

Psychophysics II

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Last week

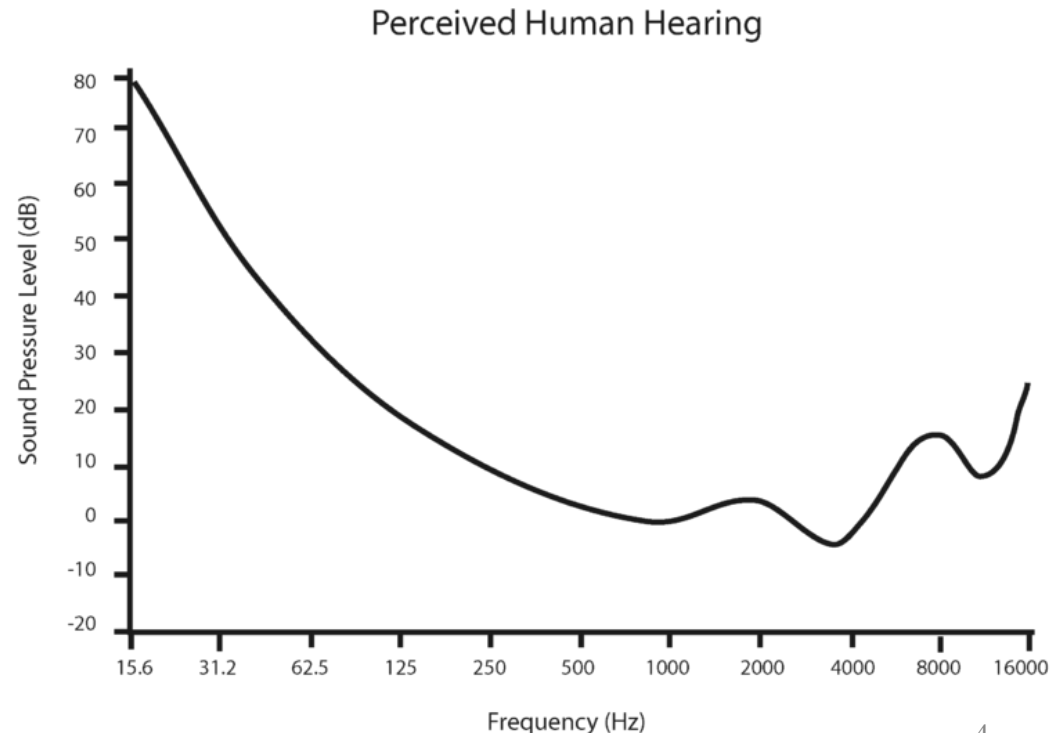
- Psychophysical Laws
 - Weber's law
 - Fechner's law
 - Stevens' power law
- Methods of experimentation
 - Method of limits
 - Method of adjustment
 - Method of constant stimuli

Homework

- Psychophysical methods in research
- Psychophysics in daily applications?

The Mosquito alarm

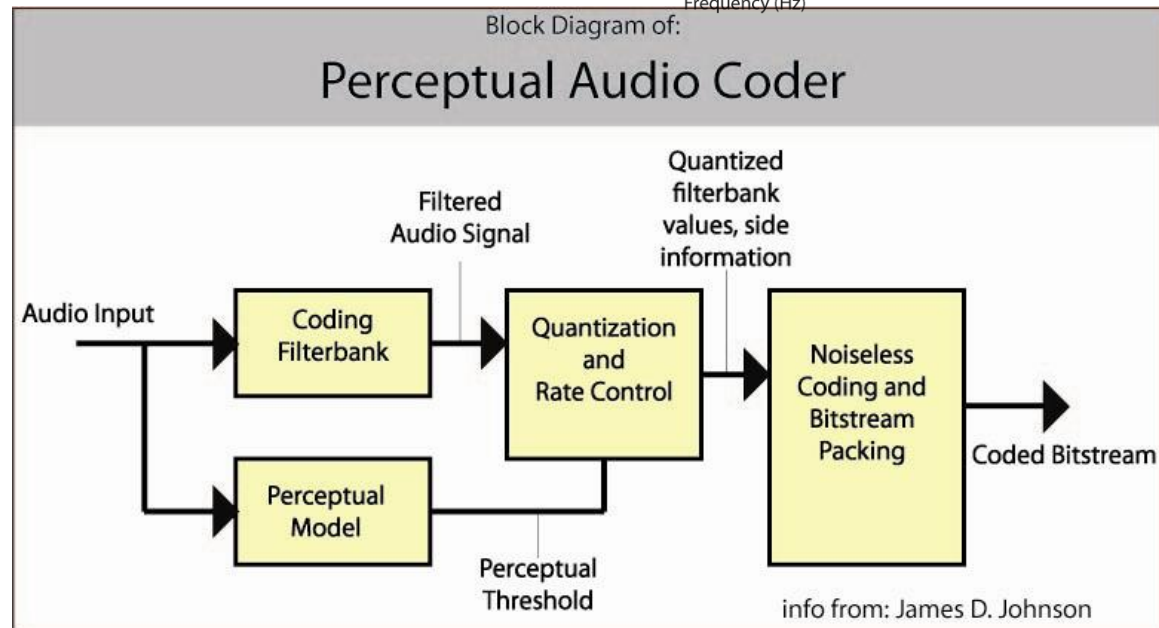
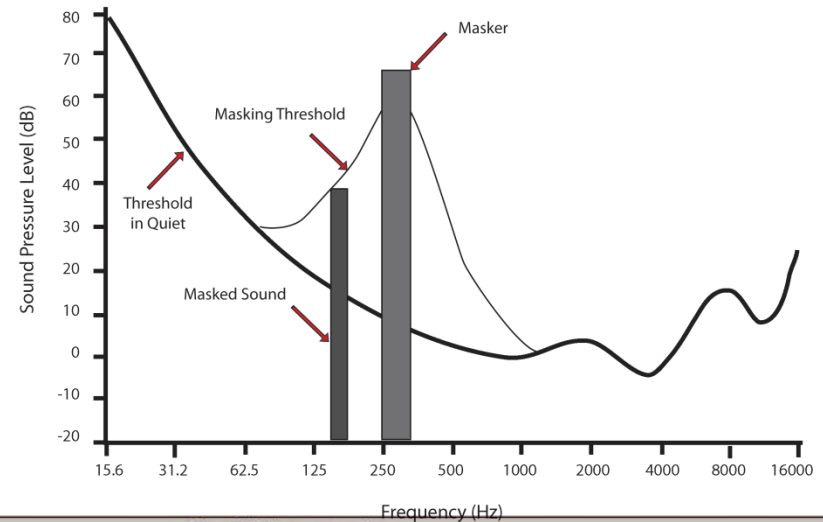
- Ig Nobel prize for ‘peace’, 2007
 - a device that makes annoying high-pitched noise designed to be audible to teenagers but not to adults; and for later using that same technology to make telephone ringtones that are audible to teenagers but probably not to their teachers.
 - Hearing limits:
 - 20 Hz – 20 kHz
 - Most adults
 - < 16 kHz
 - Device:
 - 17.4 kHz, 108 dB



Psychoacoustics and MP3 encoding

- Auditory masking
- Absolute thresholds
- High frequency limits
- Psychoacoustic model

provide high
quality lossy
signal
compression



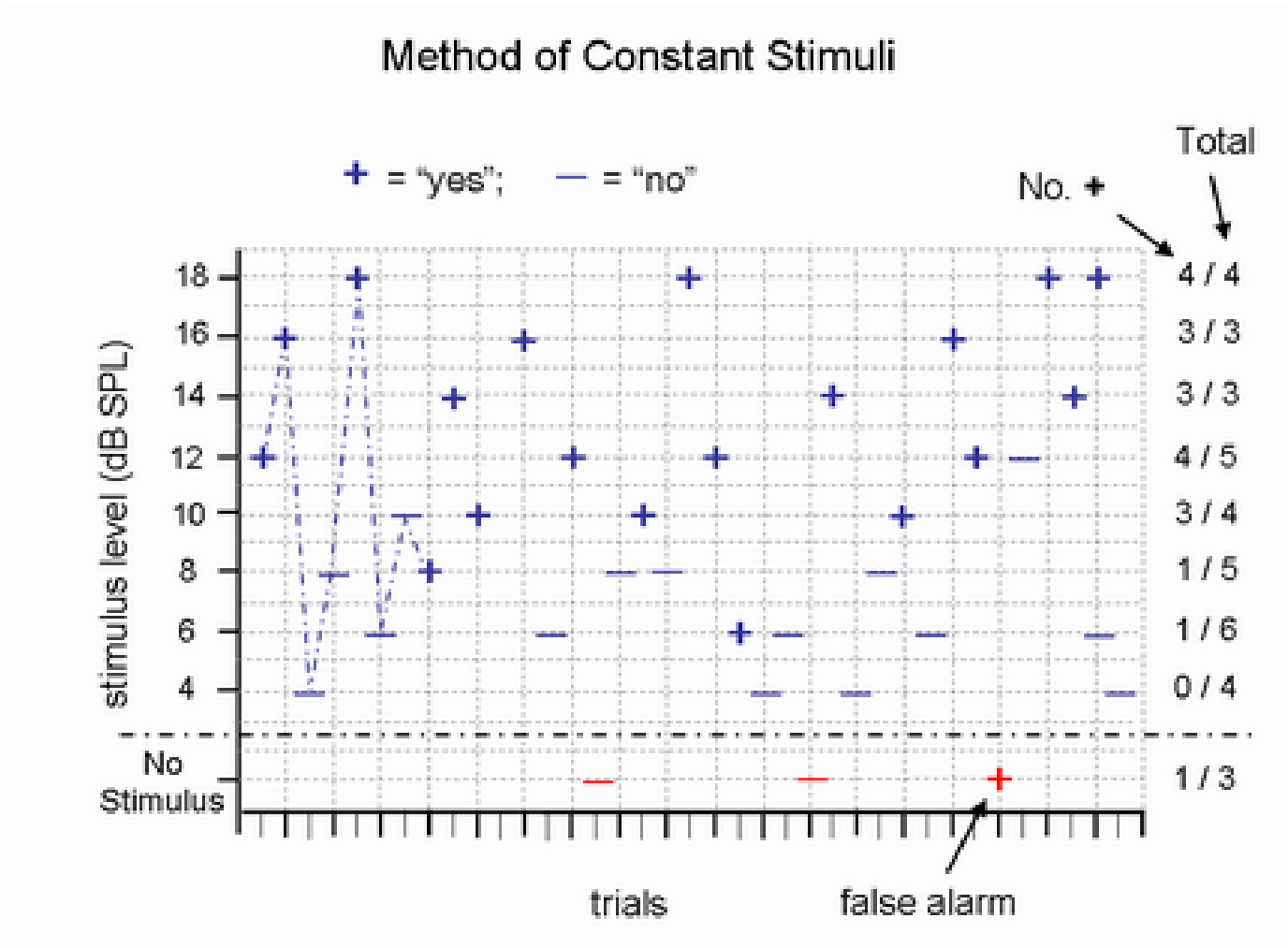
Outline

- Method of constant stimuli
- Psychometric function & estimation
- Adaptive methods
 - Staircase procedures
 - Simple staircase method
 - Adaptive staircase method
 - Adaptive psychometric methods
- Signal detection theory (I)

3. The method of constant stimuli

- Contrast to methods of limits/adjustment
 - The levels of the stimulus are not related from one trial to the next. They are *randomly* presented.
 - This will reduce errors of habituation and expectation
- Estimating AL or DL, it requires
 - Several equally distributed levels of one property of the stimulus (e.g. intensity)
 - Repeated multiple times for each level
 - psychometric curves

Example



The method of constant stimuli

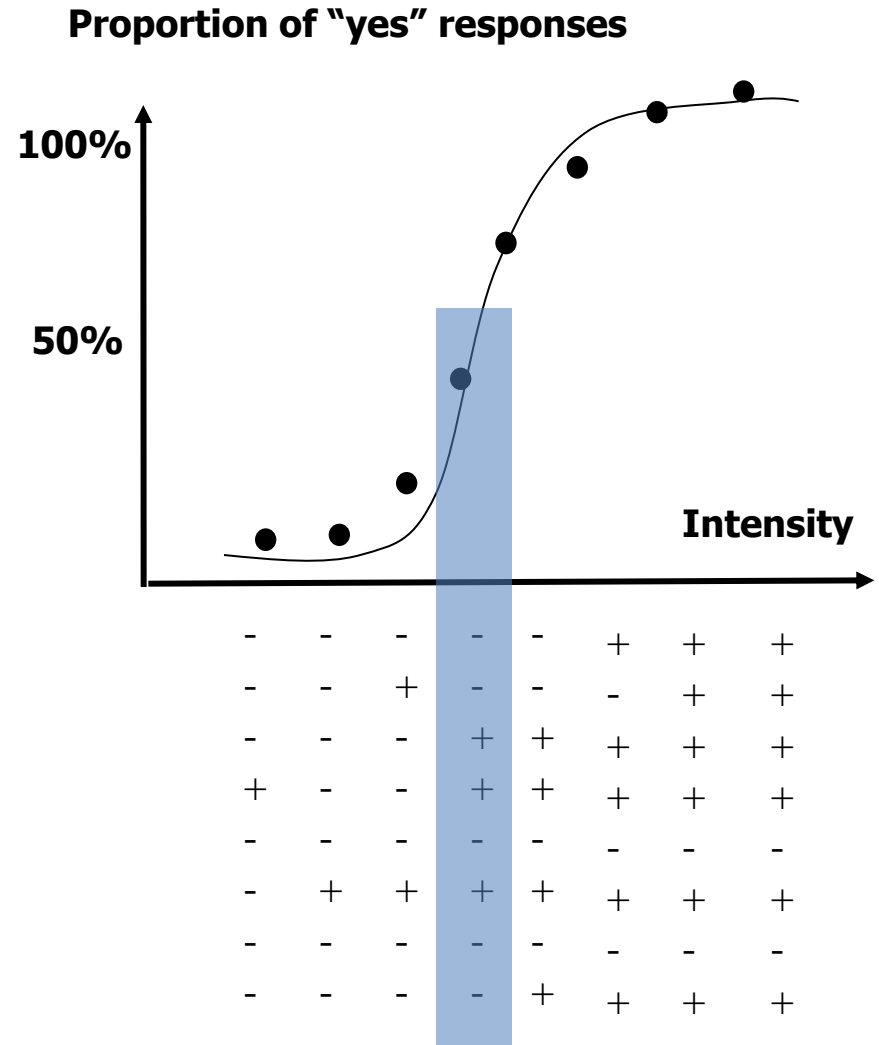
- Measuring absolute threshold (AL)
 1. A series of fixed stimulus intensities (vary from below threshold to above threshold)
 2. Presented in random order
 3. Each value repeated many times (>30)
 4. Responses: Yes / No
 5. plotting of $P(S)$ for several discrete levels and calculate point of 50% (Point of subjective equality, PSE)

The method of constant stimuli

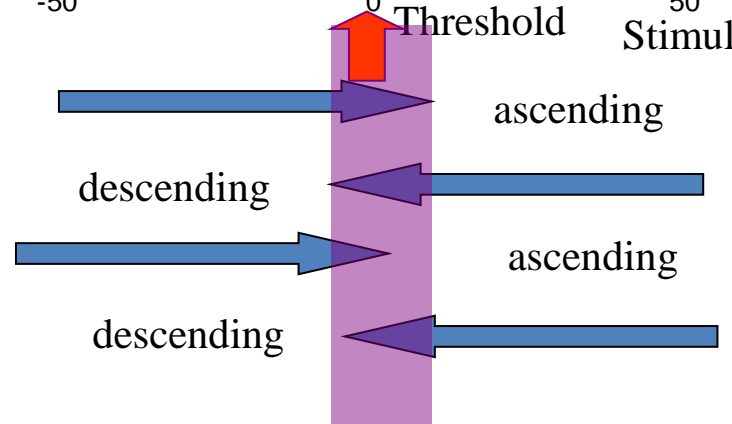
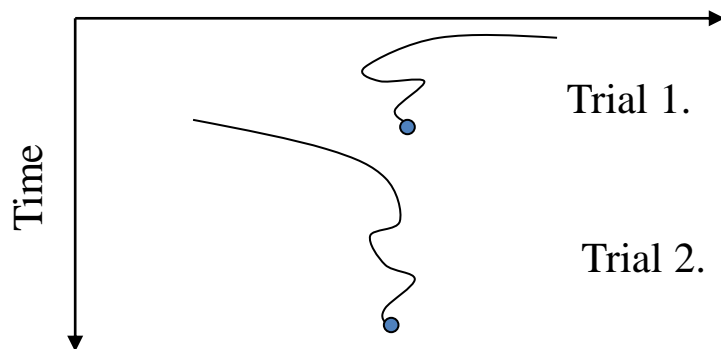
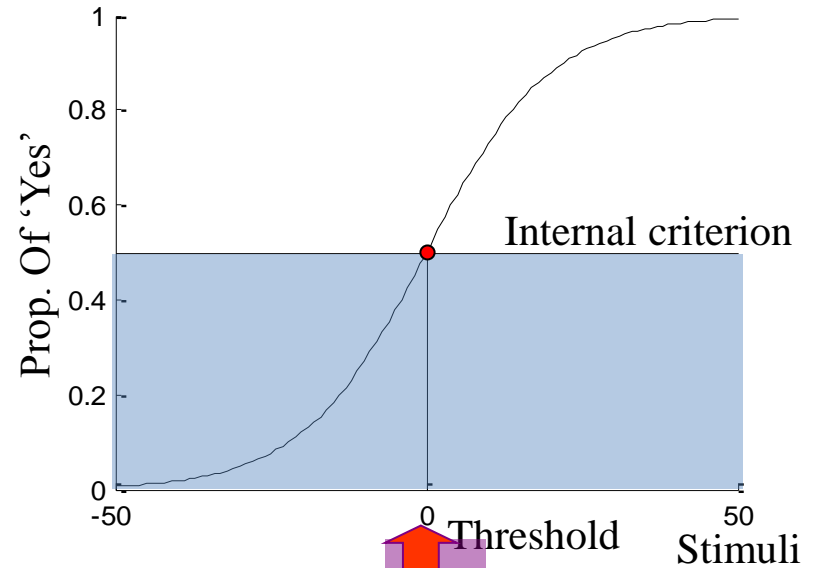
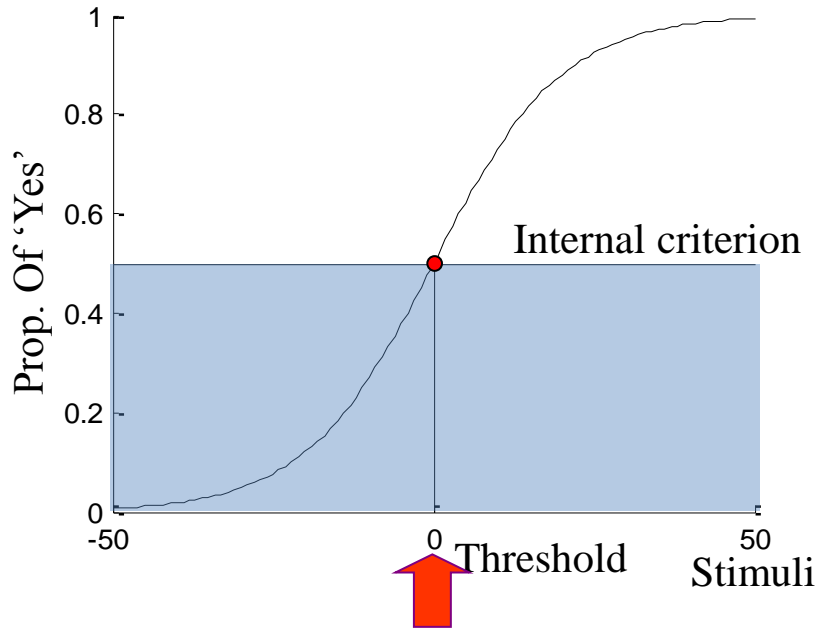
- Measuring difference thresholds (DL)
 1. Present 2 stimuli; reference and test stimulus.
 2. Reference is a standard fixed stimuli.
 3. Change test stimulus from trial to trial randomly with equal number above and below the reference value.
 4. Positions or orders of two stimuli must be counter-balanced
 5. Rest procedures are similar as in AL procedure

Method of Const. Sti. & Psy. Function

- Multiple Intensity levels, multiple repetition
- Prop. of responses
 - Roughly S-shape
 - Psychometric function can be estimate
- Multiple data points
 - Better picture of stimulus-perception relationship
 - Sensitivity (steepness of the psychometric curve)



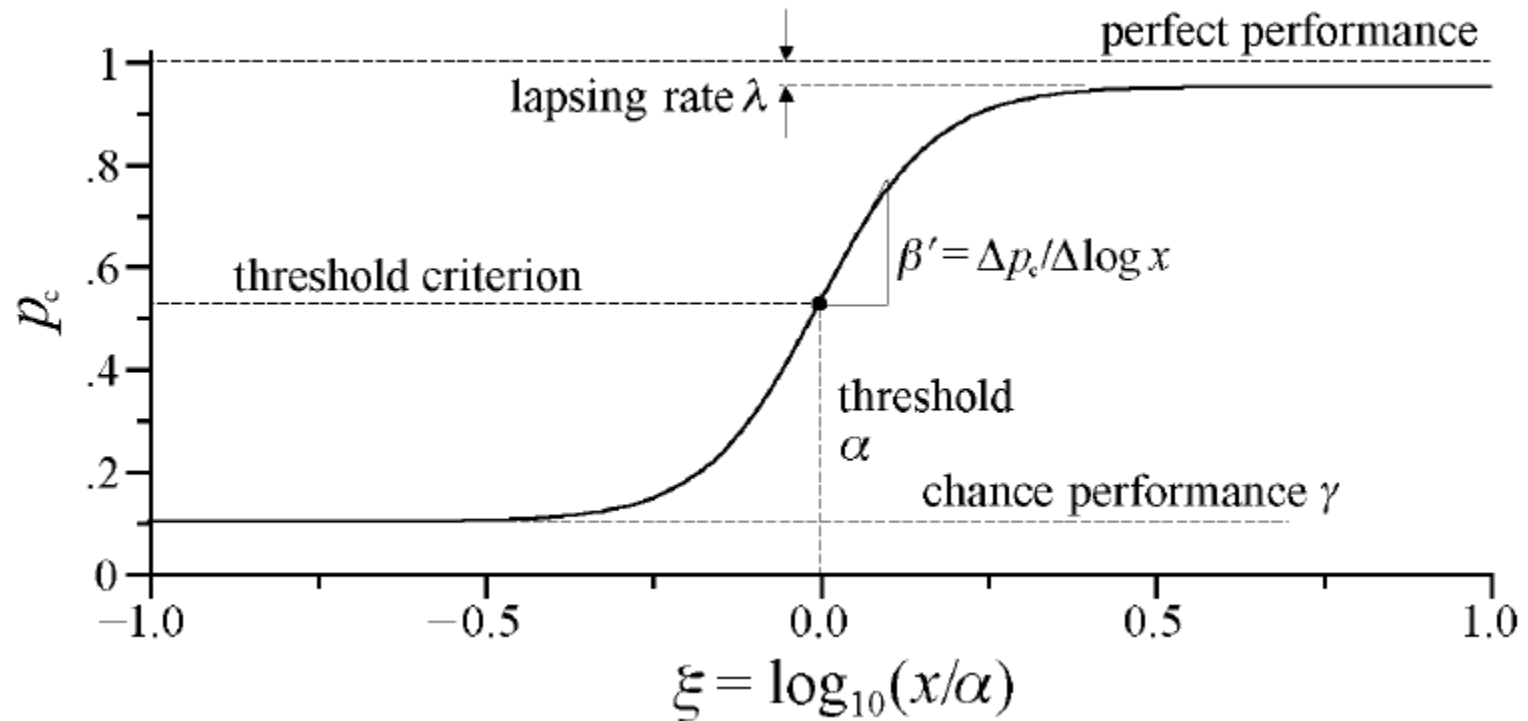
Methods of limits and methods of adjustment



method of constant stimuli

- Advantages:
 - The order of presentation is random
 - Not only 50% threshold can be estimated, other points (e.g. 75%) can also be estimated.
 - Sensitivity can also be measured
 - Steep slope: sensitive to physical stimuli variation
 - Shallow slope: relative insensitive
- Disadvantages:
 - Some experiments might take quite long time
 - Not suitable for some patient studies, or developmental studies with children
 - Learning effects

Psychometric function

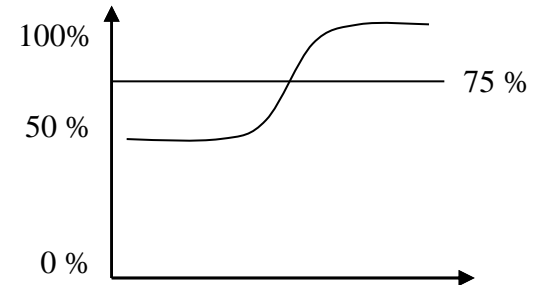
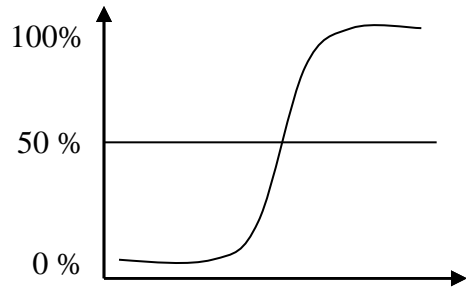


$$\psi^*(x) = \frac{\psi(x) - \gamma}{1 - \gamma - \lambda}$$

(Strasburger, 2001)

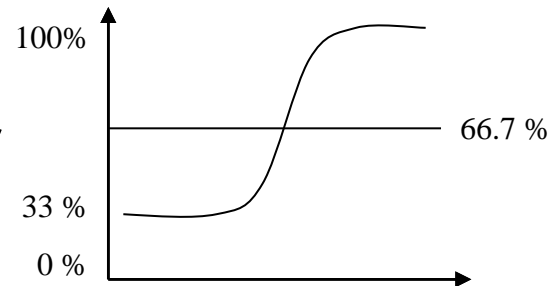
Psychometric function

- Yes / No paradigm ➤ 2 alternative force choice (2AFC)



- 3AFC (Odd one out)

$$\psi^*(x) = \frac{\psi(x) - \gamma}{1 - \gamma - \lambda}$$



Candidates of Psychometric function

- Candidate functions of Psychometric function
 - Logistic function
 - http://en.wikipedia.org/wiki/Logistic_function
 - Gauss error function
 - http://en.wikipedia.org/wiki/Error_function
 - Weibull function
 - http://en.wikipedia.org/wiki/Weibull_distribution

psychometric function estimation

- Logistic function

$$p = \frac{1}{1 + \exp^{-(x-a)/b}}$$

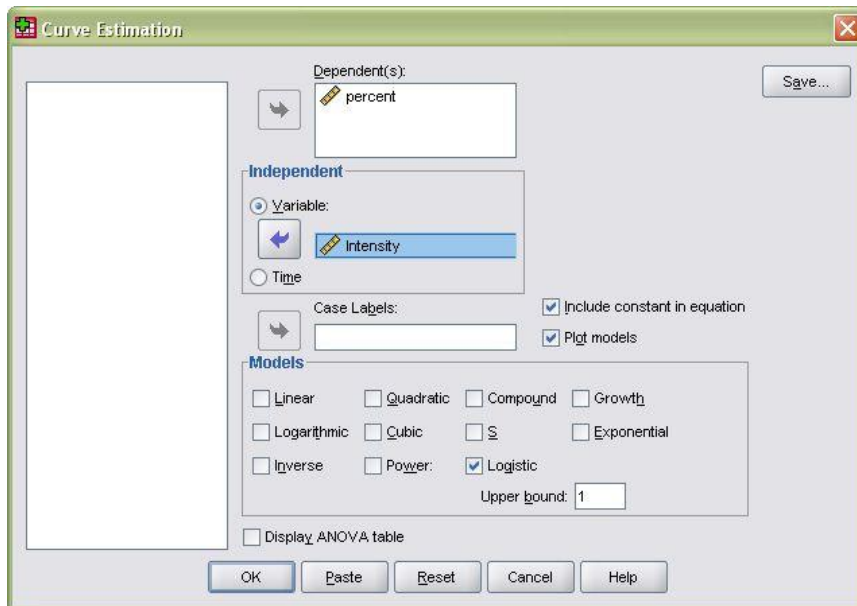
- Point of subjective equality (PSE at 50%, $p=0.5$)
 - Threshold: $x = a$
- Just noticeable difference (JND)
 - Usually is defined as half of difference between upper threshold (75%) and lower threshold (25%)
 - $JND = b * \log 3$

psychometric function estimation (SPSS)

- Method 1

- With estimated percentages of response

- Regression → Curve-Estimation → Logistic (upper bound 1)



Intensity	percent
0.10	0.01
0.20	0.10
0.30	0.30
0.40	0.50
0.50	0.72
0.60	0.90
0.70	0.97

psychometric curve estimation (SPSS)

- Method 1

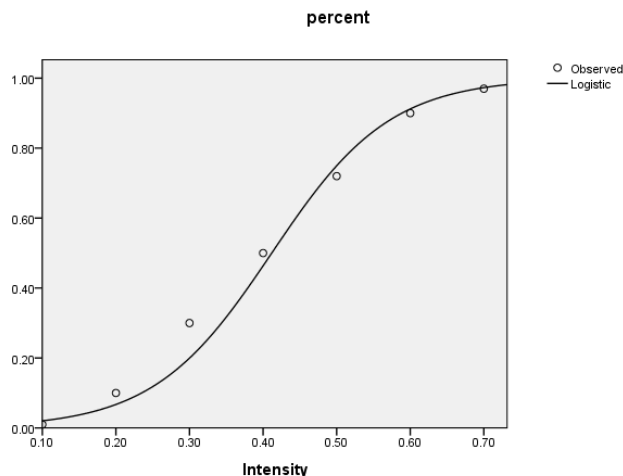
– Regression → Curve-Estimation

Model Summary and Parameter Estimates

Dependent Variable: percent

Equation	Model Summary					Parameter Estimates	
	R Square	F	df1	df2	Sig.	Constant	b1
Logistic	.976	200.649	1	5	.000	166.767	4.011E-6

The i



$$p = \frac{1}{1 + c \cdot e^{x \cdot \log b}}$$

$$\log \left(\frac{1-p}{p} \right) = \log c + \log b \cdot x$$

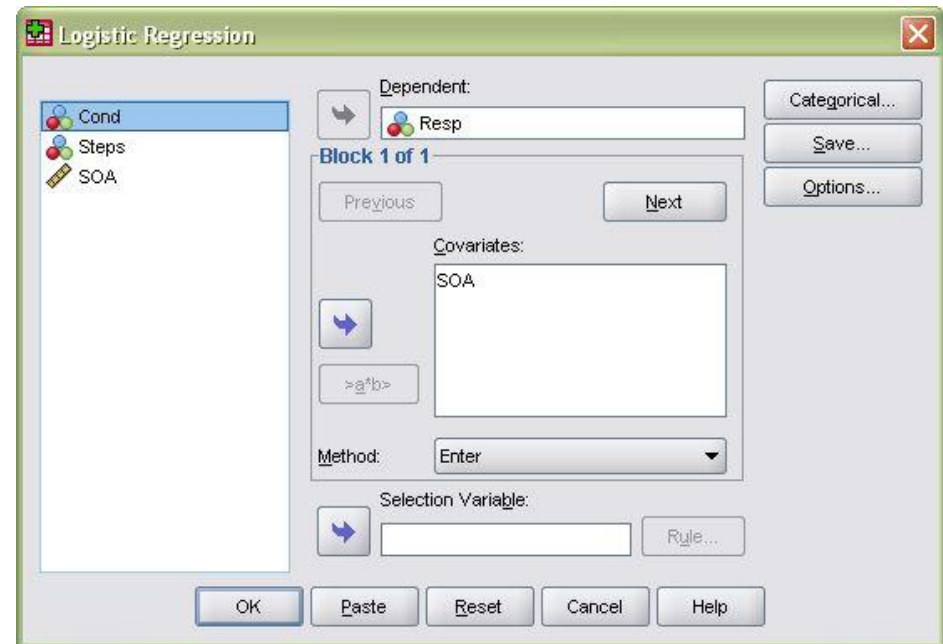
$$p = 0.5 \quad x = -\frac{\log c}{\log b}$$

psychometric function estimation (SPSS)

- Method 2: from raw response data
 - Regression → Binary logistic regression

$$\log\left(\frac{p}{1-p}\right) = a + b \cdot x$$

Cond	Steps	Resp	SOA
1	2	1	110.00
3	4	0	170.00
2	2	0	110.00
2	9	1	320.00
2	3	1	140.00
1	5	1	200.00
2	3	0	140.00
1	5	1	200.00
3	4	1	170.00
3	8	1	290.00
2	7	1	260.00
2	7	1	260.00
3	7	1	260.00
2	7	1	260.00



Fitting psychometric curve

- SPSS: raw response data
 - Regression → Binary logistic regression

$$\log\left(\frac{p}{1-p}\right) = a + b \cdot x$$

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1 ^a	SOA	.034	.002	395.811	1	.000	1.035
	Constant	-5.379	.289	345.708	1	.000	.005

a. Variable(s) entered on step 1: SOA.

$$p = 0.5 \quad x = -\frac{a}{b}$$

Practice of estimating psychometric functions will be given by NCP Tutors next week.

Adaptive methods

Adaptive methods

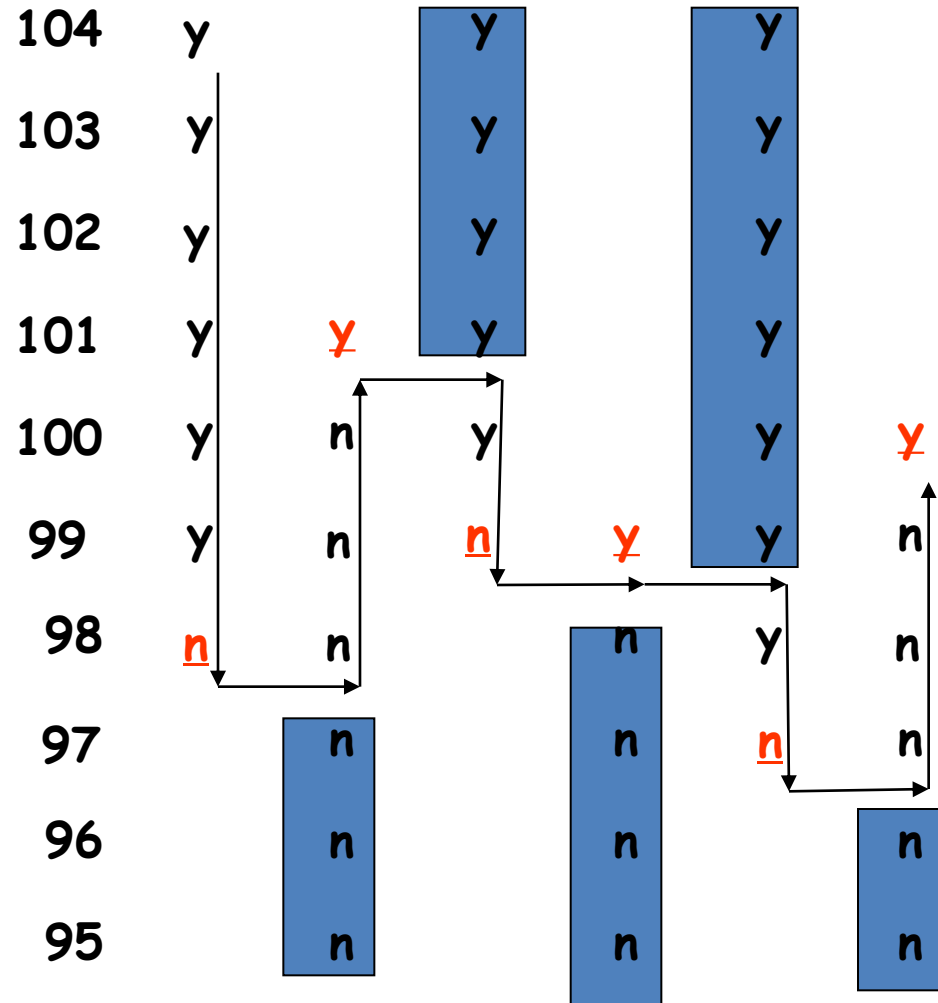
- Combine advantages of randomization from the method of constant stimuli and adaptively adjustments
 - staircase method
 - Double staircase method
 - PEST (parameter estimation by sequential testing)
 - QUEST (Maximum-likelihood adaptive procedures)

Staircase method (Cornsweet, 1962)

- ... they are designed to concentrate data sampling around some interesting region of the psychometric function and to avoid data sampling at too high or too low signal levels.
- The simplest way to arrive at some threshold value is the simple **up-down rule** introduced by the Georg von Békésy (1899-1972).
- The signal level is decreased one step after each yes response and increased one step after each no response.
 - For yes/no tasks the threshold is always defined *P50*

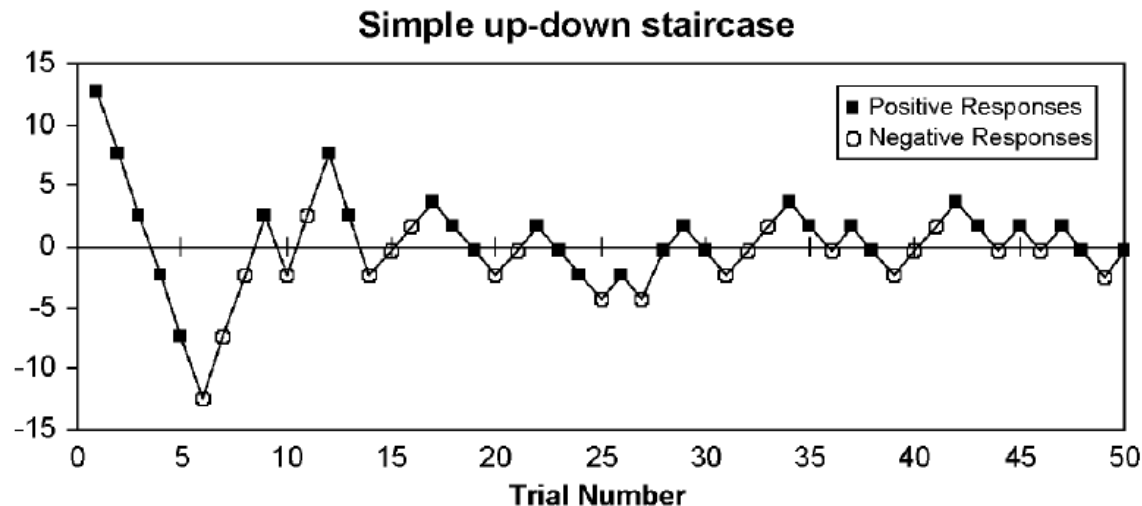
From the method of limit to staircase

Stimulus Intensity
(Brightness)



Simple up-down staircase method

- Procedure:
 - Start from above (below) threshold
 - A reduction in stimulus level when the subject's response is positive and an increase in stimulus level when the response is negative
 - Stop after a given number of zero-crossing
 - Average final several stimulus levels



Simple up-down staircase method

- Dynamic changes of thresholds

$$X_{n+1} = \begin{cases} X_n + \delta & \text{When negative response} \\ X_n - \delta & \text{When positive response} \end{cases}$$

- When δ is small enough, X_n approaches constant
- Positive and negative responses are approx. 50% to 50%
- Accuracy: δ

Example

- Tilt illusion

- Fix tilted degree of the contextual grating
- Choose an initial tilted degree X_0 for the central target grating, which is above threshold. (e.g. Figure: -7°)
- Choose step size of rotating degree: δ (e.g. 0.1°)
- When 'left tilted' response $\rightarrow X_{n+1} = X_n + \delta$
- When 'right tilted' response $\rightarrow X_{n+1} = X_n - \delta$
- Continue until the number of response reversal $> N$
- Average the last M trials



How to estimate other levels of thresholds?

- Varied up/down steps
 - Two successive positive response one step down, one negative response one step up → 70.7%

$$X_{n+1} = \begin{cases} X_n + \delta & \text{When negative response} \\ X_n - \delta & \text{When two successive positive response} \end{cases}$$

$$\gg p \times p = 0.5 \rightarrow p = 70.7\%$$

- Three-down, one-up → 79.4%
- Possible levels: 15.9%, 29.3%, 50%, 70.7%, 79.4%, 84.1%

Example

- Tilt illusion – Threshold of 70%

- Fix tilted degree of the contextual grating
- Choose an initial tilted degree X_0 for the central target grating, which is above threshold. (e.g. Figure: -7°)
- Choose step size of rotating degree: δ (e.g. 0.1°)
- Only one ‘left tilted’ response $\rightarrow X_{n+1} = X_n$
- When 2 successive ‘left tilted’ response $\rightarrow X_{n+1} = X_n + \delta$
- When ‘right tilted’ response $\rightarrow X_{n+1} = X_n - \delta$
- Continue until the number of response reversal $> N$
- Average the last M trials



- Weighted up/down methods

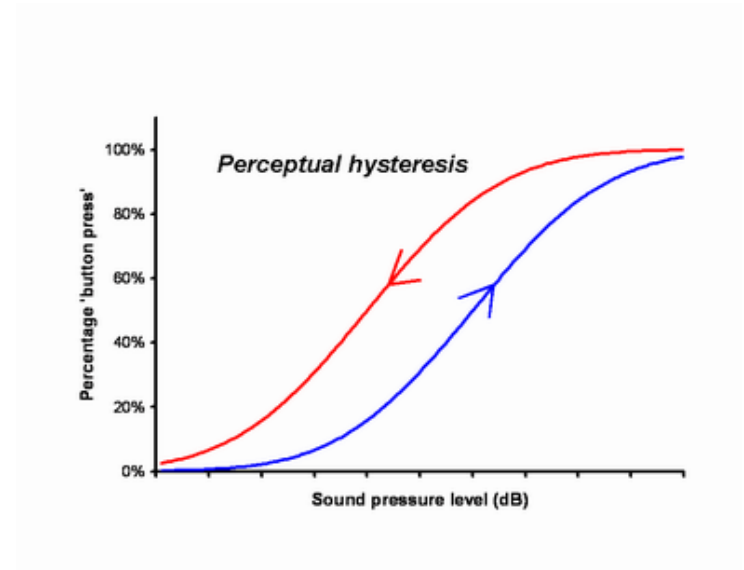
$$X_{n+1} = \begin{cases} X_n + \delta_{\uparrow} & \text{When negative response} \\ X_n - \delta_{\downarrow} & \text{When positive response} \end{cases}$$

- where $\delta_{\uparrow} = \delta_{\downarrow} \cdot \frac{p}{1-p}$
- E.g. target 75%, up step size should be 3 times of down step size.

(Kaernbach, 1991)

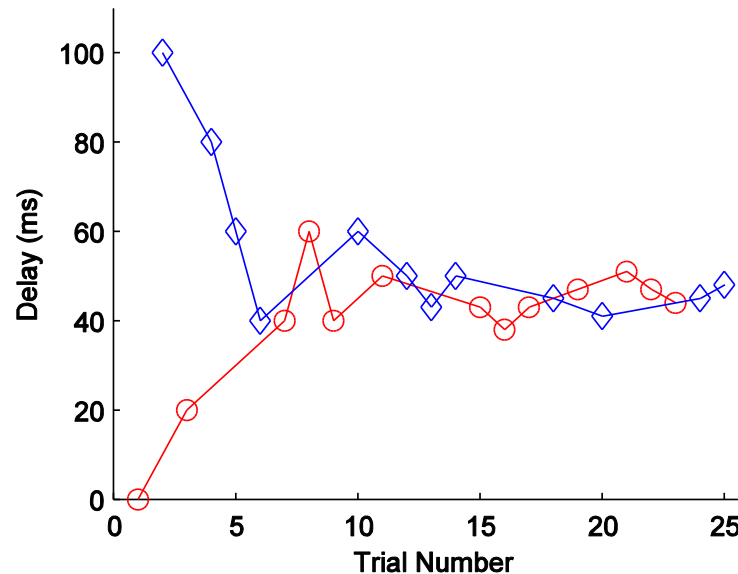
Disadvantages

- Hysteresis (Habituation) effect
 - The lagging of an effect behind its cause
- Expectation effect
- Short staircases (<20 reversals in length) are subject to some bias (Garcia-Perez, 1996)



Double staircase

- Randomly intermixed two staircase sequences together
 - To avoid knowing sequence of stimulus level change (Sekuler & Blake, 1994)



PEST: Parameter Estimation by Sequential Testing

- PEST: Taylor & Creelman, 1967
 - Method
 - You pick up a stimulus level X and present N trials at this level. The responses at this level are binomially distributed. After certain number of trials, you know if this level is far from your target value (p) or not. Then you change stimulus level close the target value
 - More details refer to Treutwein, 1995, Mini review of adaptive procedures

QUEST: A parametric method

- A Bayesian adaptive psychometric method
 - Watson & Pelli, Perception & Psychophysics, 1983
 - available in Psychtoolbox (psychtoolbox.org).
 - Method
 - User all prior knowledge to guide the placement of the trials by maximum likelihood estimation of Bayesian prob.
 - Psychometric function and shape must be assumed

Quest provided by Psychtoolbox

- `q=QuestCreate()`
 - Create parameters of a weibull psychometric function based on previous knowledge and guess
 - `q=QuestCreate(tGuess,tGuessSd,pThreshold,beta,delta,gamma)`
 - Beta: steepness of the PF
 - Delta: lapse rate, e.g. 0.01
 - Gamma: guess rate
- `QuestQuantile(q);`
 - set the stimulus level
- `QuestUpdate(..);`
 - after response, update probability density function (PDF)

Signal detection theory

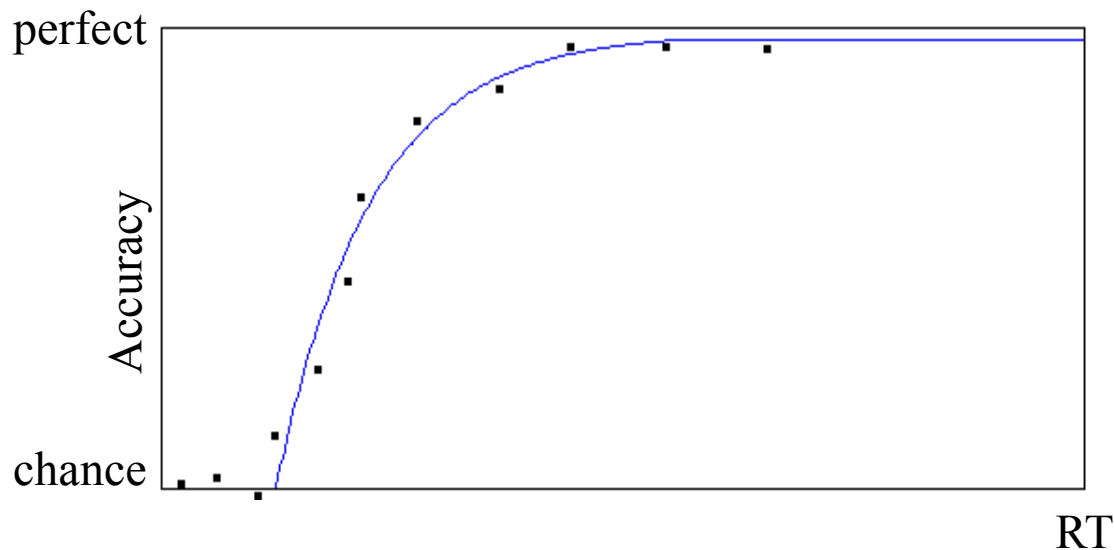
Part I

A small test



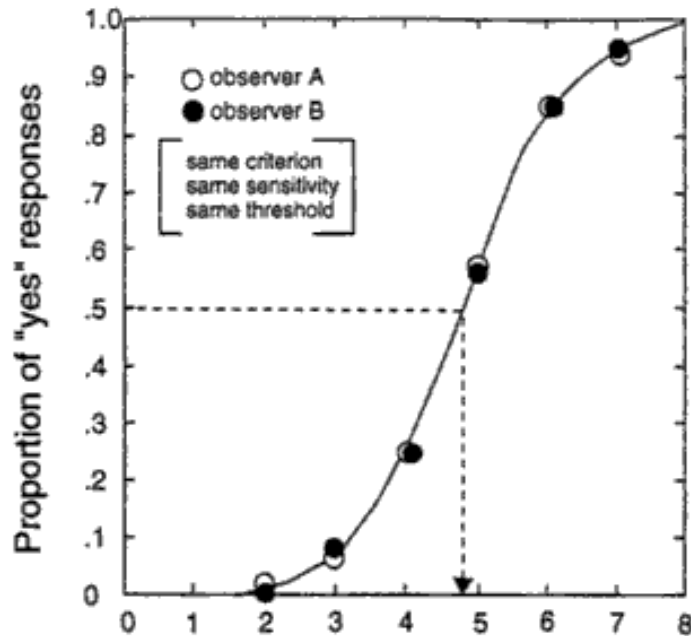
Recall ...

- Speed accuracy tradeoff
 - Trade speed for accuracy, or vice versa
 - The accuracy is indicated by percent of correct response, p .

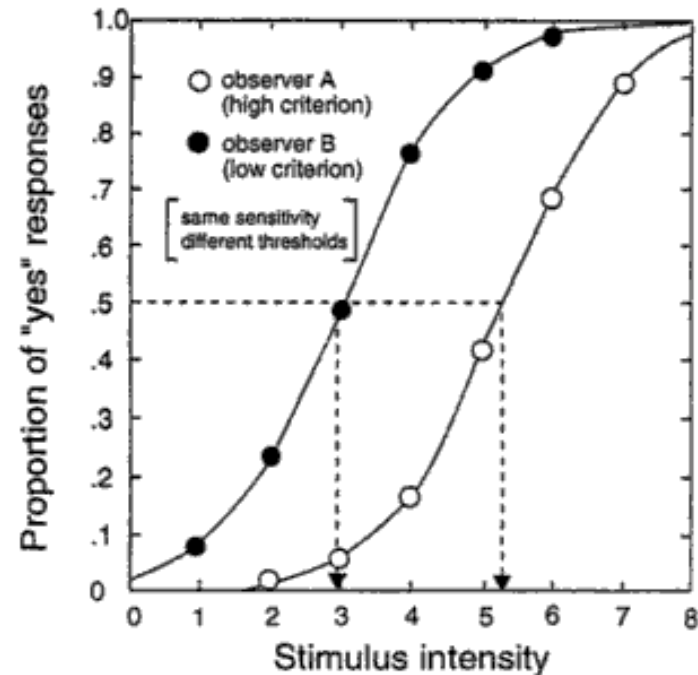


Recall ...

- Psychometric function
 - The PF may differ due to observer's criterion



Same sensitivity
Same criteria



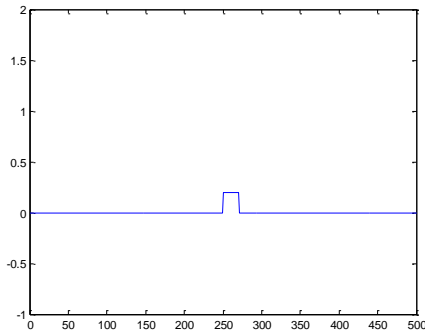
Same sensitivity
different criteria

History of signal detection theory

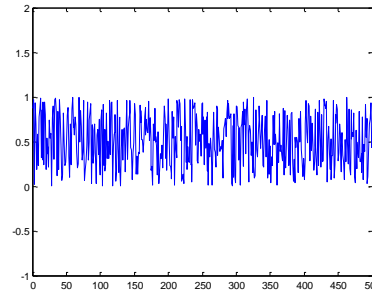
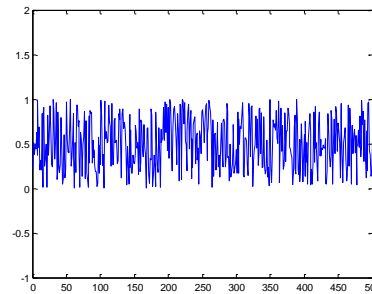
- WWII, researchers concerned with maximization of correct detection responses and minimization of false detection responses
 - No way to optimize both
- First introduced by radar researchers (Marcum, 1960)
- Psychophysics: John A. Swets and David M. Green (1966)

Signal and noise

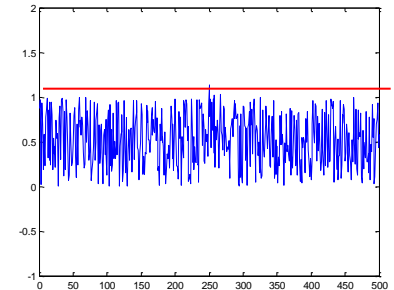
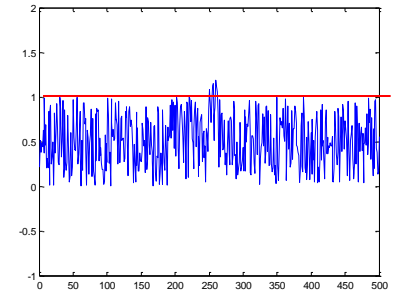
- Absolute threshold (recall last week)
 - Signal is very weak, plus noise
 - Observer perceives external signal at chance level



Signal



Noise



S+N

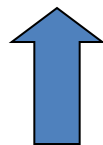
Signal and decision making

- Signals are always accompanied with background noise
 - luminance detection (background luminance)
 - target detection (against distractors)
- Decision making (Criterion)
 - Above that criterion: Yes
 - Below that criterion: No

Four possible outcomes

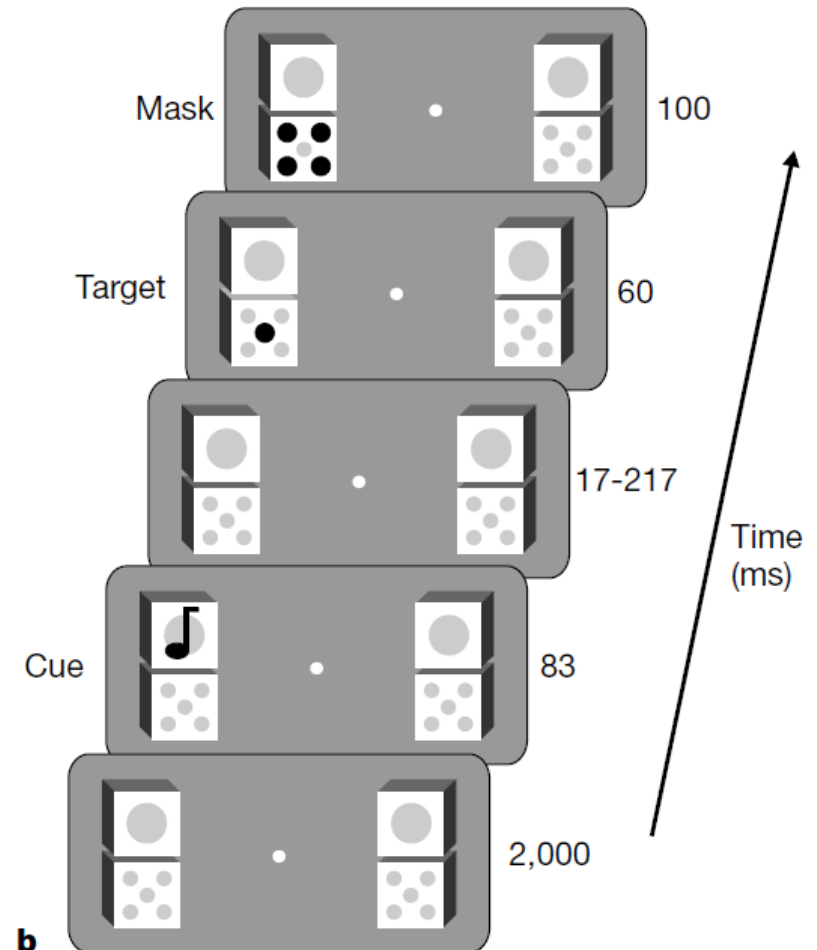
- 4 types of outcomes
 - Hit, False Alarm, Miss & Correct rejection

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



Examples

- Involuntary orienting to sound improves visual perception, McDonald et al. 2000, nature.
 - Sound enhances visual identification/search
 - Question: Whether involuntary auditory attention affects perceptual stage or post-perceptual stage (facilitation on motor responses)



Examples

		Target	
		Present	Absent
Response	Yes	Hit	False Alarm
	No	Miss	Correct Rejection

Types of Noise

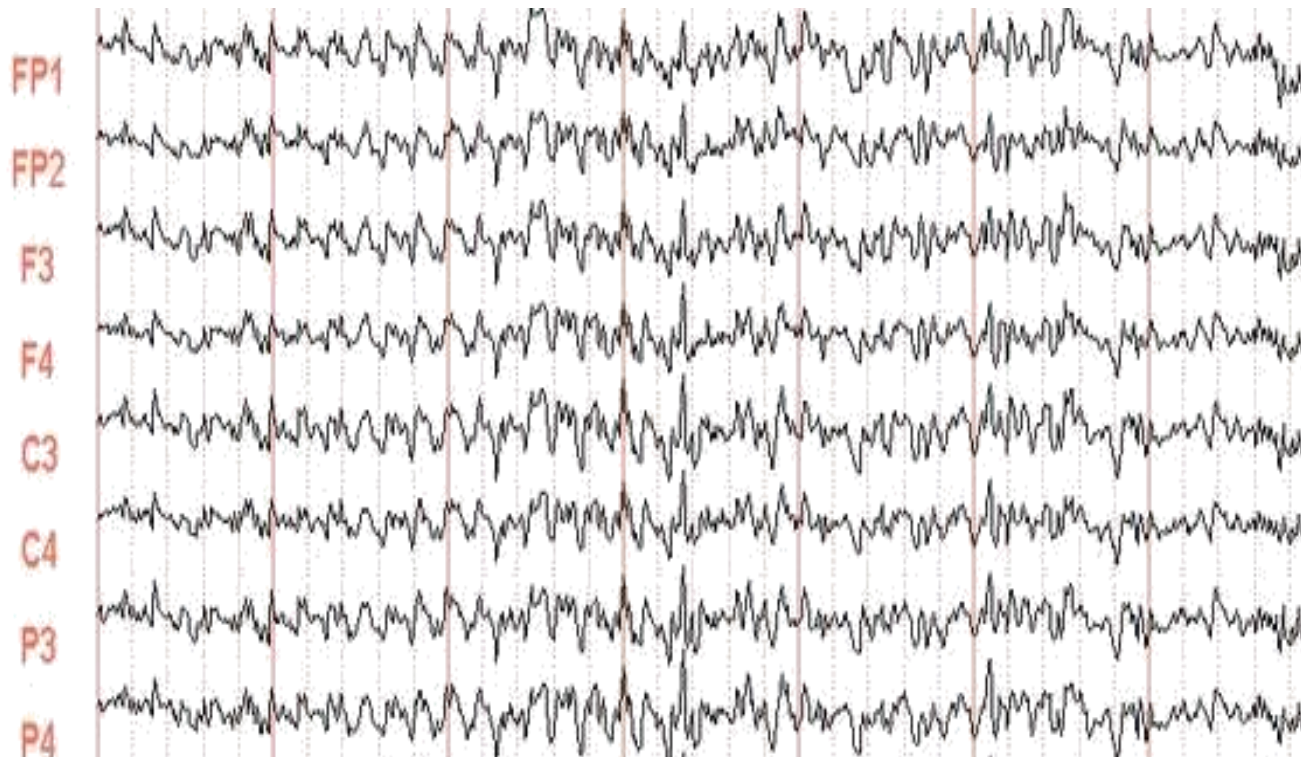
- External Noise
 - E.g. white noise; distractors
 - External noise disturbs the signal, e.g. Change blindness
 - External noise masks the signal



Regan, Rensink & Clark (1998), Nature

Types of Noise

- Internal Noise
 - E.g. neural spontaneous response; Sensory noise
 - The direct impact from internal noise is the variation of behavioral data on same external stimuli.

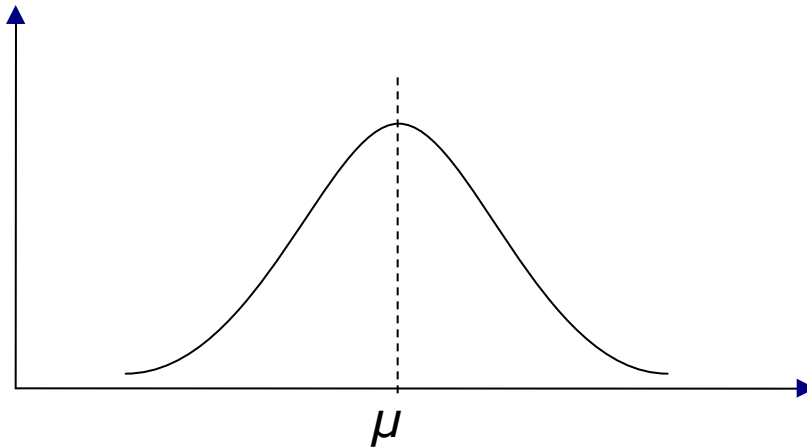


Signal and Noise: Statistical view

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

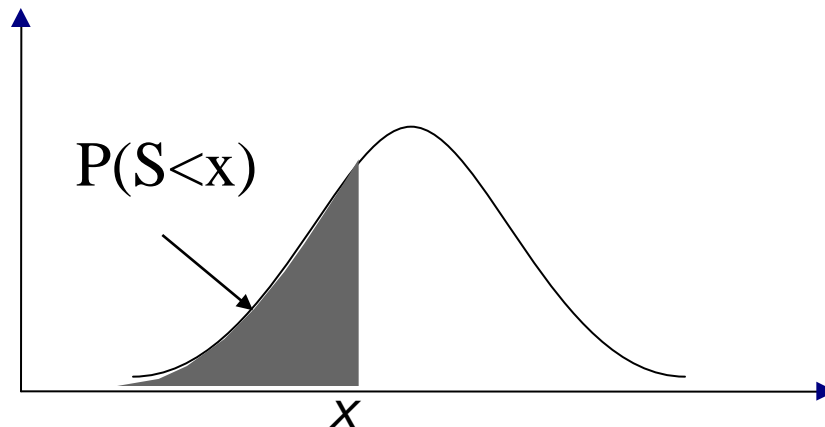
$$S = \mu + N_e + N_i$$

- Where μ is the pure signal strength, N_e is external noise and N_i is internal noise.
 - Usually N_e and N_i are assumed to have normal distributions.



Signal and Noise: Statistical view

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



Distribution of Noise and Signal

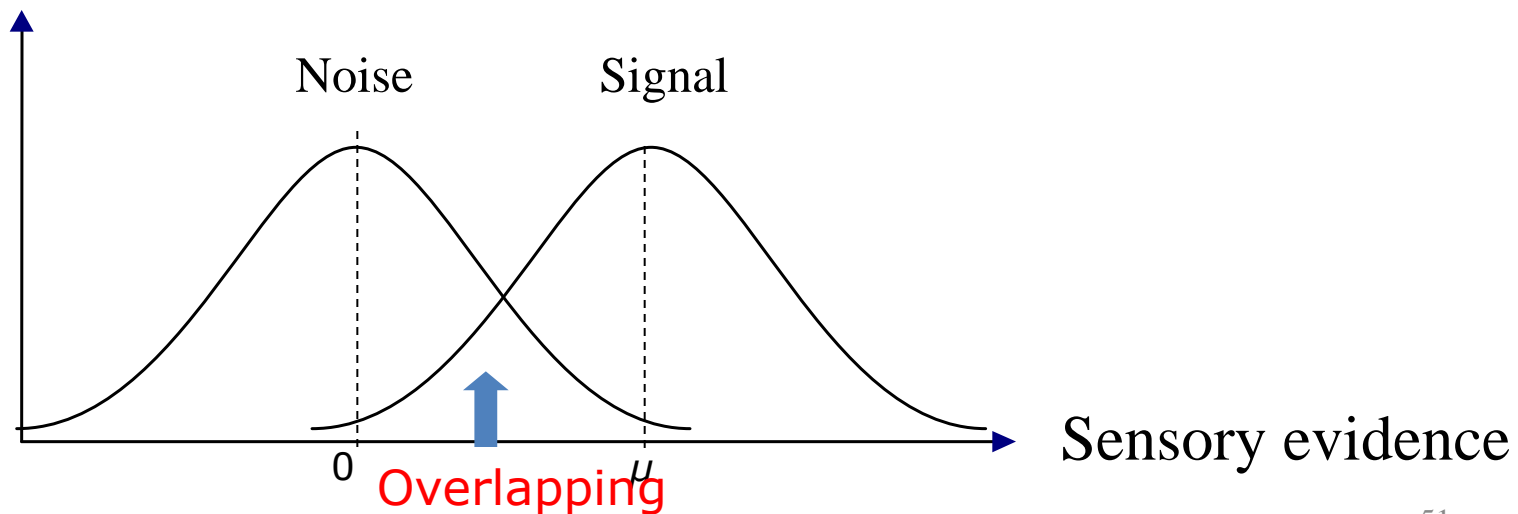
- Signal present

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

- Signal absent

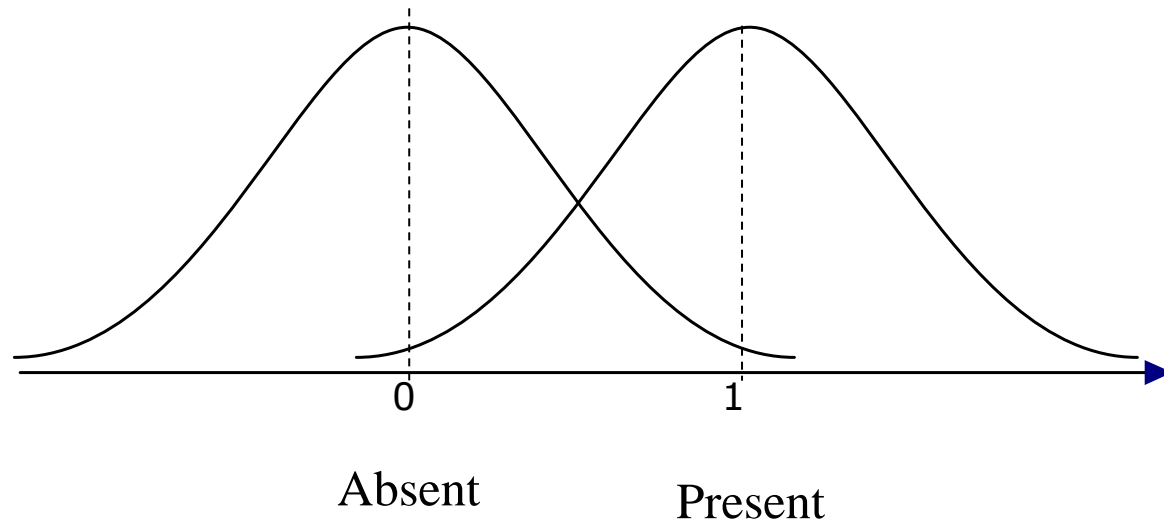
$$N = N_e + N_i \quad \sim N(0, \sigma)$$

- Shift in Abscissa



Example

- McDonald et al. 2000
 - Target present vs. Target absent



Decision criterion and probability

- On any given trial the observer usually setup a criterion C_r according stimuli. If perceived stimuli strength S_p is greater than C_r , subject gives “has signal” response; otherwise, treats as “no signal”. i.e.

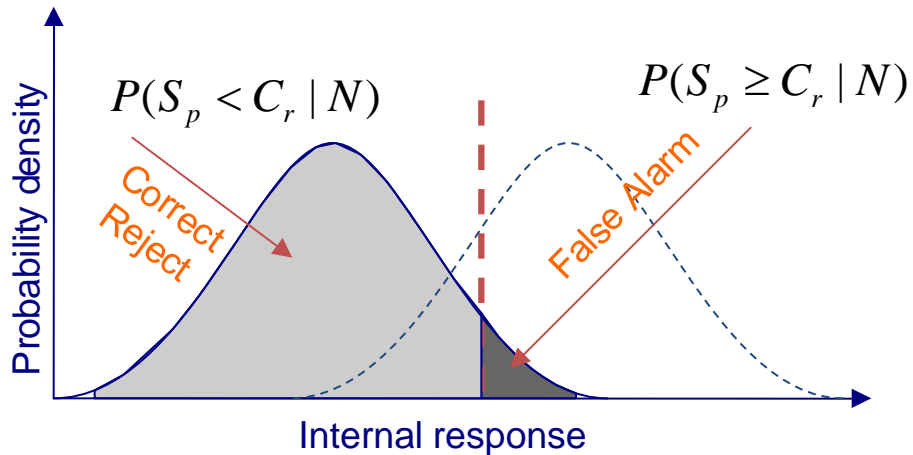
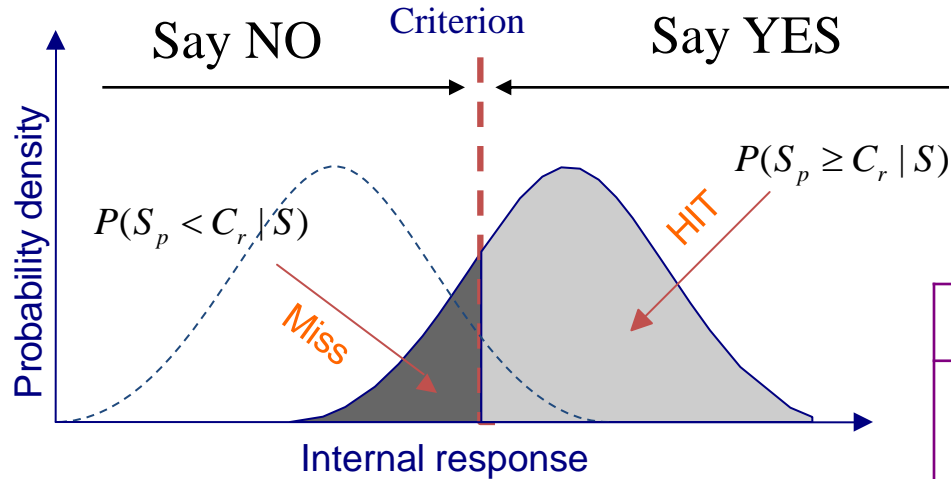
$$R = \begin{cases} \textit{Signal} & S_p \geq C_r \\ \textit{Noise} & S_p < C_r \end{cases}$$

- Because of the overlapping the observer may make two types of error

- Miss: $P(S_p < C_r | S)$

- False alarm $P(S_p \geq C_r | N)$

Responses and probabilities

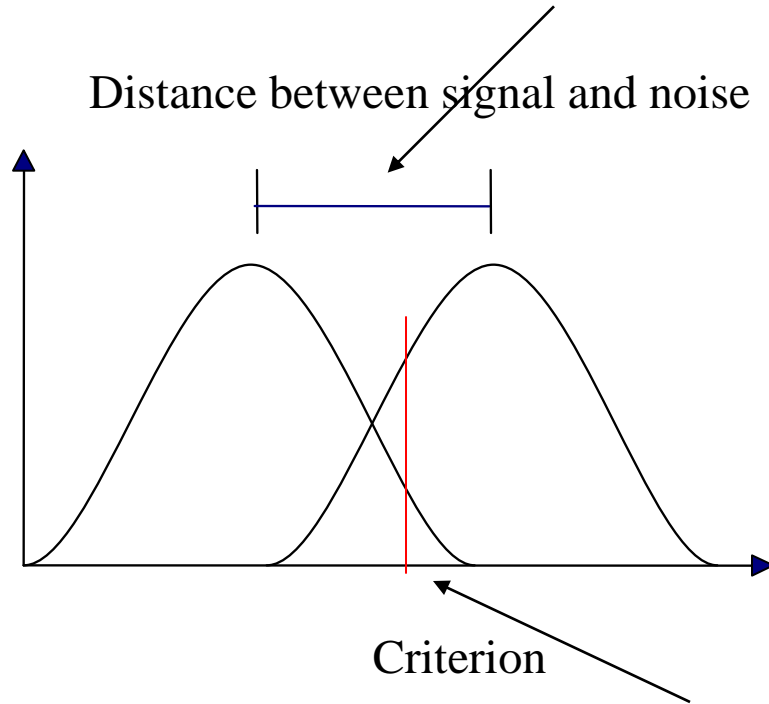


Response	Signal	Noise
"Yes"	Hit	False alarm
"No"	Miss	Correct rejection
<i>Total</i>	<i>100%</i>	<i>100%</i>

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

Two important features

Sensitivity

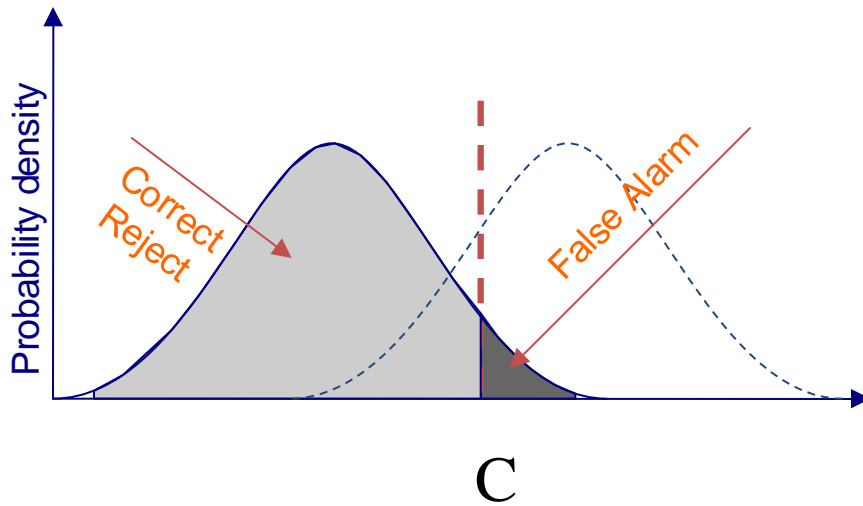
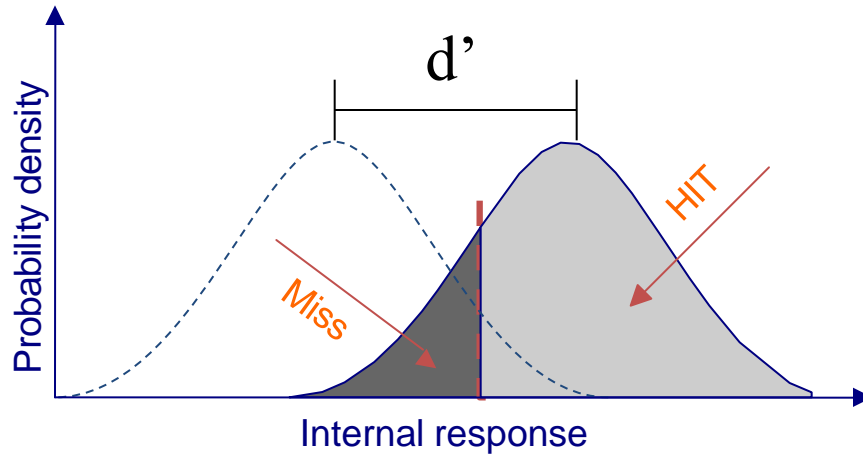


Response bias

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):**
 - Measure of internal separation baseline for noise and signal
 - influence by motivation, expectancy, pressure etc.
- Sensitivity is **independent** of decision criterion.
 - Different from classical psychophysical methods (only percentages)

Sensitivity and decision criterion

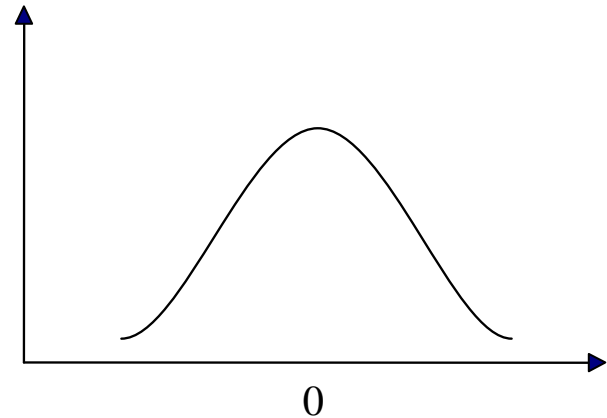


- Responses
 - Hit (Miss)
 - FA (CR)
- Estimates
 - Sensitivity d'
 - Criterion C

Normal distribution

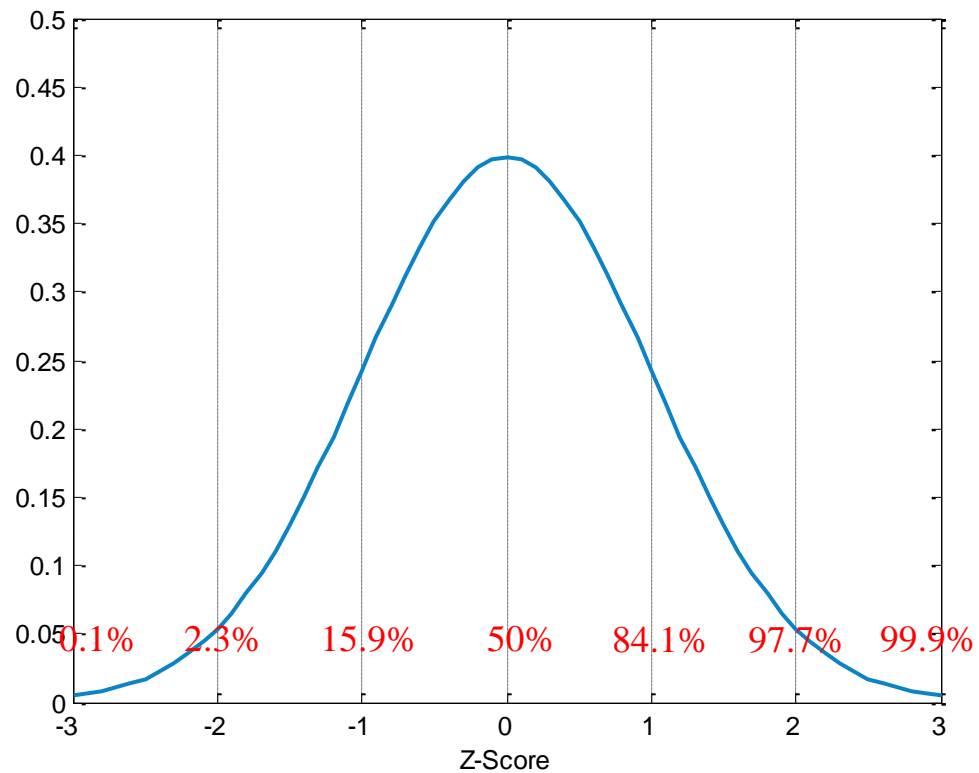
- Also called Gaussian distribution
 - Can be determined by mean and variance
 - Density function: bell curve
- Standard normal distribution
 - Mean = 0
 - Variance = 1
 - Standardization

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



Z-Score

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



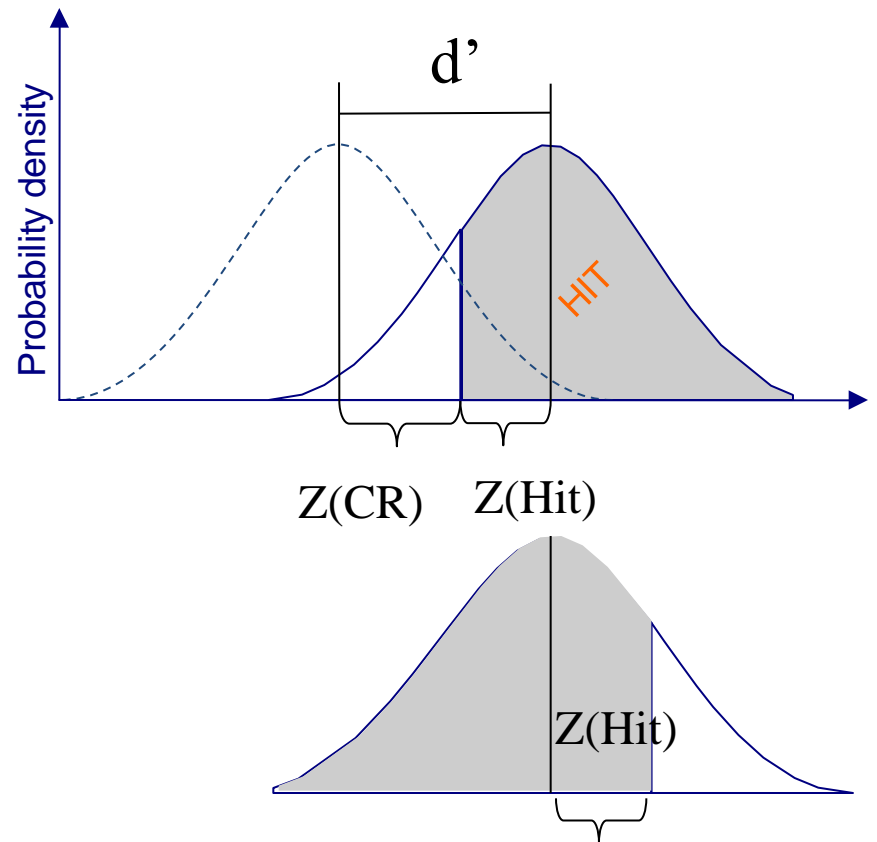
$$Z(15.9\%) = -Z(84.1\%) \rightarrow Z(p) = -Z(1-p)$$

d'

- Suppose N and S are standard normal distribution

$$\begin{aligned}d' &= z(\text{Hit}) + z(\text{CR}) \\ &= z(\text{Hit}) - z(\text{FA})\end{aligned}$$

Note: $Z(\text{CR}) = -Z(\text{FA})$



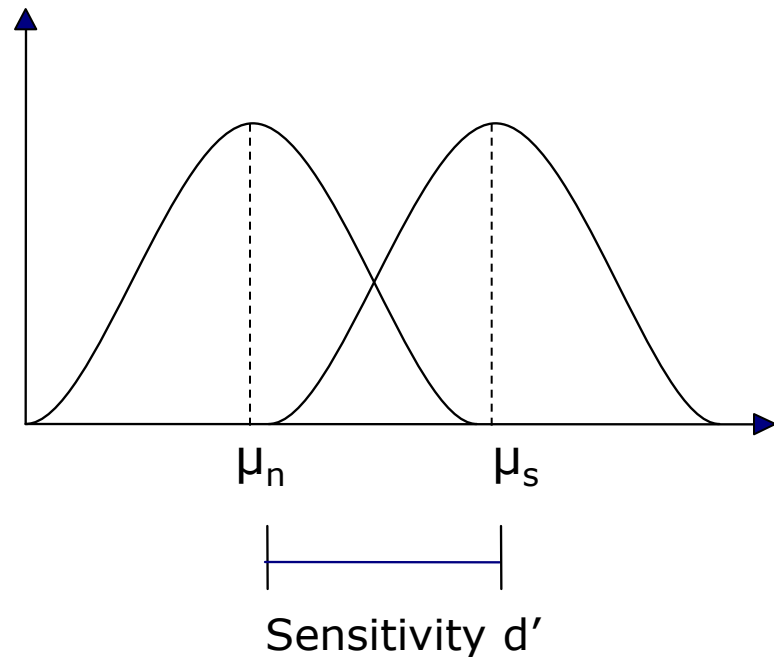
Sensitivity (Discriminability): d'

- Equal-Variance

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

- Unequal-Variance

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



Homework

- Psychometric function estimation
 - Raw data will be available at
 - <http://www.psy.lmu.de/exp/education/courses/index.html>
 - Details will be given by Course C tutors