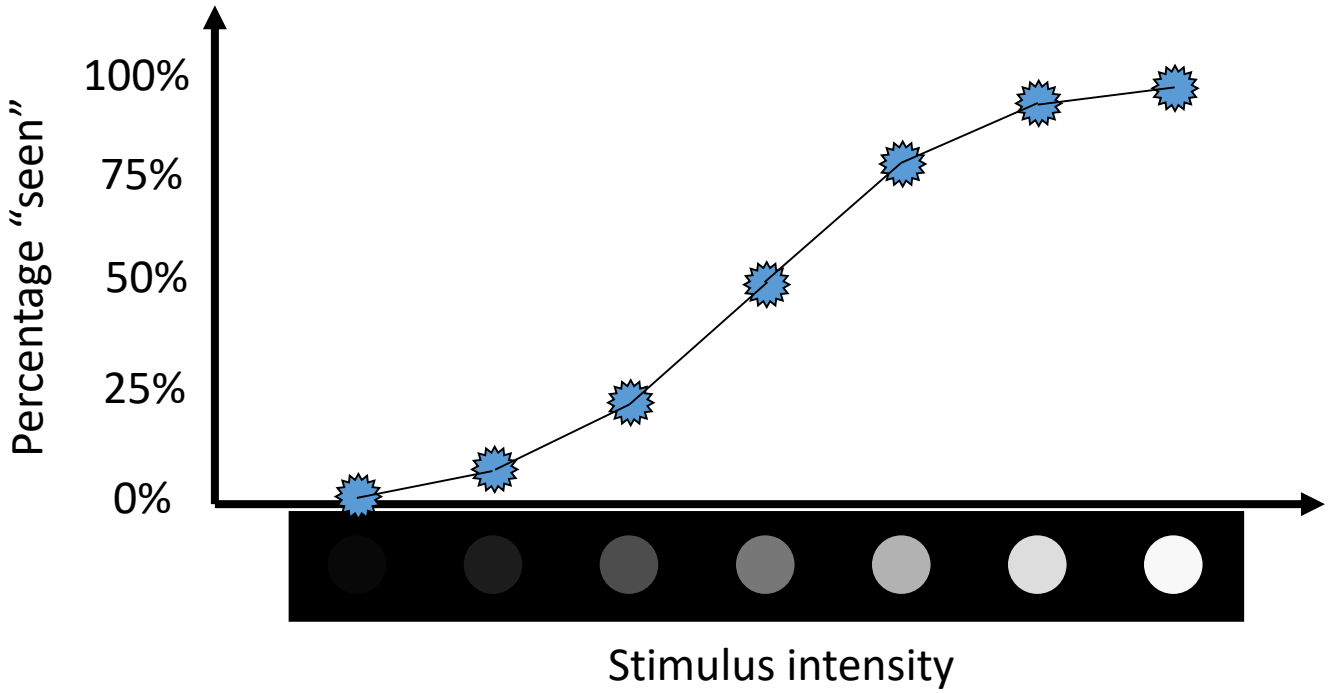
4. Present the stimuli one at a time and ask the observer if it was visible or not

Probability of perception



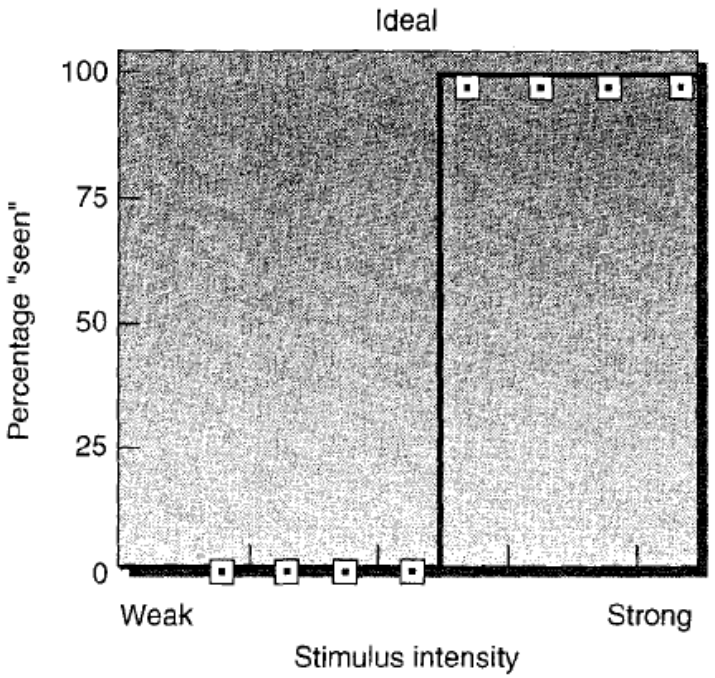
5. Calculate the proportion of “yes” and “no” responses at each light level

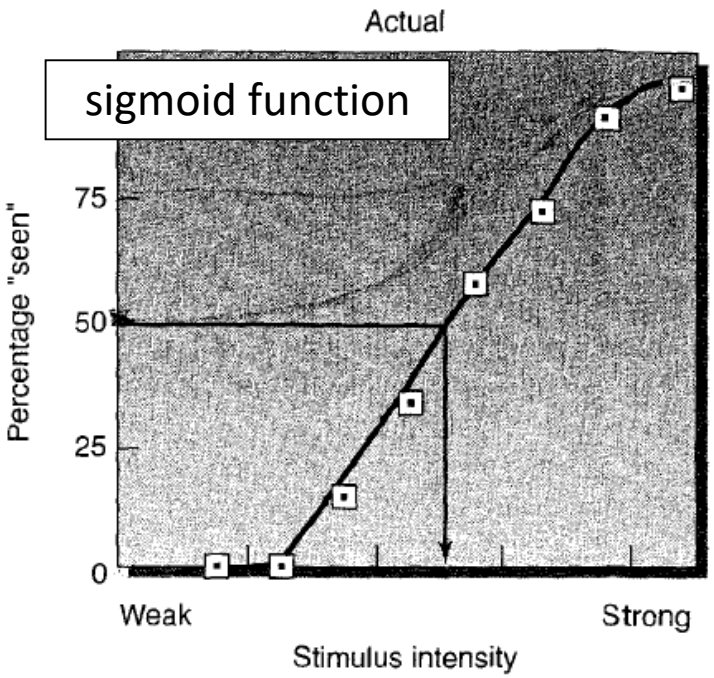
Drawing psychometric function



6. Plot the percentages against stimulus intensity
   → **psychometric function**

Psychometric function for absolute thresholds

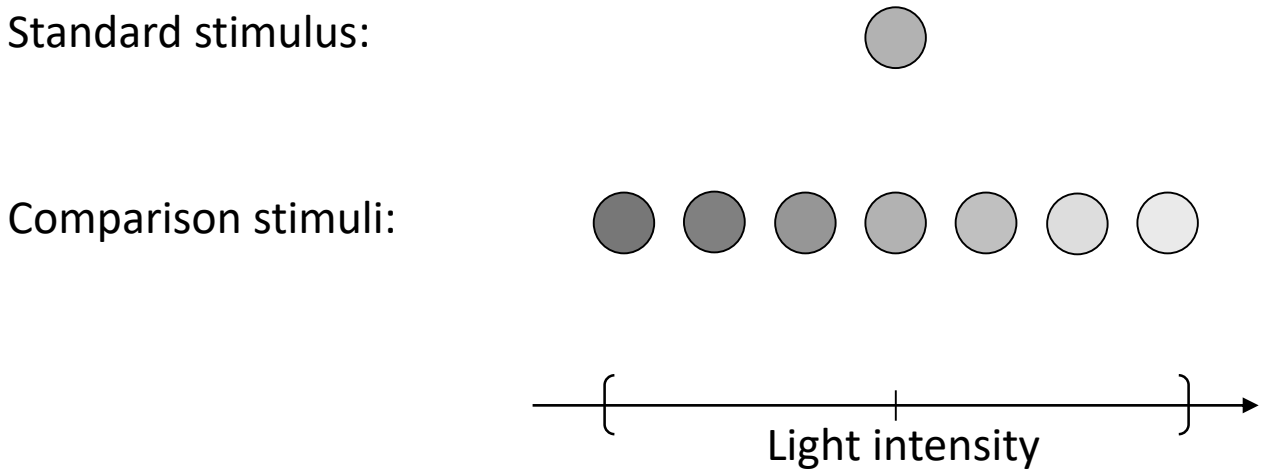




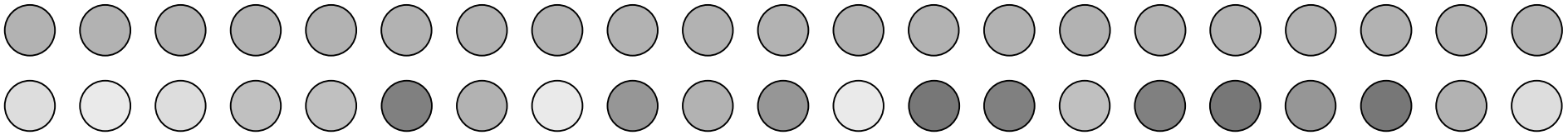
- Fixed absolute threshold
- Step function

- Absolute threshold varies somewhat from trial to trial (due to constant fluctuations in sensitivity)
- Conventionally, the intensity corresponding to **50%** is considered to be the threshold

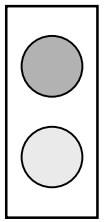
measuring difference thresholds



1. Standard stimulus has a fixed intensity
2. The intensities of comparison stimuli are in the spectrum



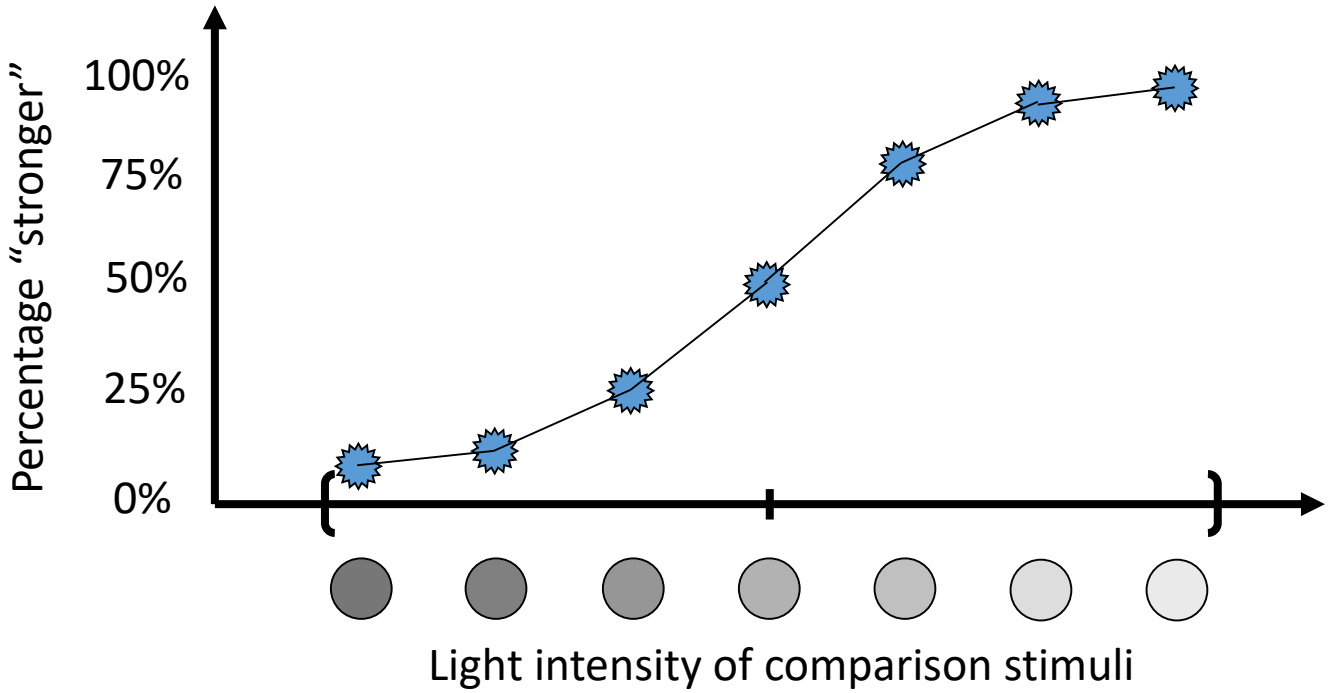
3. All pairs of standard and comparison stimuli are tested many times



STRONGER WEAKER

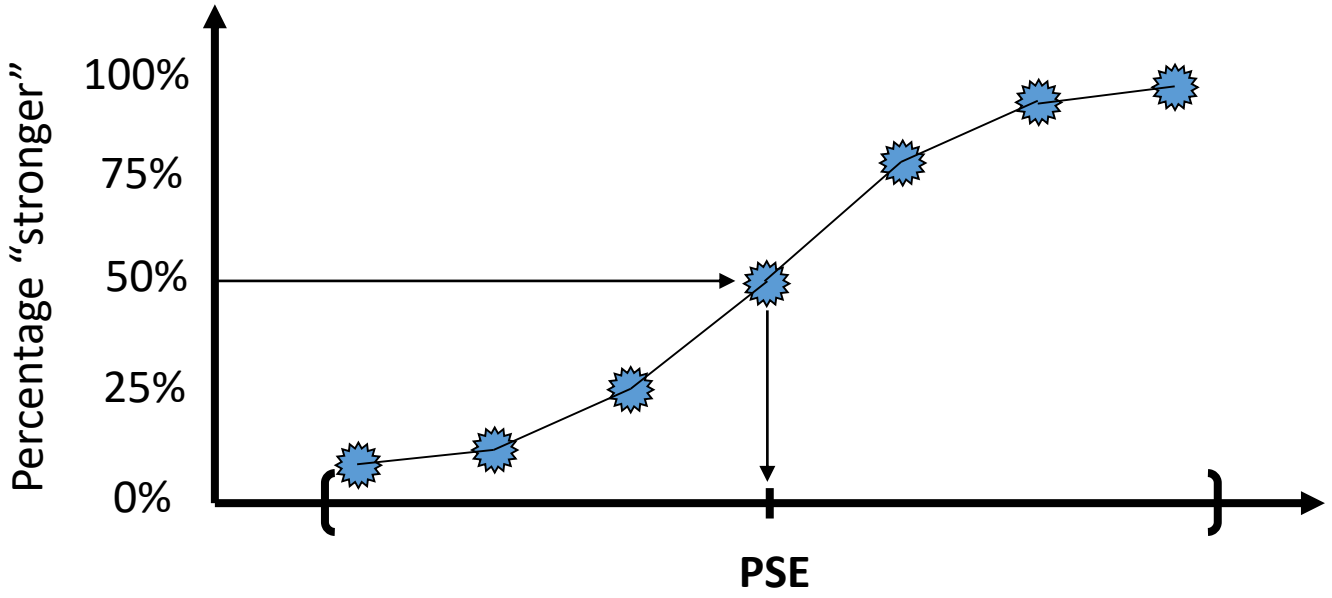
4. For each pair, the observer judges if the comparison stimulus was stronger or weaker than the standard

http://www.yorku.ca/psycho

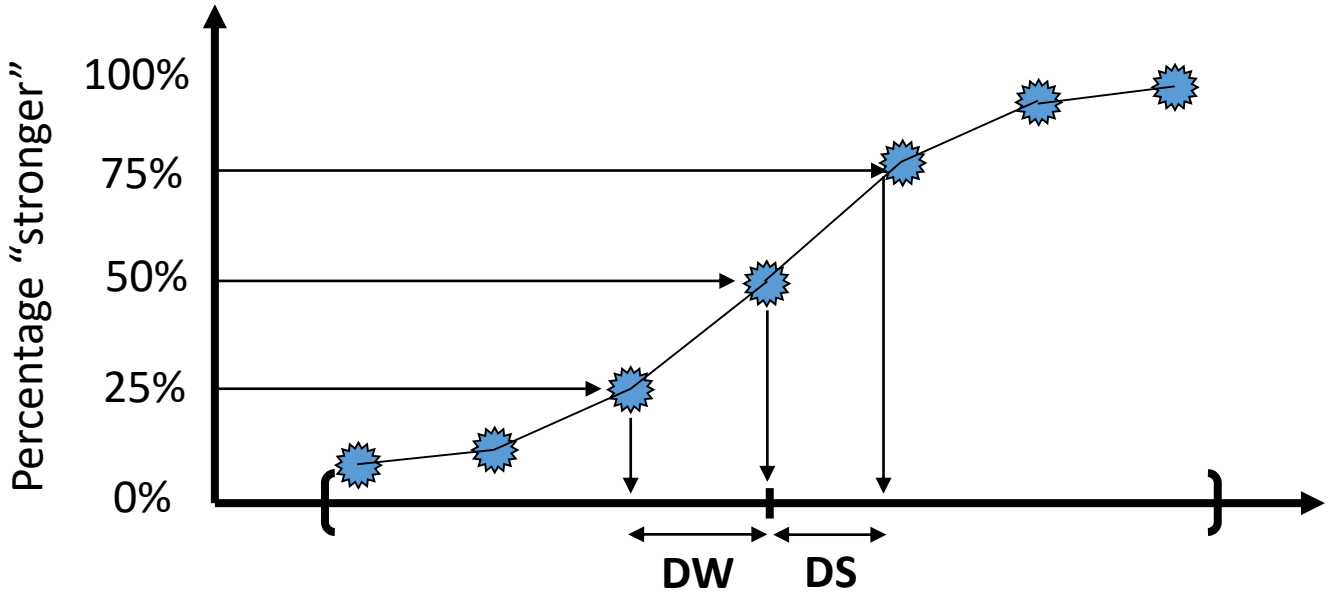


5. For each comparison level, the percentage of "stronger" responses is calculated and results are plotted as a psychometric function

PSE concept in difference thresholds method



- When the observer **cannot see a difference**, he/she chooses randomly between "stronger" and "weaker"; this corresponds to 50% on the psychometric function → **point of subjective equivalence (PSE)**



- By convention, the intensity at **75%** is considered to be just noticeably **stronger** than the standard → DS
- A comparison intensity at **25%** is just noticeably **weaker** than the standard → DW
- Difference threshold = the average of DS and DW

Method of Limits

To find absolute threshold –AL- (ascending series)

1. A series begins with a stimulus intensity well below threshold, at a value that will be called the lower limit.
2. Stimulus intensity is increased using small steps until it reaches the upper limit.
3. On each trial the subject responds whether she can perceive the stimulus.
4. Threshold for this series is estimated as the midpoint between the stimulus intensities for the last NO response and the first YES response.

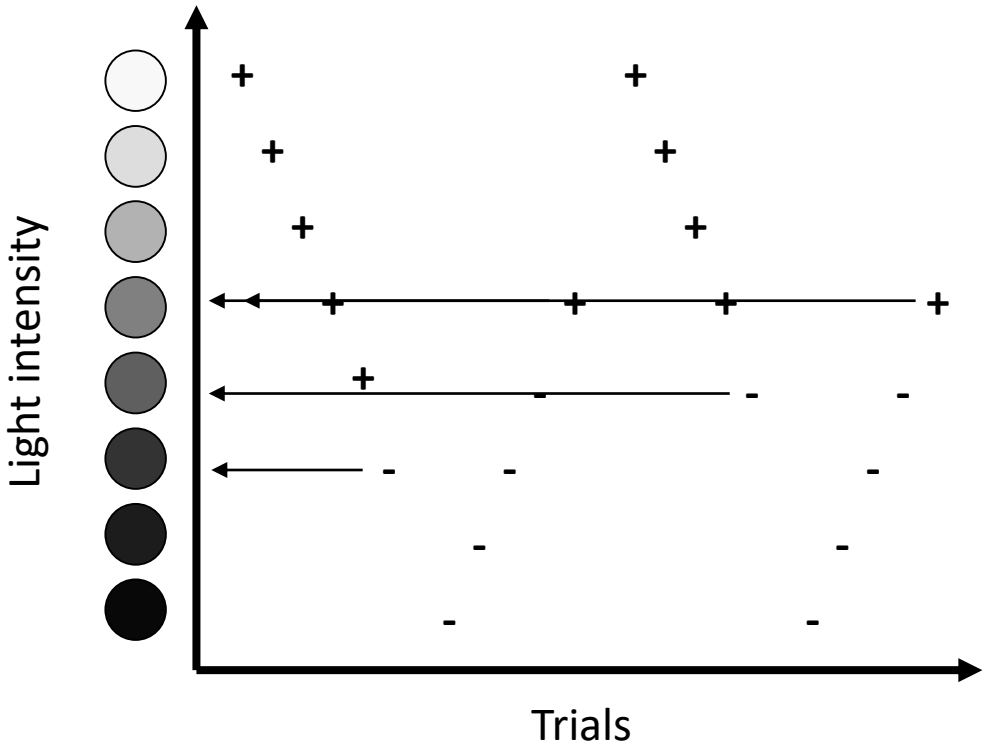
AL (descending series)

1. A series begins with a stimulus intensity at the upper limit.
2. Stimulus intensity is decreased using small steps until it reaches the lower limit.
3. On each trial the subject responds whether she can perceive the stimulus.
4. Threshold for this series is estimated as the midpoint between the stimulus intensities for the last YES response

Method of Limits
DL (symmetric design):

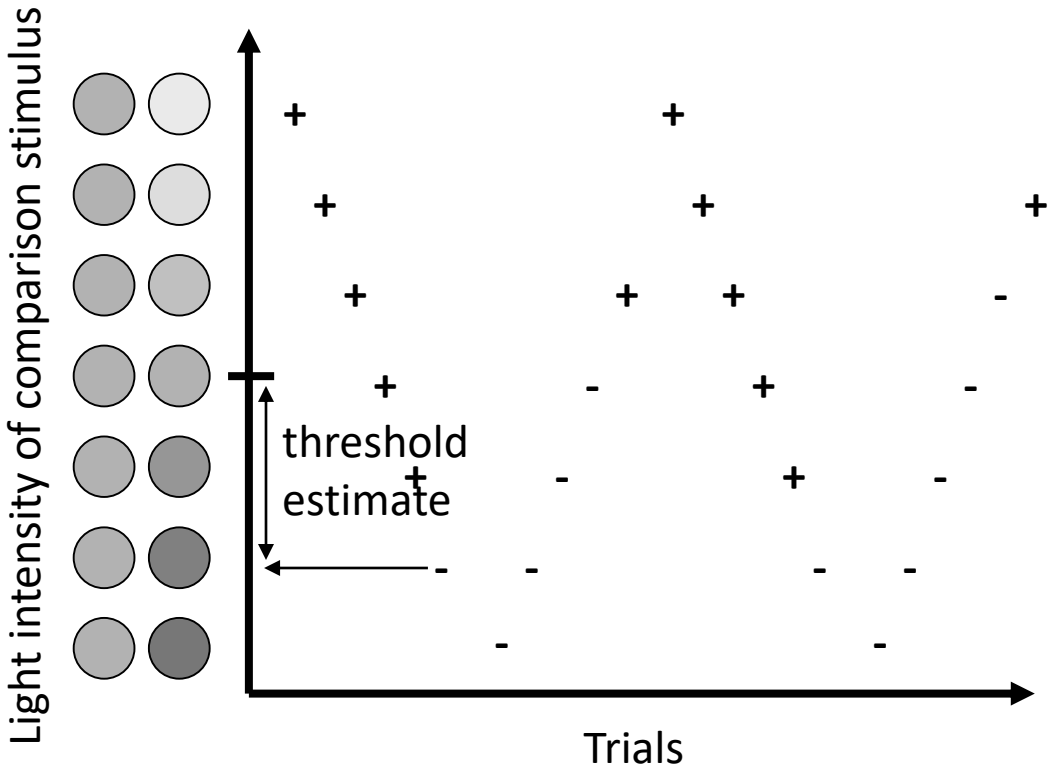
- In the symmetric design, the lower limit is well below PSE and the subject's task is to decide whether the test is greater or less than the reference.

Method of limits for measuring absolute thresholds



- Ascending and descending series may yield **different results**
  → use both
- Even in the same direction, there is variability in the threshold (inner noise, etc)
  → average many measurements
- Measured threshold corresponds to 50% point in a psychometric function (method of constant stimuli)

Method of limits for measuring difference thresholds



+ comparison brighter

- comparison weaker

- Intensity of the comparison stimulus is decreased (descending) or increased (ascending) until the response changes
- Threshold estimate: intensity difference between the standard and comparison stimuli where the response changes
- Average results from multiple series in both directions

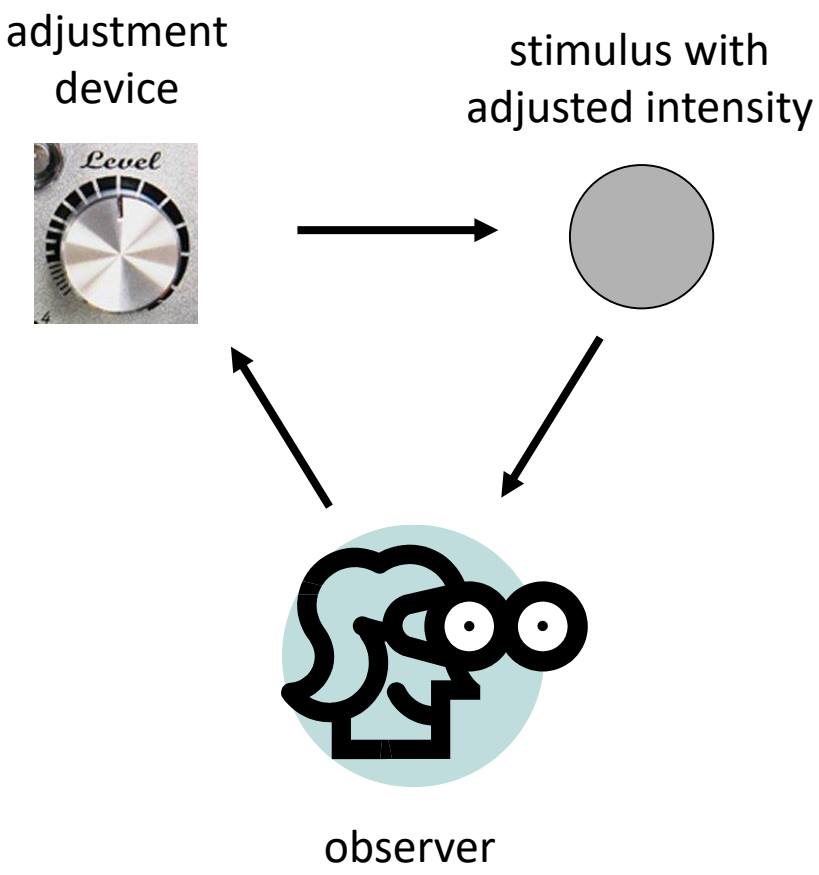
Method of Adjustment

To detect AL

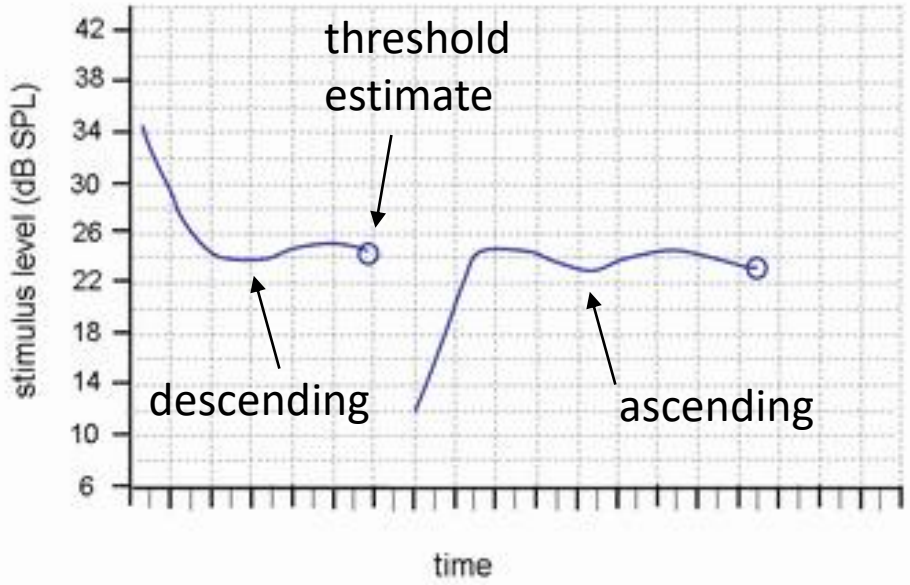
- The subject is asked to **adjust the intensity** of the stimulus so that it is just barely detectable. The value adjusted is taken as an estimate of the threshold.
- Note the **asymmetric nature** of this experiment caused by the fact that the intensity of the stimulus is never negative: The subject is asked whether the stimulus is present (greater than zero), or absent (zero). This fact makes the estimate of AL **very sensitive to response bias**

Method of adjustment for measuring absolute thresholds

- Observer can vary the stimulus intensity
- Instructed to adjust it so that it is just visible or just invisible
- **Initial intensity** is set to be far from the expected threshold value



Method of adjustment for measuring absolute thresholds



- Adjustment: by a real or a software device (e.g. knob, slider)

- Threshold estimate: final intensity value
- Descending: initial intensity is well **above** expected threshold; adjusted to just **visible**
- Ascending: initially well **below** threshold; adjusted to just **invisible**
- Ascending and descending task repeated several times and results averaged
- Similar to method of limits but observers find it easier

Adaptive Psychophysical Methods

What Do We Mean by "Adaptive"?

The stimulus intensity level on any one **trial is determined by the preceding stimuli** and responses

Why Adaptive Method

- Adaptive method **places most of the stimuli at intensity levels close to the threshold** that is being measured
- Adaptive method allows for more **efficient estimation** of thresholds

Simple Up-Down Method (Staircase Method)

- Adaptive methods reduce the number of trials at the stimulus intensity levels
- **Staircase** method is analogous to the method of limits, except that
  - an ascending (descending) sequence does not terminate after the first reversal from NO to YES (YES to NO) response.
  - Instead, the experiment **continues until** many reversals are obtained around the value to be estimated.

Staircase for detection

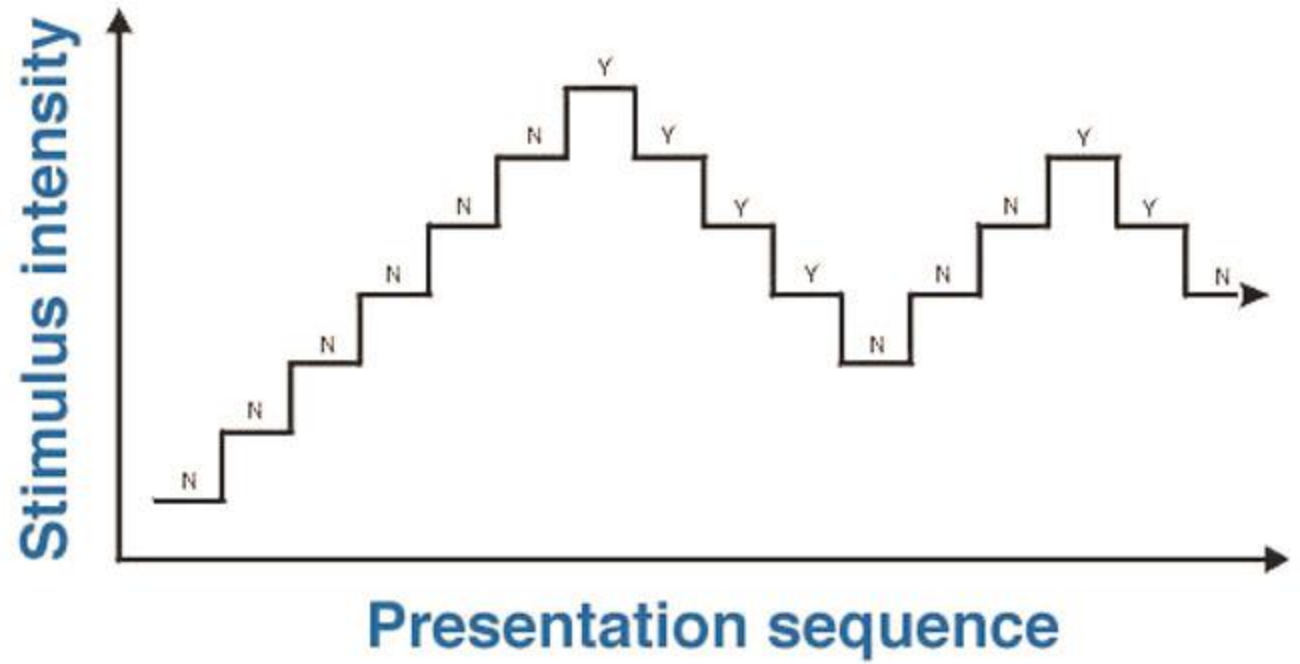
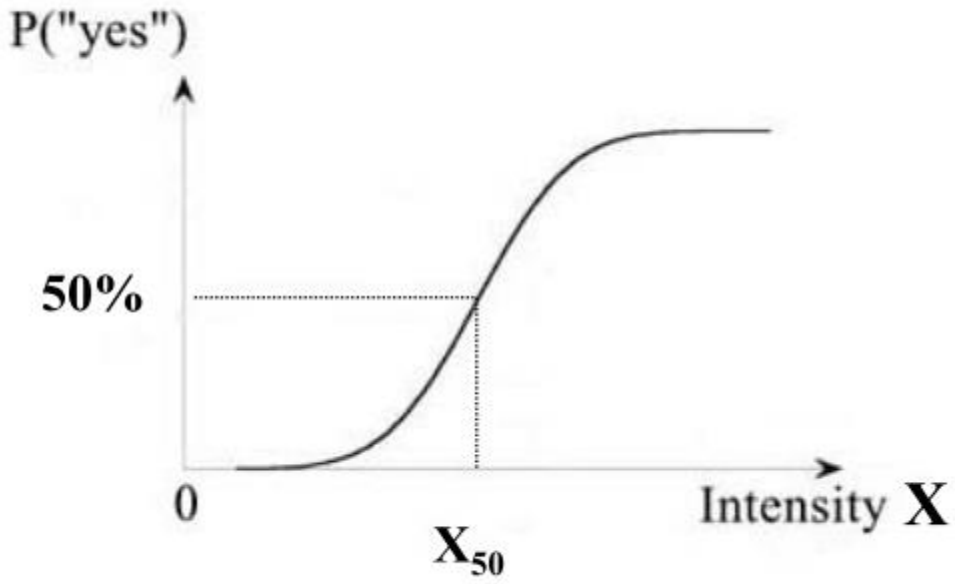


Figure 12. Staircase method. Y = Yes, the stimulus can be seen and N = No, the stimulus cannot be seen.

Source: http://webvision.med.utah.edu/Psych1.html

- The simple staircase method estimates the 50% point of the psychometric function.



Adaptive Step Size

- At the start of an experiment, a large step size is used
- The step size is gradually decreased during the course of the experiment
- **Half the step** size after a fixed number of trials

Adaptive Staircase

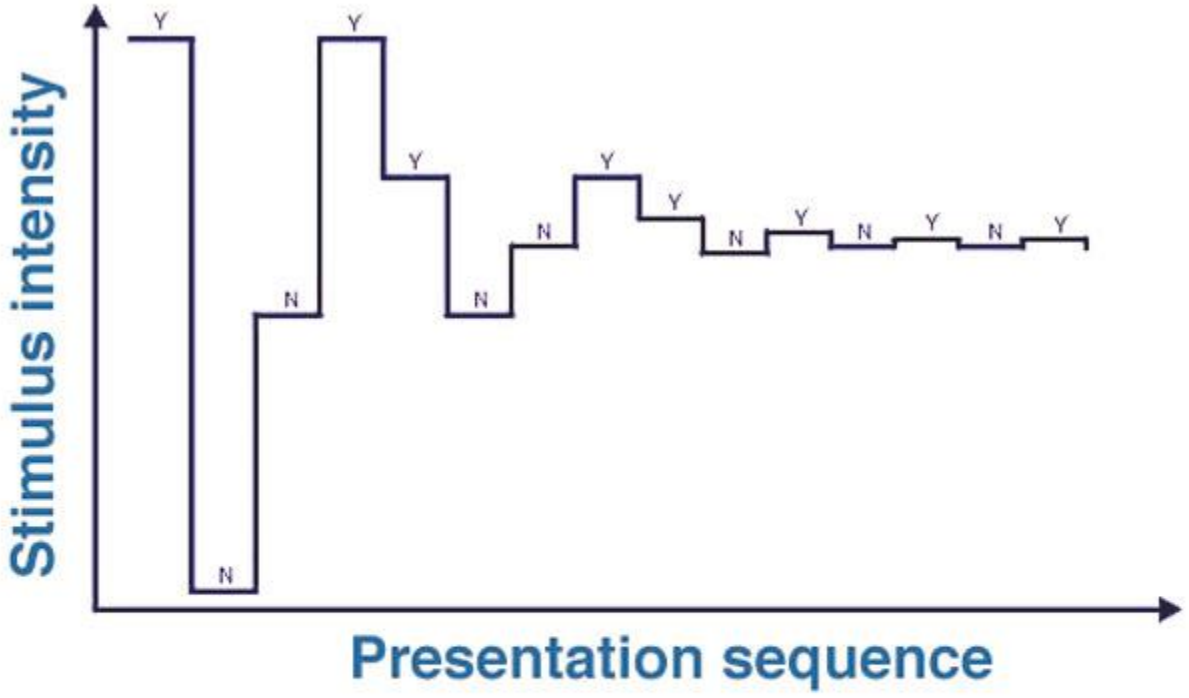


Figure 16. Tracking record using PEST. Y = Yes, there is a stimulus and N = No, there is not a stimulus.

Source: http://webvision.med.utah.edu/Psych1.html

Stimulus Generation for Vision Psychophysics

Contrast,
Orientation
Motion

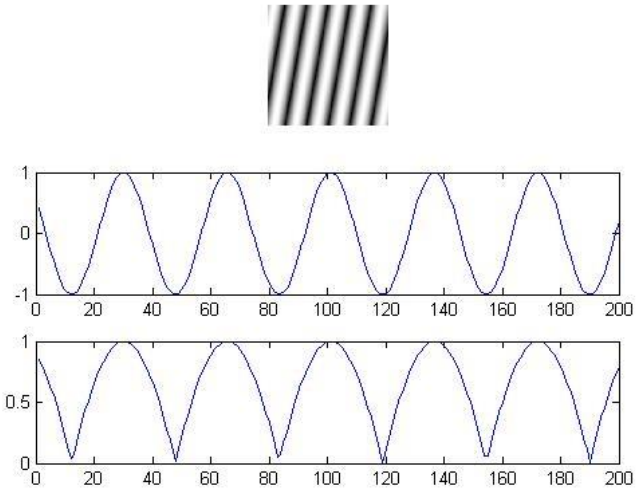
contrast

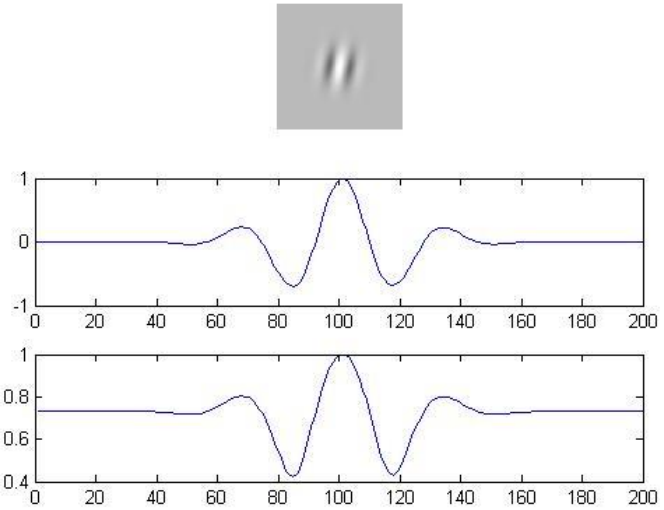
25%

75%

See contrastBlob.m

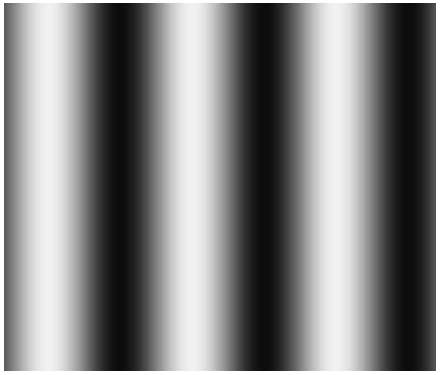
Orientation and Spatial Frequency

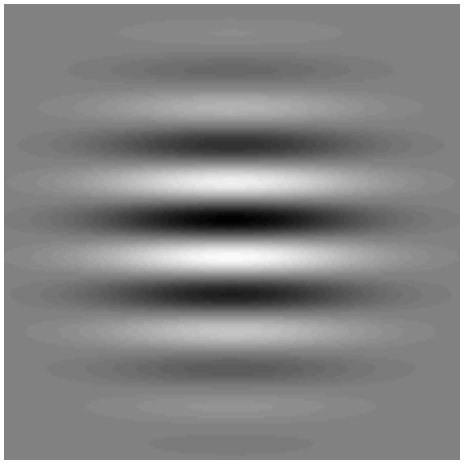




See Gabor.m

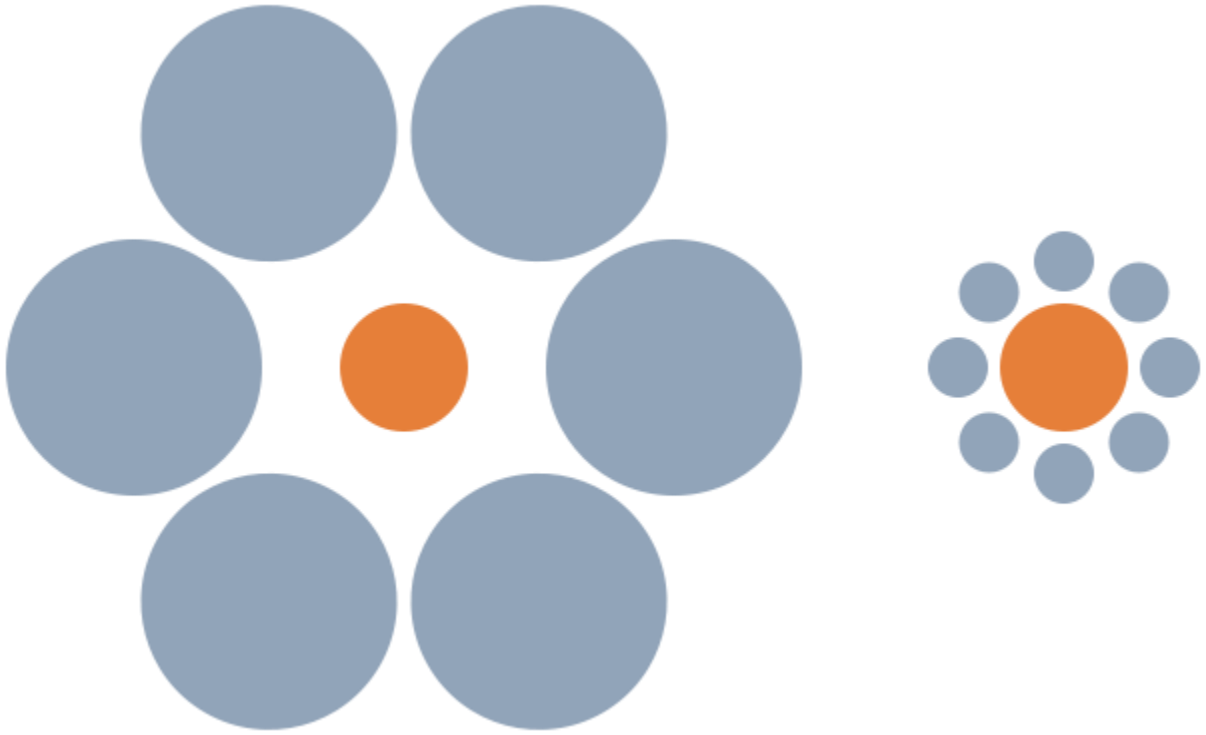
Motion





Drifting gratings

Exercise: How to estimate the size of this illusion?



See: **ebb_const.m**

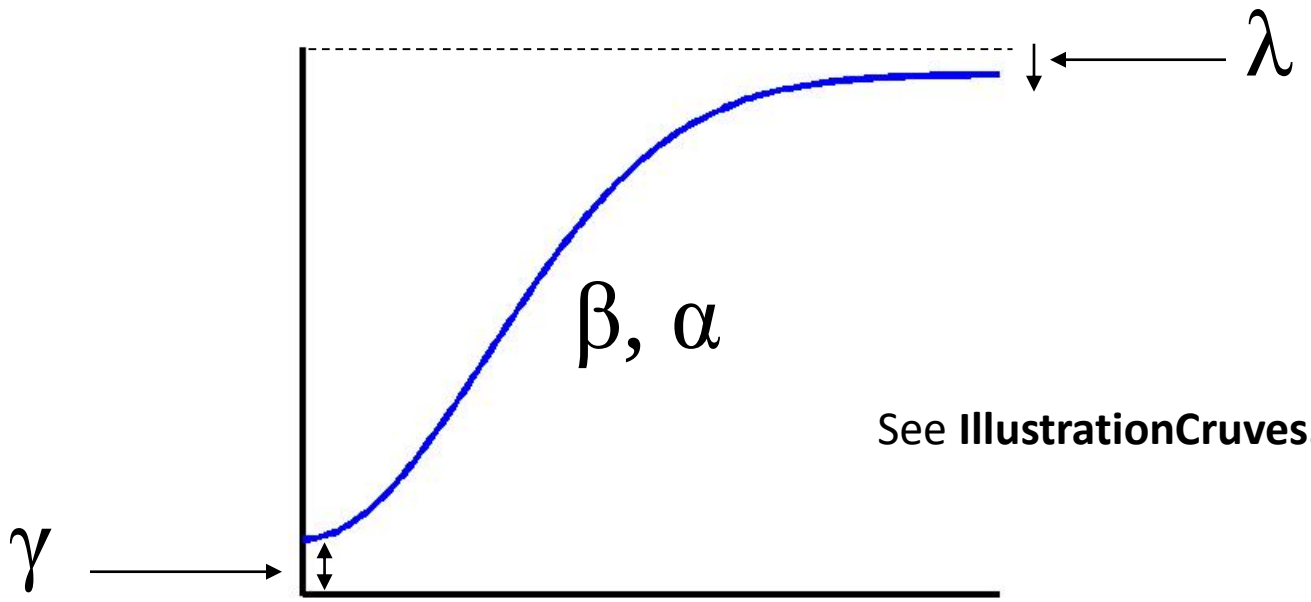
Curve fitting and quantitative analysis

Curve fitting: why should we care?

- Summarize all acquired data and increase power
- Translate raw data into variables that inform about different aspects of data (e.g. bias, sensitivity, gain, adaptation)
- Enables quantitative comparison of findings across conditions

Psychometric function

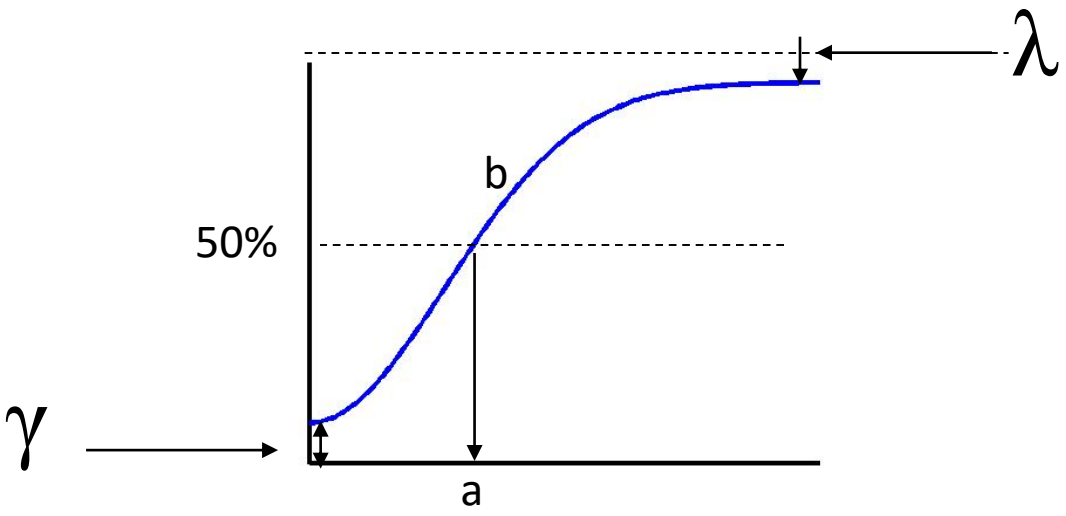
$$\psi(x;\alpha,\beta,\gamma,\lambda) = \gamma + (1-\gamma-\lambda)F(x;\alpha,\beta).$$

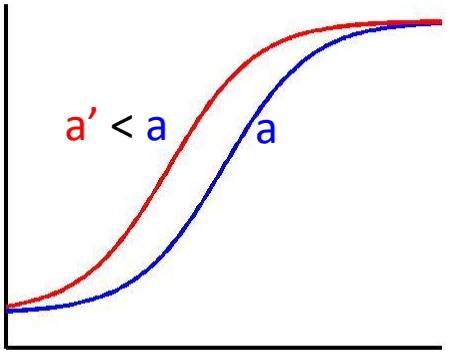


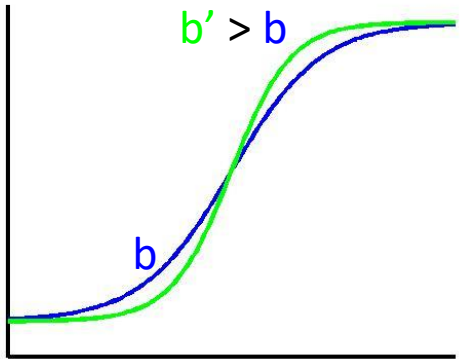
See **IllustrationCruves.m**

Logistic Function

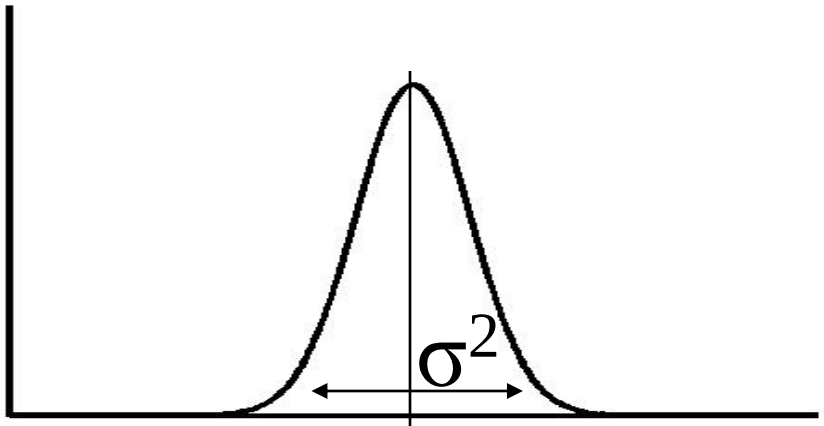
$$F(x,a,b) = \frac{1}{1 + e^{-b(x-a)}}$$



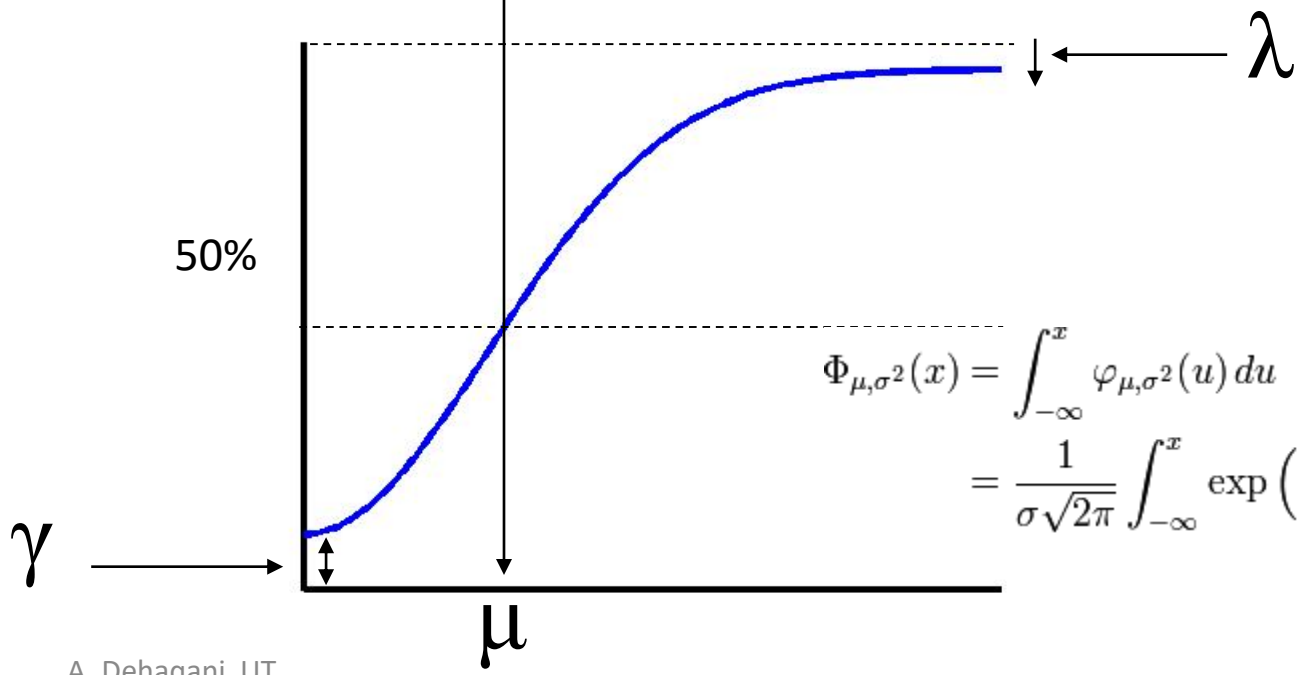




Cumulative Gaussian



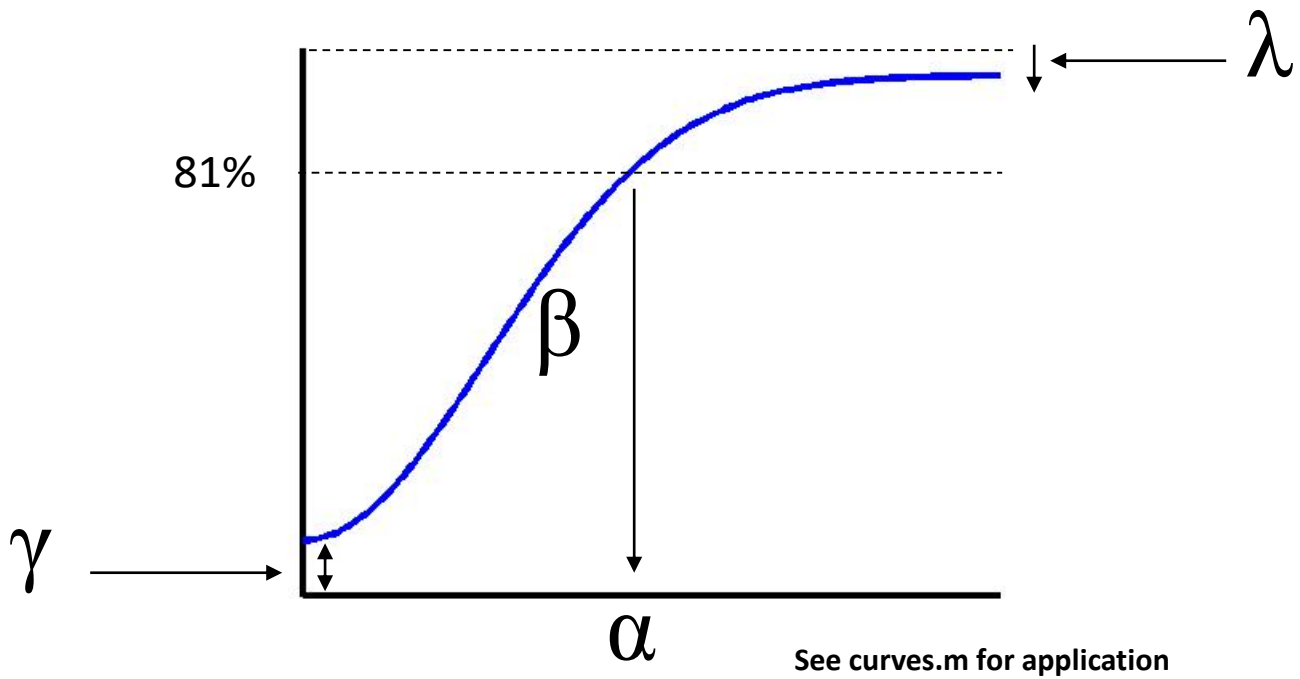
Carl F Gauss



$$\Phi_{\mu,\sigma^2}(x) = \int_{-\infty}^{x} \varphi_{\mu,\sigma^2}(u)\,du$$
$$= \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{x} \exp\left(-\frac{(u-\mu)^2}{2\sigma^2}\right) du, \quad x \in \mathbb{R}.$$

Cumulative Weibull

$$F\left(x;\alpha;\beta\right)=1-\exp\left[-\left(\frac{x}{\alpha}\right)^{\beta}\right],\qquad 0\le x<\infty.$$



See curves.m for application
Also see http://www.bootstrap-software.org/psignifit/