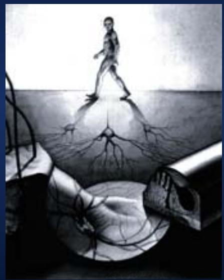
Auditory Perception



Rob van der Willigen
http://~robvdw/cnpa04/coll1/AudPerc_2007_P5.ppt

General Outline P10-13

Auditory Perception
- Detection versus Discrimination
- Localization versus Discrimination

- Electrophysiological Measurements
- Psychophysical Measurements

Audition (Hearing)

"Detecting and recognizing a sound are the result of a complex interaction of physics, physiology, sensation, perception and cognition."

John G. Neuhoff (Ecological Psychoacoustics 2004; p. 1)

Psychoacoustics

Three Approaches to Researching Audition

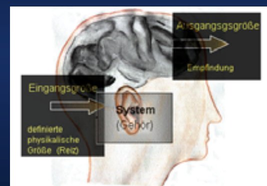
physiology • Sensorische Codierung • Lokalisation von Funktionen	Zusammenhang von physiologischen Prozessen und Wahrnehmung „Innere Psychophysik" und Leib-Seele-Problem
psychophysics • Schwellenbestimmung • Reizempfindung	Zusammenhang von Reizeigenschaften und Wahrnehmung „Äußere Psychophysik"
cognitive psychology • Einfluss von Erwartungen und Vorwissen auf die Reizidentifikation	Zusammenhang von „höheren" kognitiven Prozessen und Wahrnehmung

Today's goal

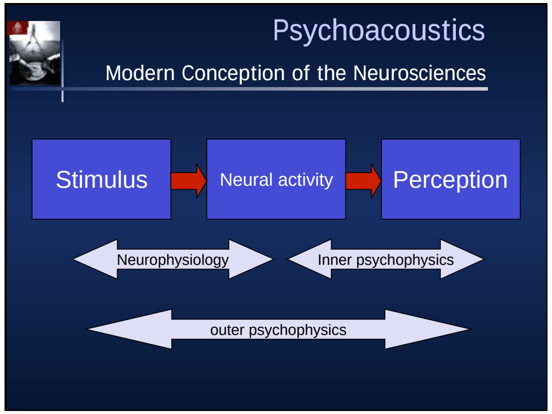
Understanding psychophysical methodology and its underlying theory

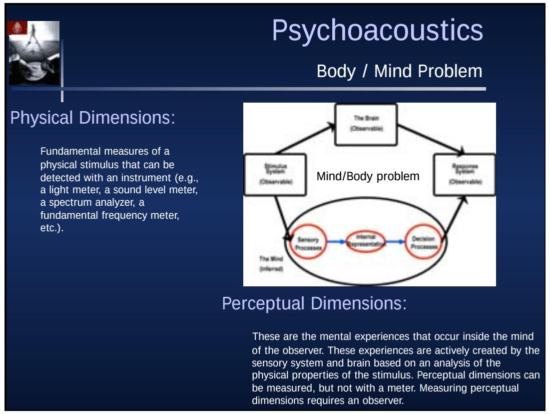
Psychoacoustics

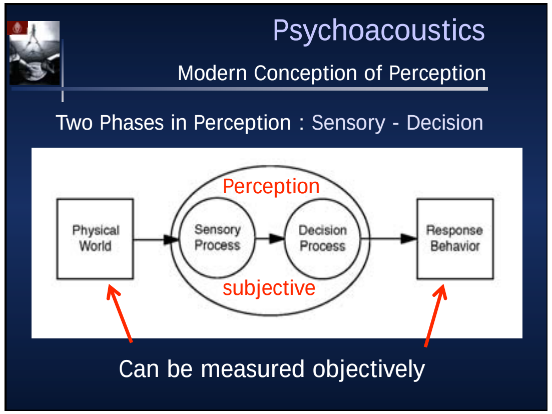
The study of Auditory Perception or Psychoacoustics is a branch of Psychophysics.

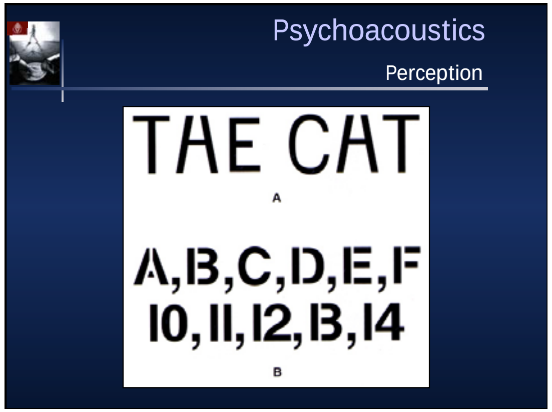


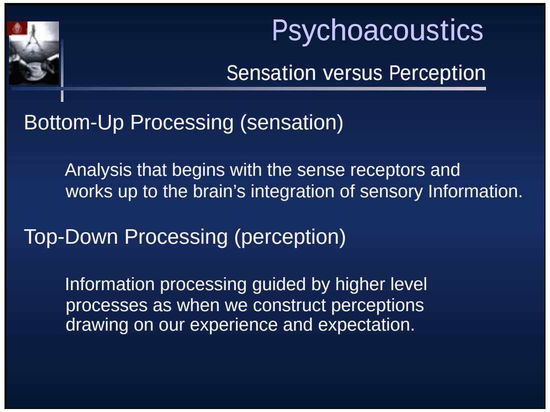
Psychophysics studies relationships between perception and physical properties of stimuli.

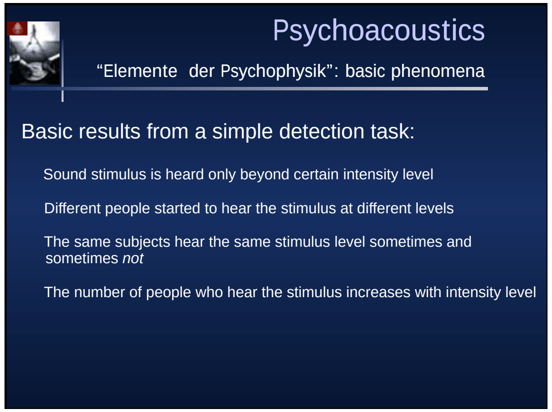

Psychoacoustics
Modern Conception of the Neurosciences
Stimulus
Neural activity
Perception
Neurophysiology
Inner psychophysics
outer psychophysics

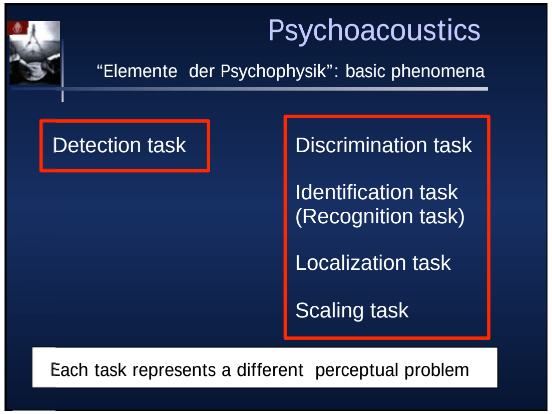

Psychoacoustics
Body / Mind Problem
Physical Dimensions:
Fundamental measures of a physical stimulus that can be detected with an instrument (e.g., a light meter, a sound level meter, a spectrum analyzer, a fundamental frequency meter, etc.).
Mind/Body problem
Perceptual Dimensions:
These are the mental experiences that occur inside the mind of the observer. These experiences are actively created by the sensory system and brain based on an analysis of the physical properties of the stimulus. Perceptual dimensions can be measured, but not with a meter. Measuring perceptual dimensions requires an observer.

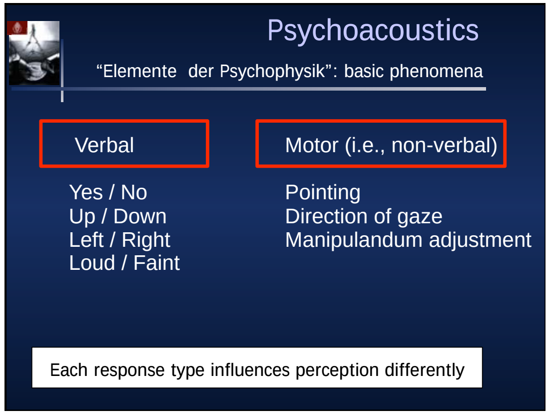

Psychoacoustics
Modern Conception of Perception
Two Phases in Perception : Sensory - Decision
Perception
Physical World
Sensory Process
Decision Process
Response Behavior
subjective
Can be measured objectively

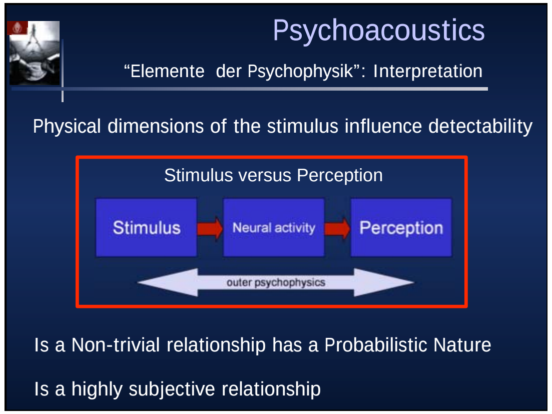

Psychoacoustics
Perception
TAE CAT
A
A,B,C,D,E,F
10,11,12,13,14
B

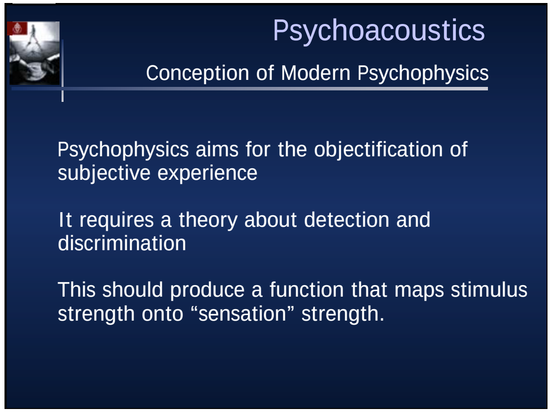

Psychoacoustics
Sensation versus Perception
Bottom-Up Processing (sensation)
Analysis that begins with the sense receptors and works up to the brain's integration of sensory Information.
Top-Down Processing (perception)
Information processing guided by higher level processes as when we construct perceptions drawing on our experience and expectation.

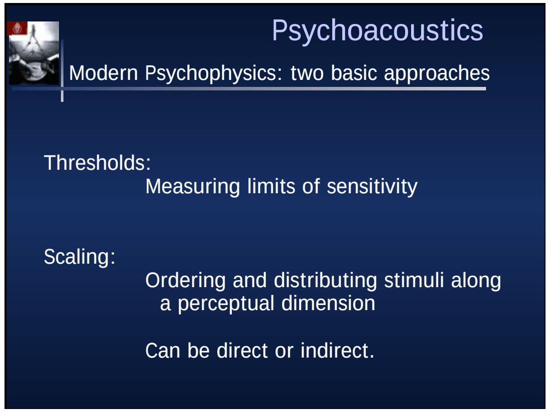

Psychoacoustics
"Elemente der Psychophysik": basic phenomena
Basic results from a simple detection task:
Sound stimulus is heard only beyond certain intensity level
Different people started to hear the stimulus at different levels
The same subjects hear the same stimulus level sometimes and sometimes not
The number of people who hear the stimulus increases with intensity level

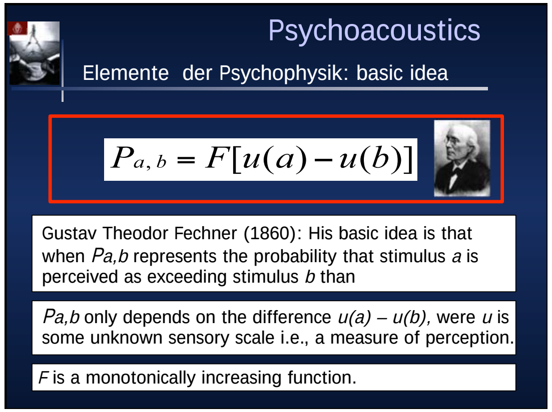

Psychoacoustics
“Elemente der Psychophysik”: basic phenomena
Detection task
Discrimination task
Identification task (Recognition task)
Localization task
Scaling task
Each task represents a different perceptual problem


Psychoacoustics
“Elemente der Psychophysik”: basic phenomena
Verbal
Yes / No
Up / Down
Left / Right
Loud / Faint
Motor (i.e., non-verbal)
Pointing
Direction of gaze
Manipulandum adjustment
Each response type influences perception differently

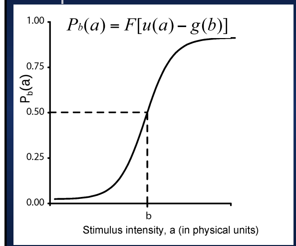

Psychoacoustics
“Elemente der Psychophysik”: Interpretation
Physical dimensions of the stimulus influence detectability
Stimulus versus Perception
Stimulus
Neural activity
Perception
outer psychophysics
Is a Non-trivial relationship has a Probabilistic Nature
Is a highly subjective relationship


Psychoacoustics
Conception of Modern Psychophysics
Psychophysics aims for the objectification of subjective experience
It requires a theory about detection and discrimination
This should produce a function that maps stimulus strength onto “sensation” strength.


Psychoacoustics
Modern Psychophysics: two basic approaches
Thresholds:
Measuring limits of sensitivity
Scaling:
Ordering and distributing stimuli along a perceptual dimension
Can be direct or indirect.


Psychoacoustics
Elemente der Psychophysik: basic idea
$P_{a,b} = F[u(a) - u(b)]$
Gustav Theodor Fechner (1860): His basic idea is that when *Pa,b* represents the probability that stimulus *a* is perceived as exceeding stimulus *b* than
Pa,b only depends on the difference *u(a) – u(b)*, were *u* is some unknown sensory scale i.e., a measure of perception.
F is a monotonically increasing function.

Psychoacoustics
A function for detection: the PMF



Consider the probability $P_b(a)$ that stimulus *a* is jugged as exceeding *b*.

Can also be denoted as $P(b \leq a)$.

The plot shows a somewhat idealized graph of function $P_b(a)$.

Note that the equation for $P_b(a)$ generalizes to that of Fechner:

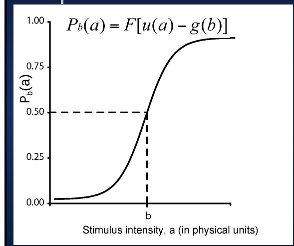
$$P_{a,b} = F[u(a) - u(b)]$$

when *g* is transformed appropriately to scaling factor *u*

F represents a cumulative distribution function (CDF), or distribution function.

The sigmoid curve defined by function *F* is called the Psychometric Function (PMF).

Psychoacoustics
A function for detection: the PMF



The psychometric function provides an answer to both the measurement of (1) a threshold and (2) the aim to order and distribute stimulus level along a perceptual dimension

The sigmoid curve defined by function *F* is called the Psychometric Function (PMF).

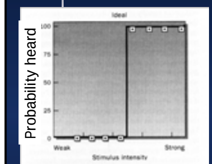
Psychoacoustics
Psychophysics requires a Concept of Threshold

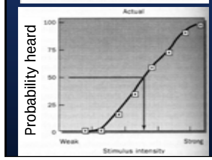
The notion of threshold seems straightforward, on the surface at least; indeed, one could define it as:

"The smallest stimulus level that can be *reliably* perceived".

However, this definition of threshold is arbitrary and solely defined in terms of level of performance.

Psychoacoustics
Psychophysics requires a Concept of Threshold





Ideally "reliable" detection should occur at the a single stimulus magnitude below which detection is not possible.

In actual effect, as already predicted by Fechner, perception acts as in a probabilistic fashion increasing monotonically with stimulus magnitude (i.e., level).

By definition if performance ranges from zero to 1 (or 100% detected) than threshold is defined as the stimulus level coinciding with 50% detected.

Psychoacoustics
Psychophysics requires a Concept of Threshold

Determining a threshold for detecting sound by use of a detection experiment determines what is called a Absolute threshold.

Note however, because of the arbitrary nature of defining threshold in terms of response level it has not much value in absolute terms.

Also note that threshold cannot be a fixed quantity because of the very nature of human and animal physiology; think for example of adaptation which acts as a gain allowing detection along a wider physical range of stimulus level with the same sensors.

A more logical approach is to define threshold in relative terms.

Psychoacoustics
Psychophysics requires a Concept of Threshold

Defining threshold relatively:

Just noticeable difference (JND):

Minimal physical change of the stimulus level such that change in response behavior is reported.

Point of subjective equivalence (PSE):

Physical strength of the stimulus that is perceived as equally strong as reference.

Psychoacoustics
Psychophysics requires a Measurement Scale

Measurement seems straightforward, on the surface at least; indeed, all measurements can be reduced to just two components: number and unit.

However, measurement depends on a quite a number of implicit assumptions about physical reality and it also involves a considerable amount of arbitrariness.

Psychoacoustics
Psychophysics requires a Measurement Scale

Stevens (1946) proposed four classes of scales that are still used:

- nominal
- ordinal
- interval
- ratio

Psychoacoustics
Psychophysics requires a Measurement Scale

Norman Robert Campbell was a scholar renowned internationally for his rigorous analysis of the foundations of physical measurement. In 1933 and 1935 he anticipated ideas that are used today for the classification of sensory scales and for non-metric scaling.

Campbell's 1933 and 1935 articles have been neglected or have been unknown by virtually every psychophysicist.

No mention of these articles can be found in subsequent important books and reviews of psychophysics.

Except for Stanley Smith Stevens, (1946):
On the theory of scales of measurement. *Science,* ***103, 677-679.***

Psychoacoustics
Measurement Scales

Nominal Scale

A nominal scale requires placing of data into categories without any order or structure.

A physical example of a nominal scale is the terms we use for colors. The underlying spectrum is ordered but the names are nominal.

In psychophysics a YES/NO scale is nominal.

It has no order and there is no distance between YES and NO.

Psychoacoustics
Measurement Scales

Ordinal Scale

The simplest ordinal scale is a ranking.

When a researcher asks you to rank 5 types of beer from most flavorful to least flavorful, he/she is asking you to create an ordinal scale of preference.

There is no objective distance between any two points on your subjective scale.

For you the top beer may be far superior to the second preferred beer but, to another respondent with the same top and second beer, the distance may be subjectively small.

An ordinal scale only lets you interpret gross order and not the relative positional distances.

Ordinal data analysis requires non-parametric statistics.

Psychoacoustics
Measurement Scales

Interval Scale

When you are asked to rate stimulus strength on a 7 point scale, from *faint* (1) to *loud* (7) , you are using an interval scale.

It is an interval scale because it is assumed to have equidistant points between each of the scale elements.

This means that we can interpret differences in the distance along the scale. We contrast this to an ordinal scale where we can only talk about differences in order, not differences in the degree of order.

Interval scales are also scales which are defined by metrics such as logarithms (i.e., dB). In these cases, the distances are note equal but they are strictly definable based on the metric used.

Psychoacoustics
Measurement Scales

Ratio Scale

The factor which clearly defines a ratio scale is that it has a true zero point.

The simplest example of a ratio scale is the measurement of length (disregarding any philosophical points about defining how we can identify zero length).

Psychoacoustics
What about scaling governed by perception

$$P_{a,b} = F[u(a) - u(b)]$$

Fechner's equation is often objected to on grounds that is to abstract and offers little intuition regarding the underlying processes responsible for the subjects' responses (or choices).

Nonetheless, it represents a powerful theoretical approach to research perception because it provides us with objectively testable hypothesizes about the choices made by an observer in response to physical stimuli.

The difficulty with scaling in psychophysics is that in absence of a stimulus there is nothing there that can be scaled or is there?

Psychoacoustics
What about scaling governed by perception

Direct Scaling in psychophysical experiments

Observers assign numbers to the magnitudes of the sensations created by each stimulus

Mean estimation for each stimulus is the scale value of sensation magnitude for that intensity

Often "anchoring" or "background" stimuli are provided, so magnitude estimates become ratio estimates.

Results are better described by Stevens' Law rather than Fechner's Law.

Psychoacoustics
What about scaling governed by perception

Indirect scaling based on thresholds

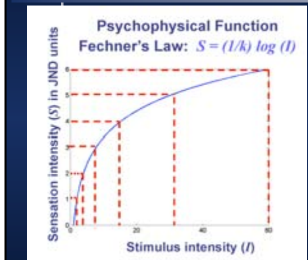
JND (Just Noticeable Difference) scale

0 sensation units (0 JND of sensation)
stimulus intensity at absolute detection threshold

1 sensation unit (1 JND of sensation)
stimulus intensity that is 1 difference threshold above absolute threshold

2 sensation units (2 JND of sensation)
stimulus intensity that is 1 difference threshold above the 1-unit stimulus

Psychoacoustics
Scaling: Magnitude of perceptual change



$$\Delta I \rightarrow dI \Rightarrow \frac{dS}{dI} = \frac{1}{k}\frac{1}{I} \Rightarrow$$

Fechner assumed that a JND for a faint background produces the same difference in sensation as does the JND for a loud stimulus.

As it turned out, this assumption is not valid, as shown by Stevens (1957) he simply asked subject to asses supra-threshold stimuli

This is an example of Direct Scaling.

Psychoacoustics
Direct Scaling: Stevens' Power law

When dealing with loudness, the subject is asked to assign a number to the perceived loudness of the given stimuli.

For example 1 is faint and 10 is very loud.

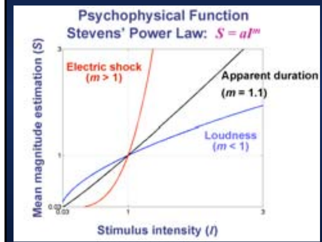
Sensation, indicated by the numerical values assigned by the subject is plotted as function of stimulus intensity.

By magnitude scaling (ordinal scaling), Stevens was able to show that the growth in magnitude of the sensation follows a power relationship, rather than a log relationship as postulated by Fechner.

Although difficult to conceptualize, this means that a constant ratio of sensation is produced by a constant ratio of stimulus

Psychoacoustics

Scaling: Stevens' Power law



Another function relating sensation magnitude to stimulus intensity:

$$S = aI^m$$

The exponent *m* describes whether sensation is an expansive or compressive function of stimulus intensity.

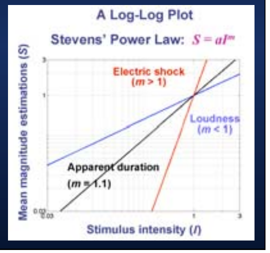
The coefficient *a* simply adjusts for the size of the unit of measurement for stimulus intensity threshold above the 1-unit stimulus

Psychoacoustics

Scaling: Stevens' Power law

Stevens' Law Exponents

Continuum	Exponent	Stimulus
Loudness	0.6	1 kHz sinusoid signal
Apparent Duration	1.1	Broadband noise
Electric Shock	3.5	60 Hz – through fingers



Psychoacoustics

Significance of scaling and threshold estimation

The determination of thresholds plays a large role in auditory research and clinical care of the inner ear.

The trade-off between the ease of the measurement and validity of the measurement determines the value of psychophysical testing.

For clinical purposes, the repeatability (reliability) of the threshold measurement is often more important than the validity.

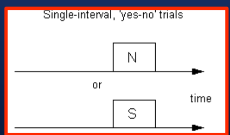
Conceptually easily applied psychophysical procedures, such as the staircase method or method of limits, provide clinically useful information.

Psychoacoustics

Testing paradigm: Yes-No Paradigm

Psychophysical procedures dispose of various testing paradigms, of which I describe the yes-no and the forced-choice (nAFC: n-alternative-forced-choice) paradigm.

With the yes-no mode subjects are given a series of trials, in which they must judge the presence or absence of a stimulus at each case.



It is essentially a detection task.

The ratio between the number of trials containing a stimulus and the total number of trials is usually 0.5, but can be any other value.

The rate of yes-responses for all tested stimulus intensities is defined as the dependent variable.

Psychoacoustics

Pay-off Matrix: Yes-No Paradigm

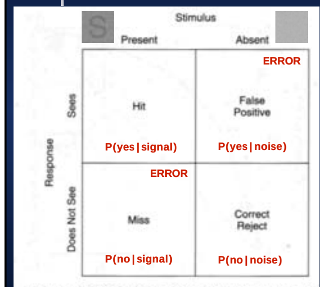


FIGURE 10–7. Possible outcomes for a signal detection experiment.

In a yes/no binary detection task there are two states of the physical world (signal or noise) and two types of responses (yes or no).

A Subject can make two types of errors:

(1) say Yes when a noise alone is presented
(2) say No when a signal is presented

The frequencies of these two types of error will be determined by two factors :

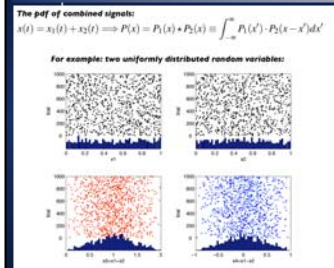
- Sensitivity of observer
- Criteria of decision

1- P(yes|signal) = P(no|signal)

1- P(yes|noise) = P(no|noisel)

Psychoacoustics

Signal detection theory (SDT)



Signal detection theory (SDT) assumes that within a given neural system there are randomly fluctuating levels of background activation.

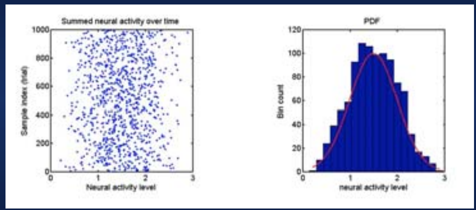
Thus, in absence of a stimulus neural activity is randomly distributed over time.

The Probability Density Function (PDF), P(x), determines how often/long spontaneous neural activity x(t) spends at a given value x

The PDF is represented by the blue bars (in each plot)) and exists independent of time. Combining of independent signals (x1 and x2) changes the shape of the PDF.

Psychoacoustics

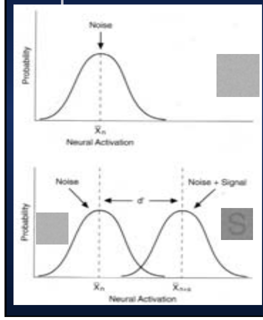
Signal detection theory (SDT)



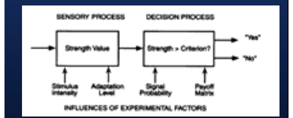
The PDF of randomly fluctuating levels of neural activation summed over time approximates the normal distribution (red line).

Psychoacoustics

Signal detection theory (SDT)

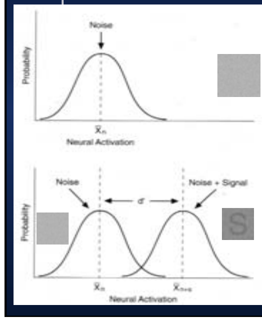


Decision requires a criterion to attribute received information to either one of the normal theoretical distributions resulting from random variation of sensory information corresponding respectively to a noise alone or to a signal superimposed to noise.



Psychoacoustics

Signal detection theory (SDT)



Signal detection theory (SDT) formally addresses the influence of spontaneous neural activity (noise) and decision criteria on the choices (responses) made by the observer when presented with a physical stimulus (signal).

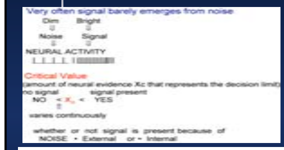
Shown are the PDFs of neural activity in absence of a stimulus and in the presence of a stimulus.

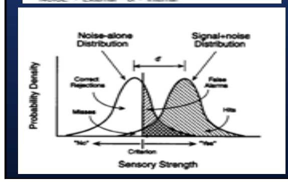
Notice the rightward shift of the PDF when a stimulus (signal) is present.

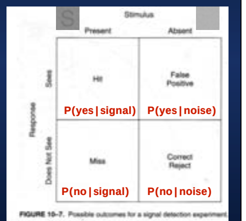
The delectability d' is a measure of the strength of a physical stimulus.

Psychoacoustics

Response Criterion (bias): Yes-No Paradigm

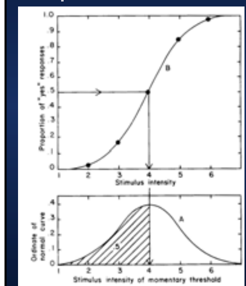






Psychoacoustics

Signal detection theory: PDF versus CDF



Relationship between the psychometric curve and its derivative which represents a probability distribution function (PDF).

The PDF (lower plot) shows the probability of a given level of neural activation in response to a given stimulus strength.

Notice that the psychometric curve represents a cumulative distribution function