Psychophysics III

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Questions

- Four outcomes of a signal detection task:

		Stimuli		
		Signal	Noise	
Resp.	Yes	___	___	
	No	___	___	
	%			

Four possible outcomes

- 4 types of outcomes
  - Hit, False Alarm, Miss & Correct rejection

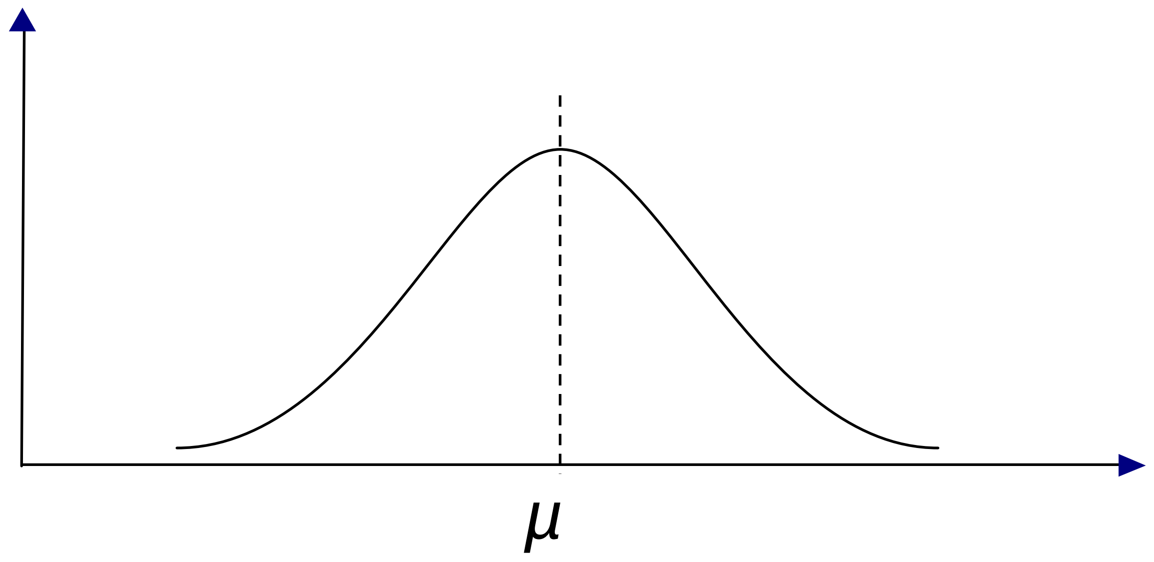
		Stimuli		
		Signal	Noise	
Resp.	Yes	Hit	False Alarm	? (≠ 100%)
	No	Miss	Correct Rejection	? (≠ 100%)
	%	100%	100%	

Signal and Noise: Statistical view

- Sensory registration of external stimuli is consist of noise and signal together, i.e.

$$S = \mu + N_e + N_i$$

  - Where μ refers to the pure signal strength, N_e external noise, and N_i internal noise respectively.
  - In most cases, N_e and N_i have characteristics of normal distribution.



Normal distribution

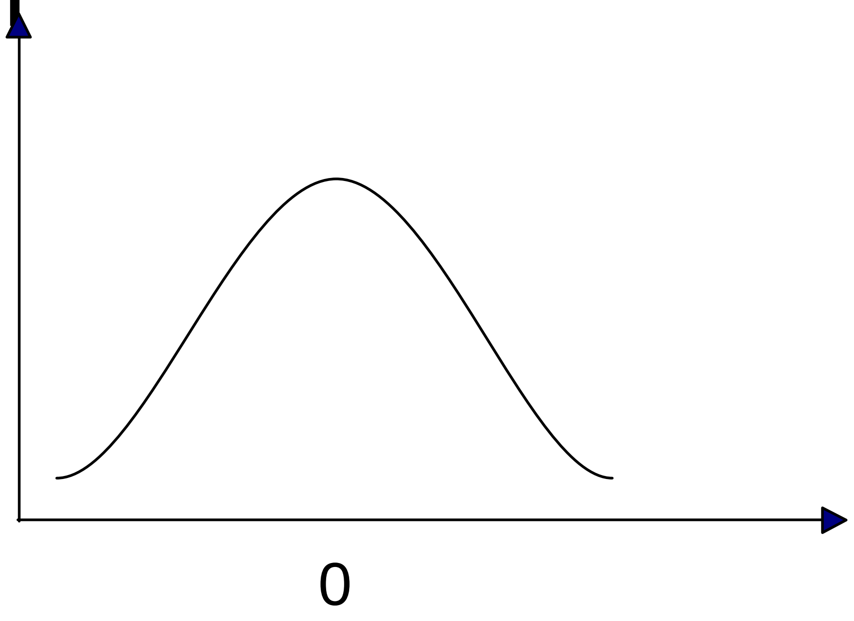
- i.e. Gaussian distribution
  - Can be determined by mean and variance

$$N(\mu,\sigma)$$

  - Density function: bell curve

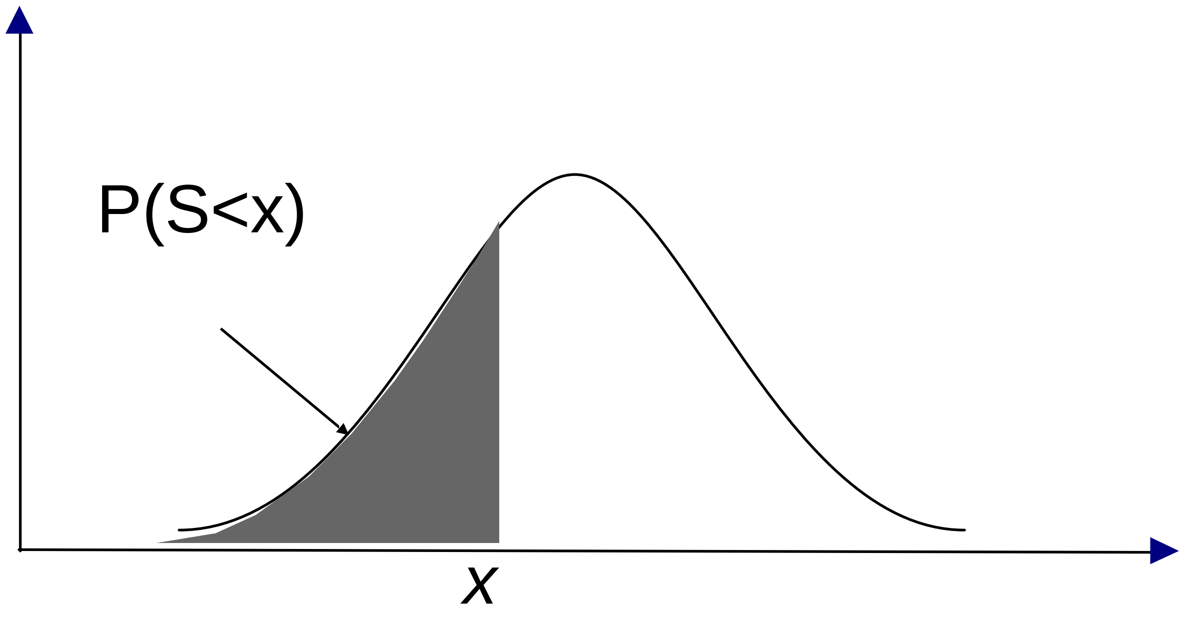
- Standard normal distribution
  - Mean = 0
  - Variance = 1
  - Standardization

$$z = \frac{x-\mu}{\sigma}$$



Signal and Noise: Statistical view

- The perceive strength of stimuli is perturbed by noise.
  - The following probability density function describes such variation and probabilities.
    - Area -> Probability
    - Abscissa -> Z-Score (if it is standard normal distribution)



http://wise.cgu.edu/sdtmod/measures2.asp

Distribution of Noise and Signal

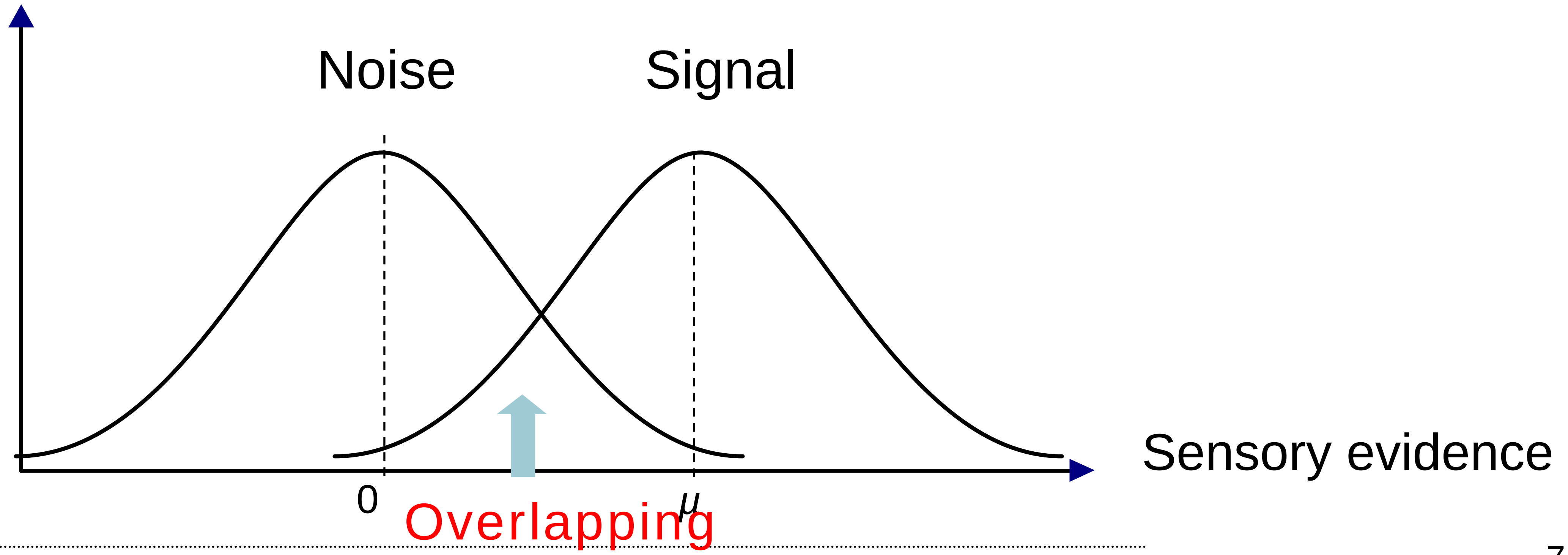
- Signal + Noise

$$S = \mu + N_e + N_i \qquad \sim N(\mu, \sigma)$$

- Noise only (Without signal)

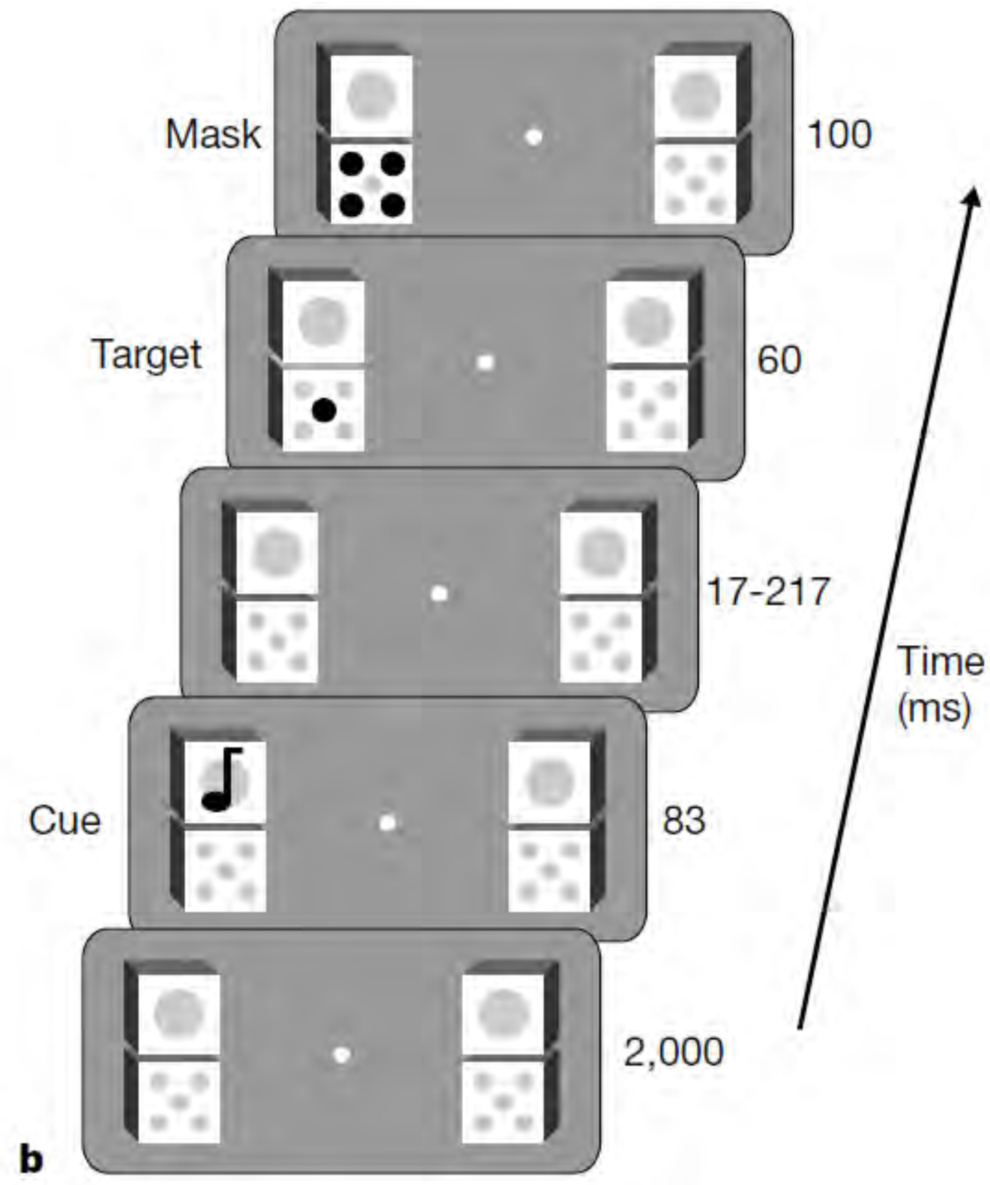
$$N = N_e + N_i \qquad \sim N(0, \sigma)$$

- sensory evidence distributions

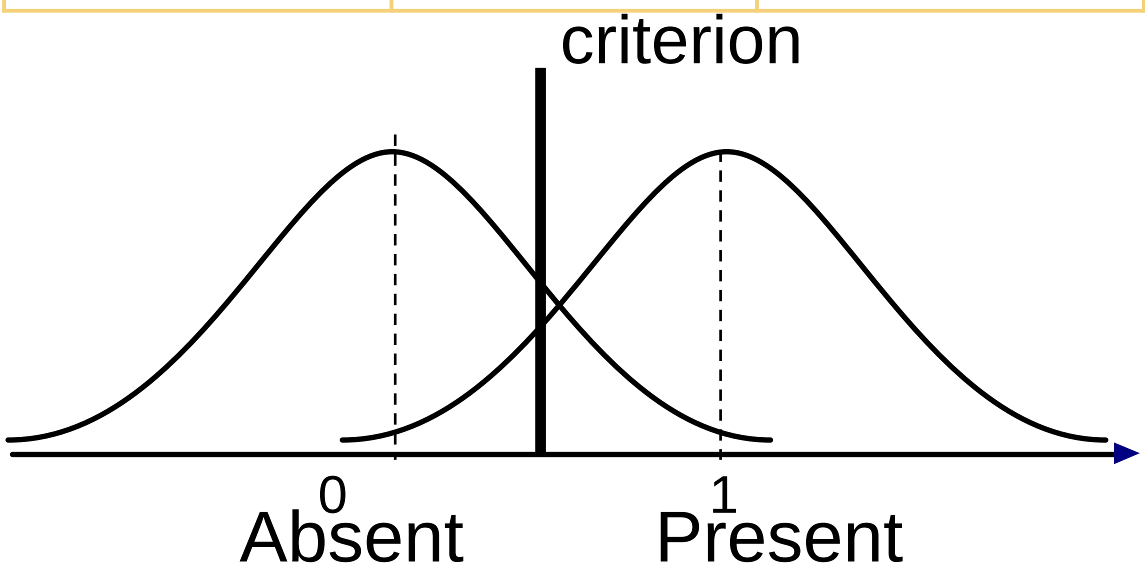


Examples

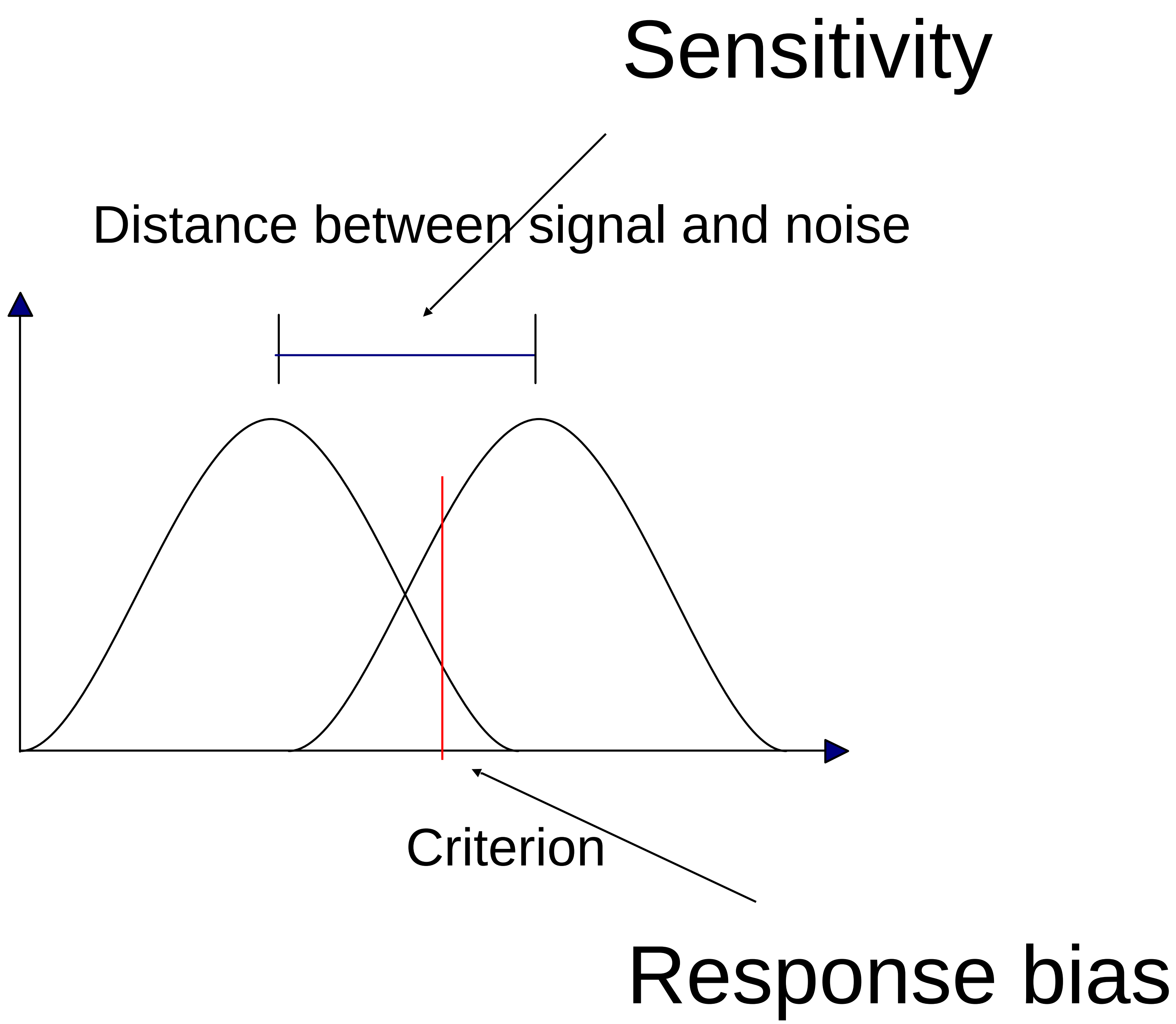
- Involuntary orienting to sound improves visual perception, McDonald et al. 2000, nature.



Response	Target present	Target Absent
"Yes"	Hit	False alarm
"No"	Miss	Correct rejection
Total	*100%*	*100%*

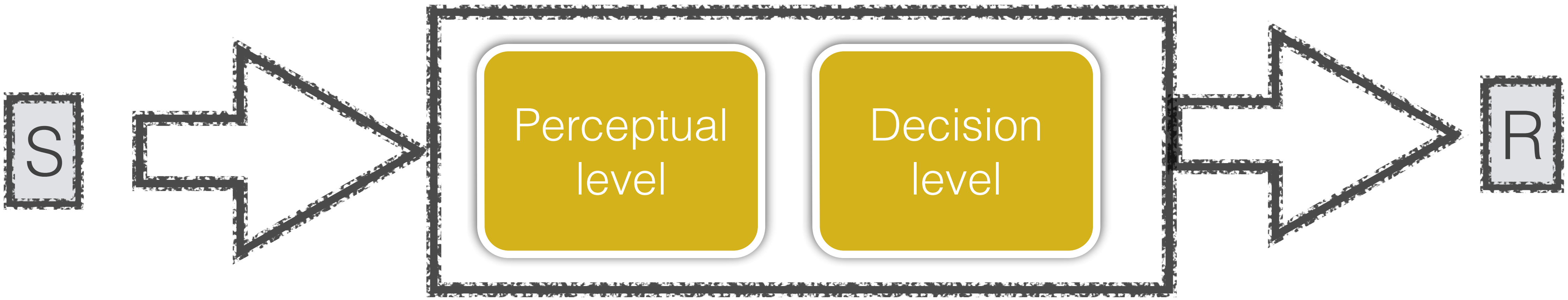


Two important parameters



Sensitivity and decision criterion

- **Sensitivity (Discriminability):**
  - Measure of how close between signal and noise
  - supposed to be a property only of the sensory process
- **Decision Criterion (Response Bias):**
  - internal separation baseline for noise and signal
  - influence by motivation, expectancy, pressure etc.
- Sensitivity is independent of decision criterion.
  - Contrast to classical psychophysical methods



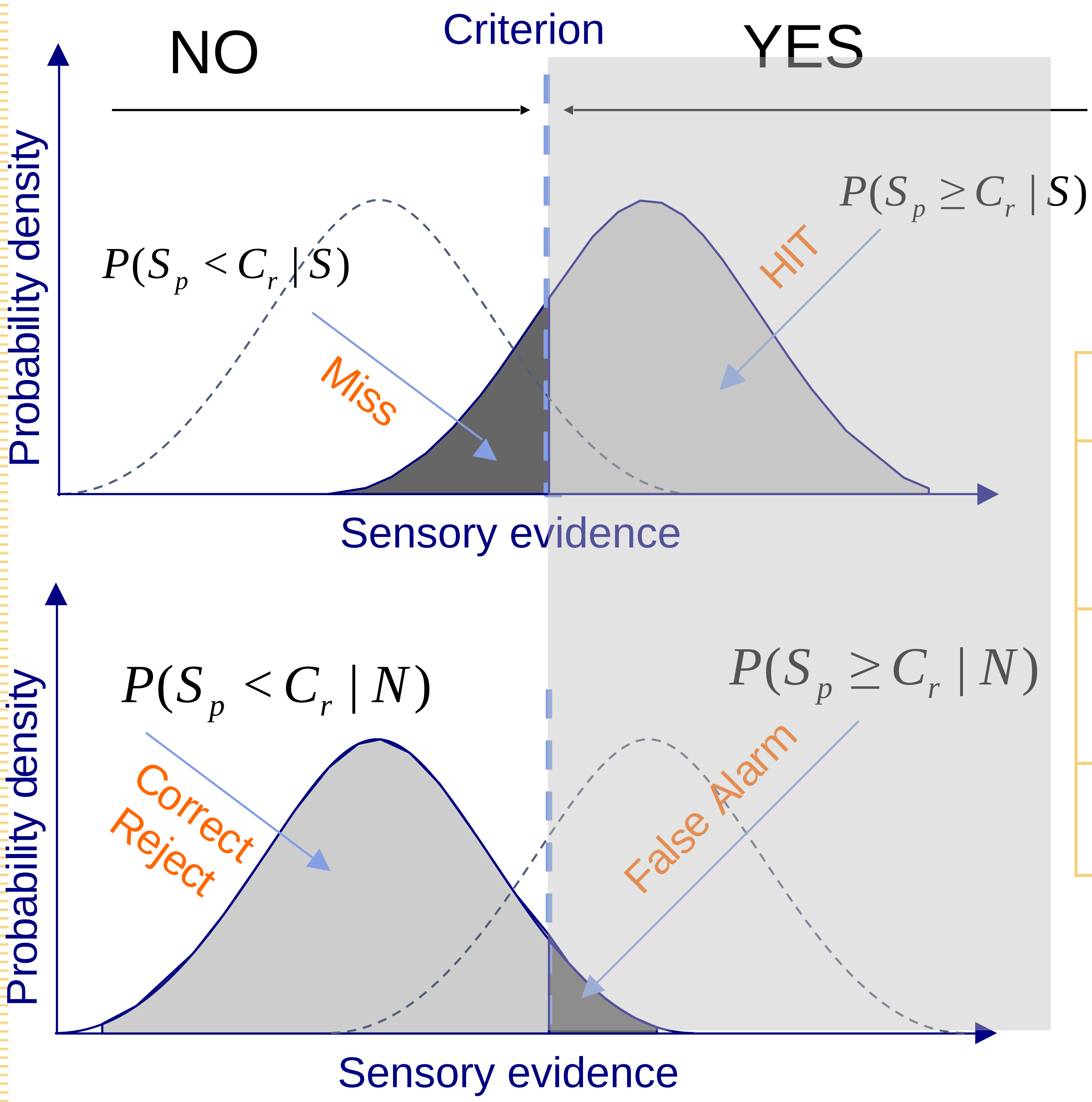
Decision criterion and two types of errors

- Criterion C_r and perceived stimuli strength S_p

$$\text{Response} = \begin{cases} Yes & \text{if } S_p \geq C_r \\ No & \text{if } S_p < C_r \end{cases}$$

- two types of errors may happen:
  - Miss
    - Signal is present, however sensory evidence is below the criterion ($S_p < C_r$)
  - False alarm
    - Signal is absent, however sensory evidence is above the criterion ($S_p > C_r$)

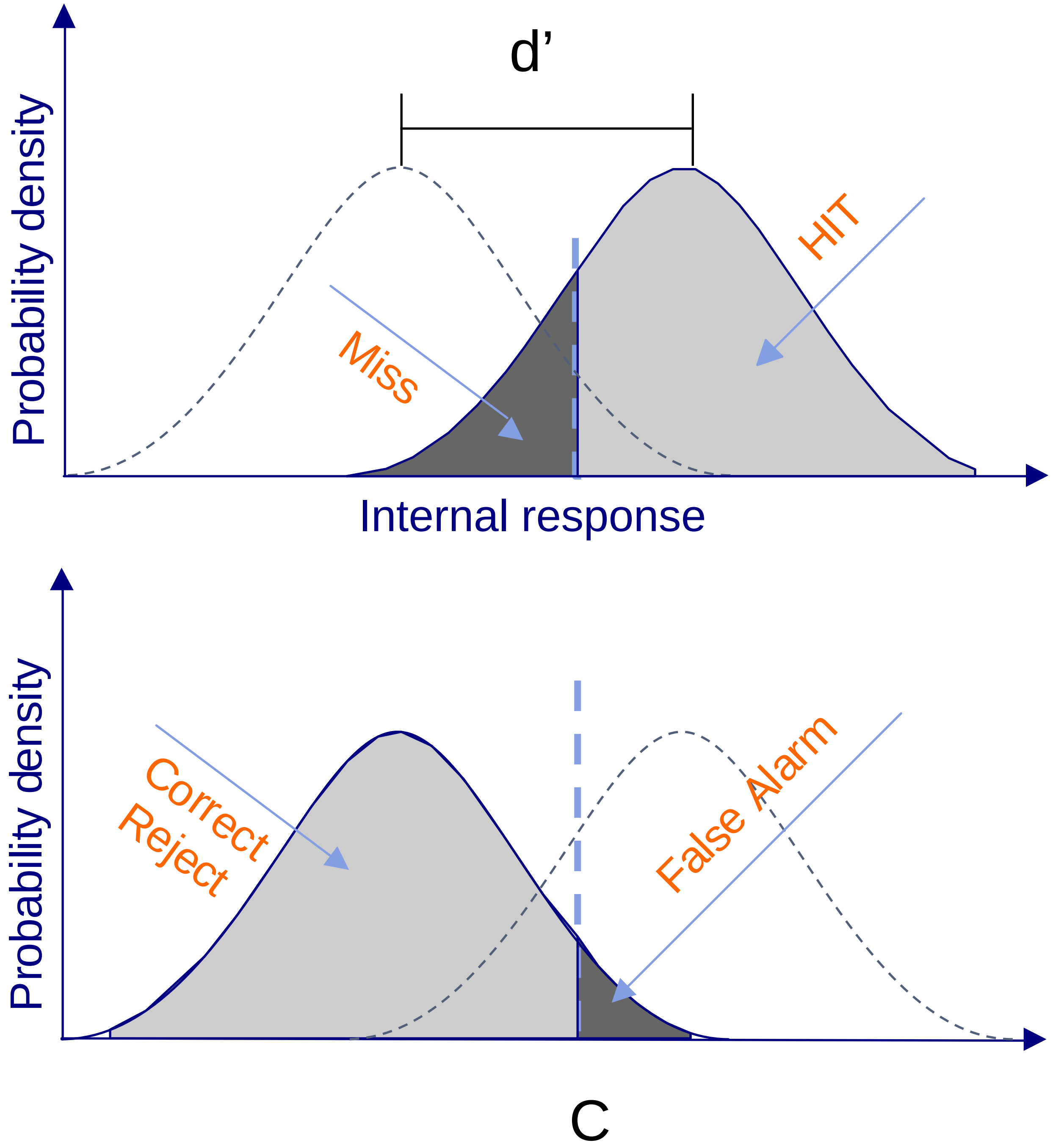
Responses and probabilities



Response	Signal	Noise
"Yes"	Hit	False alarm
"No"	Miss	Correct rejection
Total	*100%*	*100%*

http://wise.cgu.edu/sdtmod/overview.asp

Main goals of SDT

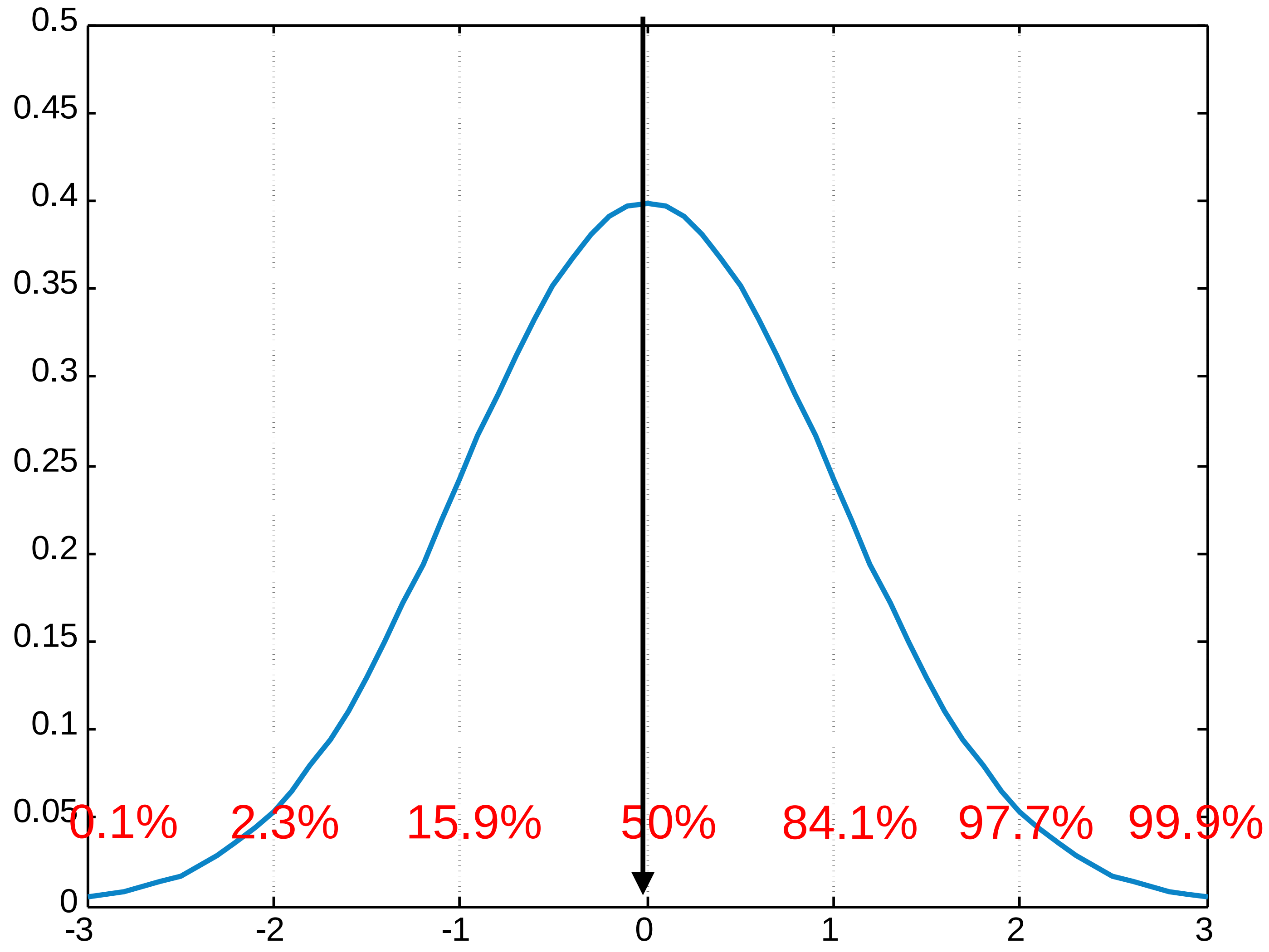


- Responses
  - Hit (Miss)
  - FA (CR)
- Estimates
  - Sensitivity d'
  - Criterion C

Z-Score

- Also called 'Standard score '

$$z = \frac{x - \mu}{\sigma}$$



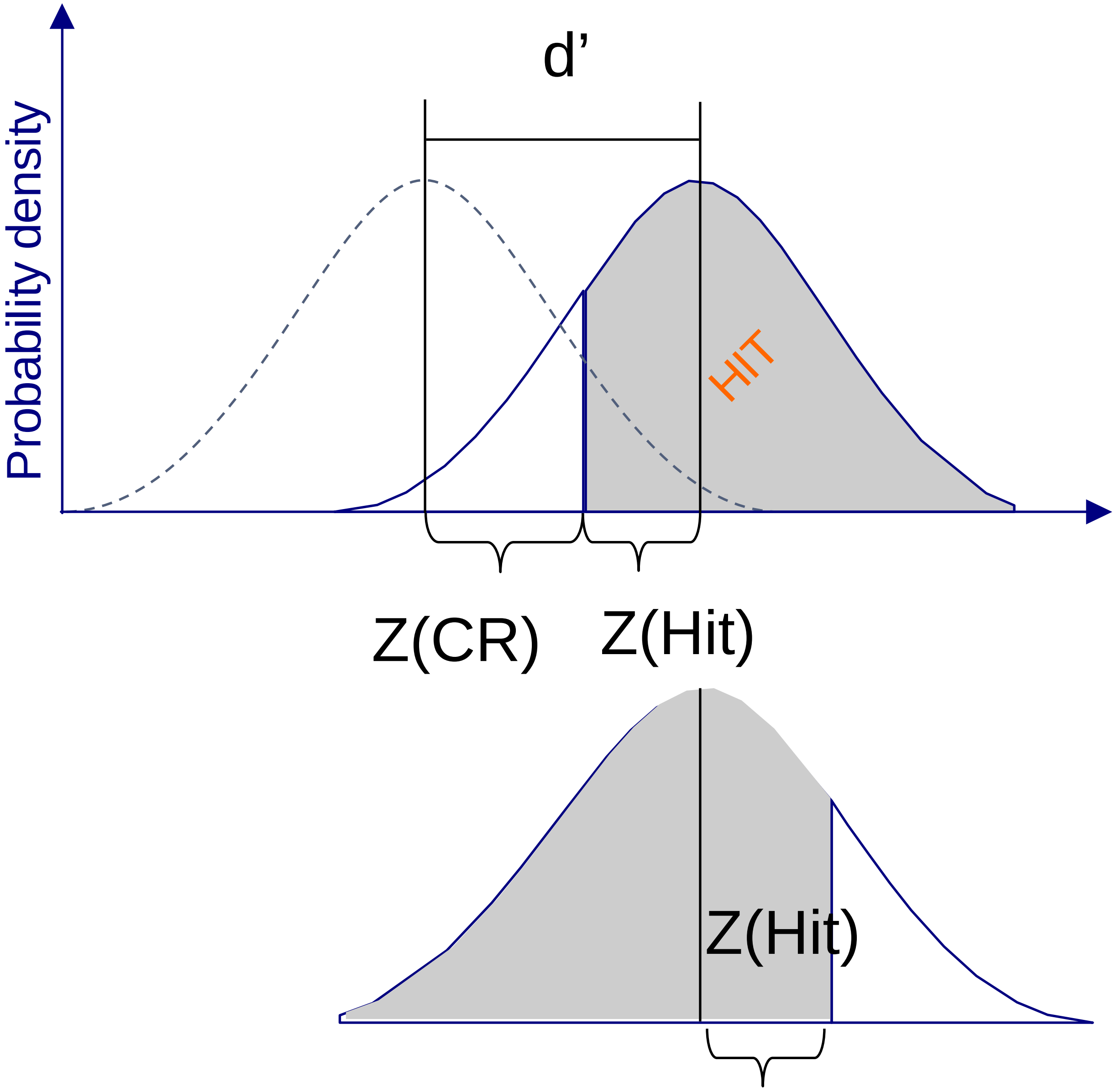
Z(15.9%) = - Z(84.1%) -> Z(p) = -Z(1-p)

Calculation of d'

- Suppose N and S are standard normal distribution

$$d' = z(Hit) + z(CR)$$
$$= z(Hit) - z(FA)$$

Note: Z(CR) = - Z(FA)



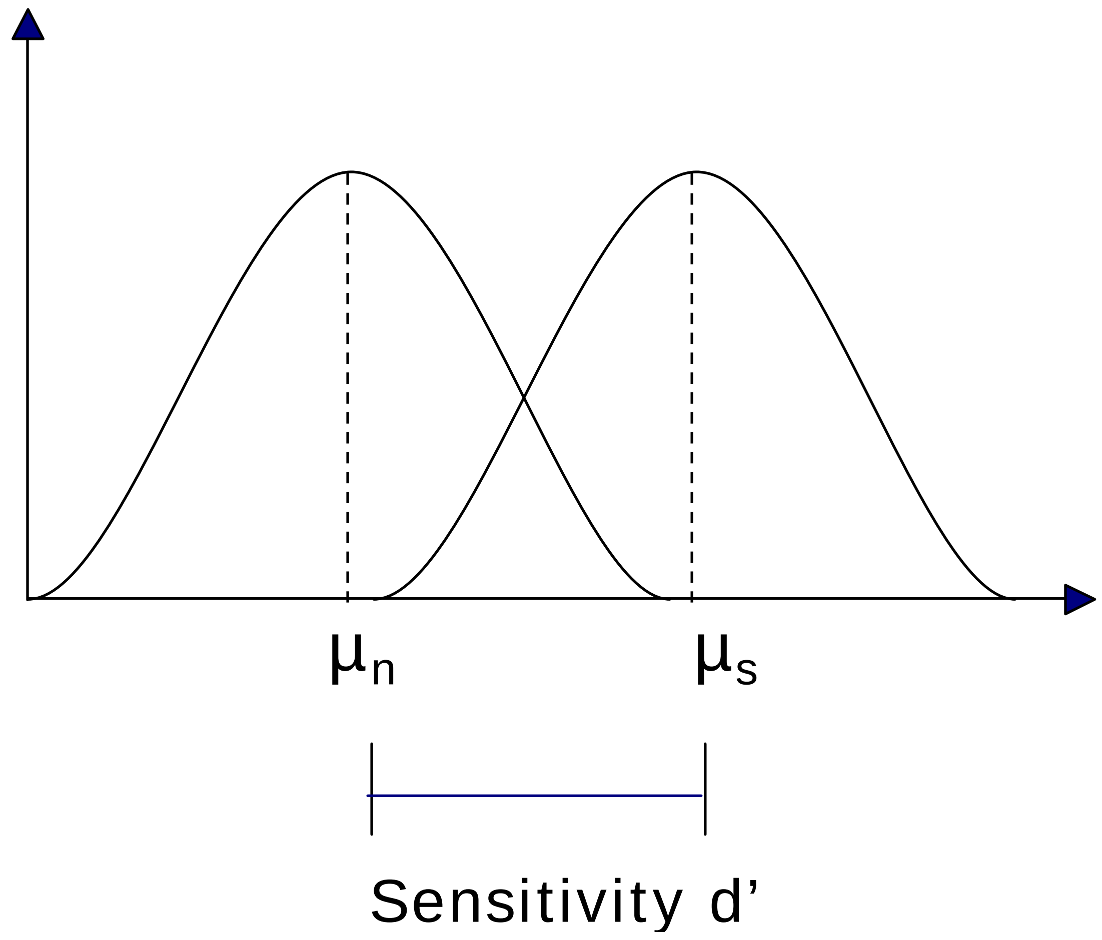
Sensitivity (Discriminability): d'

- Equal-Variance

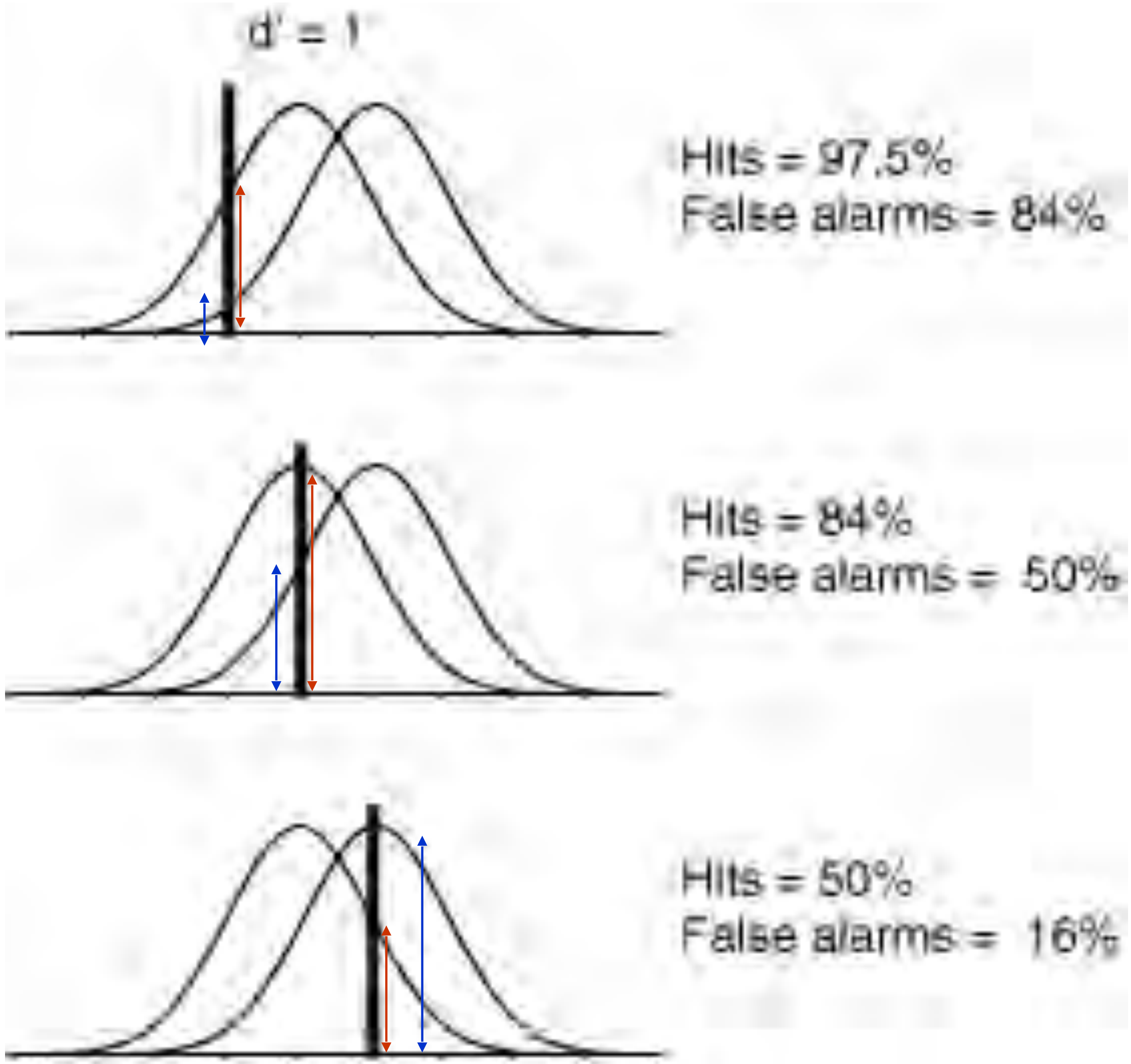
$$d' = \frac{\mu_s - \mu_n}{\sigma} = z(Hit) - z(FA)$$

- Unequal-Variance

$$d_a = \frac{(\mu_s - \mu_n)}{\sqrt{\frac{\sigma_s^2 + \sigma_n^2}{2}}}$$



Decision Criterion (Response bias)

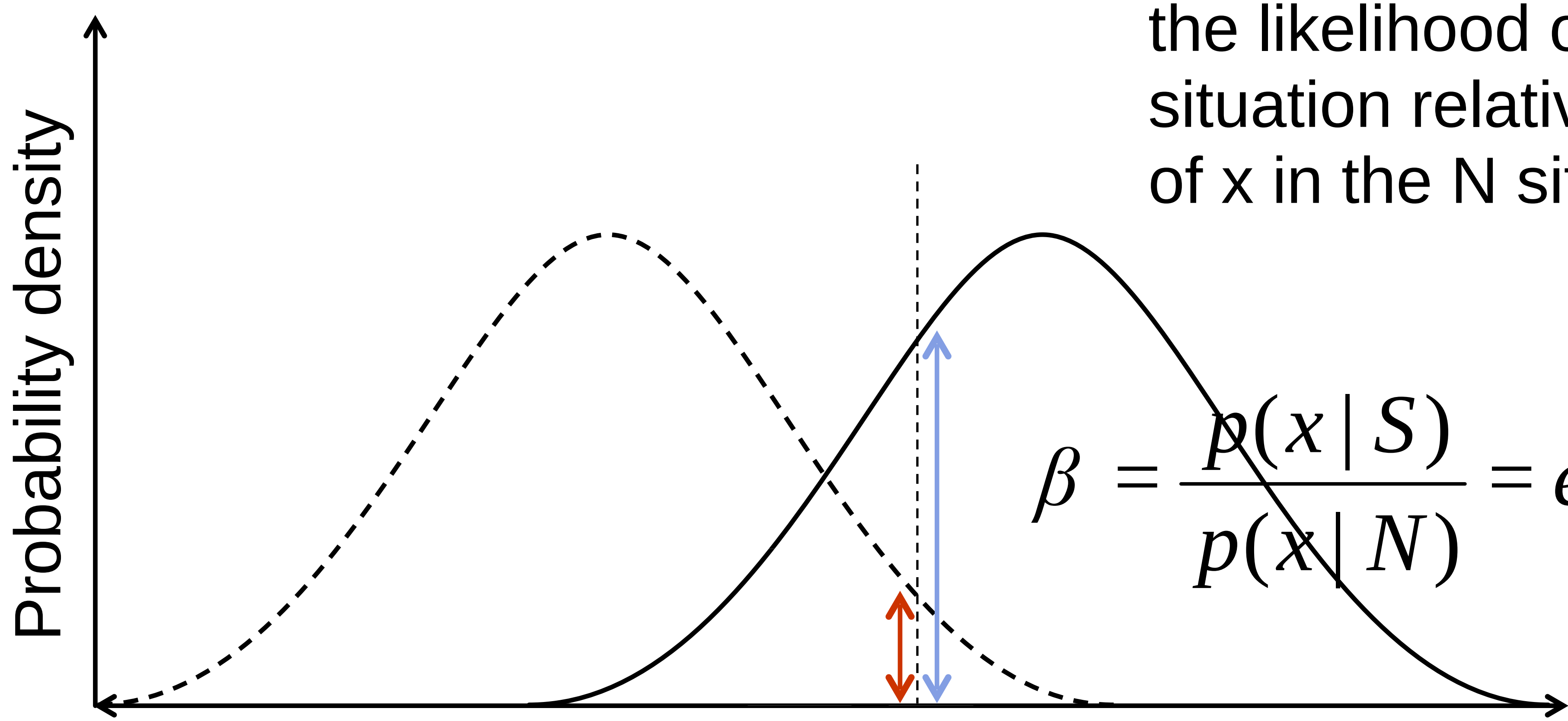


	Hit	FA
C1	0.975	0.84
C2	0.84	0.5
C3	0.5	0.16

The likelihood ratio and Criterion β

$$l(x) = \frac{\text{ordinate of S}}{\text{ordinate of N}} = \frac{p(C_r \mid S)}{p(C_r \mid N)} = \beta$$

The likelihood ratio provides the observer with a basis for making a decision, since it expresses the likelihood of x in the S situation relative to the likelihood of x in the N situation.



$$\beta = \frac{p(x \mid S)}{p(x \mid N)} = e^{-\frac{z(Hit)^2 - z(FA)^2}{2}}$$

β <1:Liberal — More ‘Yes’ !

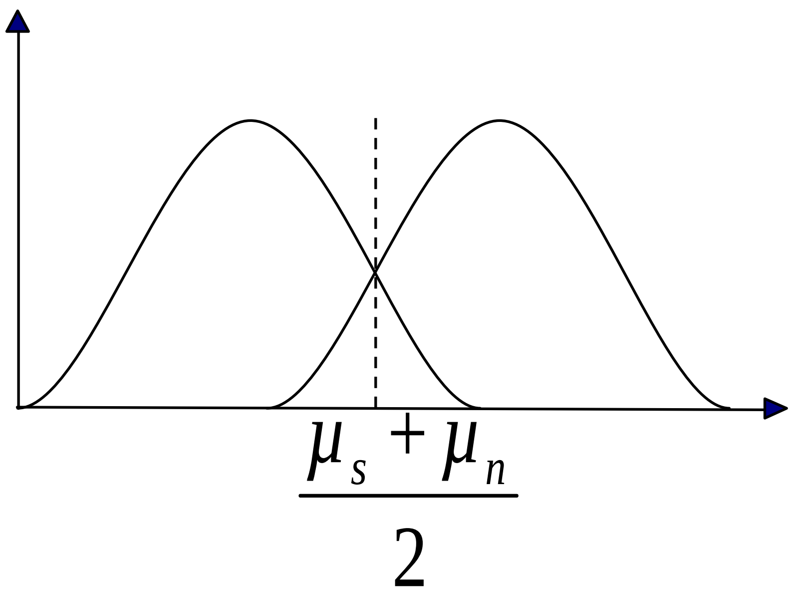
β=1:Neutral — P(Miss)=P(FA)

β>1: Conservative — More ‘No’!

Response Bias C

- Bias measure C theoretically represents the normalized distance between the criterion (C_r) and the zero-bias point
- Empirical measure for C:

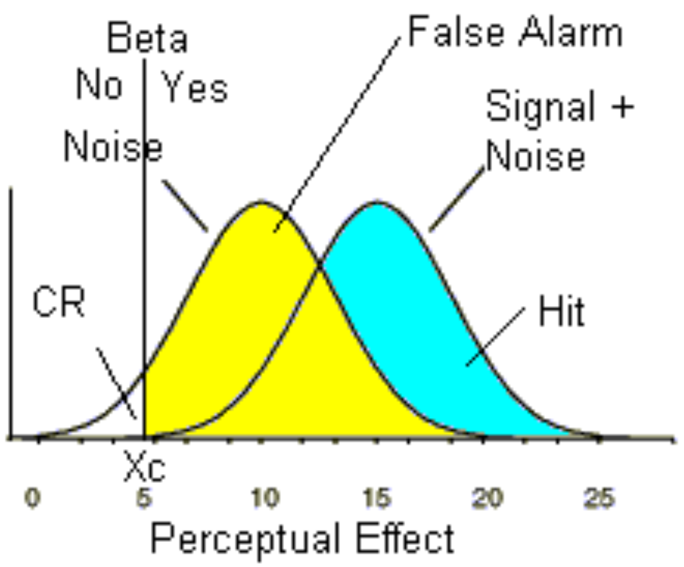
$$C = -\frac{Z(Hit) + Z(FA)}{2}$$

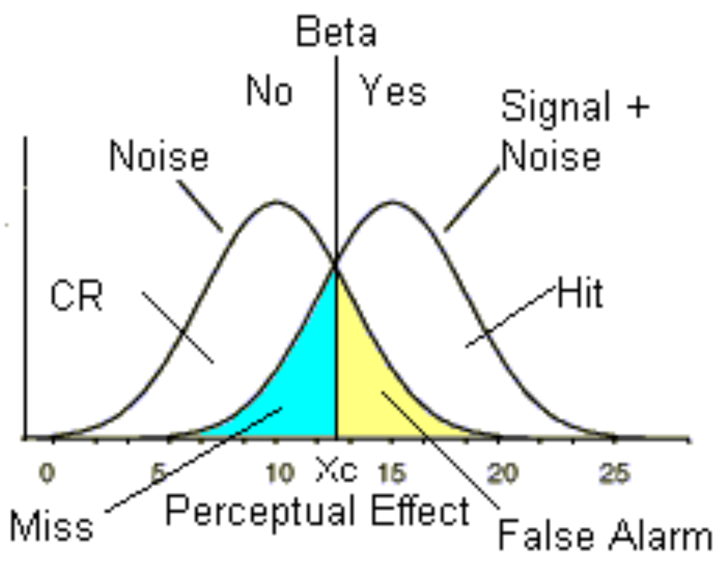


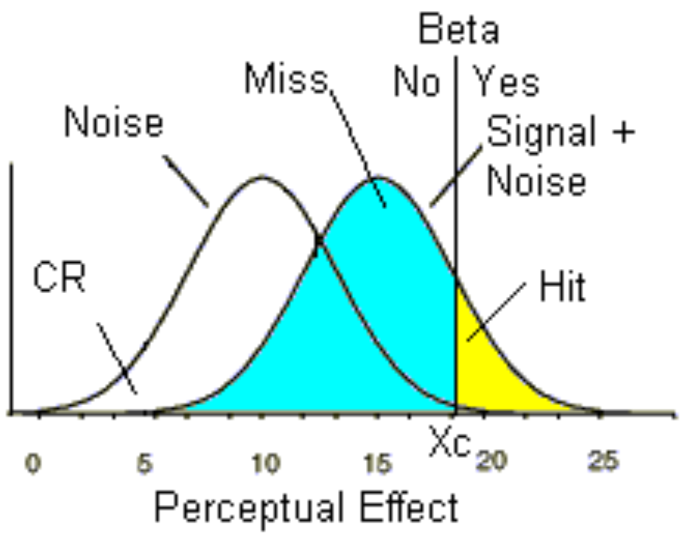
  - C = 0 : neutral
  - C > 0 : conservative
  - C < 0 : liberal

Response Bias Index C

$$C = -\frac{Z(H) + Z(F)}{2}$$







c <0:Liberal

More Yes!

c=0:Neutral

P(Miss)=P(FA)

c>0: Conservative

More No!

Factors influence Decision Criterion

- Motivation, expectancy

- Benefits and costs associated with the various decision outcomes
  - Reward at ‘hit’ target
  - Punishment at ‘wrong’ trials
- the prior probabilities of the stimulus

P(noise) and P(signal)

  - Expectancy

Empirical Measures

- Equal variance

$$d' = z(H) - z(F)$$

$$C = -\frac{Z(H) + Z(F)}{2}$$

$$\beta = e^{-\frac{z(Hit)^2 - z(FA)^2}{2}}$$

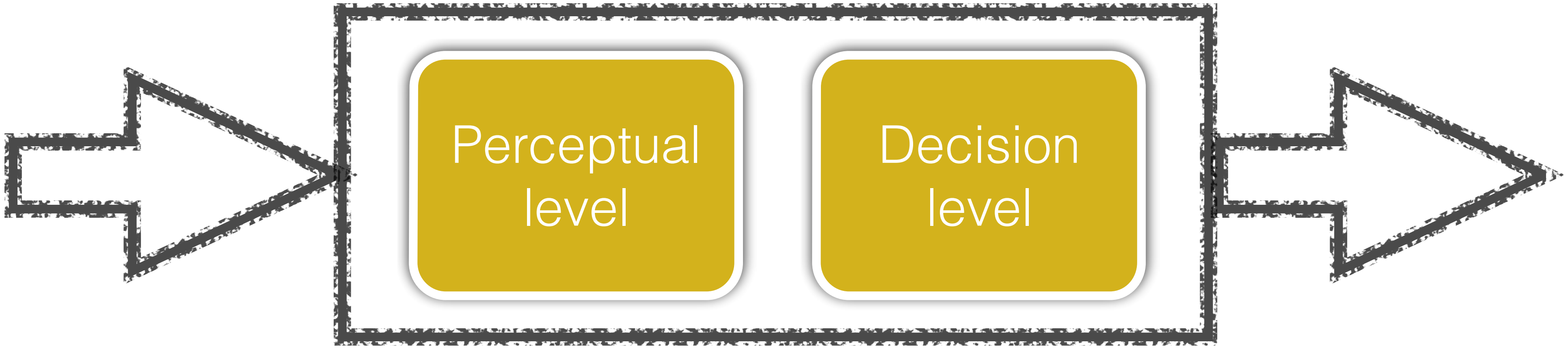
Example

Response	Signal	Noise
“Yes”	0.35	0.02
“No”	0.65	0.98

Z(H) = -0.39
Z(FA) = -2.05
d’ = 1.66
C = 1.22
beta = 7.58

Example

- Audiovisual interactions in apparent motion
  - Sanabria et al, Cognition, 2007
- Auditory apparent motion is influenced by visual apparent motion
  - Audiovisual perceptual interaction (**visual capture**)
    - Influence on perceptual level -> sensitivity
  - Response bias (post-perceptual stage)
    - Influence on decision level -> bias

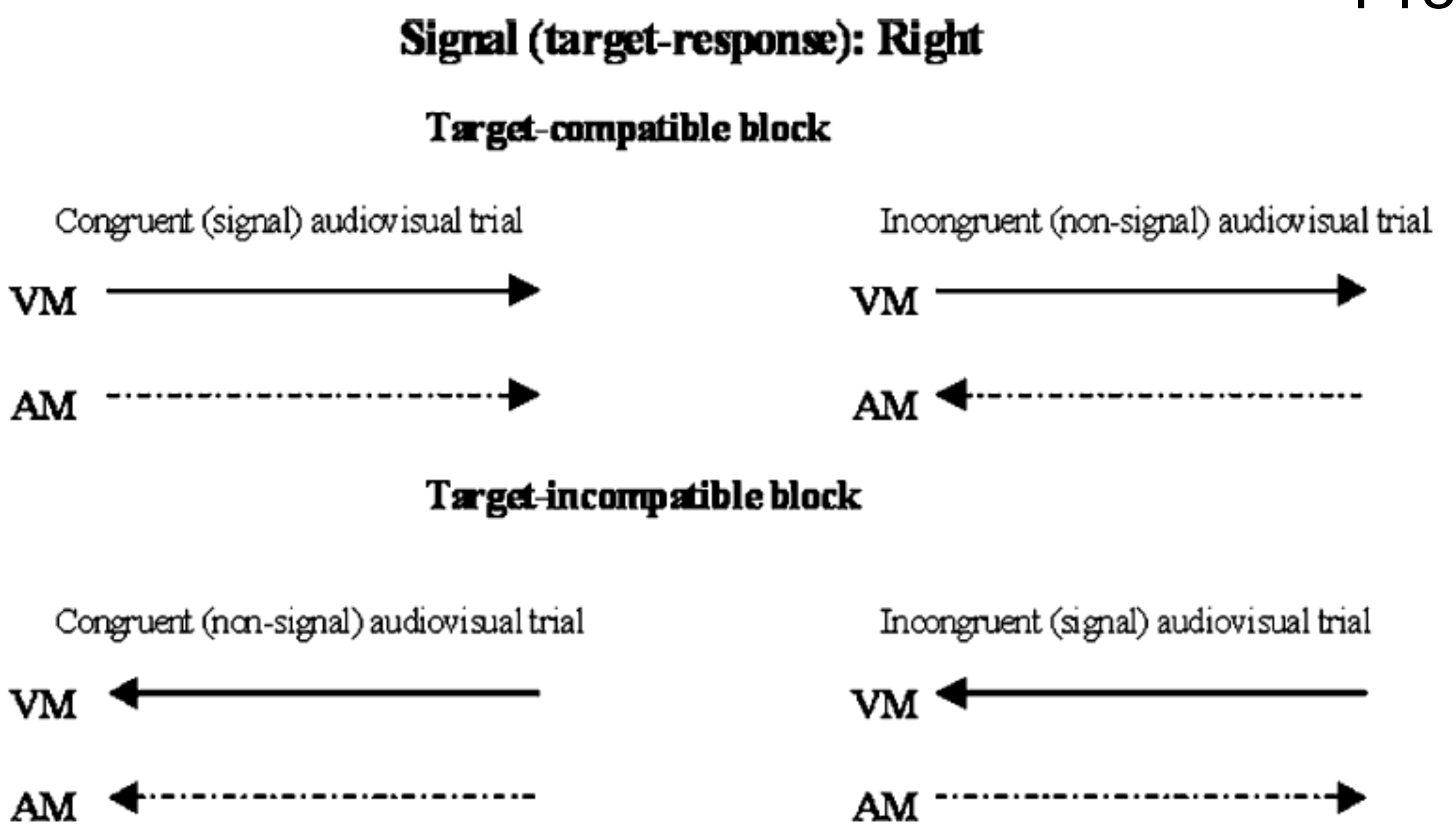


Example

- Three conditions
  - Target compatible
  - Target incompatible
  - Unimodal
- Signal & Noise (Go/No go task)
  - AM right: signal
  - AM left: noise

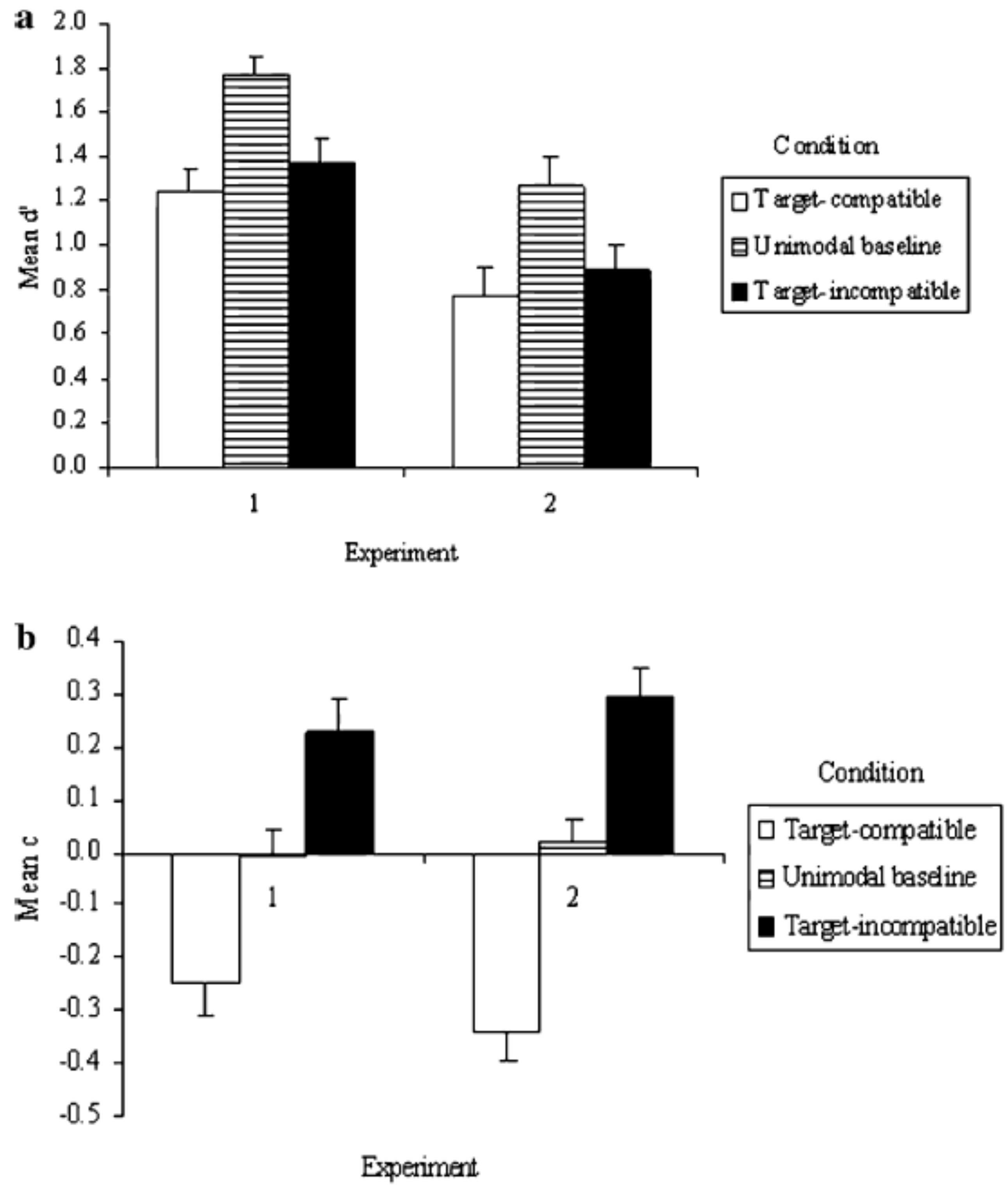
Prop. 'Go' Trials = Hit

Prop. 'Go' Trials = FA



Example

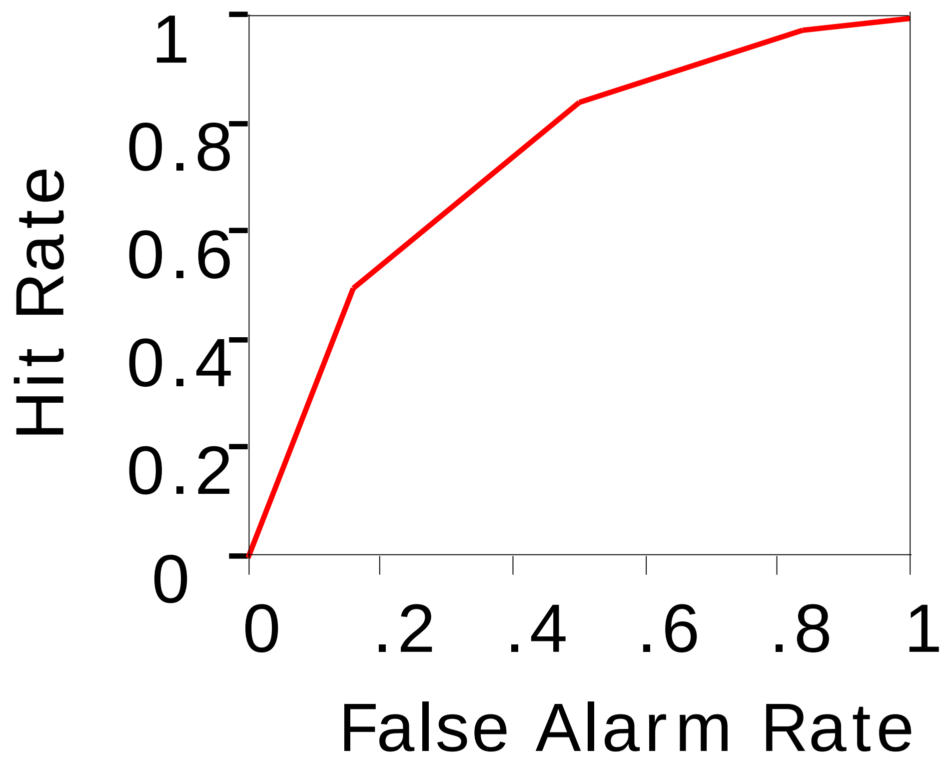
- Results



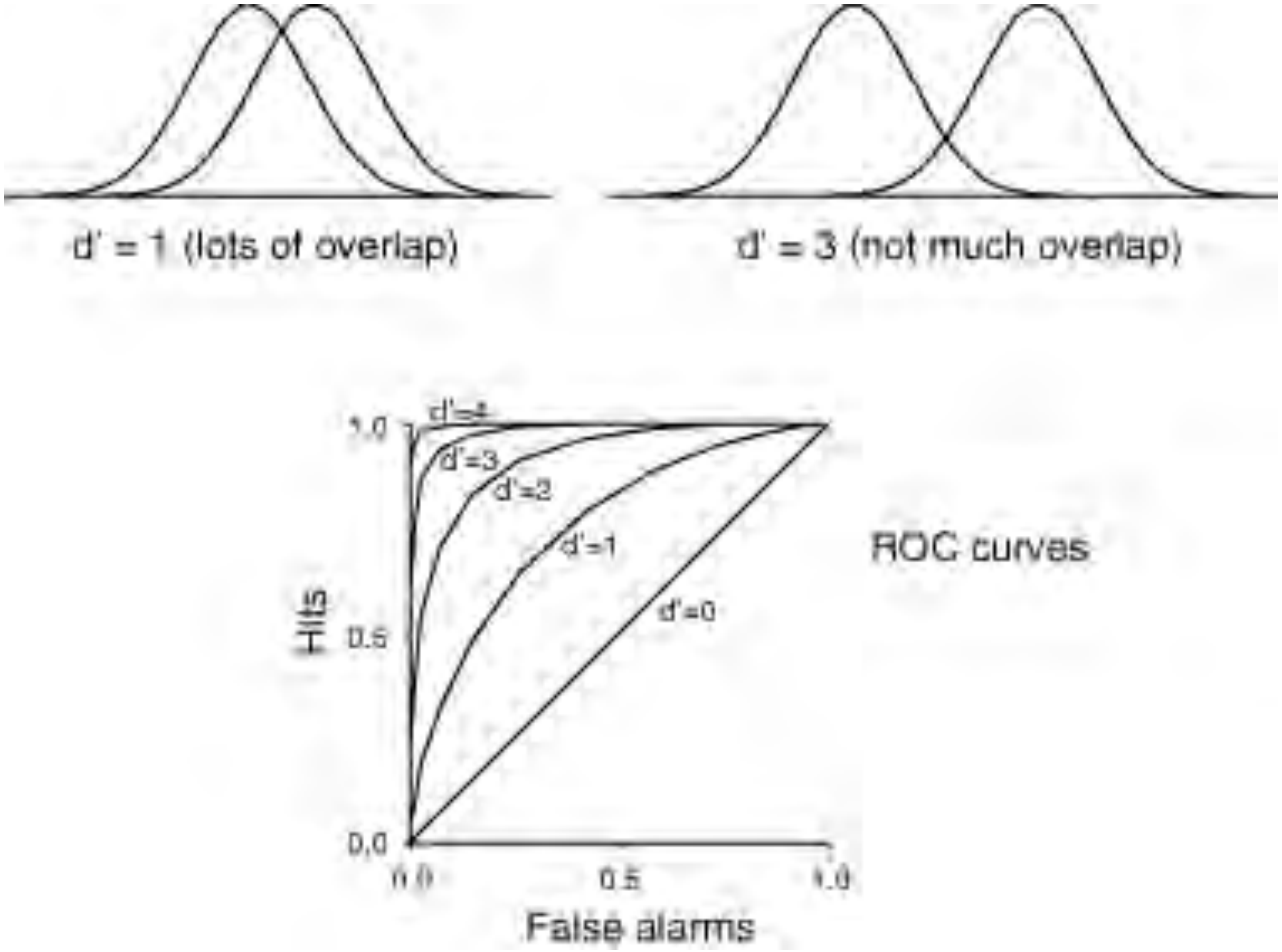
Receiver Operating Characteristic Curve (ROC)

- A graph of P(HIT) vs. P(FA)
- with same sensitivity d', multiple criteria
  - by changing pay-off for subject
- Example:

	Hit	FA
C1	0.975	0.84
C2	0.84	0.5
C3	0.5	0.16

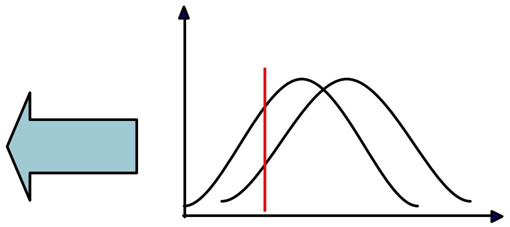


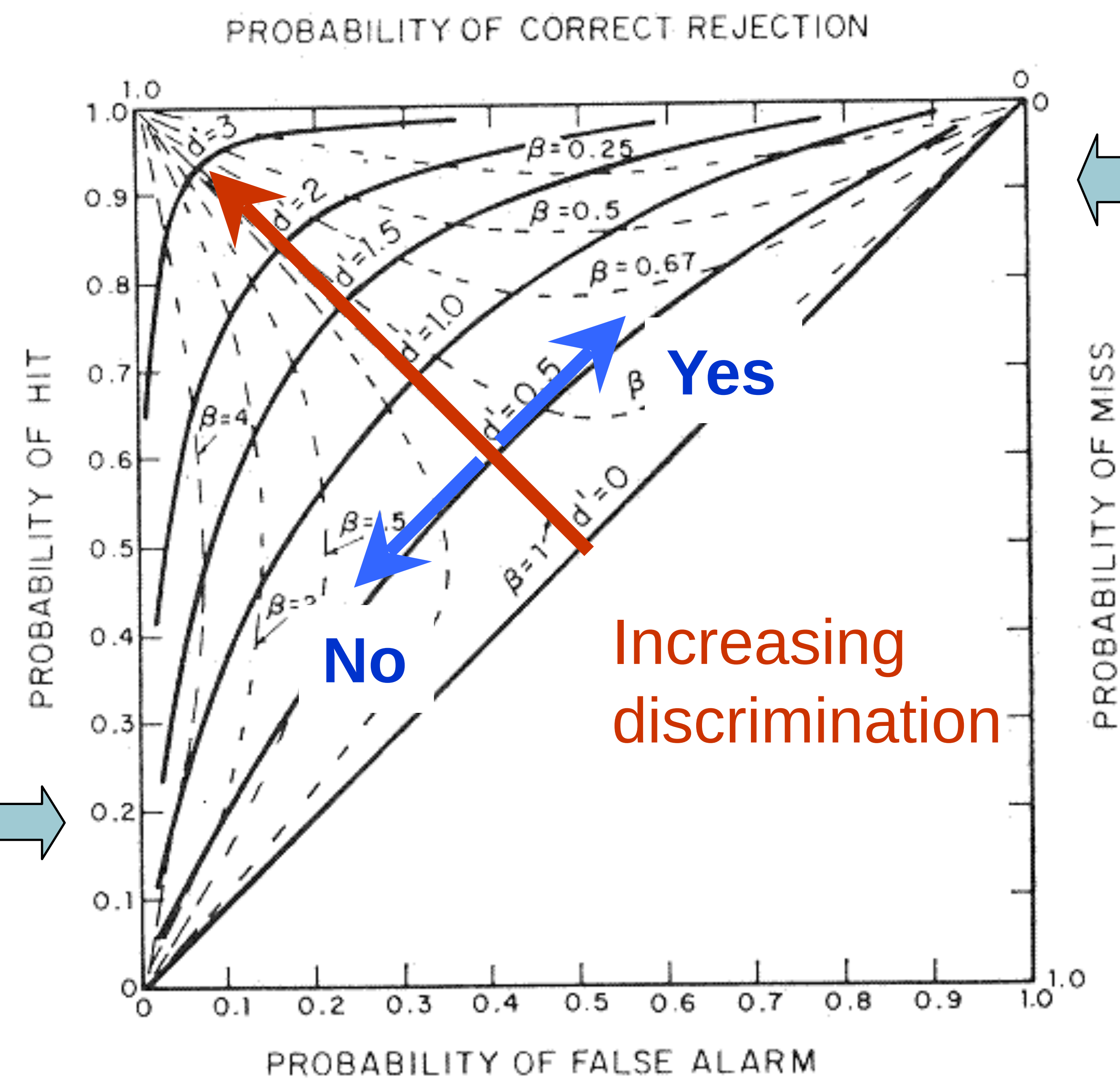
ROC Curves

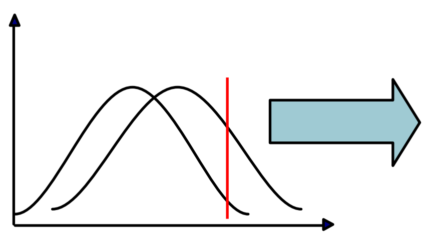


Demo at: http://wise.cgu.edu/sdtmod/signal_applet.asp

ROC Curves



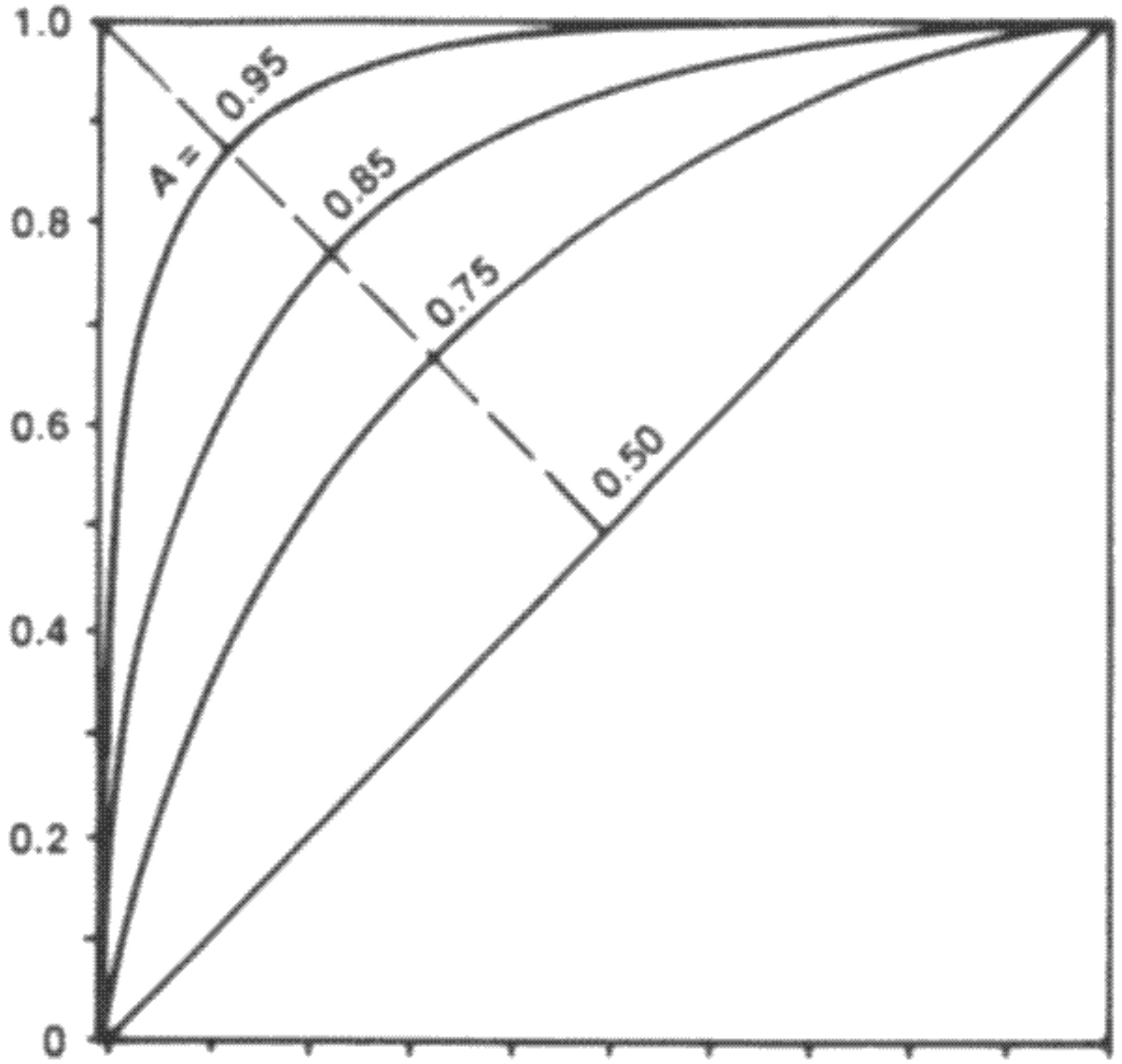

PROBABILITY OF CORRECT REJECTION
PROBABILITY OF HIT
PROBABILITY OF MISS
PROBABILITY OF FALSE ALARM
d'=3
d'=2
d'=1.5
d'=1.0
d'=0.5
d'=0
β=0.25
β=0.5
β=0.67
β=4
β=1.5
Yes
No
Increasing
discrimination



Another Index of discrimination: Accuracy

- Az (Dorfman & Alf, 1969)
  - Area under ROC curve

$$A_z = \Phi\left[\frac{(\mu_S - \mu_n)}{\sqrt{\sigma_n^2 + \sigma_s^2}}\right] = \Phi\left[\sqrt{2}\cdot d_a\right]$$



Where Φ is inverse function of Z

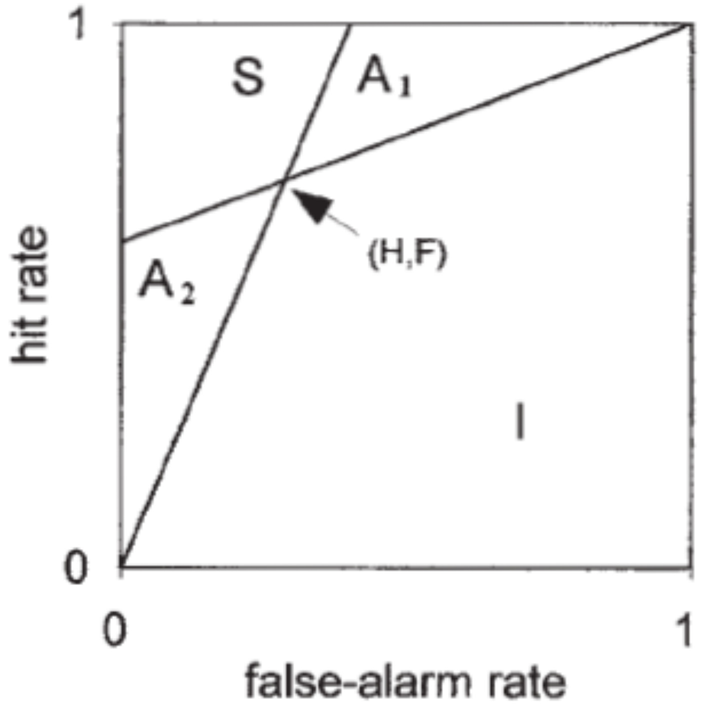
A’ & B”: non-parametric approach

- single HIT/FA pair :
  - Sensitivity A’ (Green, 1964)

$$A' = I + \frac{1}{2}(A_1 + A_2).$$

$$A' = \frac{1}{2} + \frac{1}{4}\frac{(H-F)(1+H-F)}{H(1-F)}$$

  - Hodos’s Bias Measure, B″ (1970)
    - the normalized difference between the areas of the larger triangles *A*1 and *A*2.

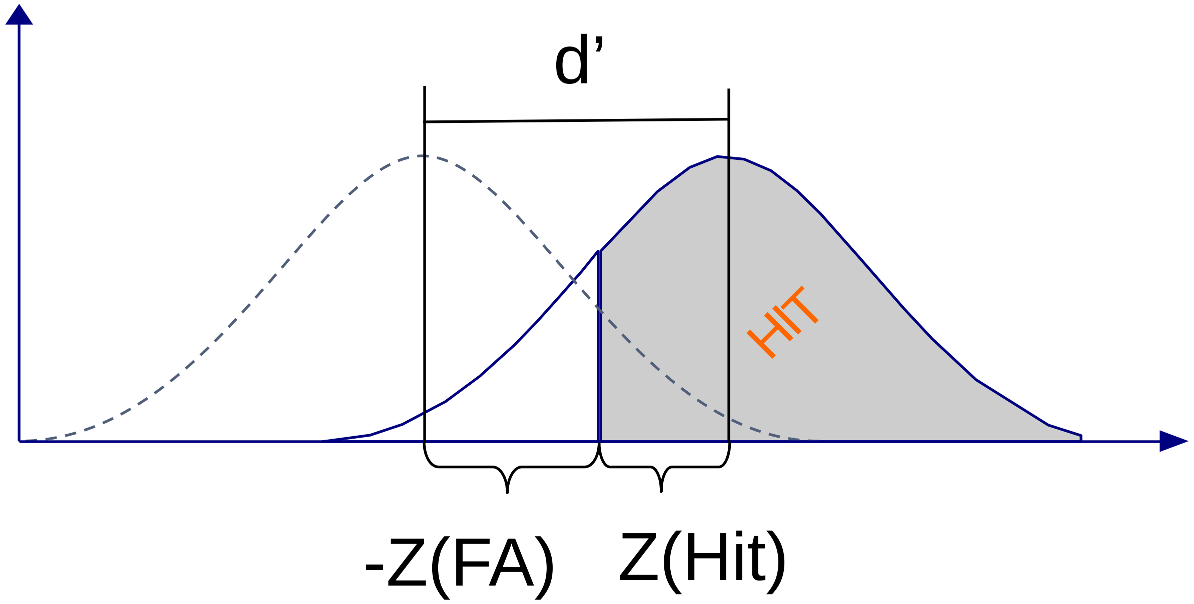


$$B'' = \frac{H(1-H)-F(1-F)}{H(1-H)+F(1-F)}$$

Advantage: without any distribution assumptions

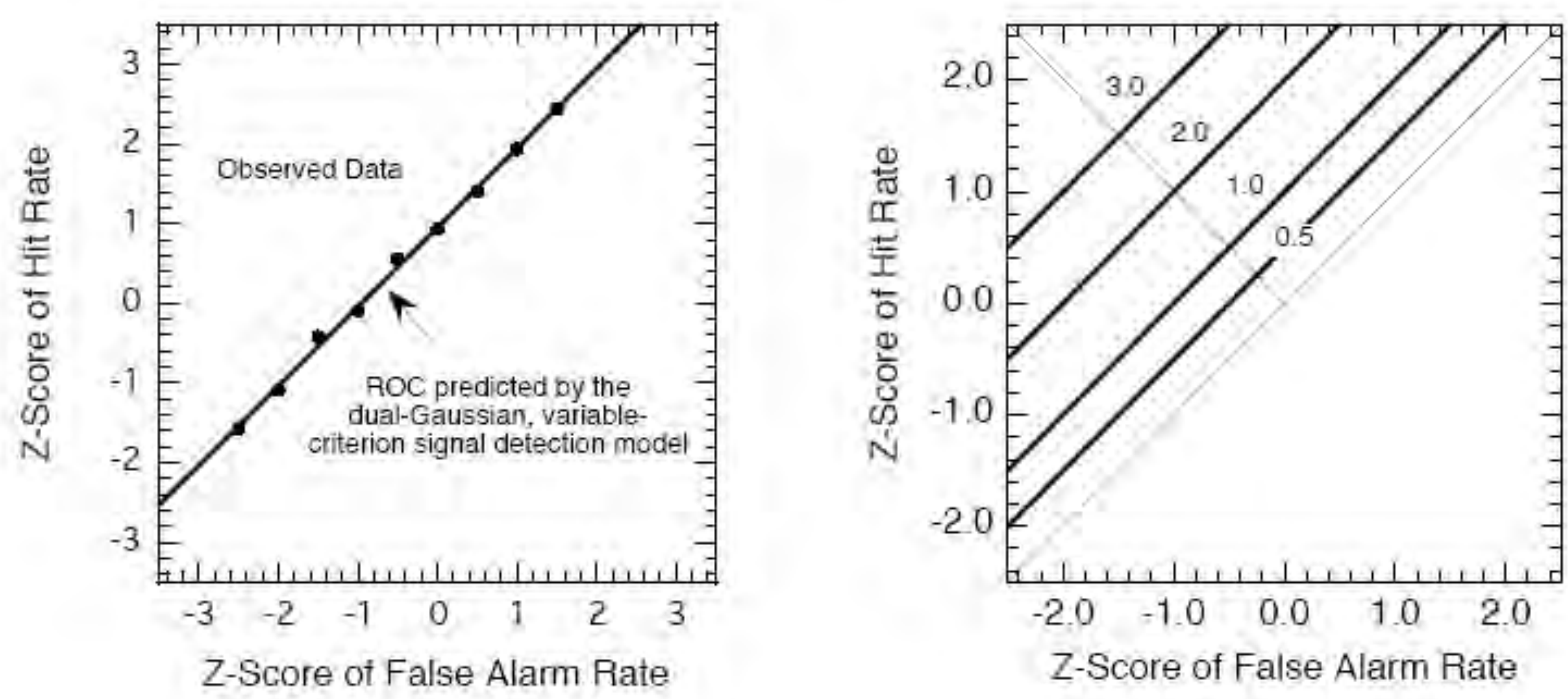
Triangles in ROC space (Macmillan & Creenlman, 1996)

- Recall the calculation of d’



$$z(H) = d' + z(F)$$

- ROC can be plotted in ‘z-coordinates’



Equal variance: slope b=1
Different variances: slope b≠1

Z-score ROC

- Unequal-variance model (b≠1):

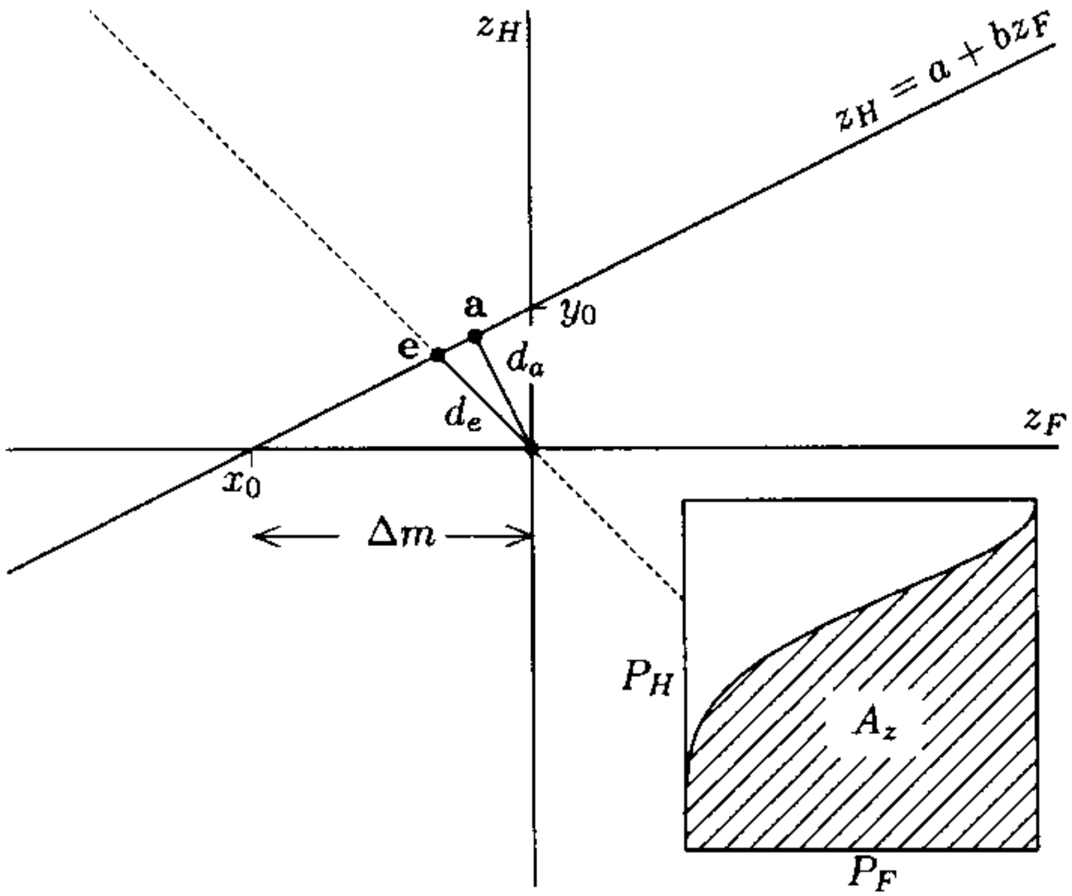
$$z(H) = a + b \cdot z(F)$$

  - Distances to the isosensitivity line

$$d_a = \sqrt{\frac{2}{1+b^2}} \cdot a$$

  - Area under ROC curve

$$A_z = \Phi\left[\frac{a}{\sqrt{1+b^2}}\right]$$



z-score ROC

- Unequal-variance model (b≠1):
  - Response bias (Macmillan & Creelman,1991)

$$C_a = -\frac{\sqrt{2}\cdot b}{\sqrt{\left(1+b^2\right)\cdot\left(1+b\right)}}\cdot\left[z(H)+z(F)\right]$$

  - Note: b=1, Ca = C

$$C = -\frac{Z(Hit)+Z(FA)}{2}$$

Calculation via Excel

- Z-score (from p to z)
  - Normsinv(p)
- Φ (standard normal cumulative distribution)
  - From z to p
  - Normsdist(z)
- Data analysis
  - Office 2007 (2010): Data -> Data analysis
  - Office 2003: ‘Analysis Toolpak’ as add-in
    - Regression
    - Anova
    - Correlation etc…

Calculation via Matlab Statistics toolbox

- Z-Score

$$X = norminv(p, 0, 1)$$

- Φ (normal CDF)

$$P = normcdf(x, 0, 1)$$

- Normal probability density function (PDF)

$$Y = normpdf(X, 0, 1)$$

- Regression

$$[b, bint] = regress(y,X)$$

  - Note: first column of X usually is 1.

SDT for different paradigms

- Empirical measures
  - d',
  - Az,
  - C
  - β
- types of experiments
  - Yes / No paradigm
  - Forced Choice paradigm
  - Confidence rating procedure

Yes-No paradigm

- Various stimuli intensities with blockwise design
  - In same block stimulus intensity keeps constant (present) or blank stimulus (absent)
  - Hit rates & False alarm rates
    - For stimulus present condition
  - d' and C

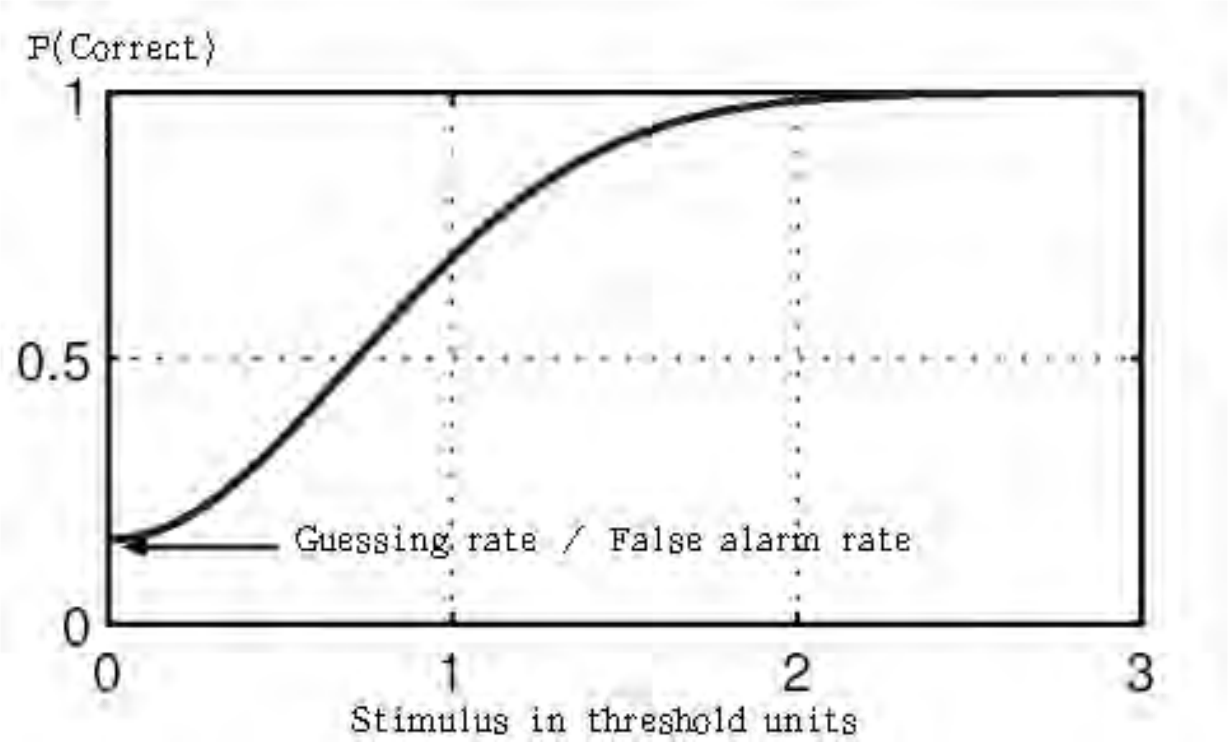
$$d' = z(H) - z(F)$$

$$C = -\frac{Z(H) + Z(F)}{2}$$

Yes-No paradigm

- Method of constant stimuli with one condition is stimulus absent.
  - It produces psychometric function
  - Guessing rate γ = FA rate
  - Covert P(x) to z(x),

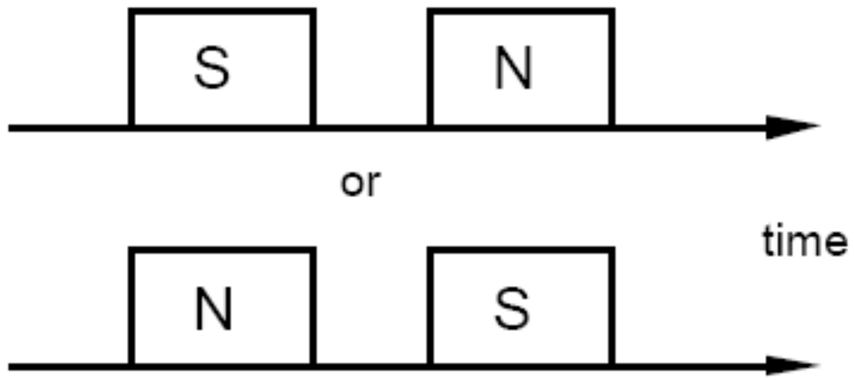
$$d'(x) = z(P(x)) - z(P(0))$$



Two-alternative forced choice (2AFC) paradigm

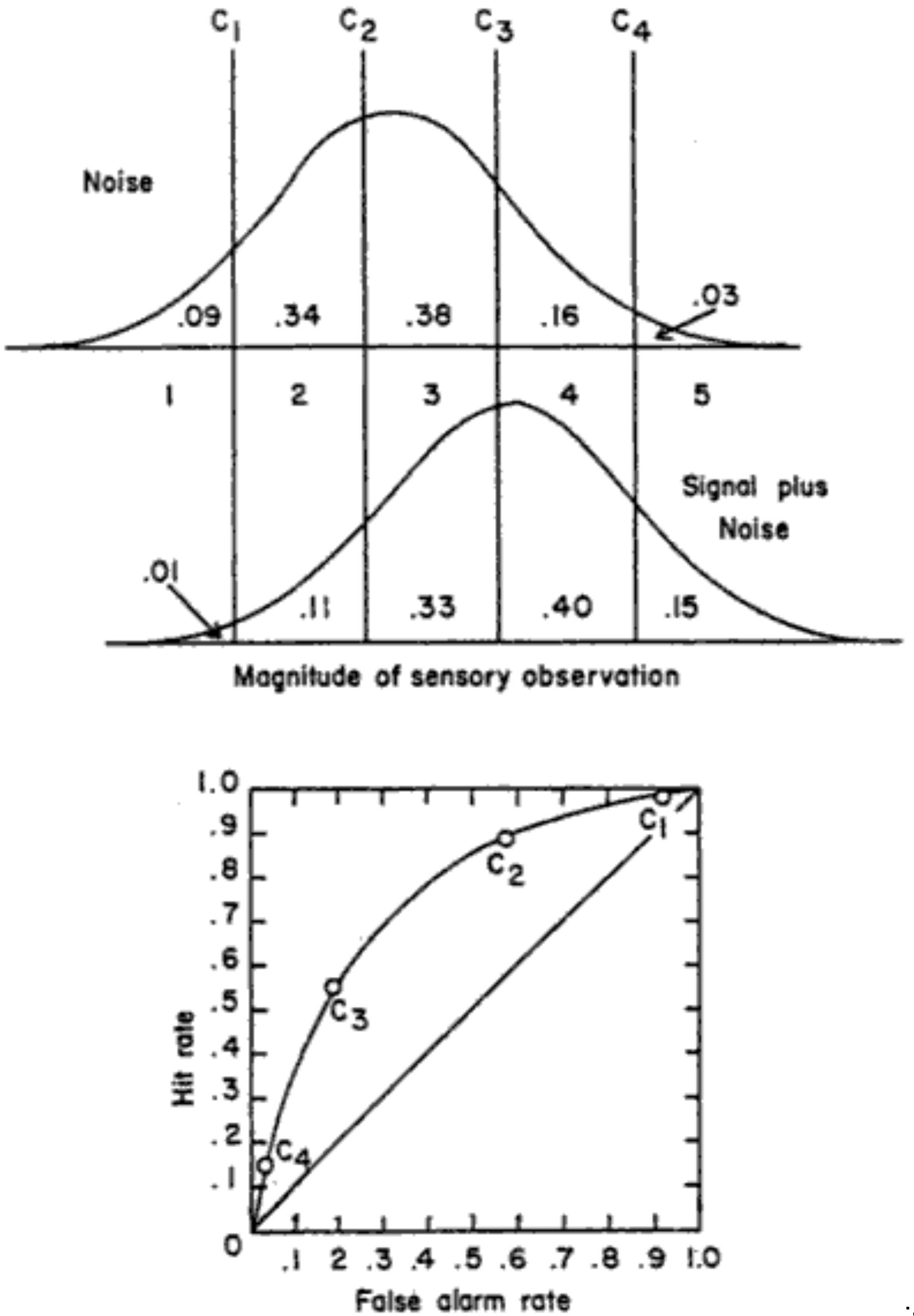
- Procedure
  - On a particular trial, two observation intervals are presented (I1 and I2)
  - Task: to report which observation intervals contained a signal
  - Proportion of correct responses, p(c), are averaged across two intervals
  - sensitivity d’ and p(c) has following relation:

$$d' = \sqrt{2} z(p)$$



Confidence rating paradigm

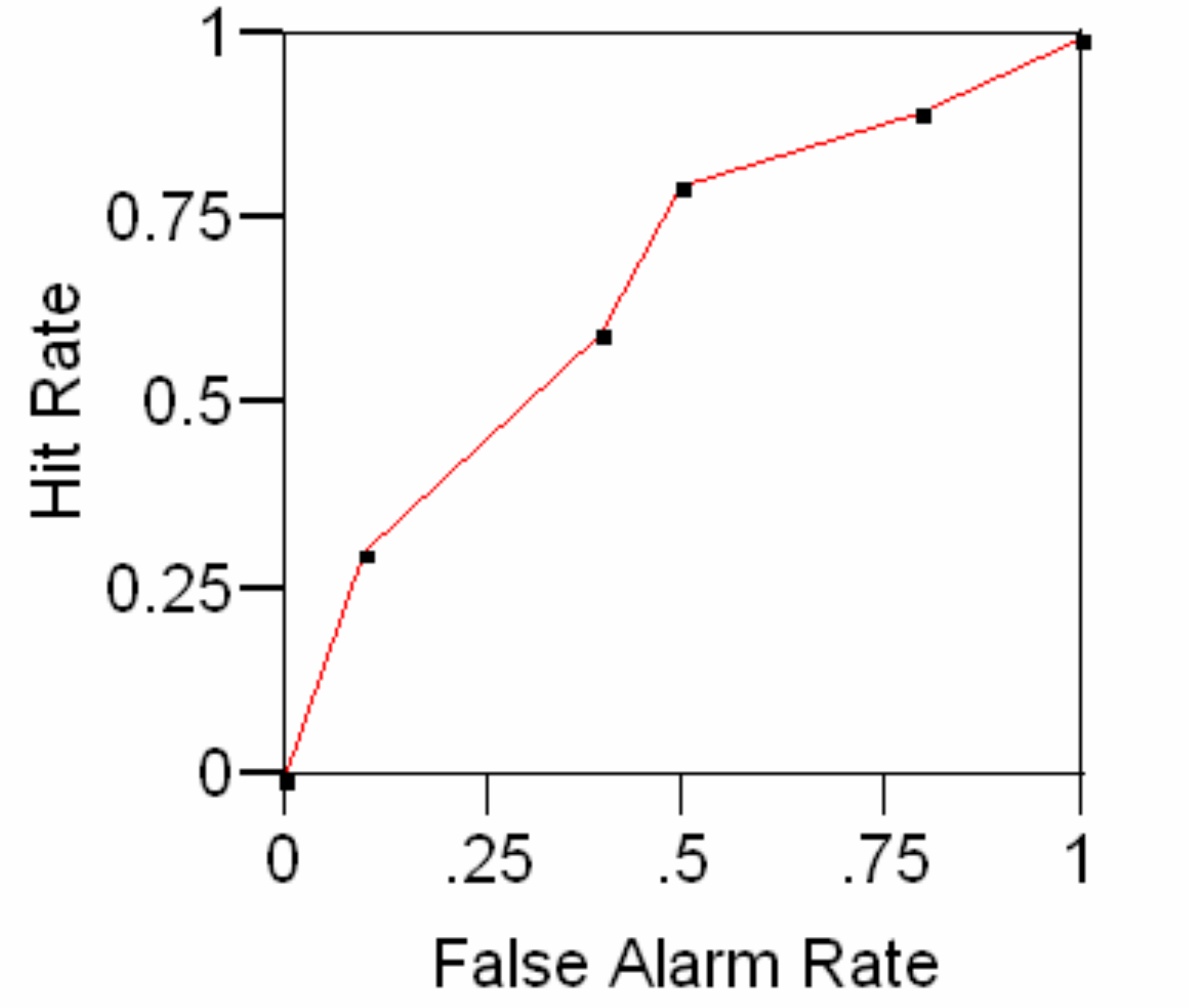
- Procedure
  - Instead of yes-no judgment, the observer is instructed to rate how sure the signal is presented
    - E.g. 4 points rating
  - Calculate P(H) and P(FA) by accumulating probability



Confidence rating paradigm

- Example

Response	S	N	CS	CN
“No” 1	0.3	0.1	0.3	0.1
2	0.3	0.3	0.6	0.4
3	0.2	0.1	0.8	0.5
4	0.1	0.3	0.9	0.8
“Yes” 5	0.1	0.2	1.0	1.0

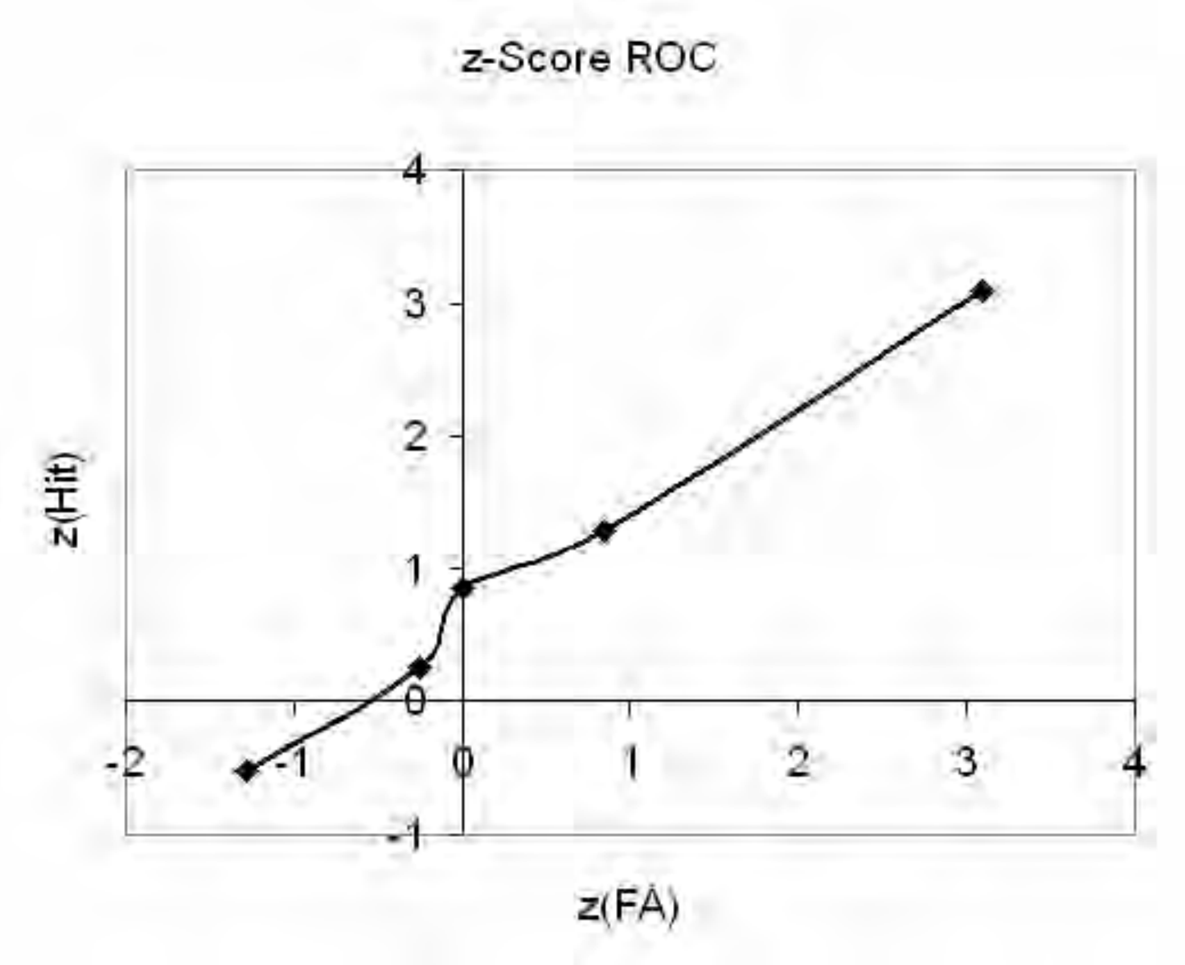


Confidence rating paradigm

- Using linear regression

$$z(H) = a + b \cdot z(F)$$

  - estimate intercept **a** and slope **b** from z-score ROC



Confidence rating paradigm

- Sensitivity

$$d_a = \sqrt{\frac{2}{1+b^2}} \cdot a$$

- Accuracy Az

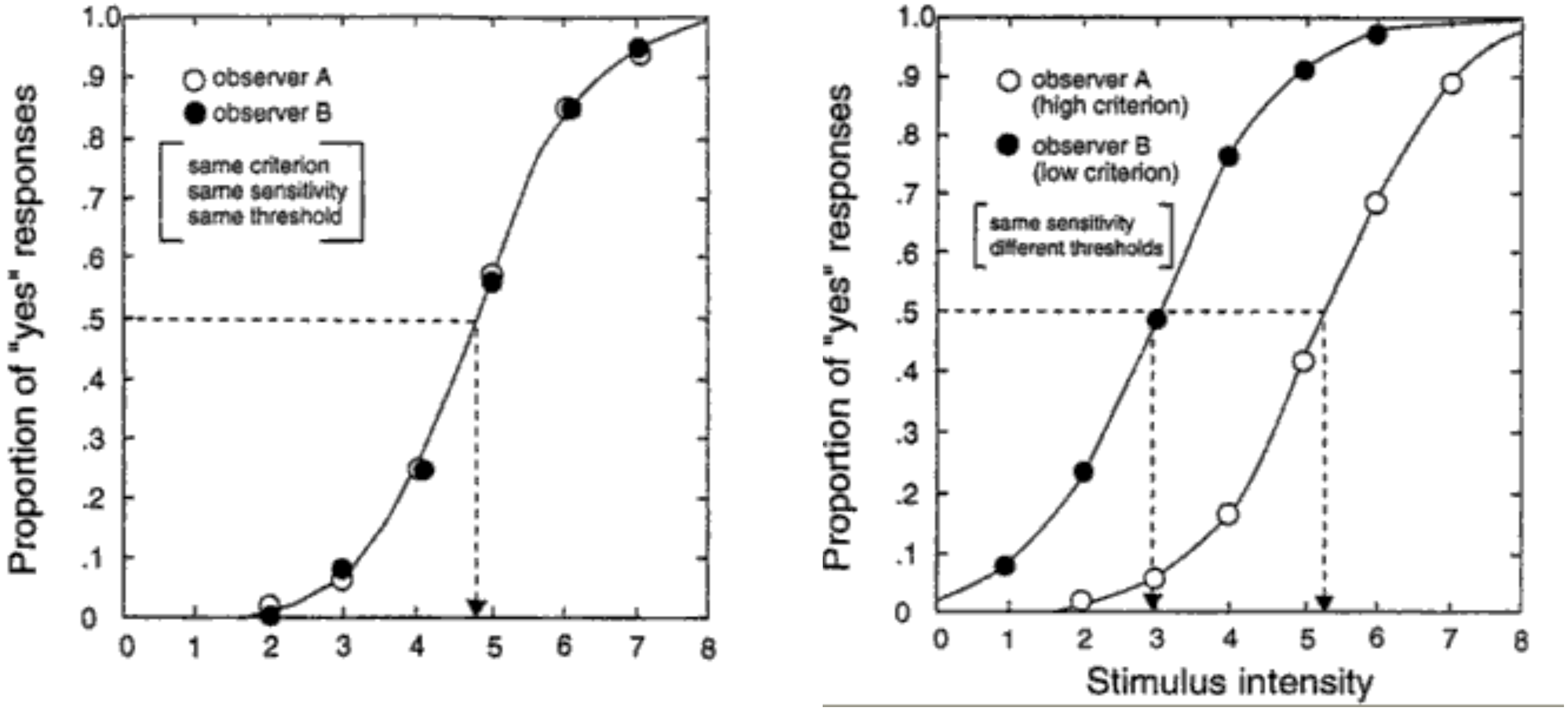
$$A_z = \Phi\left[\frac{a}{\sqrt{1+b^2}}\right]$$

- Response bias

$$C_a = -\frac{\sqrt{2} \cdot b}{\sqrt{(1+b^2) \cdot (1+b)}} \cdot [z(H) + z(F)]$$

Threshold and sensitivity

- Threshold is often defined as the stimulus strength that produces a probability correct halfway up the PF.
  - This is often contaminated by subjective criterion



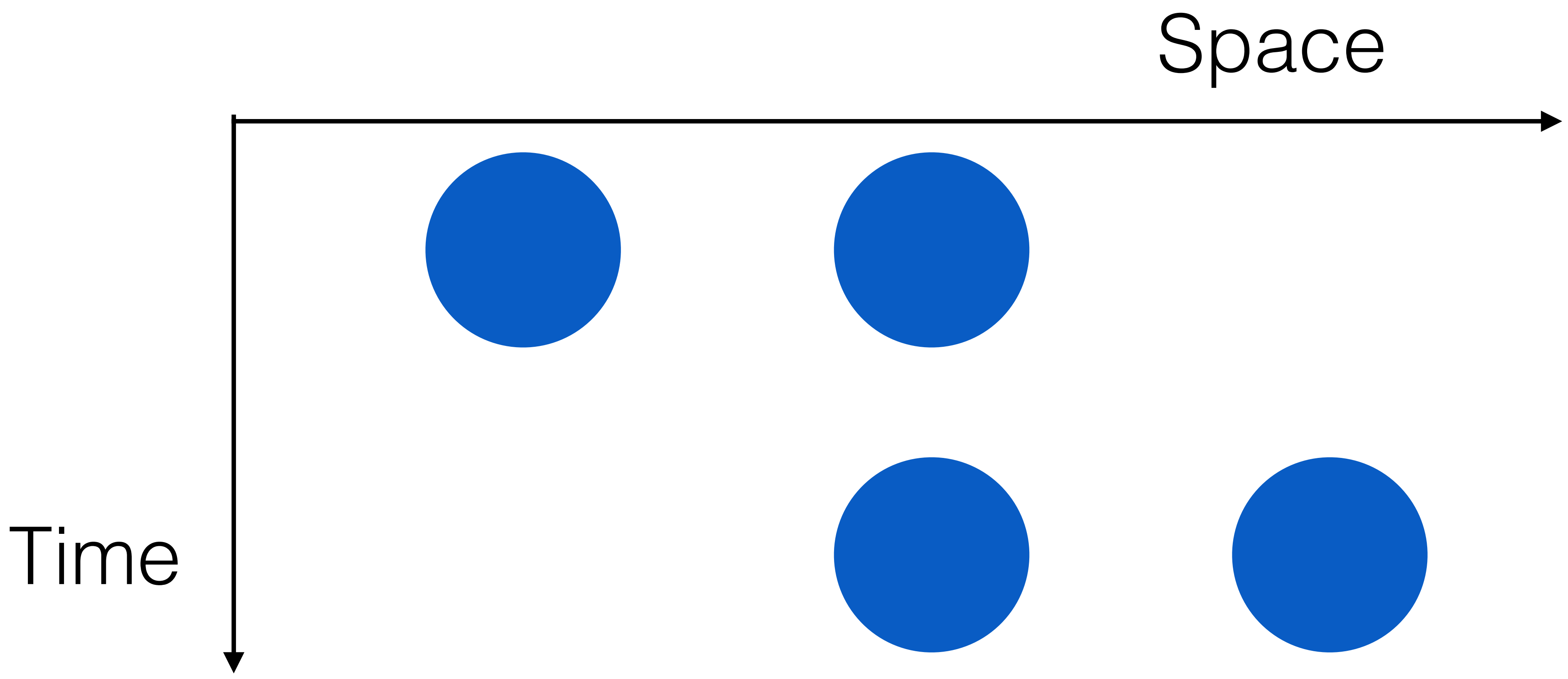
Threshold and sensitivity

- A relatively stable of definition of threshold is to define threshold as the stimulus strength that gives a fixed value of d' (Klein, P&P, 2001)
  - For example for 2AFC paradigm, one could define threshold at d'=1
    - 76% correct for 2AFC

$$d' = z(p)\cdot\sqrt{2} \rightarrow p = \Phi(d'/\sqrt{2})$$

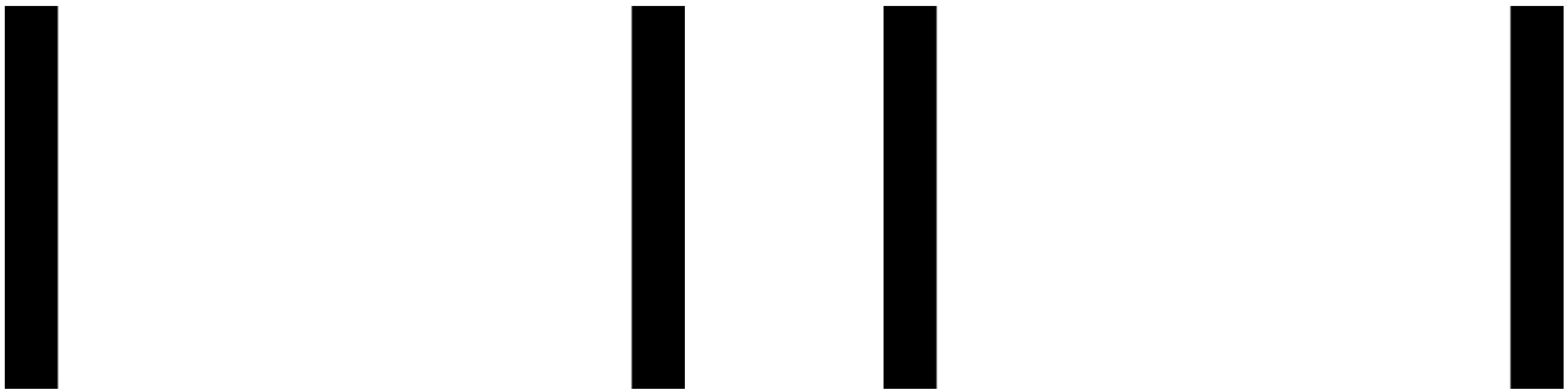
    - d' calcuated by z(Hit) and z(FA)

- 1. Psychometric function estimation
  - Ternus apparent motion



Tutorial Part II

- 1. Psychometric function estimation
  - Ternus apparent motion



- Dataset
  - psychophysics.xls, tab: psychometric function

SOA (ms)	Response
110	1
200	1
110	0
260	1
80	0

Tutorial Part II

- 1. Psychometric function estimation
- Tasks:
  - to estimate the psychometric curve (using logistic function) from the data
  - to estimate the transition threshold from the 'element motion' to the 'group motion'.
- SPSS
  - Regression à Binary logistic regression

Tutorial Part II

- 2. Signal detection
  - Visibility and backward masking
  - Dataset:
    - psychophysics.xls, tab: Signal detection
  - Tasks
    - Plot ROC curve for this dataset.
    - Estimate Az (da) and Ca

Response	S	N
“No” 1	0.3	0.1
2	0.3	0.3
3	0.2	0.1
4	0.1	0.3
“Yes” 5	0.1	0.2

Next week

- Exam
- 20 minutes
- Several questions from RT methods
- several questions from psychophysics
- Multiple choices