Psychophysics and neuroscience

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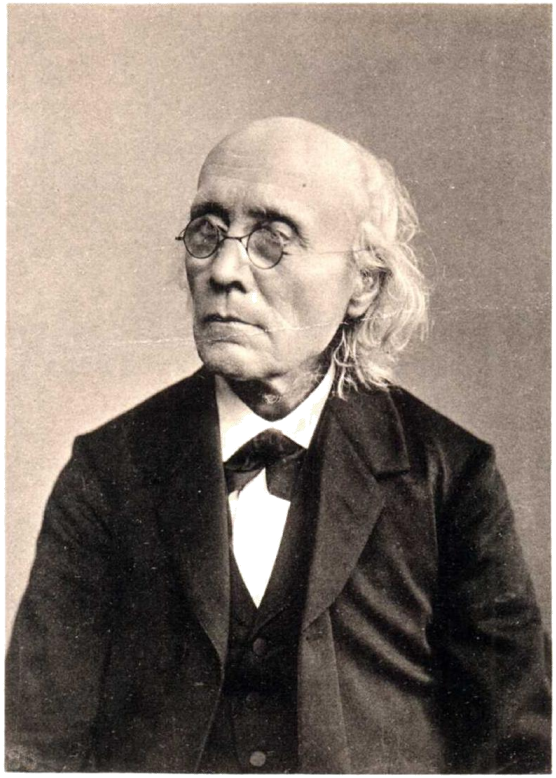
Part I

Psychophysics and Psychophysical Laws

Psychophysics

- Investigate the relationship between external stimuli and internal sensation
  - Sensation = F(stimuli intensity)

  - If internal sensation is the direct representation of external stimuli
    - Why do we still need to investigate the relationship?

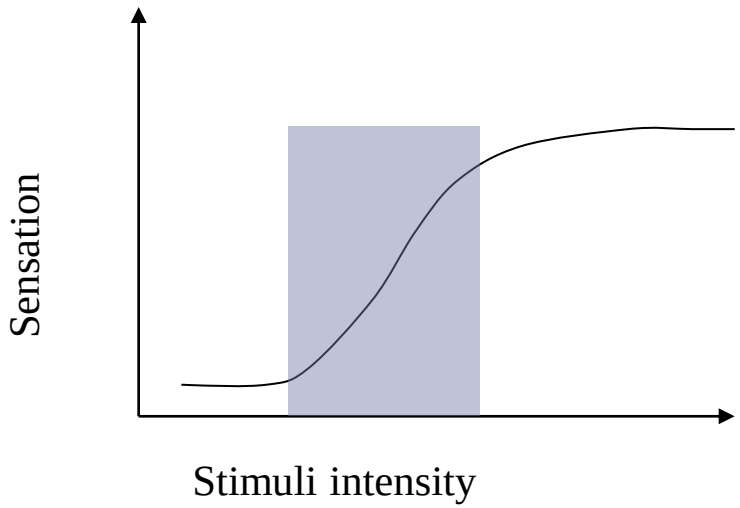


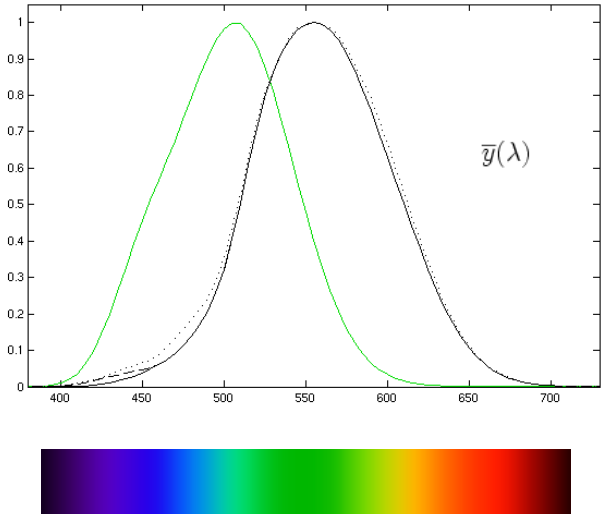
Gustav-Theodor Fechner

Elements of Psychophysics, 1860

Psychophysics

- Stimuli intensity & sensation
  - Our senses are usually only tuned to response activity to a special bandwidth of the external stimuli.

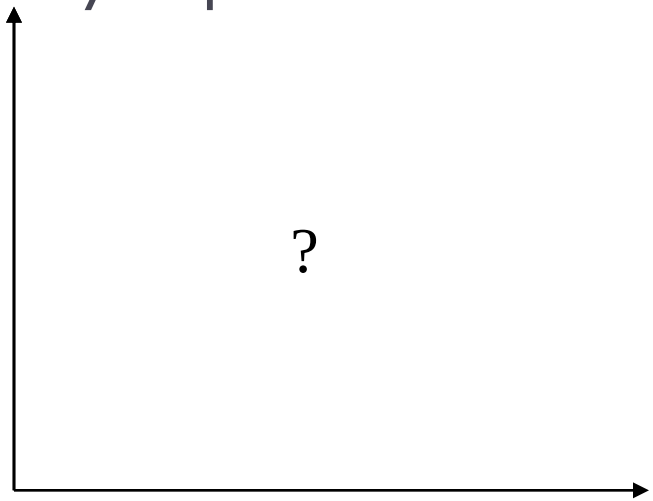




Photopic (black) and scotopic luminosity functions.

Demo

- ***Demo:*** Try to increase your voice equally…
  - Subjective percept:
    - Whisper, Normal voice & Loud
  - Measures:
    - dB1, dB2 and dB3
  - Try to plot the curves and see the relationship



On the **decibel scale**: the smallest audible sound (near total silence) is 0 dB. A sound 10 times more powerful is 10 dB.

* Near total silence - 0 dB
* A whisper - 15 dB
* Normal conversation - 60 dB
* A lawnmower - 90 dB
* A car horn - 110 dB
* A rock concert or a jet engine - 120 dB
* A gunshot or firecracker - 140 dB

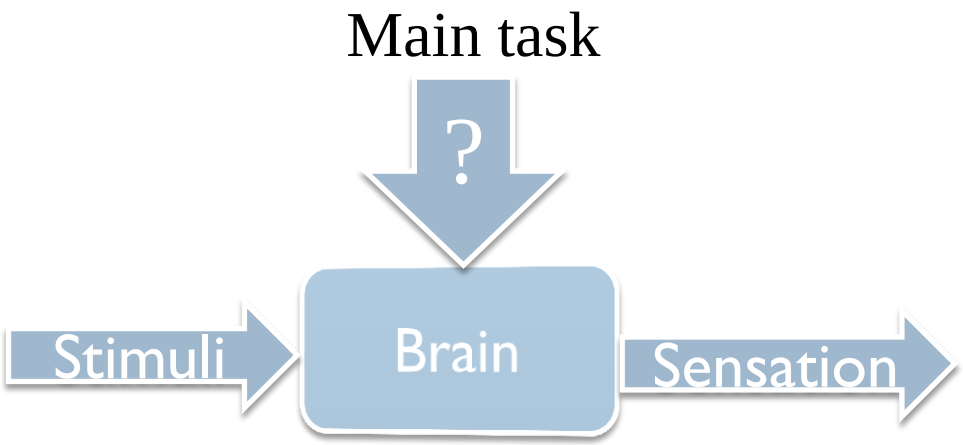
Psychophysics

- Stimuli intensity & sensation
  - Sensation (perception) can be biased by surround context

  - Another example: Tube illusion

Psychophysics

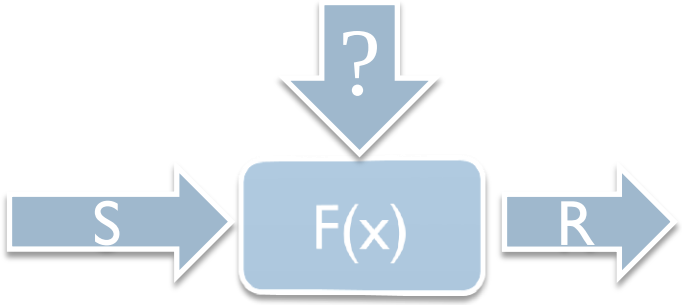
- relationship between external stimuli and internal sensation



Psychophysics and Neuroscience

Psychophysics (classical)

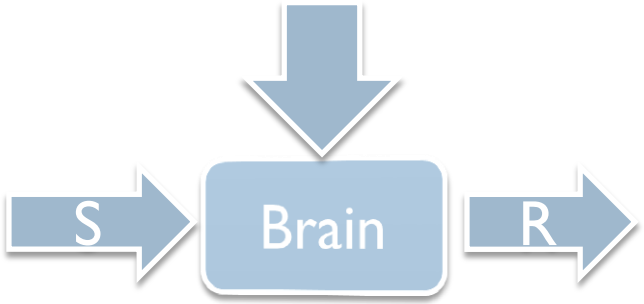
- behavioral relationships
- Macro



Psychophysics (modern)

- Neural mechanisms
- Micro

EEG, MEG, fMRI, PET …



An Example

- Tilt illusion

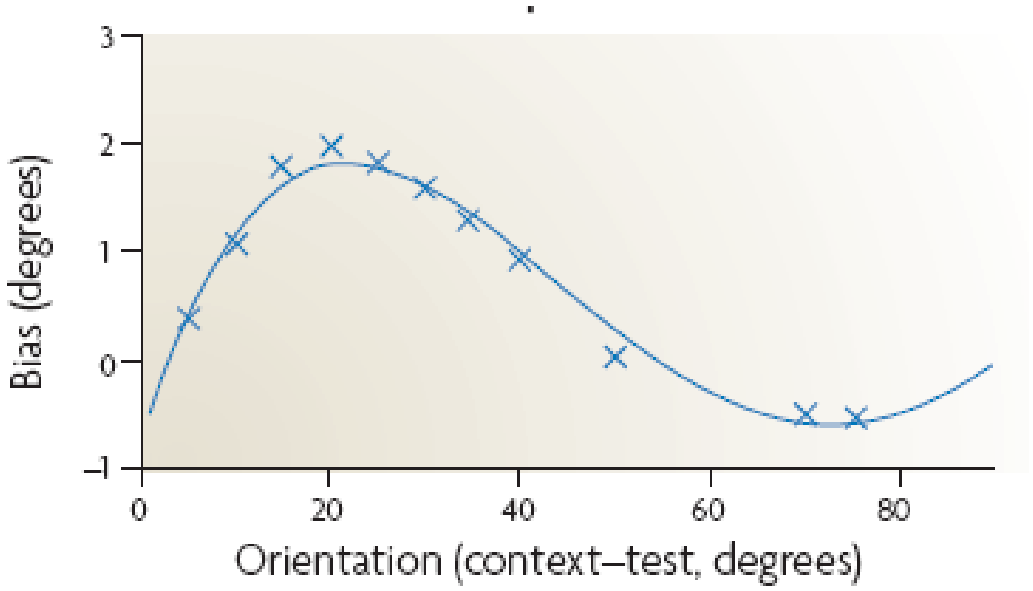
- Zollner illusion

Psychophysics: relationship between background context and target percept

Neuroscience: Neural mechanisms underlying these illusions

Example: Tilt illusion

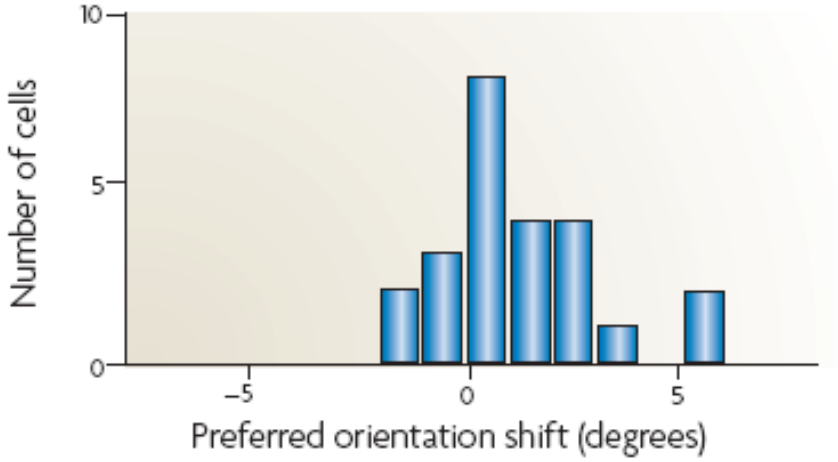
- Psychophysics: Behavioral measure
  - Set background orientation
  - Vary target orientation (various methods)
    - … until central target becomes 'perceptual' vertical → the degree of physical tilt is defined as bias



Schwartz, et al., 2007, NRN

Example: Tilt illusion

- Neural mechanism
  - Electrophysiological measure
  - responses of populations of neurons to local orientation stimuli



Repulsive tuning shifts in primary visual cortex neurons for space and time, for context target differences of 15°

Example: Tilt illusion

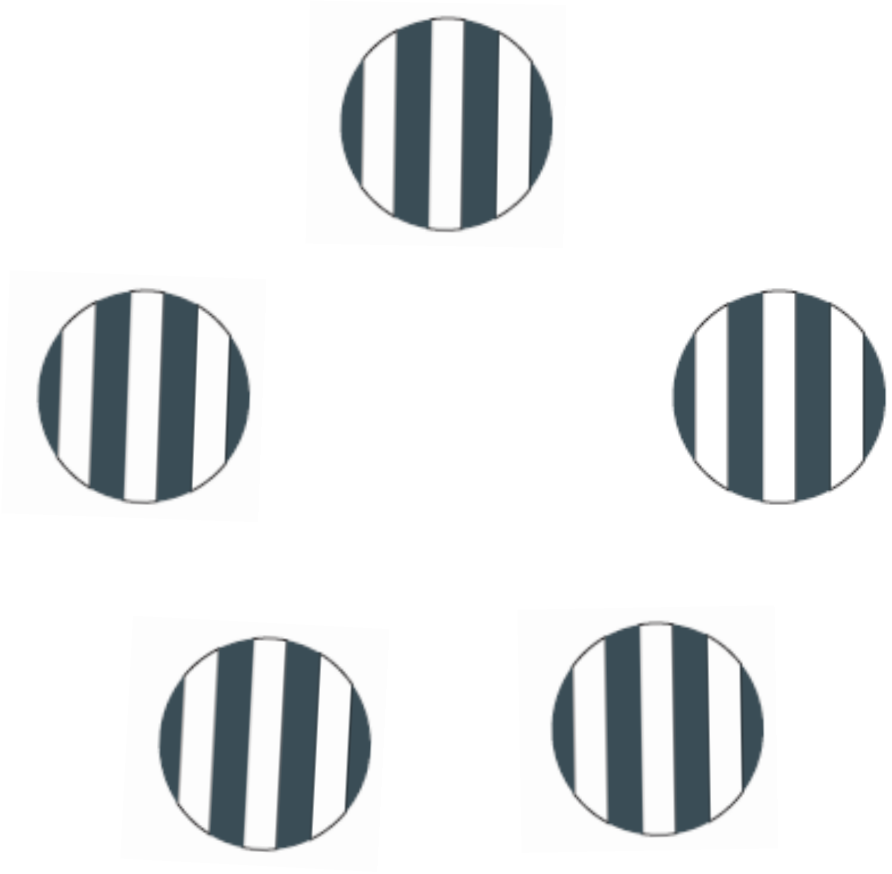
- Tuning shift on neuronal level (Fairhall, Lewen et al, 2001)
  - Tuning shift caused by contextual stimuli, but decoding mechanisms are assumed to be **unaware** of it.
  - The brain receives the **changed** input, but do not 'know' that changes have occurred due to the context → illusion occurs

Main topics in classical Psychophysics

- To measure the relationship between external world and internal perception
  - absolute thresholds (Absolute limen, AL)
    - the level of intensity of a stimulus at which the subject is able to detect (a level of 50% is often used).
  - discrimination thresholds (Difference limen, DL)
    - the *difference* between two stimuli intensities that the participant is able to detect (again, 50% is often used).
    - just noticeable difference, JND

Absolute thresholds

- Which grating has vertical orientation?



Discrimination thresholds

- Compare the following pairs, do they have different orientations?

3°  0°

27°  30°

Large orientation→ Discrimination: Harder, i.e. DL becomes larger
Just noticeable difference (JND) increases

Psychophysics and Psychophysical laws

- Psychophysics
  - External intensity → internal sensation
    - Sensation difference (JND) depends on absolute intensity level

Psychophysical laws & Scientific laws

- Physical laws
  - Newton's law of inertia
    - $F = ma$
  - Mass-energy equivalence
    - $E = mc^2$
  - Ohm's Law
    - $V = IR$

Weber's law

- Just noticeable difference (JND) & stimulus intensity
  - i.e. that they can be added in an analogous manner to the addition of units of a physical quantity.

$$\Delta\phi = c\phi \quad \text{or}$$

the size of the *just noticeable difference* (i.e., $\Delta\Phi$) is a constant proportion of the original stimulus value(Φ).

Ernst-Heinrich Weber (1795-1878)

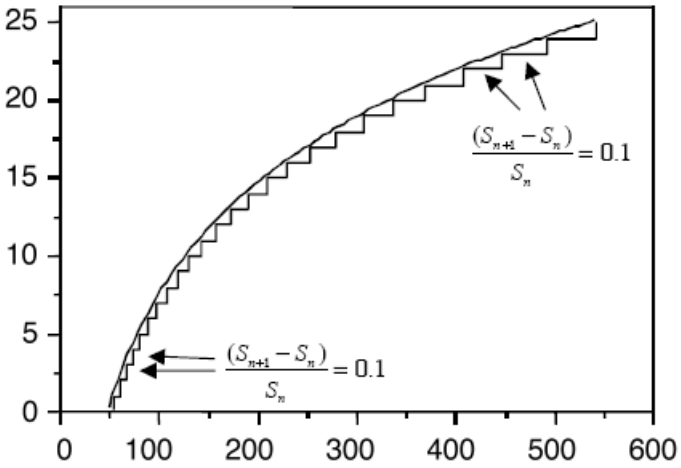
Fechner's Law

- Fechner believed that Weber had discovered the fundamental principle of mind/body interaction. He connected with sensation

$$\frac{\Delta\phi}{\phi} = c \quad \rightarrow \quad \Delta\psi = k \cdot \frac{\Delta\phi}{\phi}$$

$\Delta\Psi$: differential change in perception
$\Delta\Phi$: differential change in stimulus

$$\psi = k \cdot \log\phi + c$$



Fechner's Logarithmic Law (1860)

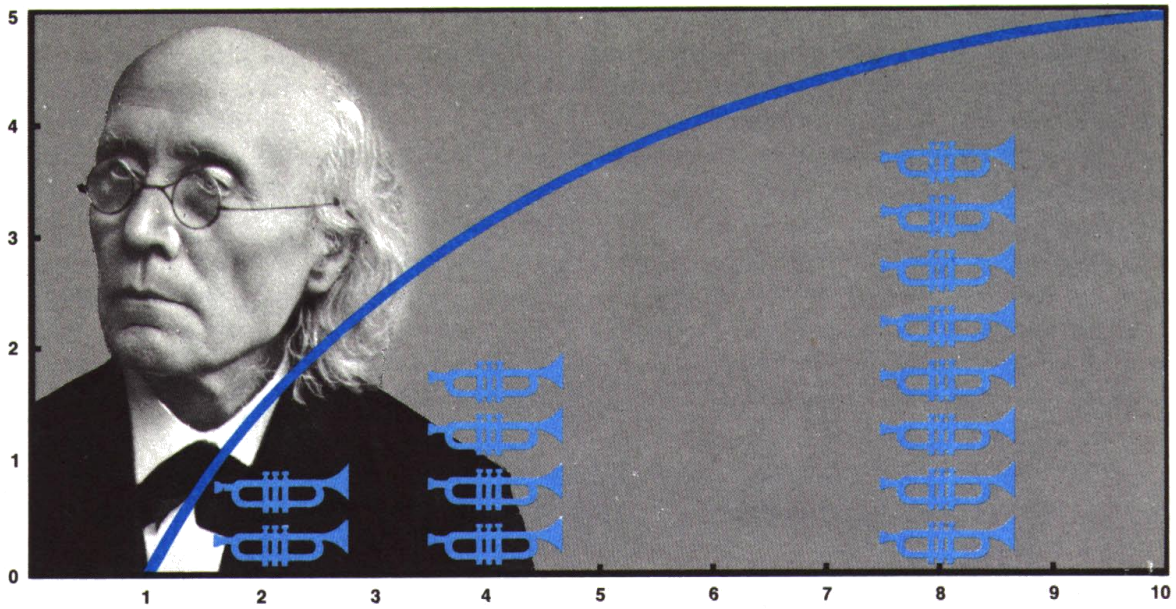
$$\psi = k \cdot \log \phi + c$$

- Takes sensation magnitude (Ψ), (Φ) as the intensity of the stimulus in units above absolute threshold, and *k* as a constant multiplier the value of which depends upon the particular sensory dimension and modality

Fechner's Logarithmic Law (1860)

- Sound pressure

$$\psi = k \cdot \log \phi + c$$



- http://en.wikipedia.org/wiki/Weber%27s_Law

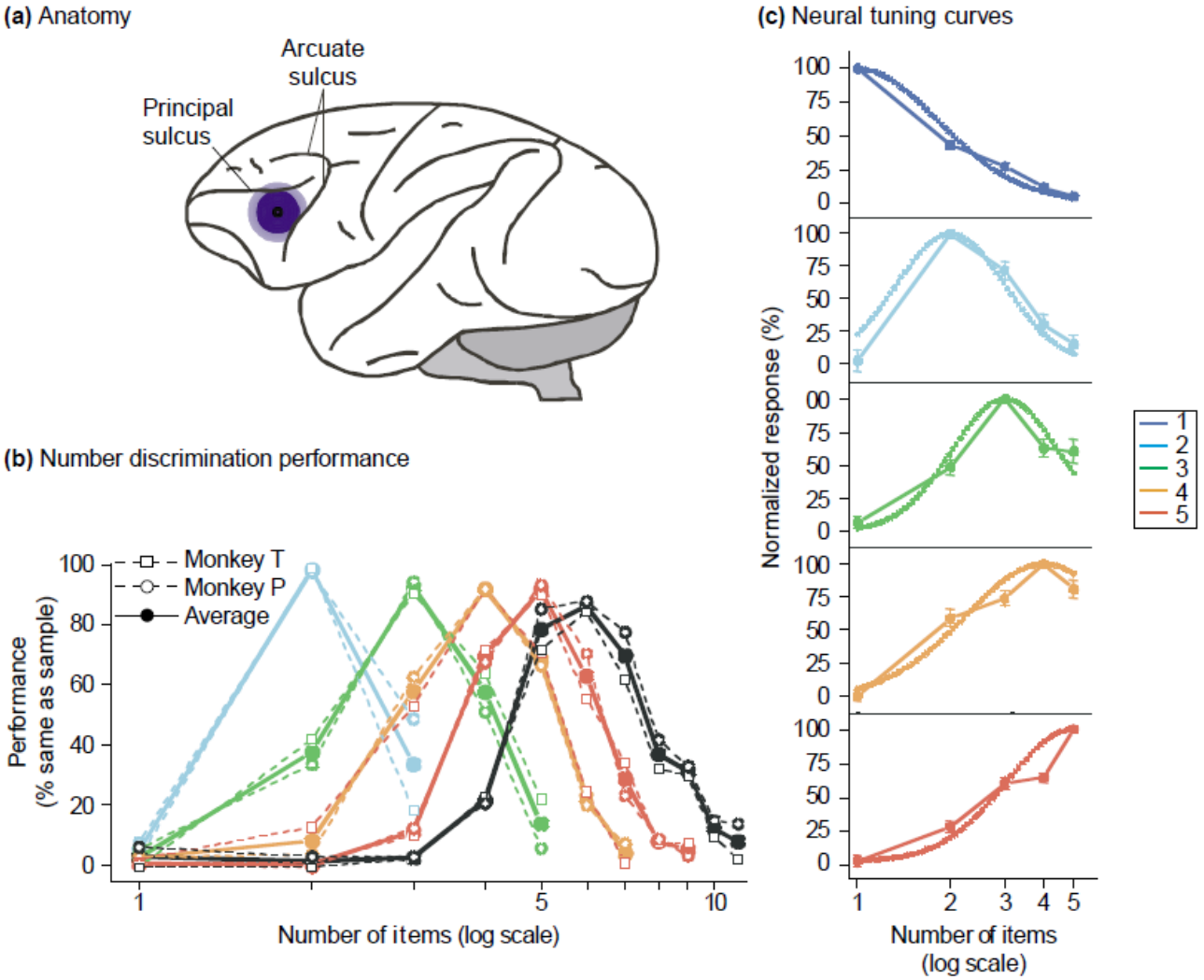
Examples of Fechner-Weber's law

- Sensory modalities:
  - Vision: brightness, orientation, size …
  - Audition: pitch…
  - Tactile: vibration …
- High level:
  - Decision making
    - Deco, Scarano, Soto-Faraco, JON, 2007

Neural basis of Weber-Fechner law

- Number representation (Dehaene, 2003, TiCS, Nieder, Miller, 2003, Neuron)
  - linear increase in their discrimination thresholds as the numerosity increased
  - In PFC, neural tuning curves exhibit similar pattern
    - Logrithmic scale: they were fitted by a Gaussian with a fixed variance across the entire range of numbers tested.

Neural basis of Weber-Fechner law



TRENDS in Cognitive Sciences

Neural basis of Weber-Fechner law

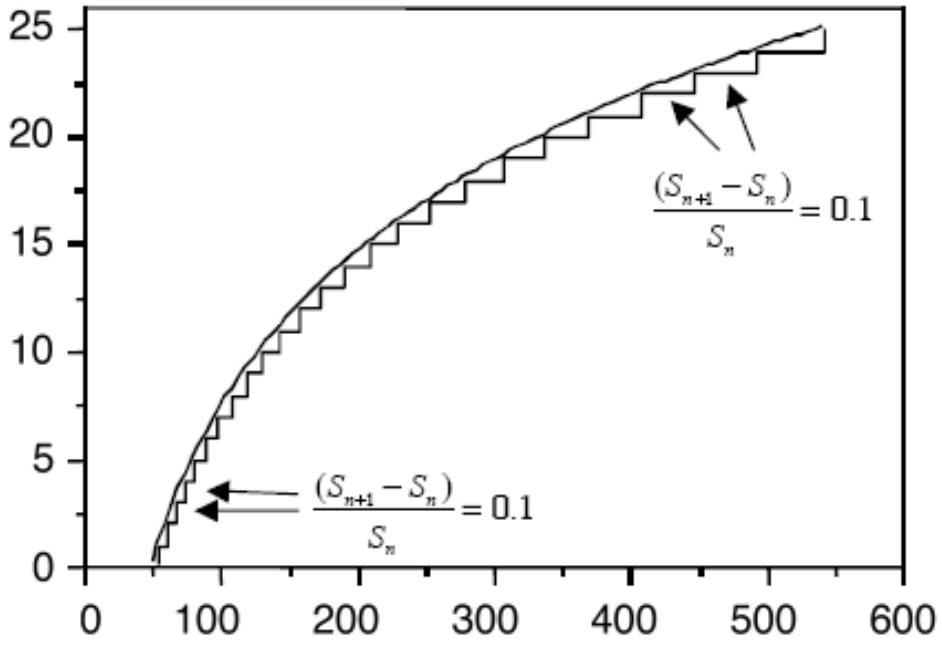
- Internal noise and Weber's law
  - Characteristics of sensory transmission
    - Internal noise is assumed to increase as the input level increases
    - Multiplicative noise (Green & Swets, 1988)

    - Discrimination on external stimuli intensity will follow Weber's law

Weber-Fechner's law

$$\frac{\Delta\phi}{\phi} = c$$

$$\psi = k \cdot \log\phi + c$$



Stevens' Power Law

- Stanley Smith Stevens (1906-1973) was the founder of the psycho-acoustic laboratory at Harvard and the progenitor of the Psychophysical Power Law.

Stevens' Power Law

- After nearly three decades and dozens of experiments using magnitude scaling techniques, Stevens proposed that the relation between sensation magnitude and stimulus intensity could be described by the function:

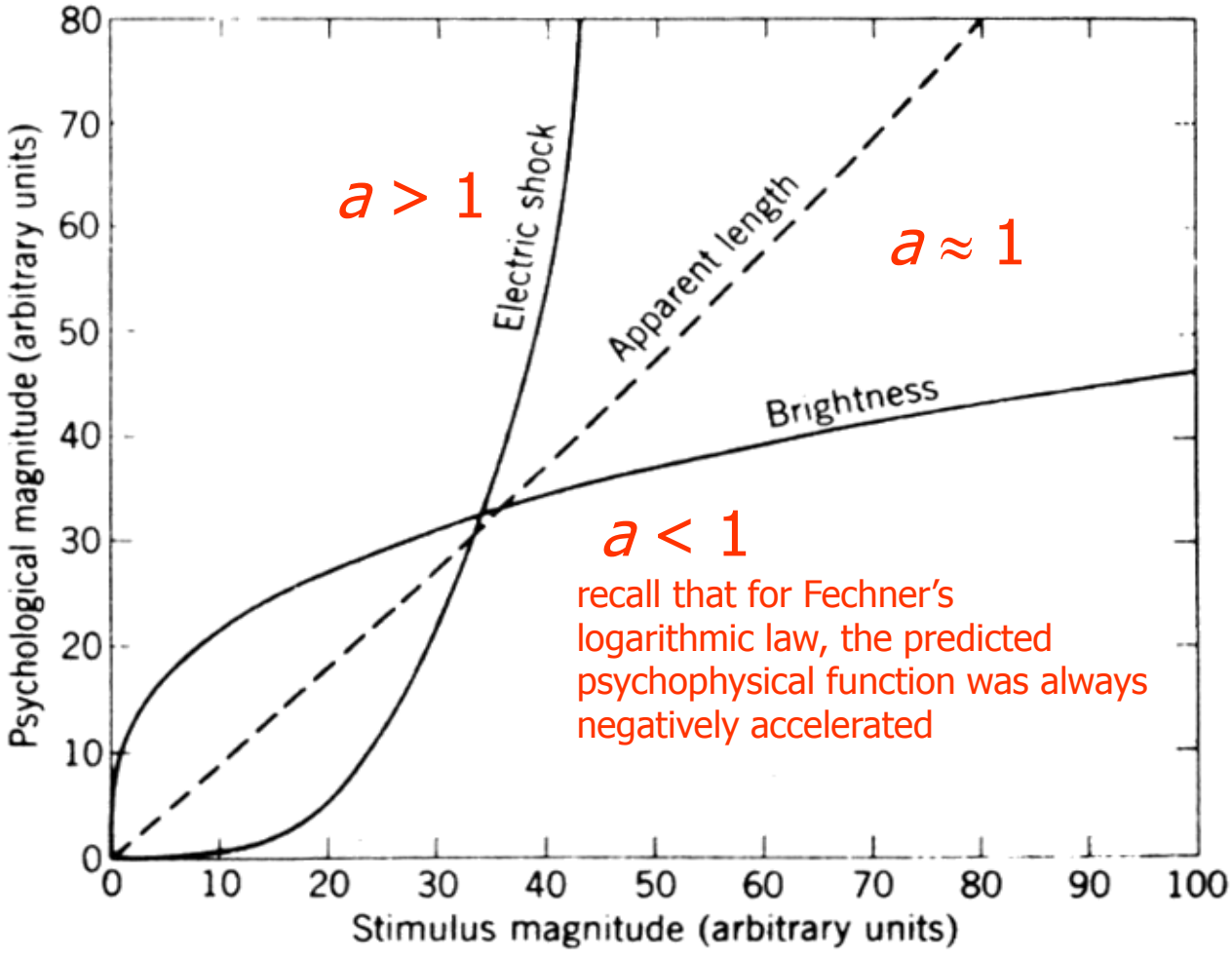
where (Ψ) is sensation magnitude, (Φ) stimulus intensity, *k* an arbitrary constant (to determine the scale unit) and *a* the power exponent which depends upon sensory modality and/or stimulus conditions

magnitude scaling techniques

- the experimenter presents a stimulus called a *standard* and assigns it a number called the *modulus*.
- For subsequent stimuli, subjects report numerically their perceived intensity relative to the standard so as to preserve the ratio between the sensations and the numerical estimates (e.g., a sound perceived twice as loud as the standard should be given a number twice the modulus).

Ratio scale

Stevens' Power Law



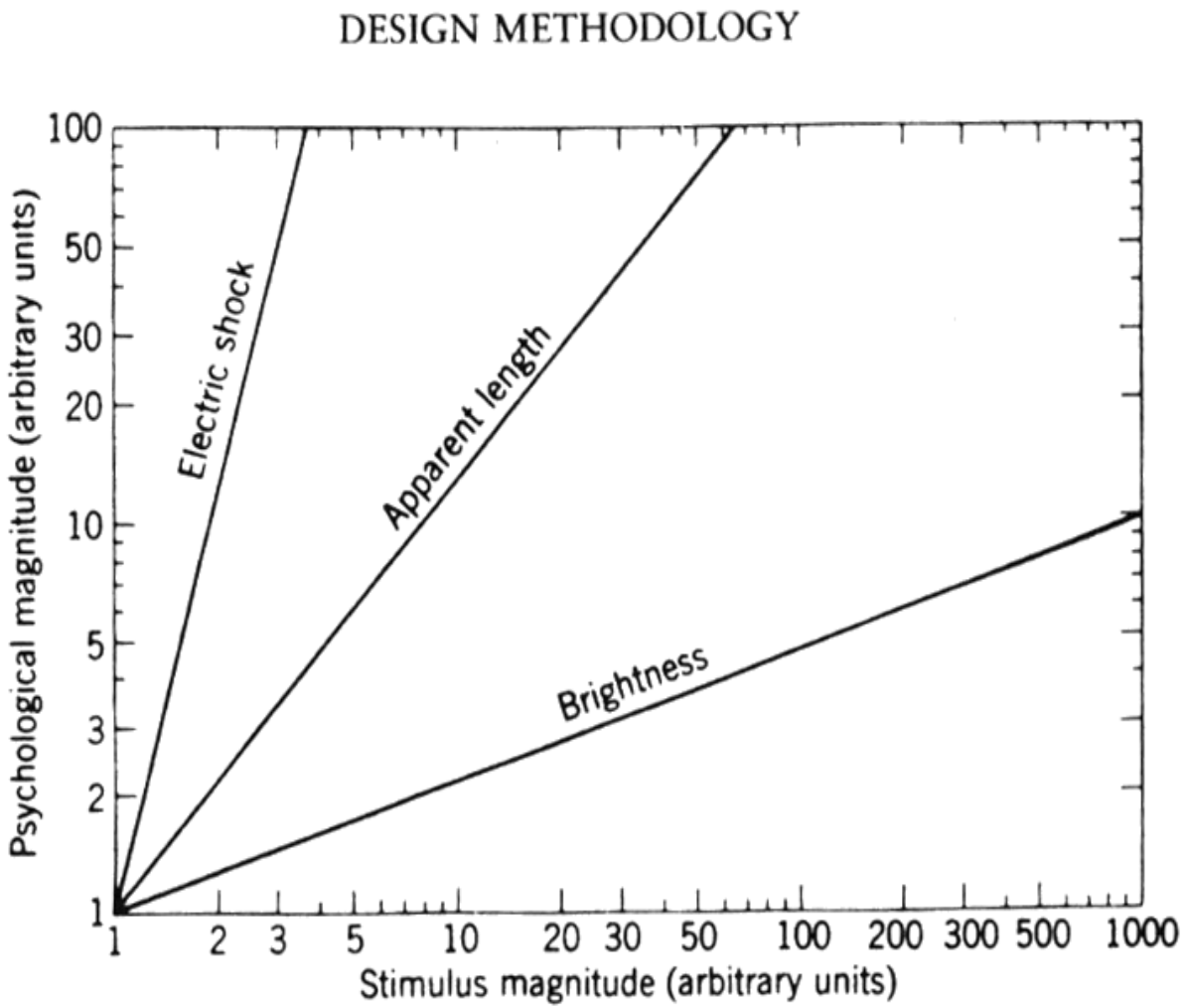
Stevens' Power Law

The power function:

has the convenient feature of becoming a linear function with a slope equal to the value of the power exponent when a logarithmic transformation is performed on either side of the equation:

The exponent of the power function can thus be found as a function of the slope of log plotted against log

Stevens' Power Law



Stevens' Power Law: Typical exponents

Continuum	Exponent (*a*)	Stimulus condition
Loudness	**0.67**	**Sound pressure of 3000 Hz tone**
Vibration	**0.95**	**Amplitude of 60 Hz on finger**
Vibration	**0.6**	**Amplitude of 250 Hz on finger**
Brightness	**0.33**	**5° target in dark**
Brightness	**0.5**	**Point source**
Brightness	**0.5**	**Brief flash**
Brightness	**1**	**Point source briefly flashed**
Lightness	**1.2**	**Reflectance of gray papers**
Visual length	**1**	**Projected line**
Visual area	**0.7**	**Projected square**
Redness (saturation)	**1.7**	**Red-gray mixture**

http://en.wikipedia.org/wiki/Stevens%27_power_law

Stevens' Power Law: Criticisms

- ignores any individual differences
  - averaged the data across subjects
  - not always hold for individual respondents

    (Green & Luce, 1974).
- Method has problem
  - Judgements on ration scale (Narens, 1996)
- the approach provides neither a direct test of the power law itself nor the underlying assumptions of the magnitude estimation/production method.
  - Only a product from estimation

Part II

Psychophysical methods

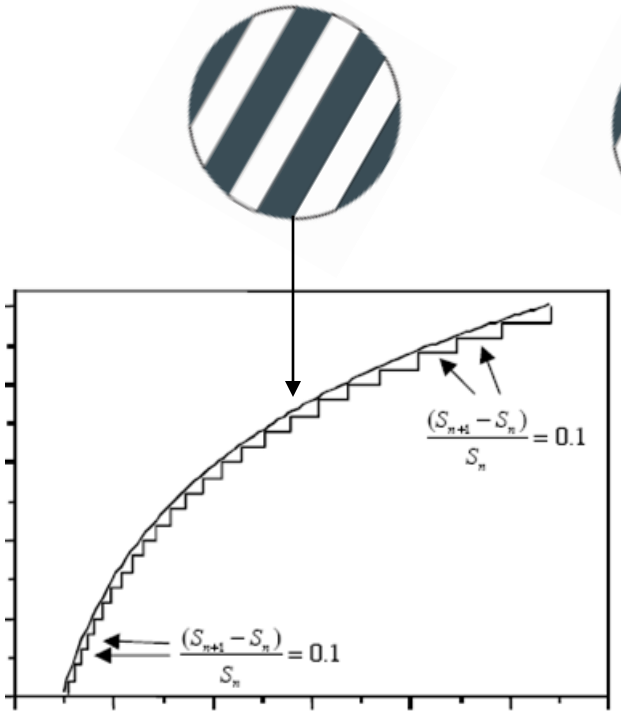
Measures in Psychophysics

- absolute thresholds (Absolute limen, AL)
  - the level of intensity of a stimulus at which the subject is able to detect (a level of 50% is often used).
- discrimination thresholds (Difference limen, DL)
  - the *difference* between two stimuli intensities that the participant is able to detect (again, 50% is often used).
  - just noticeable difference, JND

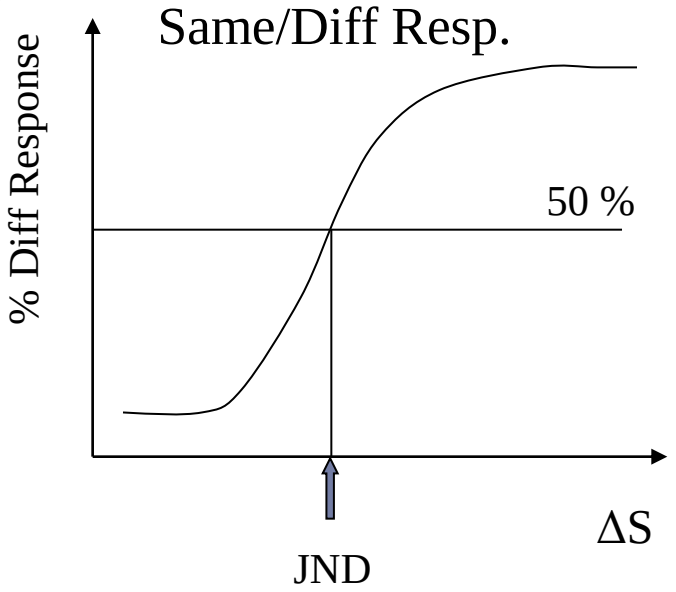
Example

- discrimination threshold of line orientation

Standard stimuli Comparison stimuli

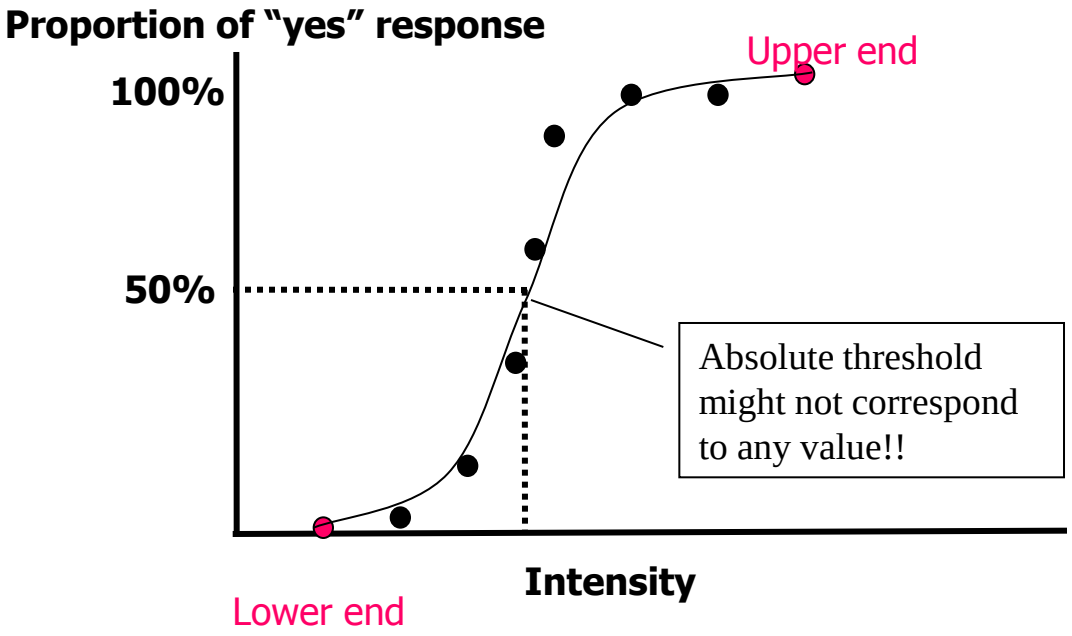


Orientation difference: ΔS

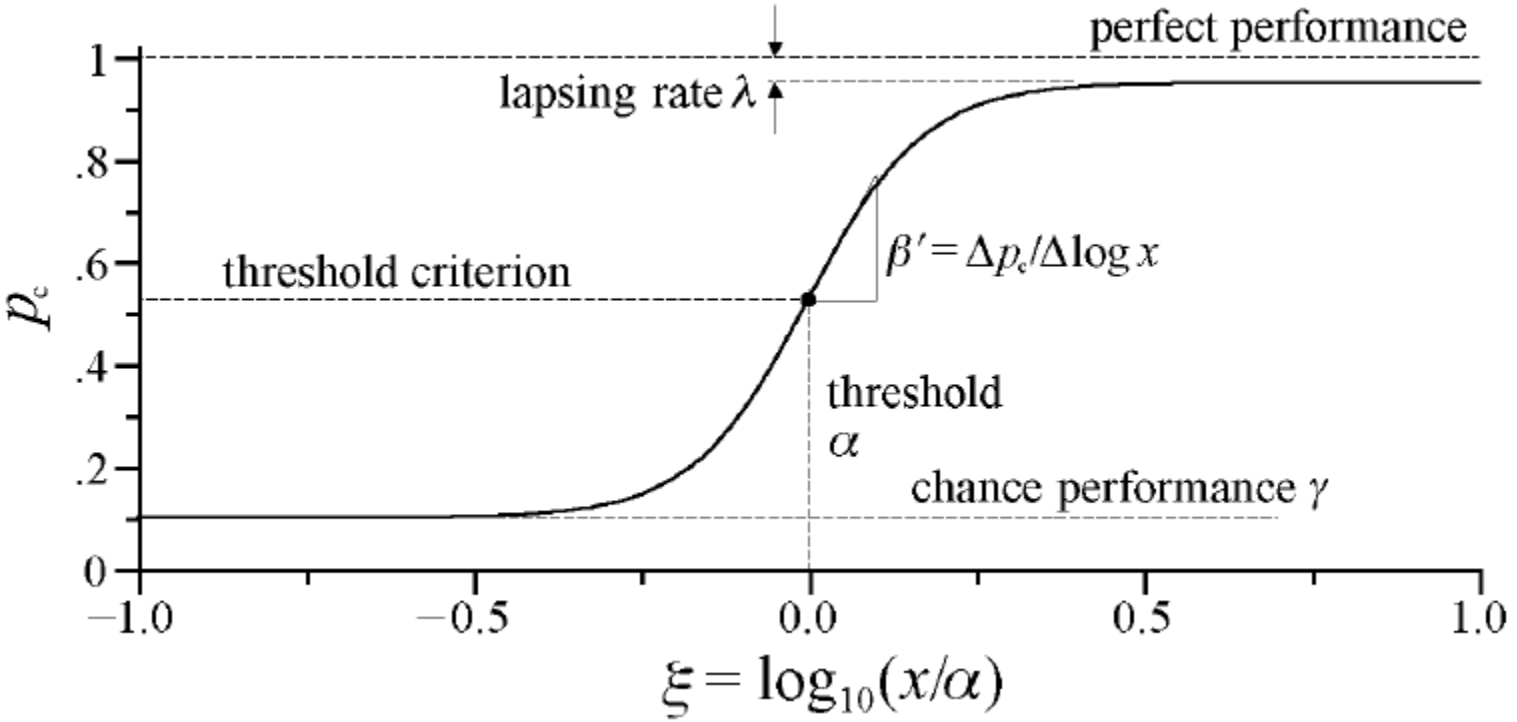


Psychometric function

- describes the relationship between a physical stimulus and sensation
  - sigmoid function



Psychometric function



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

(Strasburger, 2001)

Classical psychophysical methods

Psychophysical experiments have traditionally used three methods for testing subjects' perception in stimulus detection and difference detection experiments:

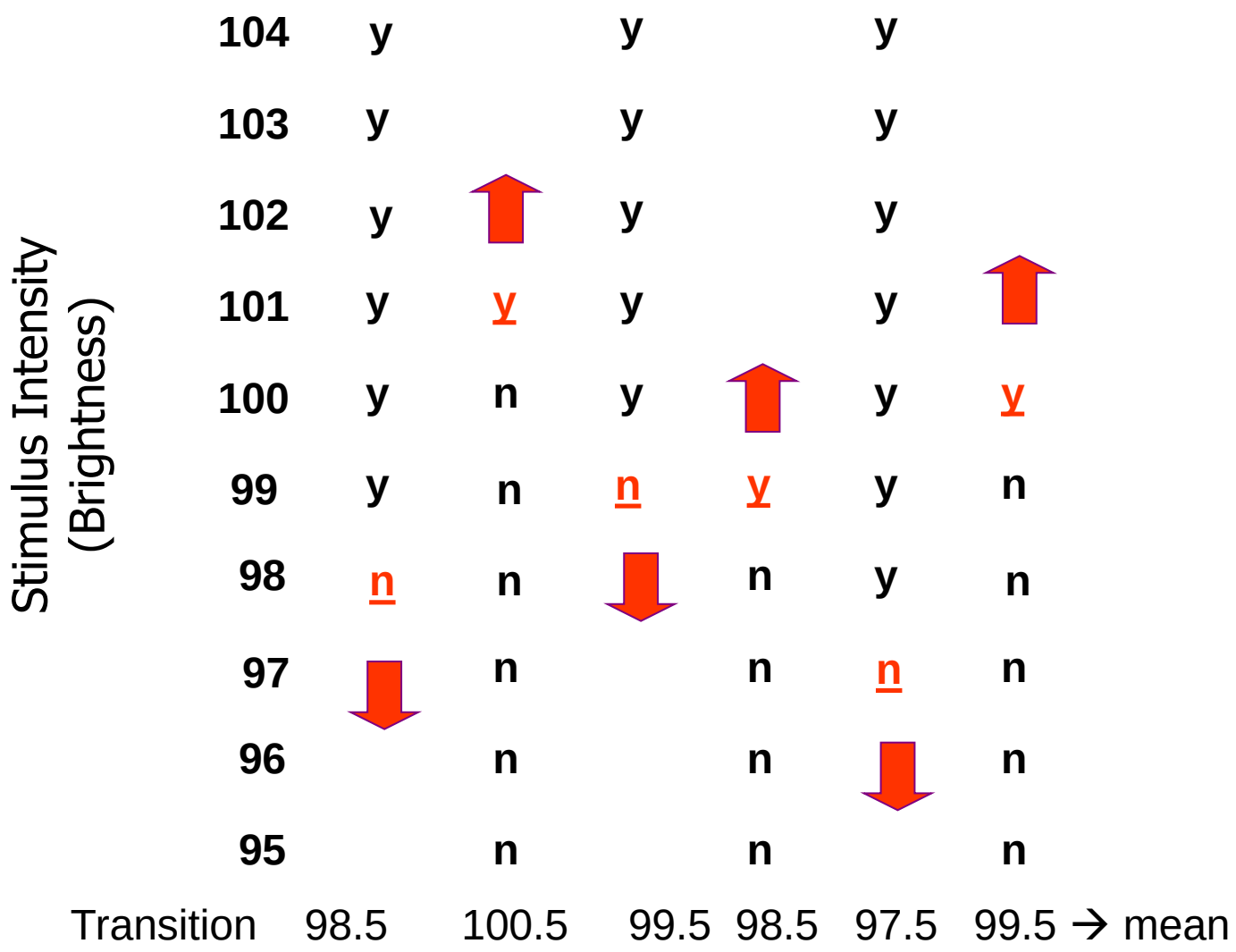
- the method of limits
- the method of adjustment
- the method of constant stimuli

(Snodgrass, 1975).

1. the method of limits

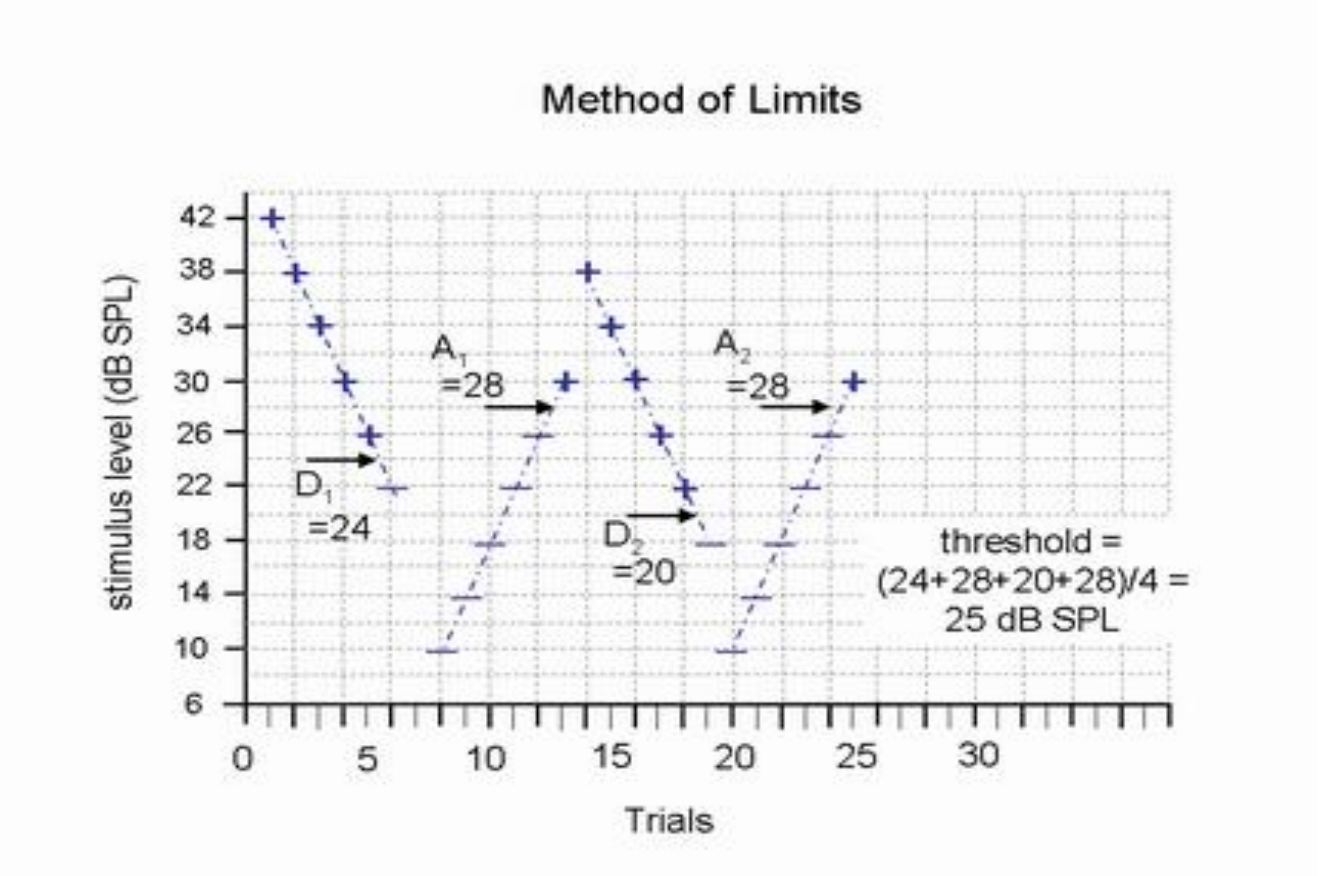
- Procedures:
  - Stimulus intensity increased (or decreased) trial by trial until subjects starts (or ceases) to see the stimulus (or difference)
    - ascending method of limits
    - descending method of limits
  - the ascending and descending methods are used alternately and the thresholds are then averaged.

Example of the method of limits



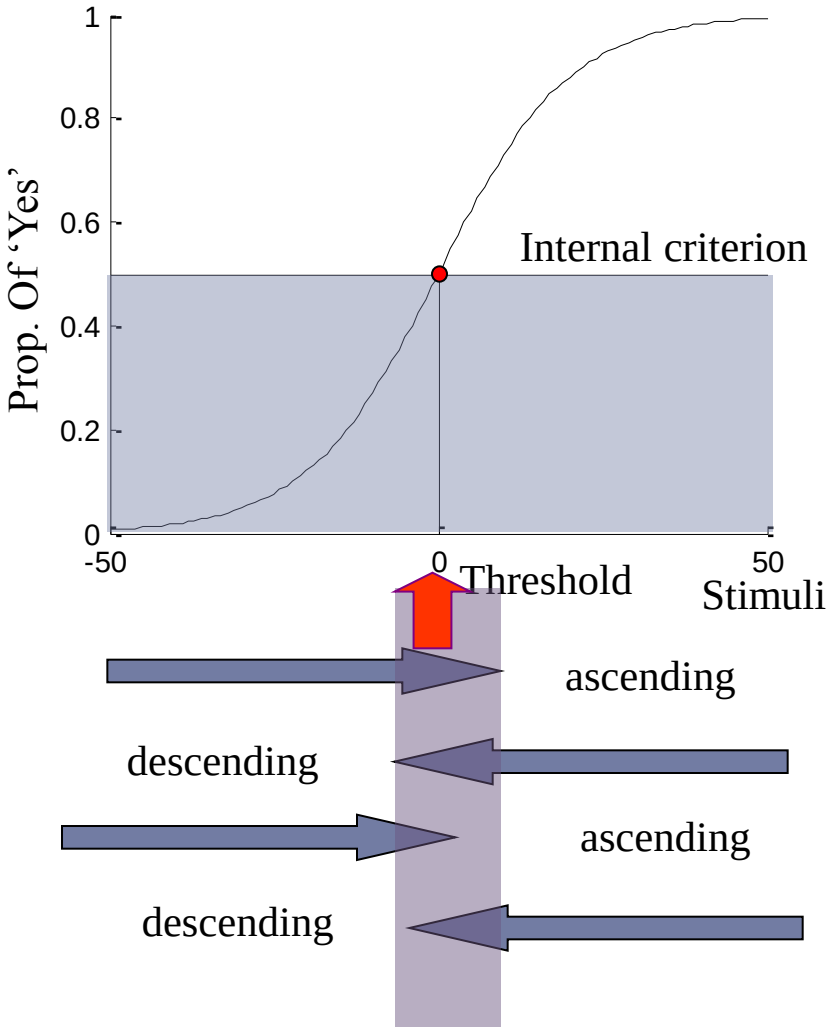
Example of the method of limits

- Sound



Method of limits and psychometric function

- Psychometric function
  - Unknown
- Threshold
  - Internal criterion of responses
- Multiple ascending and descending method of limits
- Only estimate one point, i.e. threshold



The method of limits: Measure JND

- Two stimuli:
  - Standard stimulus (fixed)
  - Comparison stimulus (varied)
- Report:
  - + (more, larger…)
  - = (equal)
  - - (less, smaller …)
- Similar procedure as in absolute limen measurement

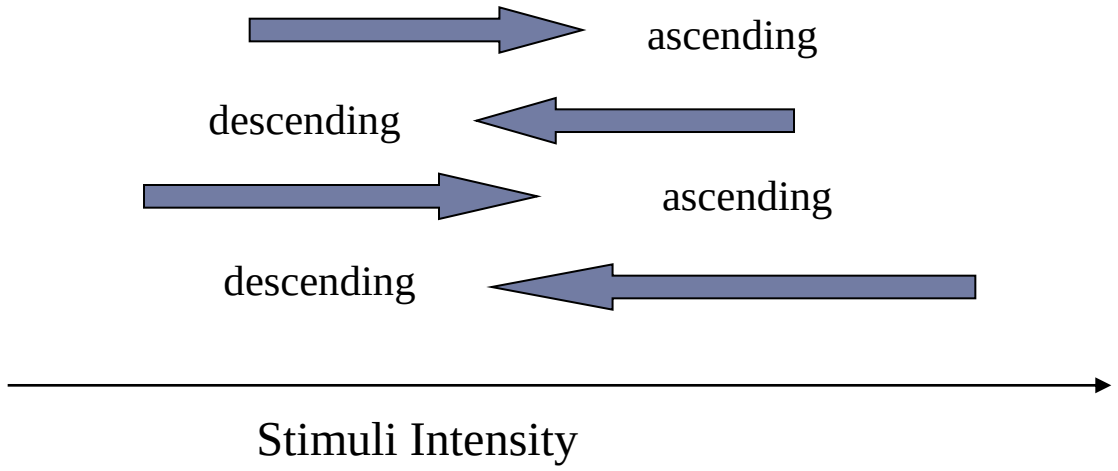
Potential errors

- Habituation Errors
  - Falsely increases thresholds on ascending trials.
  - Falsely decreases thresholds on descending trials.

- Expectation Errors
  - Anticipation of the stimulus arrival and prematurely report.
  - Falsely decreases thresholds on ascending trials.
  - Falsely increases thresholds on descending trials.

How to control the potential errors

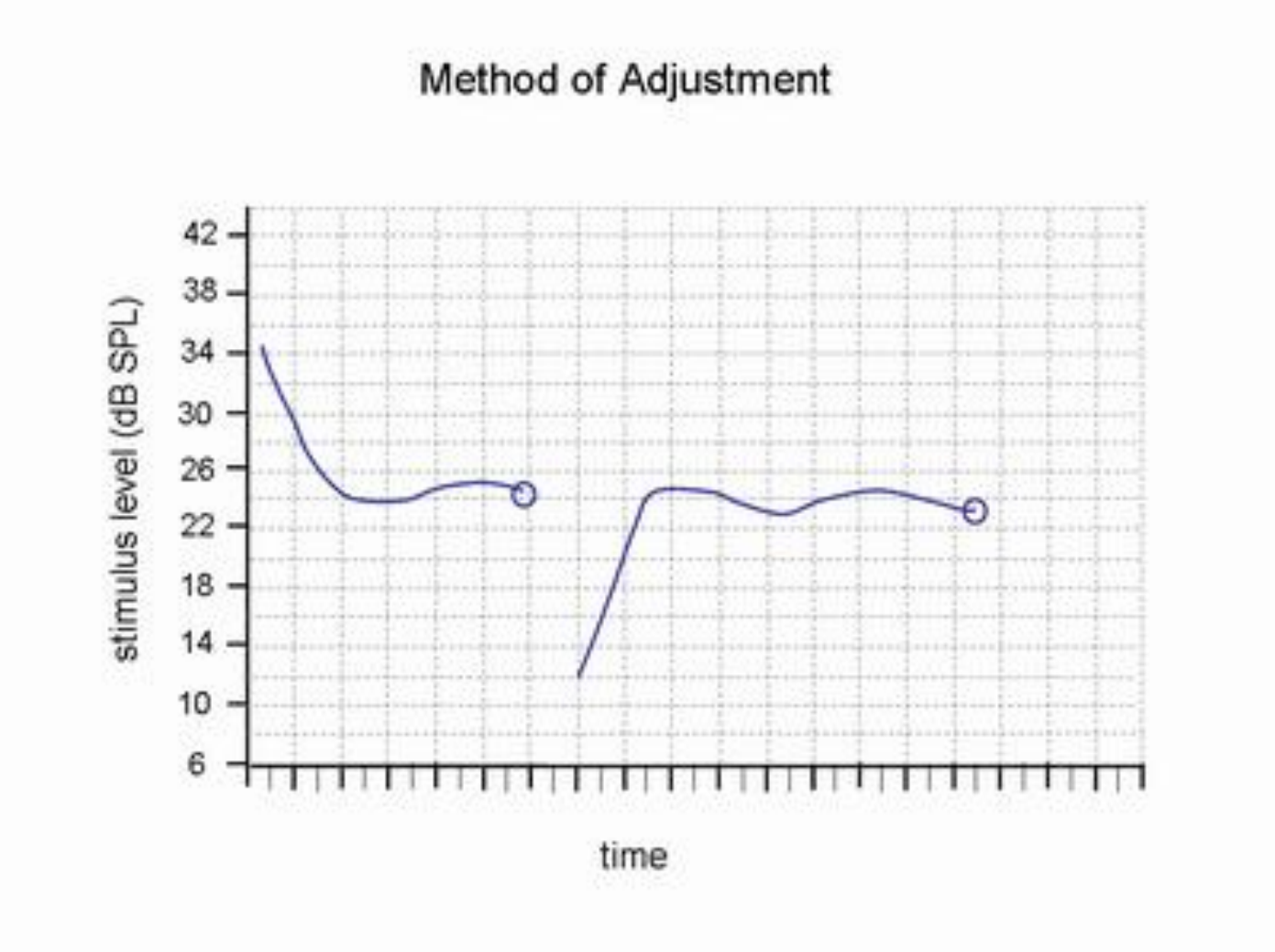
- avoid long trial series
- vary the starting points.
- counterbalance spatial position and temporal orders for optimal localization of the Difference Limen.



2. The method of adjustment

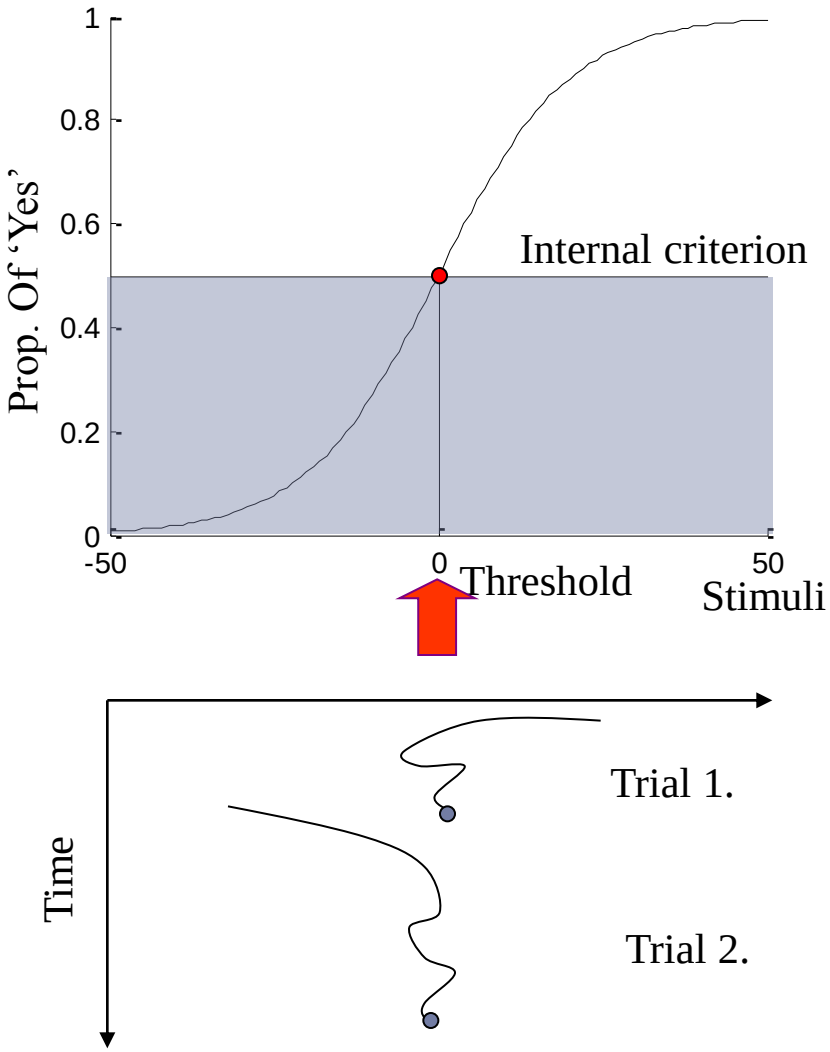
- Similar to the method of limits, but
  - Subject controls (adjust) the stimulus intensity
  - Absolute Limen
    1. subject adjusts stimulus intensity so that the stimulus is barely perceived
    2. Average all trials
  - Difference Limen
    1. One standard stimulus and one continuous adjustable stimulus
    2. Subject adjusts stimulus intensity to the level of standard one
    3. Average error of all trials

Example


Method of Adjustment
stimulus level (dB SPL)
42
38
34
30
26
22
18
14
10
6
time

Method of adjustment and Psy- function

- Psychometric function
  - Unknown
- Threshold
  - Internal criterion of responses
- Continuous adjustment of stimuli intensity
- Fine tuning at the end of trial
- Only estimate one point
  - Threshold



Advantages and disadvantages

- Advantages
  - Faster, A few trials are sufficient
- Disadvantages:
  - Subject knows direction of intensity change
  - Systematic Habituation
  - Expectation errors

3. The method of constant stimuli

- Contrast to methods of limits
  - 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

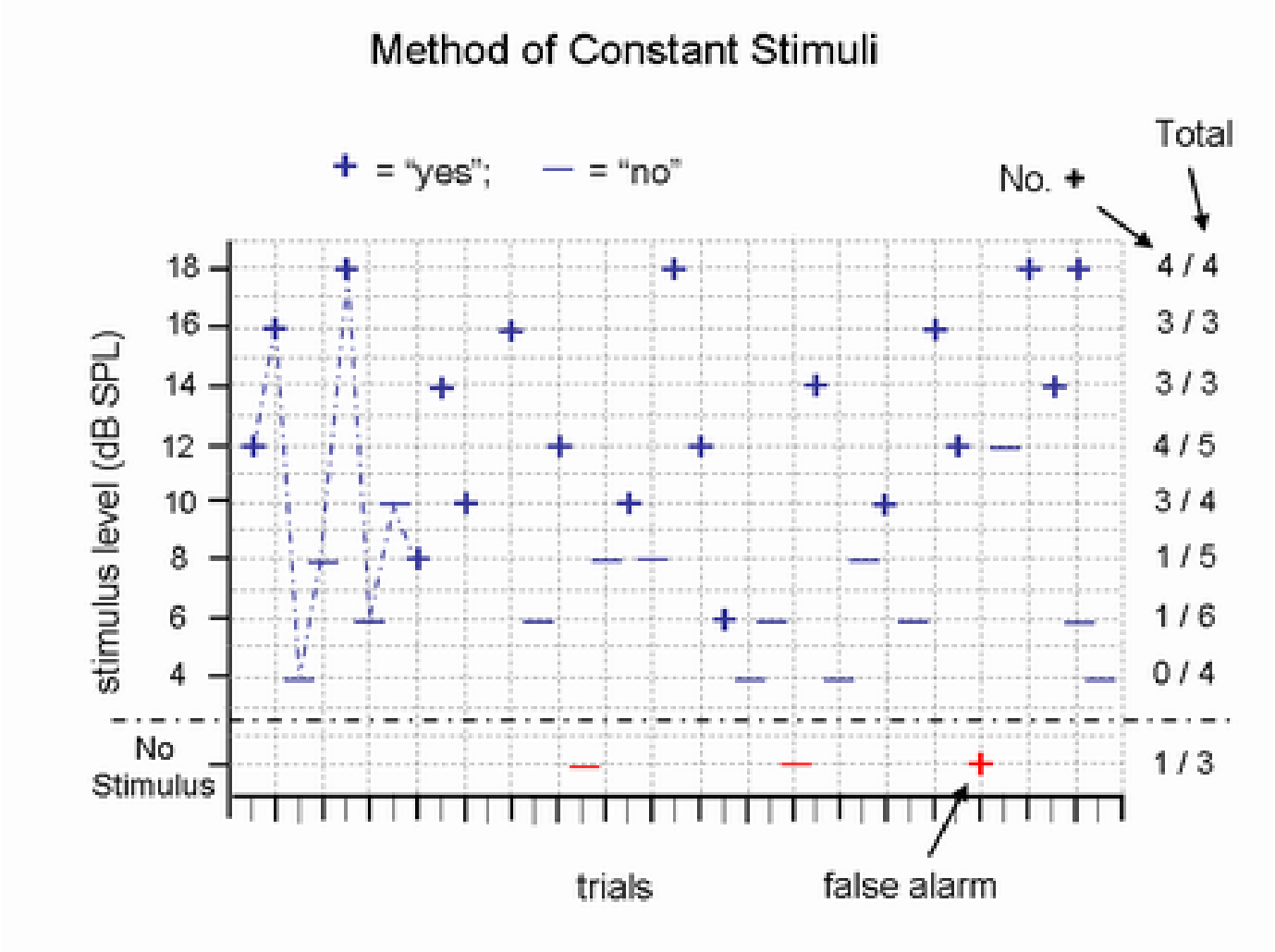
The method of constant stimuli

- For 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. Ask subject if they perceive the stimulus
  5. plotting of *P(S)* for several discrete levels and calculate point of 50% (Point of subjective equality, PSE)

The method of constant stimuli

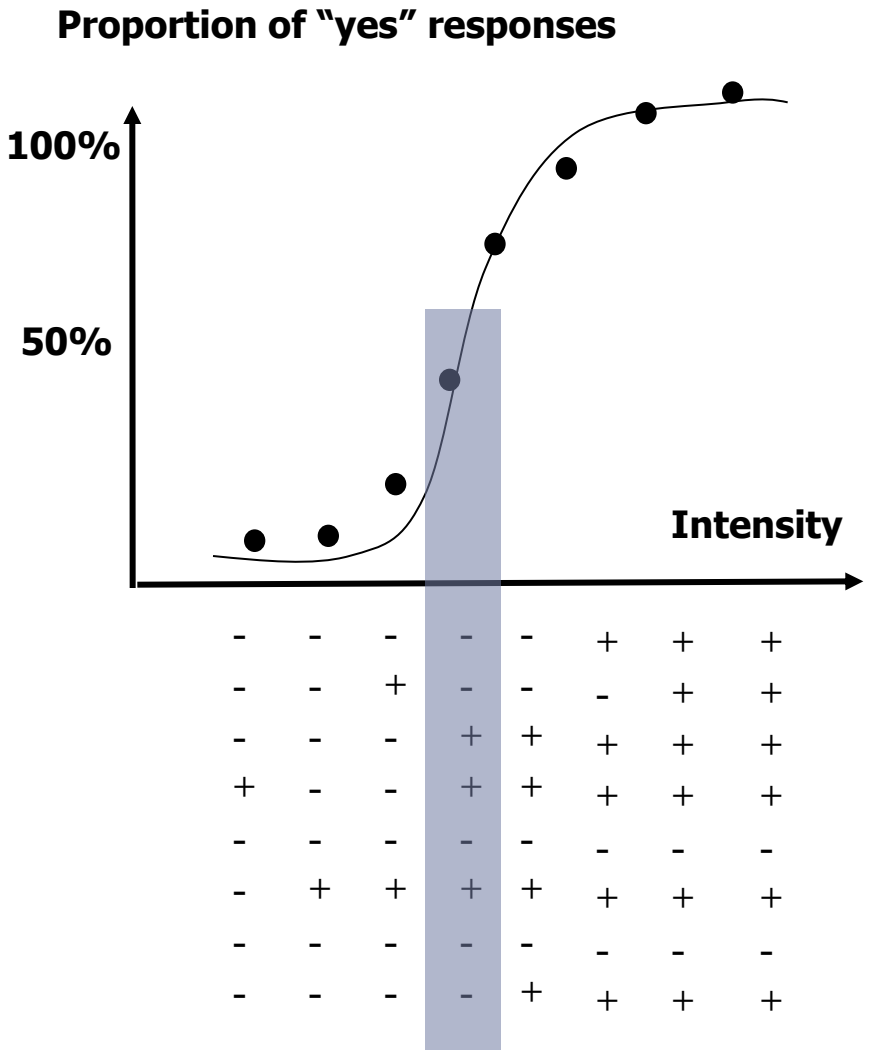
- For difference thresholds (DL)
  1. Present 2 stimuli; reference and test stimulus.
  2. Reference is fixed at all times.
  3. Change test stimulus from trial to trial randomly with equal number above and below the reference value. One stimulus as reference.
  4. Two stimuli must be presented to different receptive areas at the same time or to the same receptive area but at different times.
  5. Rest procedures are similar as in AL procedure

Example


Method of Constant Stimuli
+ = "yes"; — = "no"
Total
No. +
4 / 4
3 / 3
3 / 3
4 / 5
3 / 4
1 / 5
1 / 6
0 / 4
1 / 3
stimulus level (dB SPL)
18
16
14
12
10
8
6
4
No Stimulus
trials
false alarm

Method of Const. Sti. & Psy. Function

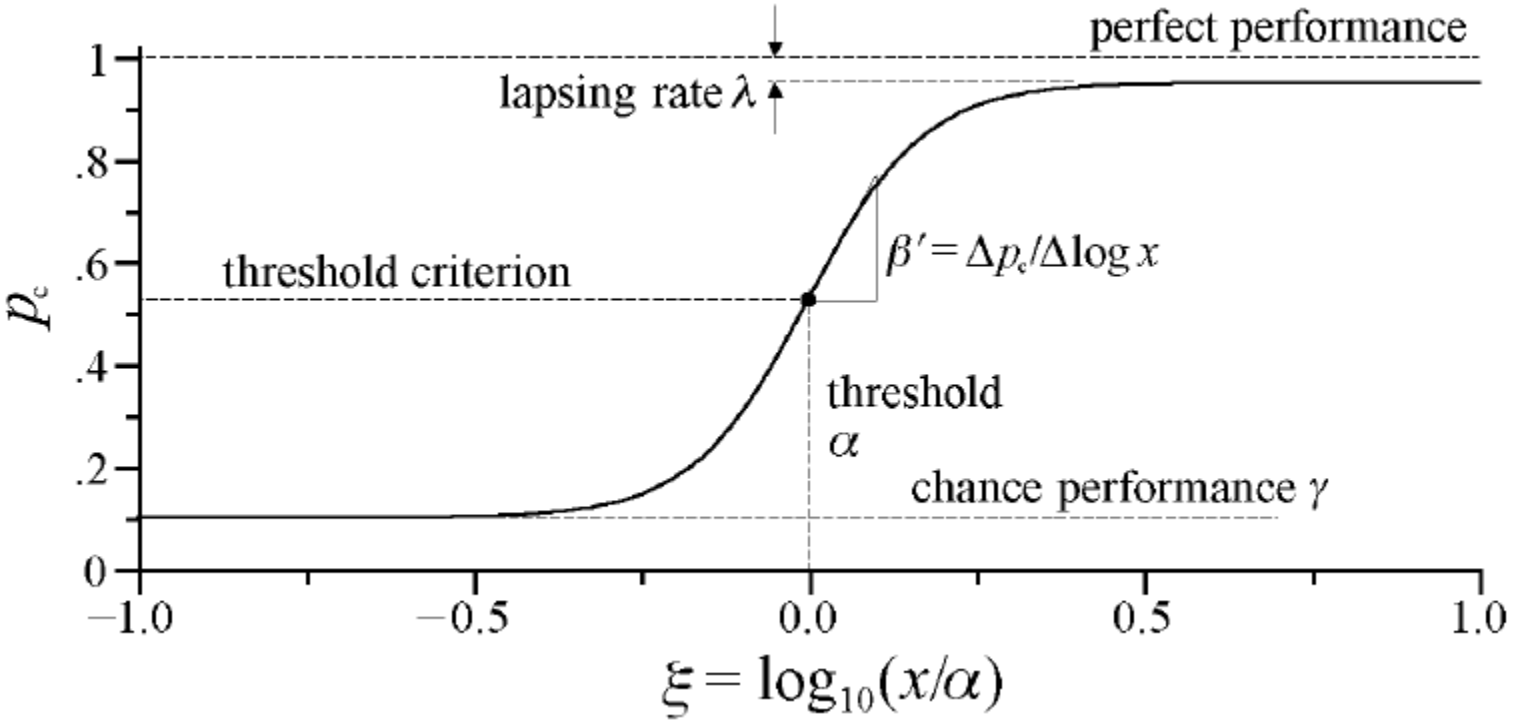
- Multiple Intensity levels, multiple repetition
- Prop. of responses
  - Represented roughly shape of psychometric curve
- Psychometric function can be estimate
- Not only measure the threshold, but also the shape (steepness) of the psy. Function



method of constant stimuli

- Advantages:
  - Subject does not know order of presentation
  - Not only threshold can be estimated, any subjective points (e.g. 75%) can also be estimated.
  - Psychometric function has information of the sensitivity of the sensation
    - Steep slope: sensitive to physical stimuli variation
    - Shallow slope: relative insensitive
- Disadvantages:
  - Some experiments might take quite long time
  - With patient studies, they may not be able to stay too long
  - Learning effects

Psychometric function

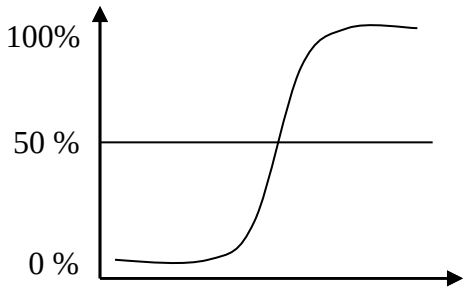


$$\psi^*(x) = \frac{\psi(x) - \gamma}{1 - \gamma - \lambda}$$

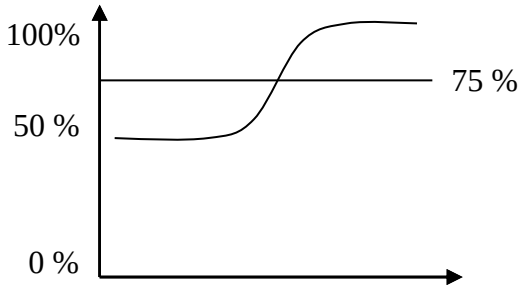
(Strasburger, 2001)

Psychometric function

- Yes / No paradigm

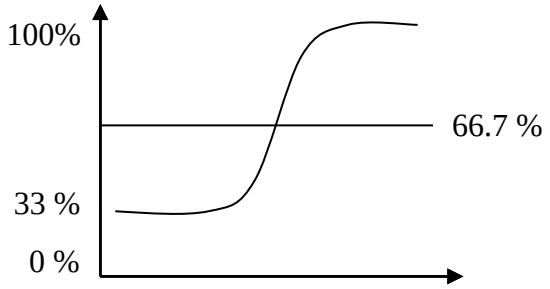


- 2 alternative force choice (2AFC)



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

- 3AFC (Odd one out)



Psychometric function Ref.

- 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

Fitting psychometric curves

- Logistic function

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

  - p=0.5
    - Threshold: x = a
  - JND is defined as half of difference between upper threshold (75%) and lower threshold (25%)
    - JND = b*log3