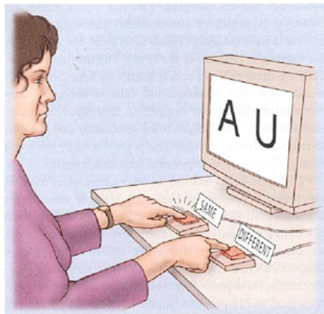
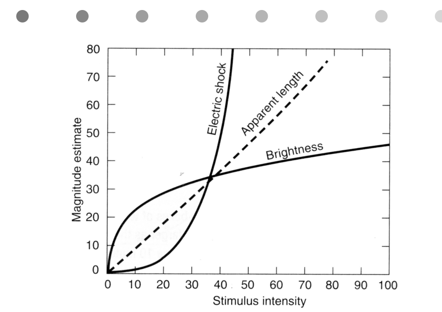
Three methods for measuring perception

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

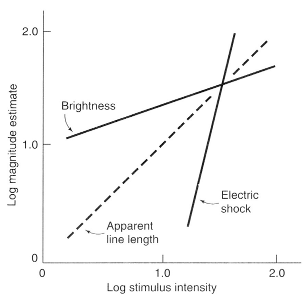


Magnitude estimation

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



Steven's power law



$$P = k\,S^n$$

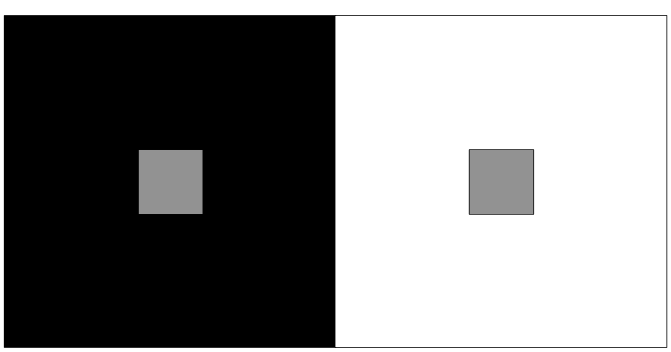
P: perceived magnitude
S: stimulus intensity
k: constant

Relationship between intensity of stimulus and perception of magnitude follows the same general equation in all senses

Matching

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.

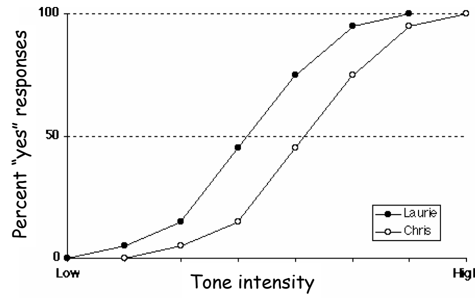
Psychophysical procedures for detection experiments:
- Method of adjustment.
- Yes-No/method of constant stimuli.
- Simple forced choice.
- Two-alternative forced choice

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.

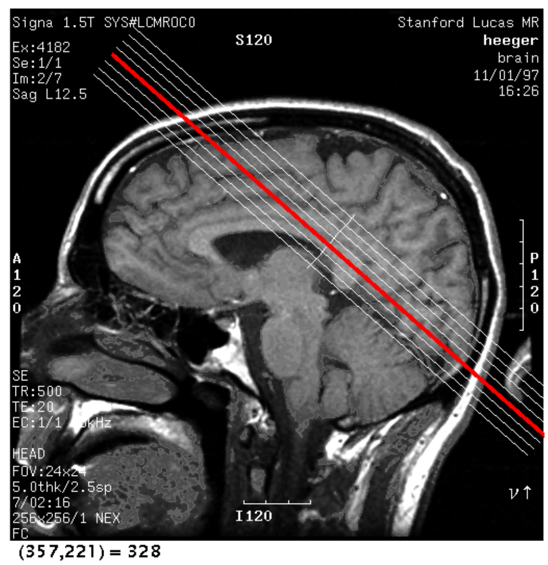
Yes/no method of constant stimuli



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

	Doctor responds "yes"	Doctor responds "no"
Tumor present	Hit	Miss
Tumor absent	False alarm	Correct reject

Information acquistisition

	Doctor responds "yes"	Doctor responds "no"
Tumor present	Hit	Miss
Tumor absent	False alarm	Correct reject

Criterion shift

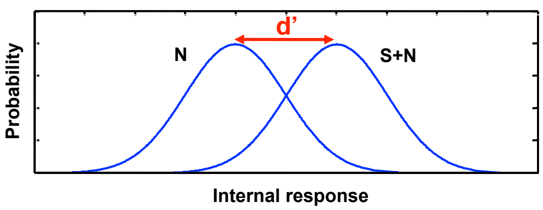
	Doctor responds "yes"	Doctor responds "no"
Tumor present	Hit	Miss
Tumor absent	False alarm	Correct reject

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 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)

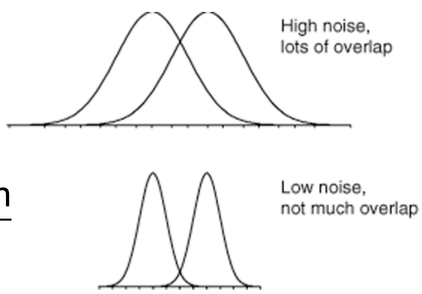
S+N: signal plus noise (tumor present)

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

Discriminability (d')

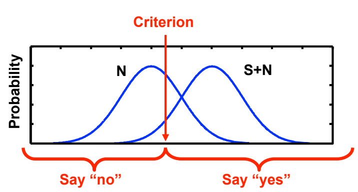
$$d' = \frac{\text{separation}}{\text{spread}}$$

$$= \frac{\text{signal}}{\text{noise}}$$

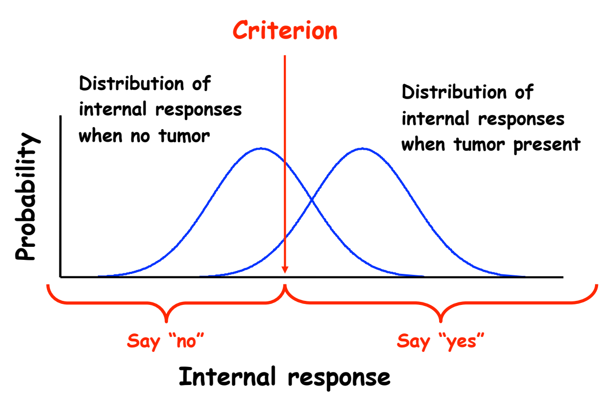


Example applications of SDT

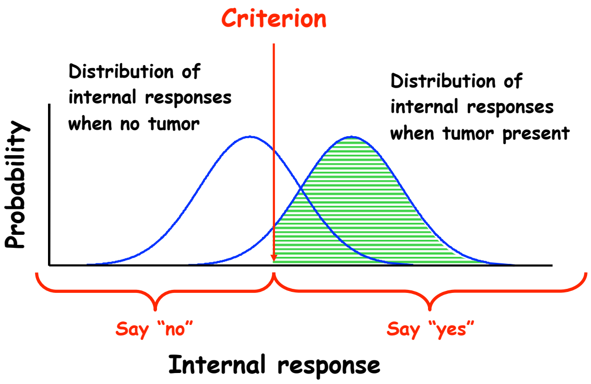
- Vision
  - Detection (something vs. nothing)
  - Discrimination (lower vs greater level of: intensity, contrast, depth, slant, size, frequency, loudness, ...
- Memory (internal response = trace strength = familiarity)
- Neurometric function/discrimination by neurons (internal response = spike count)



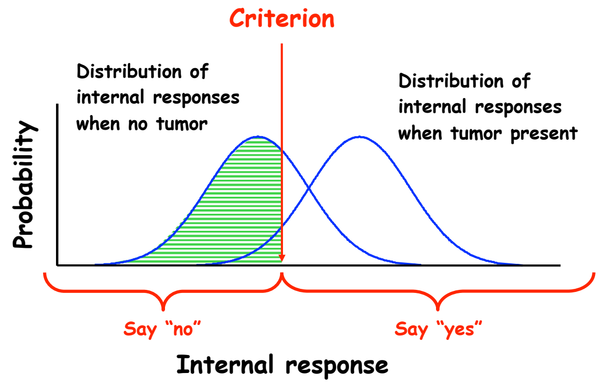
Criterion



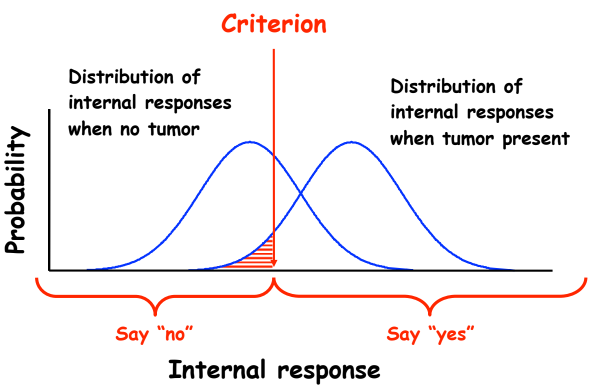
Hits: respond “yes” when tumor present



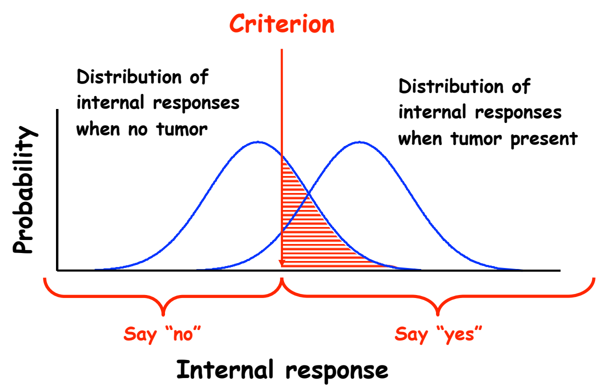
Correct rejects: respond “no” when tumor absent



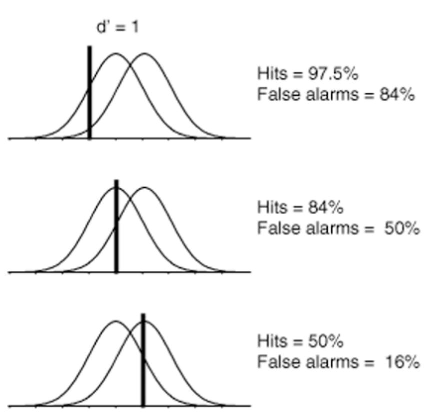
Misses: respond “no” when present



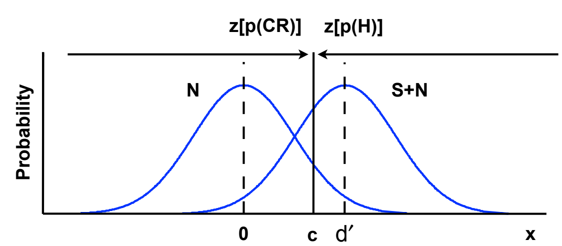
False alarms: respond “yes” when absent



Criterion shift



SDT: Gaussian case

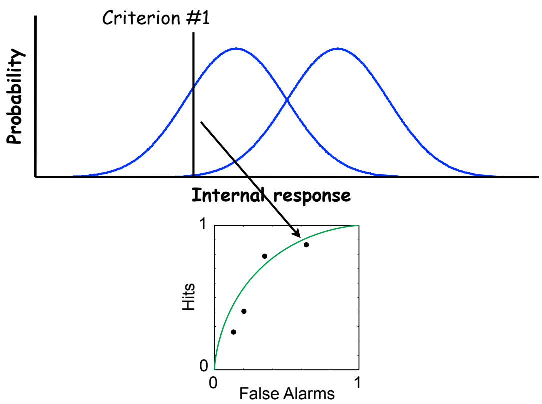


$$d' = z[p(H)] + z[p(CR)] = z[p(H)] - z[p(FA)]$$

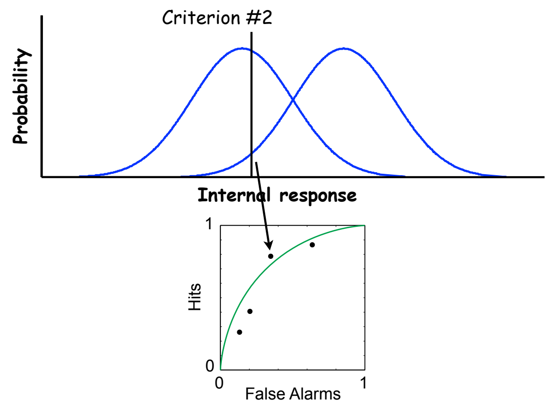
$$c = z[p(CR)] \qquad G(x;\mu,\sigma) = \frac{1}{\sqrt{2\pi}\sigma} e^{-(x-\mu)^2/2\sigma^2}$$

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

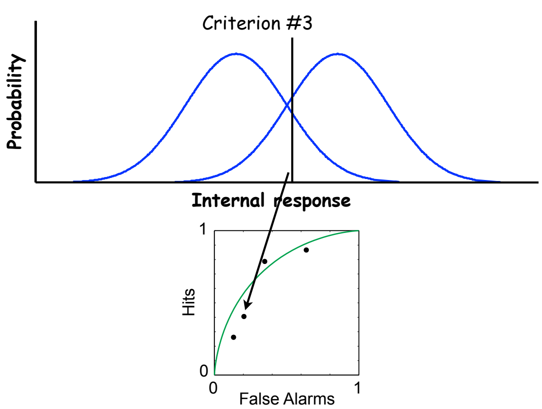
ROC



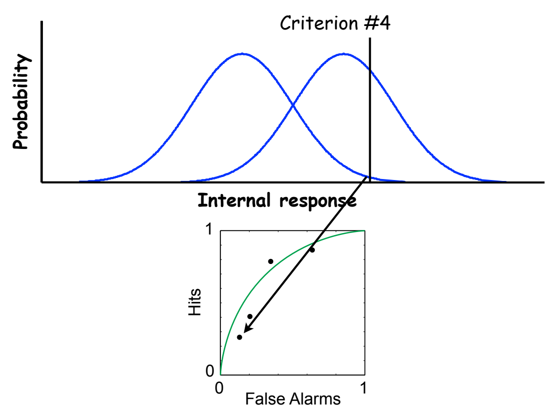
ROC



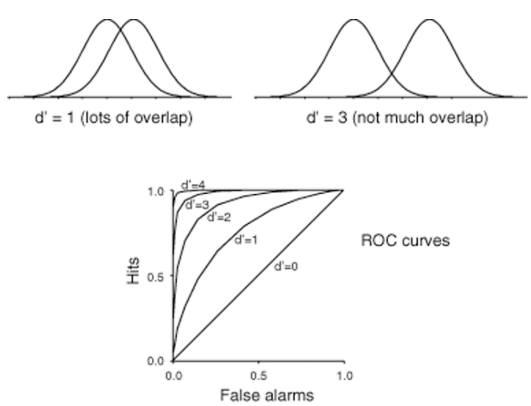
ROC



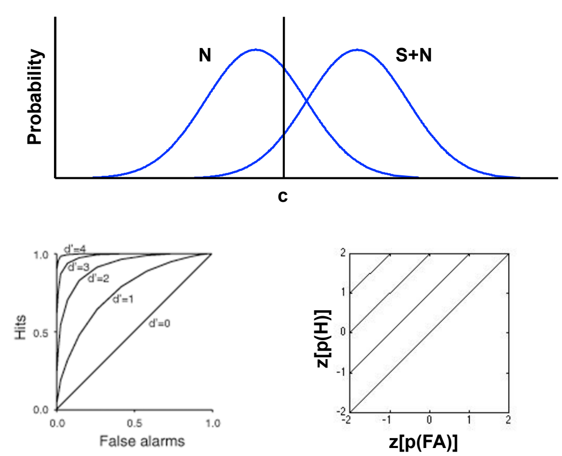
ROC



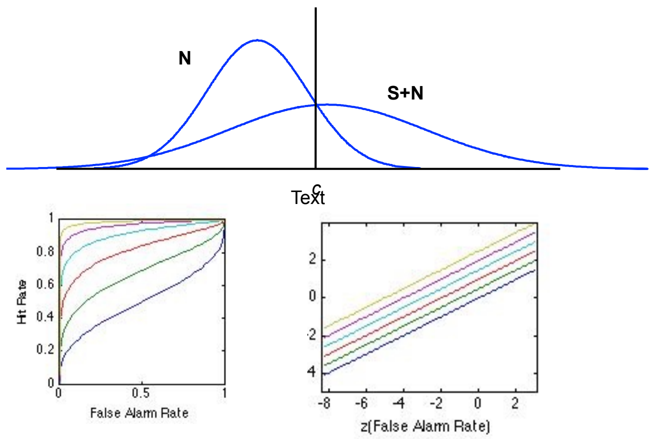
Receiver operating characteristic (ROC)



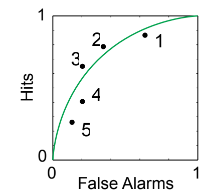
ROC: Gaussian case

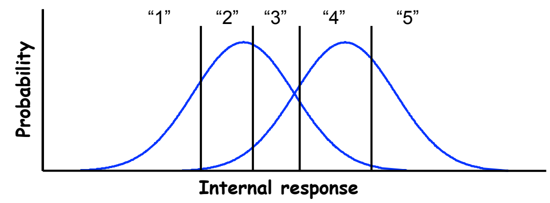


Gaussian unequal variance



Rapid estimation of full ROC: confidence ratings

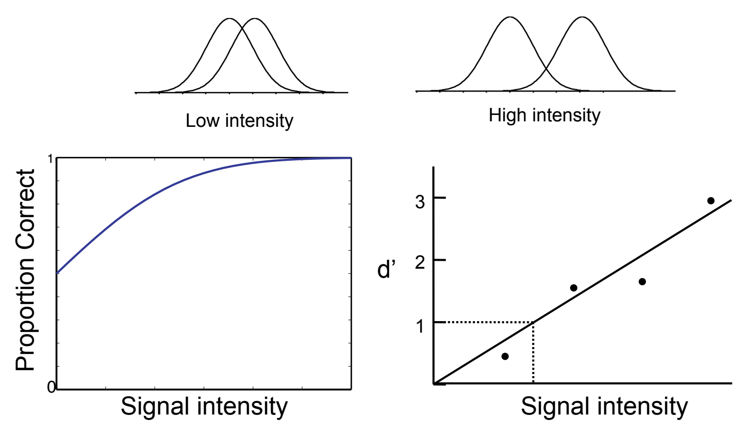




SDT review

- 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



Assumptions: $x \propto$ signal strength, σ constant

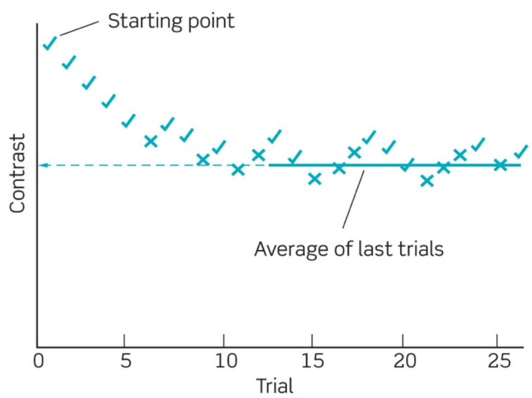
Two-alternative forced choice

- 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.

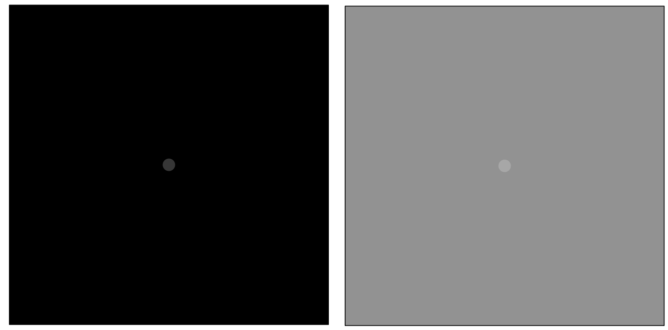
Aside: 2-IFC and Estimation of Threshold

- Frequently one wishes to estimate the signal strength corresponding to a fixed, arbitrary value of d', defined as threshold signal strength.
- For this, one can measure performance at multiple signal strengths, estimate d' for each, fit a function (as in the previous slide) and interpolate to estimate threshold.
- Staircase methods are often used as a more time-efficient method. The signal strength tested on each trial is based on the data collected so far, trying to concentrate testing at levels that are most informative.
- Methods: 1-up/1-down (for PSE: point of subjective equality), 1-up/2-down, etc., QUEST, APE, PEST, ...

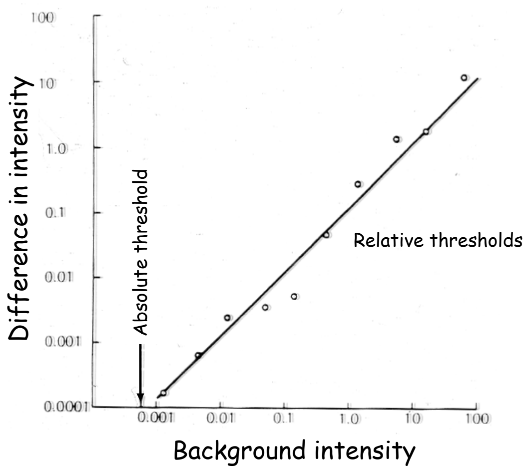
Staircase



Absolute and relative thresholds

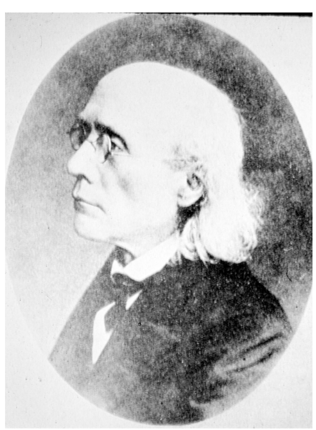


Weber's law



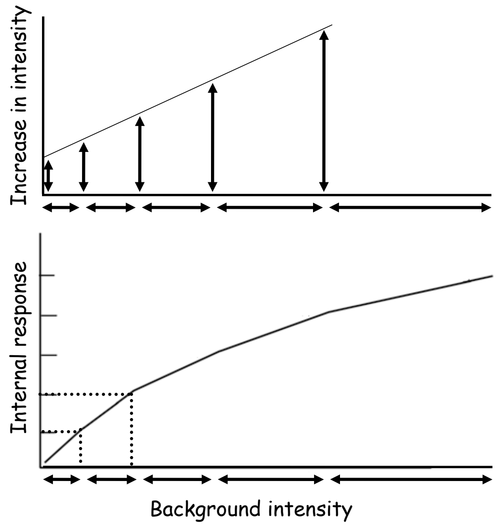
Ernst Weber, c1850

Gustav Fechner, c1850

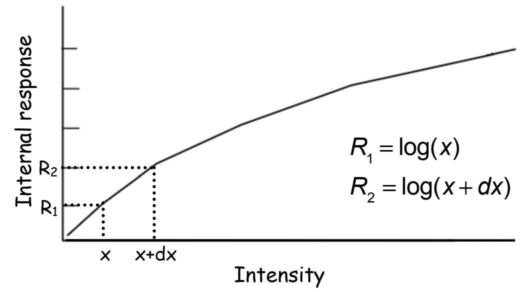


Weber's law

Fechner's analysis



Weber's law: Fechner's derivation



$$d' = \frac{R_2 - R_1}{\sigma}$$

At threshold: $d' = 1$

$$R_2 - R_1 = \sigma$$

Weber's law: Fechner's derivation

$$R_1 = \log(x)$$
$$R_2 = \log(x + dx)$$
$$R_2 - R_1 = \sigma$$
$$\sigma = \log(x + dx) - \log(x)$$
$$= \log\left(\frac{x + dx}{x}\right)$$
$$= \log\left(1 + \frac{dx}{x}\right)$$
$$e^{\sigma} - 1 = \frac{dx}{x}$$

$$\frac{dx}{x} = k$$

Weber's law: contrast ratio derivation

Internal response = $\dfrac{\text{intensity of test flash}}{\text{intensity of background}}$

$$R_1 = \frac{x}{x}$$
$$R_2 = \frac{x + dx}{x}$$
$$R_2 - R_1 = \frac{dx}{x}$$

$$d' = \frac{R_2 - R_1}{\sigma}$$

At threshold: $d' = 1$

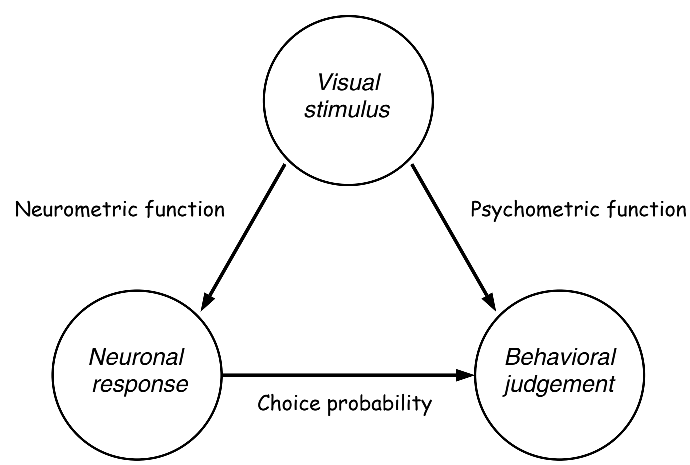
$$R_2 - R_1 = \sigma$$

$$\frac{dx}{x} = \sigma$$

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 x where k is a constant.

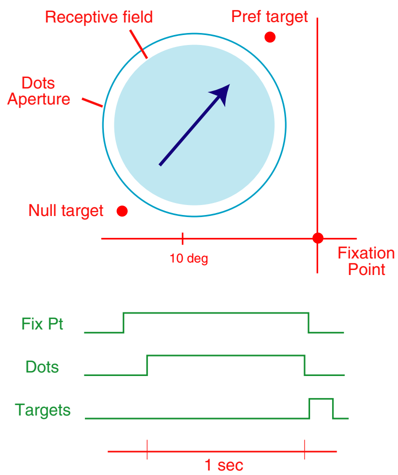
Fechner's interpretation: The relationship between the stimulation level x and the perceived sensation s(x) is logarithmic, s(x) = log(x).

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

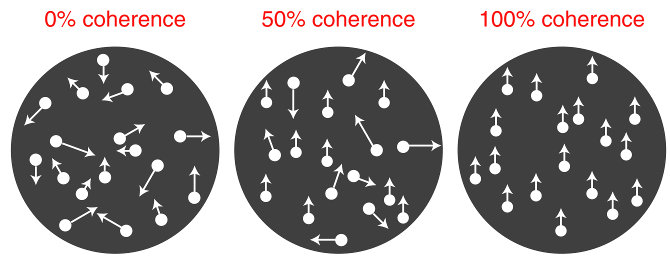


Behavioral protocol

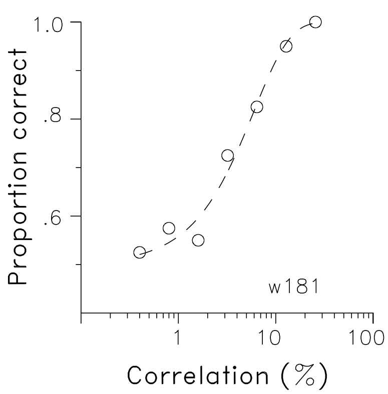
Two-alternative forced choice



Stimulus manipulation: motion coherence

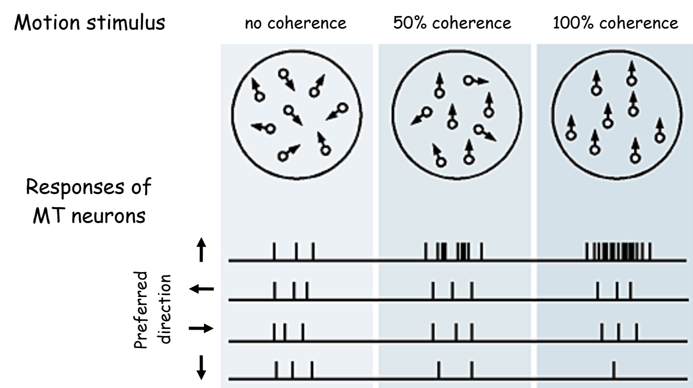


Psychometric function

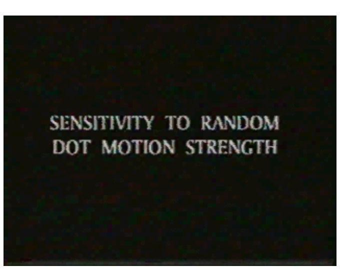


Britten, Shadlen, Newsome & Movshon, 1992

Motion coherence and MT neurons



Motion coherence and MT neurons

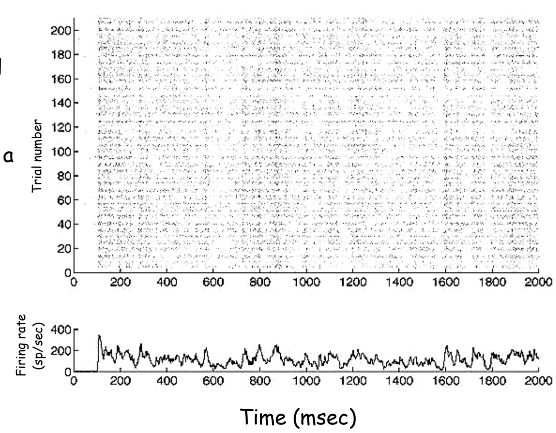


Neural responses are noisy

Each tick is an action potential

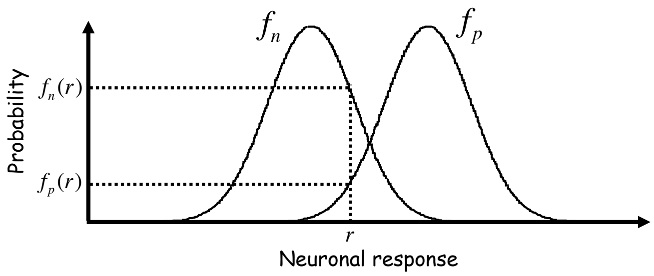
Each line corresponds to a stimulus presentation

Average across all trials



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.



$f_p(r)$: response PDF for pref direction

$f_n(r)$: response PDF for non-pref direction

Probability correct

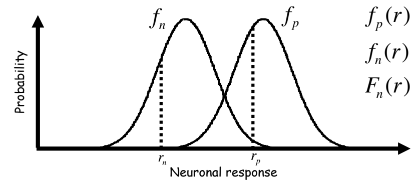
r_p : response to pref direction

r_n : response to non-pref direction

$f_p(r)$: response PDF for pref direction

$f_n(r)$: response PDF for non-pref direction

$F_n(r)$: response CDF for non-pref direction



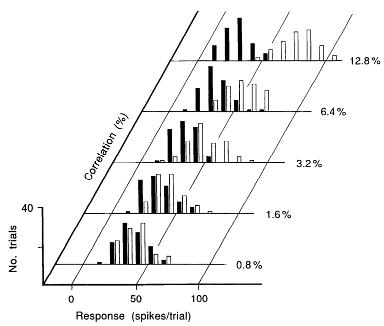
$$\mathrm{P(correct)} = \mathrm{P}(r_p > r_n) = \int_0^\infty f_p(r)\left[\int_0^r f_n(r')dr'\right]dr$$

$$\int_0^r f_n(r')dr' = F_n(r)$$

$$\mathrm{P(correct)} = \int_0^\infty f_p(r)F_n(r)dr$$

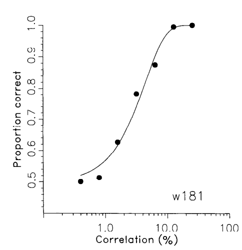
Neurometric function

Response distributions



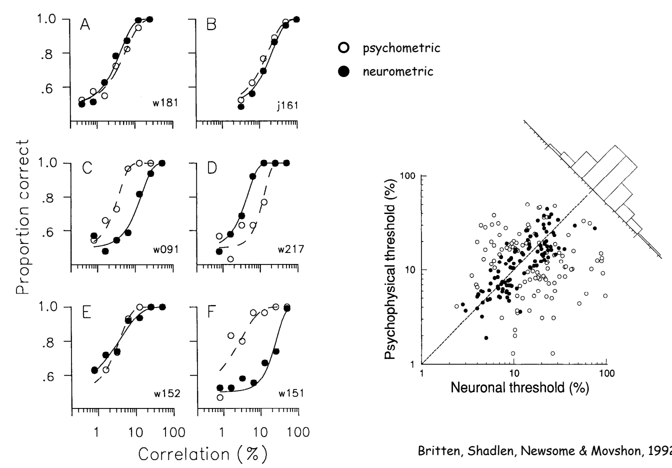
$$\mathrm{P(correct)} = \sum_r f_p[r]F_n[r]$$

Neurometric function

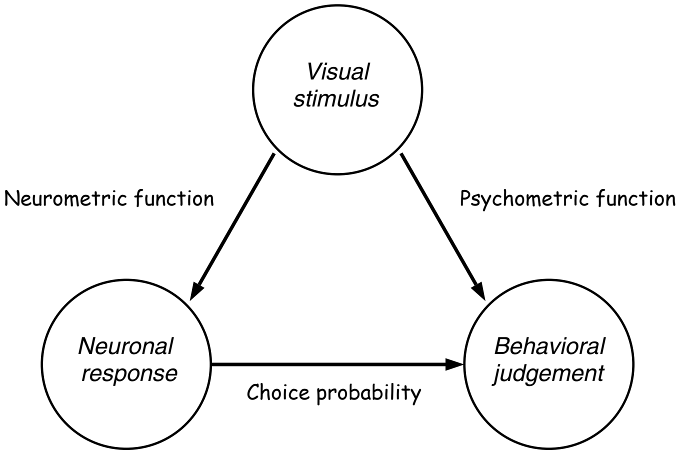


Britten, Shadlen, Newsome & Movshon, 1992

Neurometric vs. psychometric functions

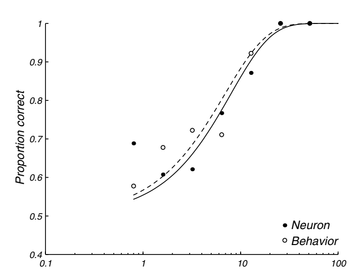


Britten, Shadlen, Newsome & Movshon, 1992

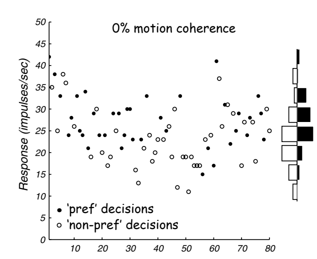


Predicting the monkey's decisions

Neurometric & psychometric functions: accuracy vs motion coherence



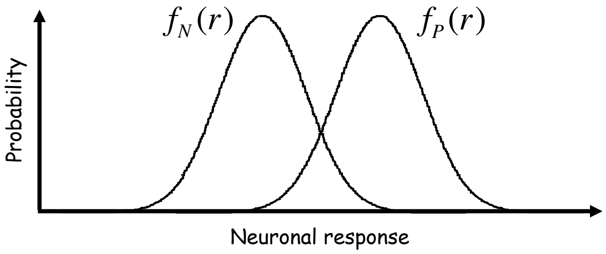
Response distributions for pref and non-pref decisions at a fixed motion coherence



Shadlen, Britten, Newsome & Movshon, 1996

Predicting the monkey’s decisions

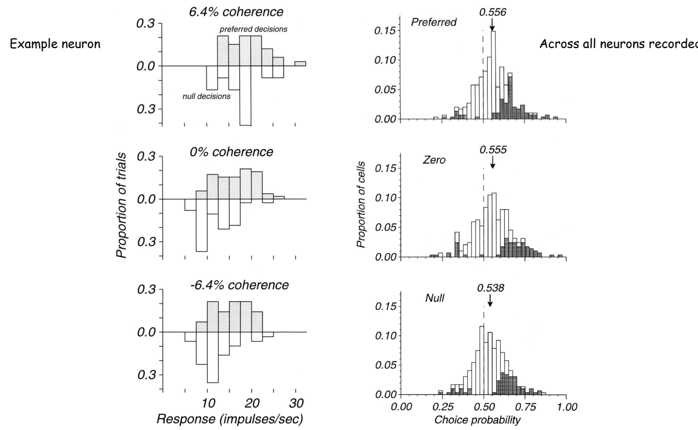
Choice probability: Accuracy with which one could predict monkey’s decision from the response of the neuron given that you know the distributions.



$f_P(r)$: response PDF when monkey reports pref direction

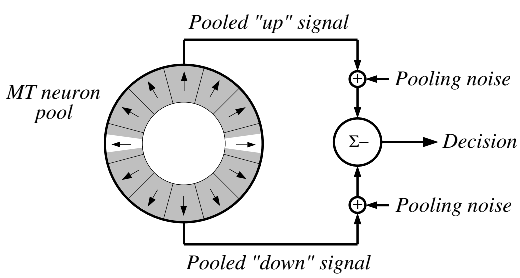
$f_N(r)$: response PDF when monkey reports non-pref direction

Choice probability



Britten, Newsome, Shadlen, Celebrini & Movshon, 1996

Computational 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.

Shadlen, Britten, Newsome & Movshon, 1996