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System Bioengineering II: Neurosciences

Study the Brain through Behavior

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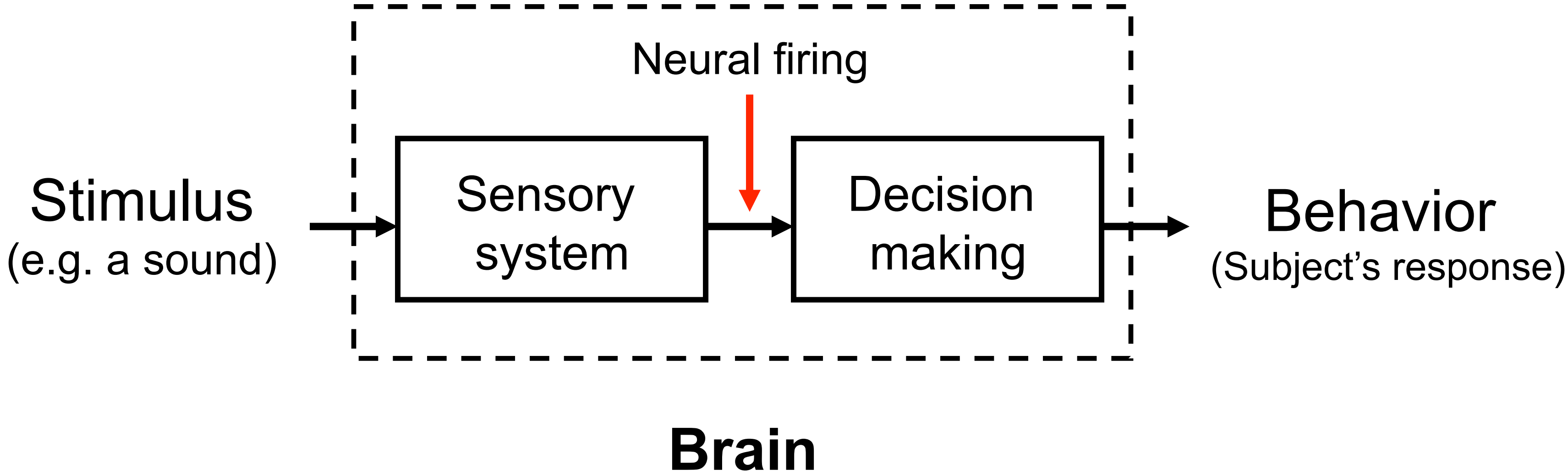
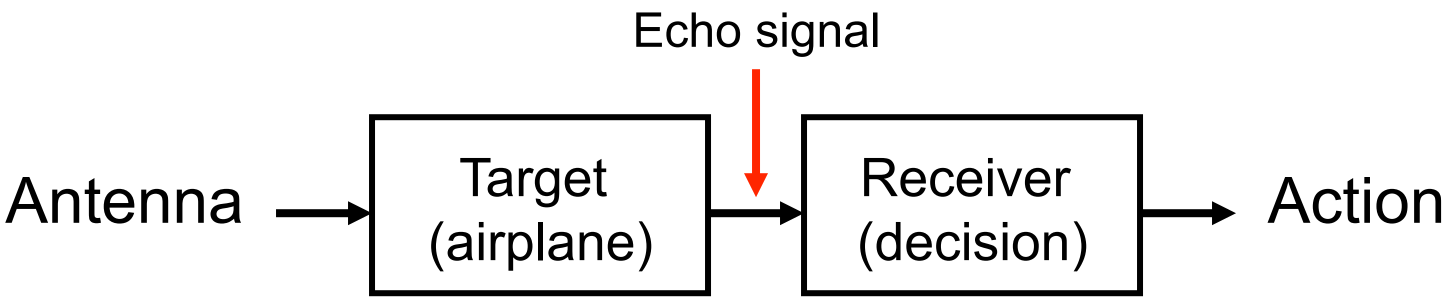
How to quantify behaviors?



How does radar system work?



Radar

Psychophysics: Quantitative analysis of behaviors

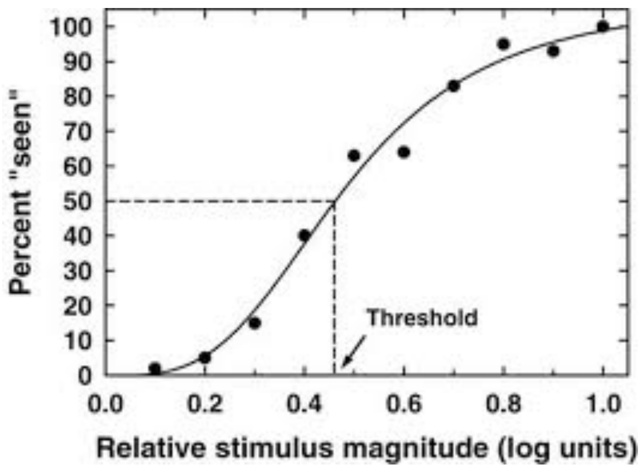
- Psychophysics is the scientific discipline that explores the connection between physical stimuli and subjective responses.

- "Psychometric function" provides the fundamental data for psychophysics. It relates the subject's response to the physical stimulus and is used to quantitatively measure behaviors.
Its abscissa (x-axis) plots the physical parameter of a stimulus and the ordinate (y-axis) plots the observer's response.

Reference: Klein SA, "Measuring, estimating, and understanding the psychometric function: a commentary". *Perception and Psychophysics* 63(8):1421-55 (2001)

Two different types of commonly used psychometric functions

Psychometric function derived from a detection paradigm

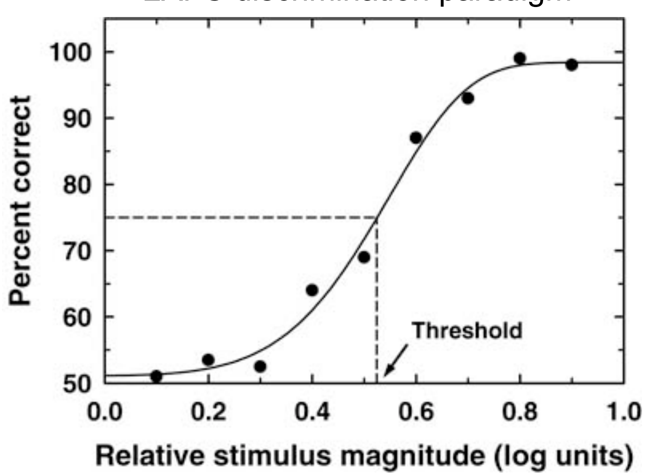


(1) Absolute threshold measurement (a detection task)

For example, to determine whether a light flash is seen on a computer screen.

The proportion of "seen" responses is plotted on the y-axis and the physical parameter on the x-axis.

Psychometric function derived from a 2AFC discrimination paradigm



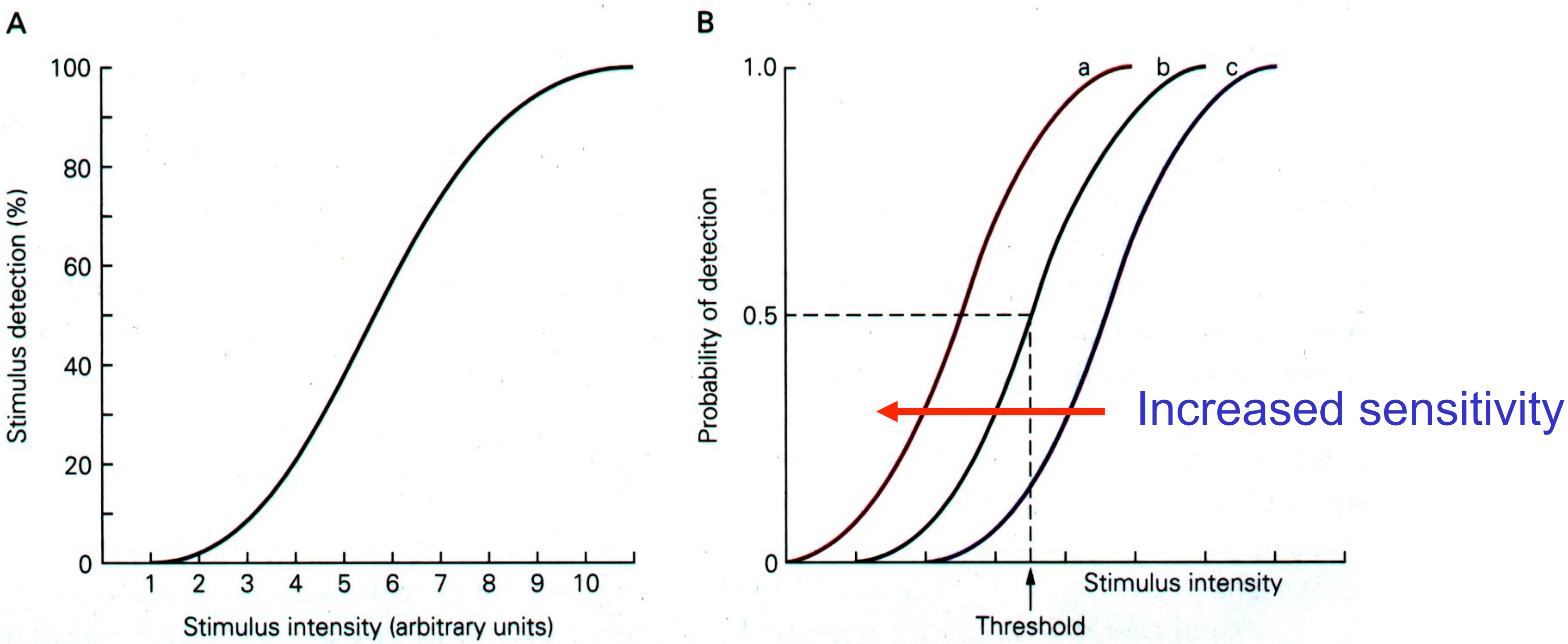
(2) Relative threshold measurement (a discrimination task)

For example, to determine if two sounds heard are the same or different (also referred to as "Two-alternative forced choice (2AFC)" paradigm).

The percentage of correct responses (or a similar value) is plotted on the y-axis and the physical parameter on the x-axis.

(Source: MIT CogNet)

Psychometric function: Measure stimulus sensitivity



Sensory thresholds and the just noticeable difference (JND) between stimuli that differ in intensity, frequency, or other parametric features are quantifiable.

A. The psychopathic function plots the percentage of stimuli detected by a human observer as a function of stimulus intensity. Threshold is defined as the stimulus intensity detected on 50% of the trials. .

B. The absolute sensory threshold (curve *b*) is an idealized relationship between stimulus intensity and the probability of stimulus detection. If the sensory system's ability to detect the stimulus is increased or the subject's response criterion is decreased, curve *a* would be observed; curve *c* illustrates the converse.

Sensory thresholds are modified by psychophysical and pharmacological factors

Sensory thresholds depend upon psychological factors and the context in which the stimulus occurs. The threshold for pain is often heightened during competitive sports or in childbirth, as reflected in a shift in the psychopathic function to higher stimulus intensities (curve c). Similarly, sensory thresholds can be lowered. Consider a runner at the starting line prepared to respond to the starter's shot. It is advantageous to respond as rapidly as possible, and the slightest noise resembling the start gun may trigger a leap to action. The runner's response to a lower stimulus intensity is represented as a shift in the psychopathic function to lower stimulus intensities (curve a).

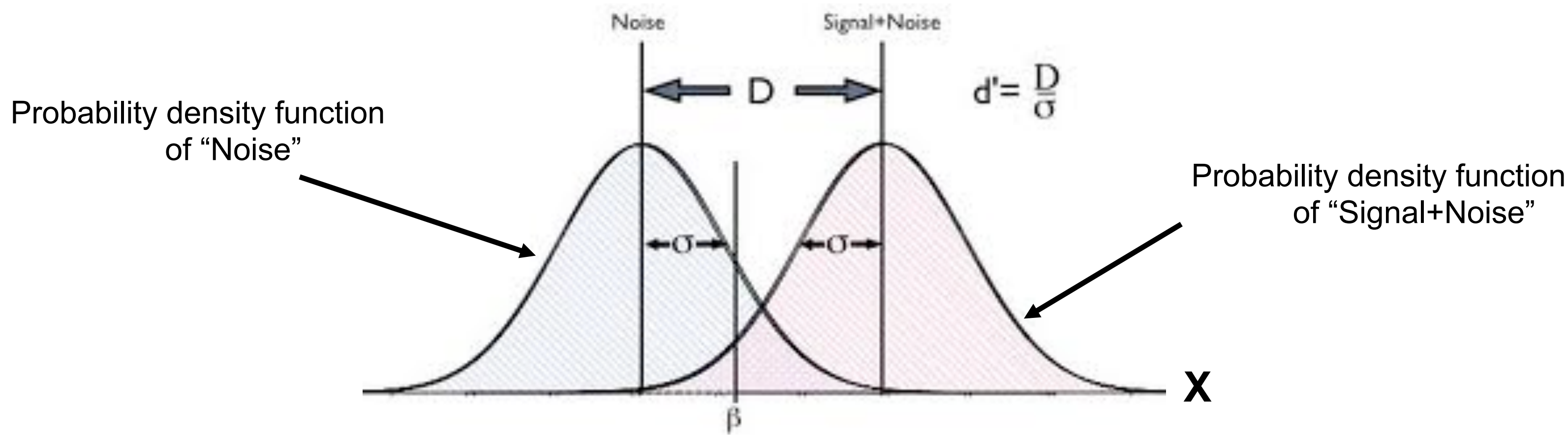
The modifiability of sensory thresholds can be under- stood by considering two aspects of sensation: (1) the absolute detectability of the stimulus and (2) the criterion the subject uses to evaluate whether a stimulus is present. Detectability measures the capacity of a sensory system to process a stimulus, whereas the response criterion reflects an attitude or bias of the subject toward the sensory experience.

In the 1950s Wilson Tanner and John Swets developed the signal detection theory to explain the observation that subjects often report a sensory experience (i.e, detection of a stimulus) when no stimulus is actually presented. A consequence of this decrease in response criterion (or bias) is that a subject is more likely to make mistakes. For example, the runner at the starting block is likely to make a false start in a crucial race. Similarly, elderly patients with sensory loss may falsely report feeling stimuli tested in a neurological examination as a denial of aging. The opposite condition-ignoring the occurrence of a stimulus such as pain-is also common.

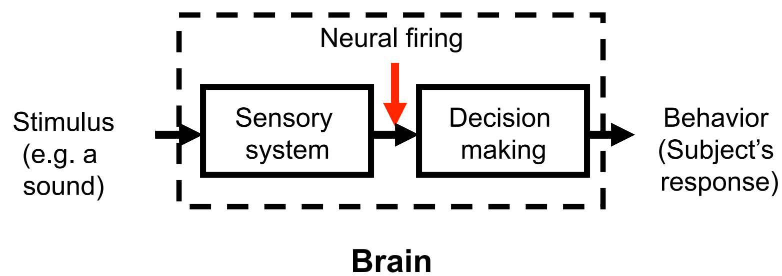
The separate measures of stimulus detectability and response criterion can be combined with the concept of thresh- old to explain the mechanisms of drug action. For example, morphine, a potent analgesic, elevates the pain threshold both by reducing the detectability of a painful stimulus and by elevating the criterion the subject uses to determine whether a stimulus is painful or not. Marijuana also increases pain thresholds, but does so by increasing the response criterion rather than decreasing stimulus detectability-the stimulus is just as painful but the subject is more tolerant.

Discriminability Index (*d'*)

A measure to quantify the discriminability of a stimulus independent of the criterion an observer adopts

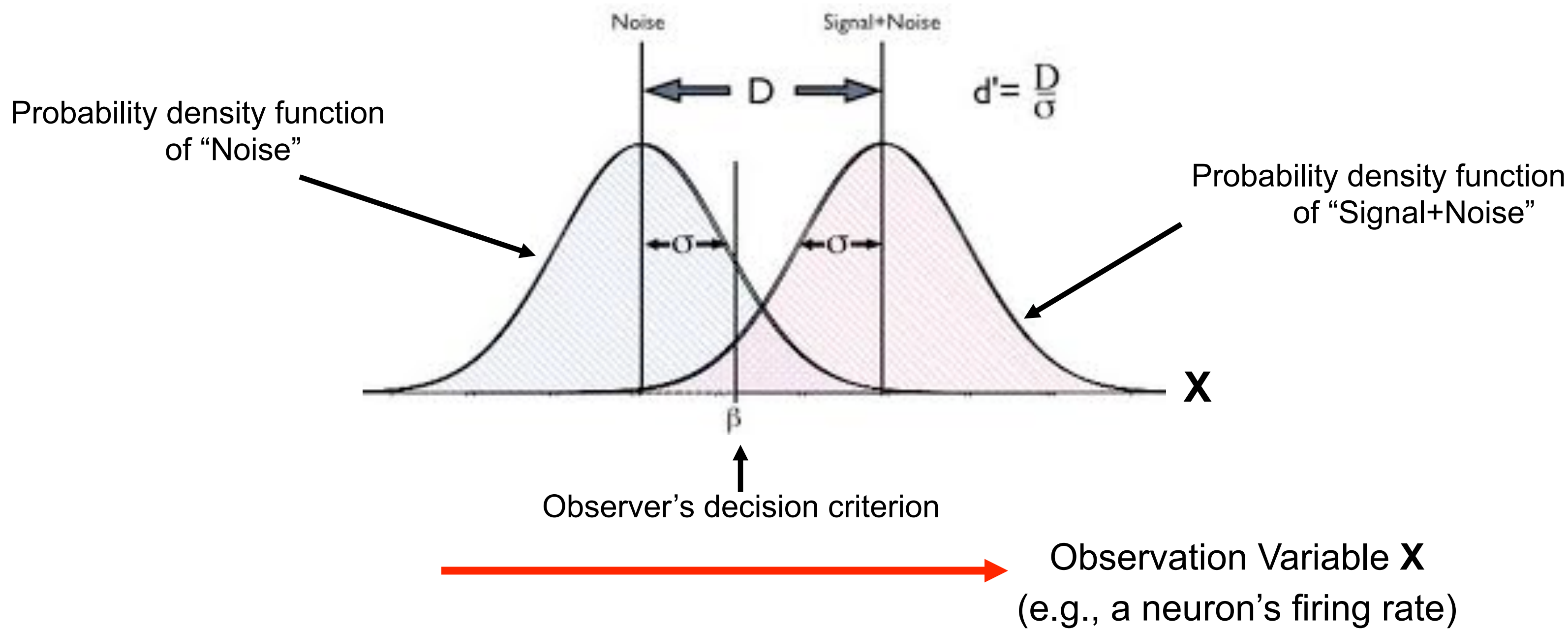


Observation Variable **X**
(e.g., a neuron's firing rate)



Signal Detection Theory

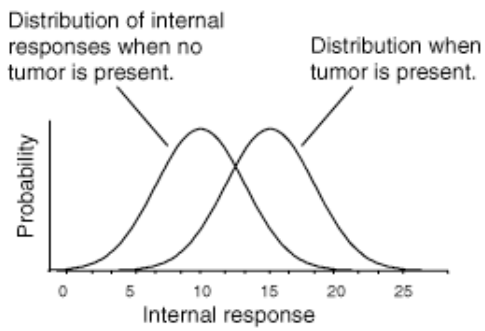
A mathematical theory to analyze an observer's decision in detecting or discriminating two (or multiple) random variables



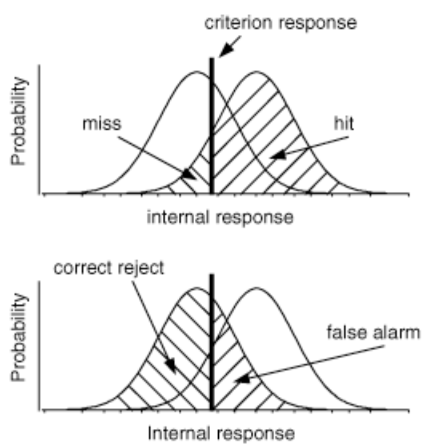
		$X < \beta$	$X > \beta$
		Respond "Absent"	**Respond "Present"**
P(Signal+Noise)	**Stimulus Present**	Miss	Hit
P(Noise)	**Stimulus Absent**	Correct Rejection	False Alarm

Example

Detecting whether there is a tumor from a patient’s radiograph

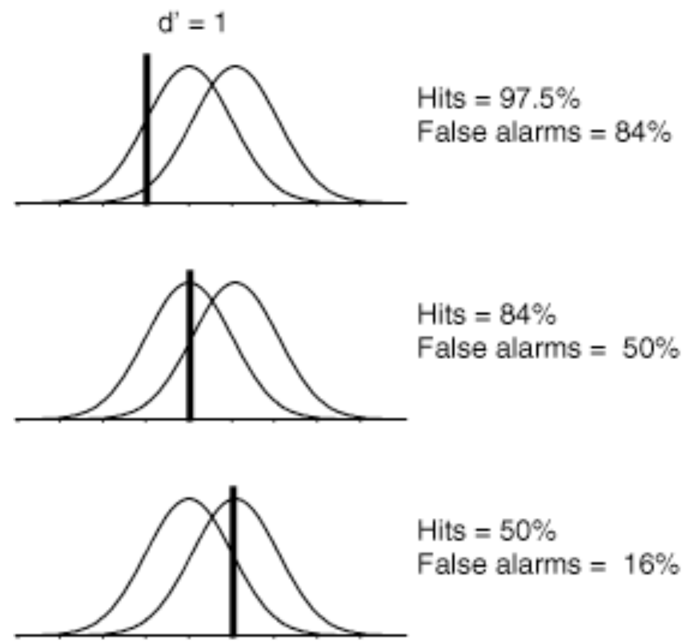


Internal response probability of occurrence curves for noise-alone and for signal-plus-noise trials.



Internal response probability of occurrence curves for noise-alone and signal-plus-noise trials. Since the curves overlap, the internal response for a noise-alone trial may exceed the internal response for a signal-plus-noise trial. Vertical lines correspond to the criterion response.

Effect of shifting the criterion

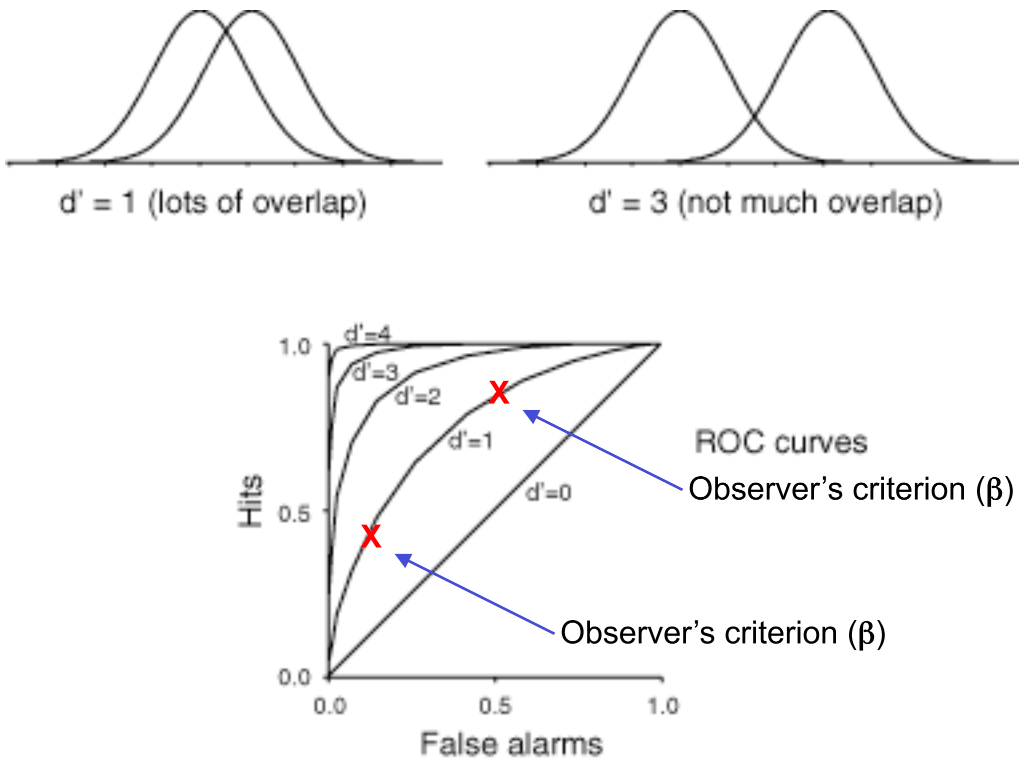


Is there a tumor?

From: “Signal Detection Theory” lecture notes, Prof. David Heeger (NYU)

The Receiver Operating Characteristic (ROC)

An analytic method to quantify an observer's decision



Internal response probability of occurrence curves and ROC curves for different signal strengths. When the signal is stronger there is less overlap in the probability of occurrence curves, and the ROC curve becomes more bowed.

From: "Signal Detection Theory" lecture notes, Prof. David Heeger (NYU)

Perception is brain's interpretation of the sensory environment

Mathematics (e.g. Signal Detection Theory) is a powerful tool to analyze the brain, but the brain does not always obey mathematical rules, not till we model it properly.

What’s in this picture?

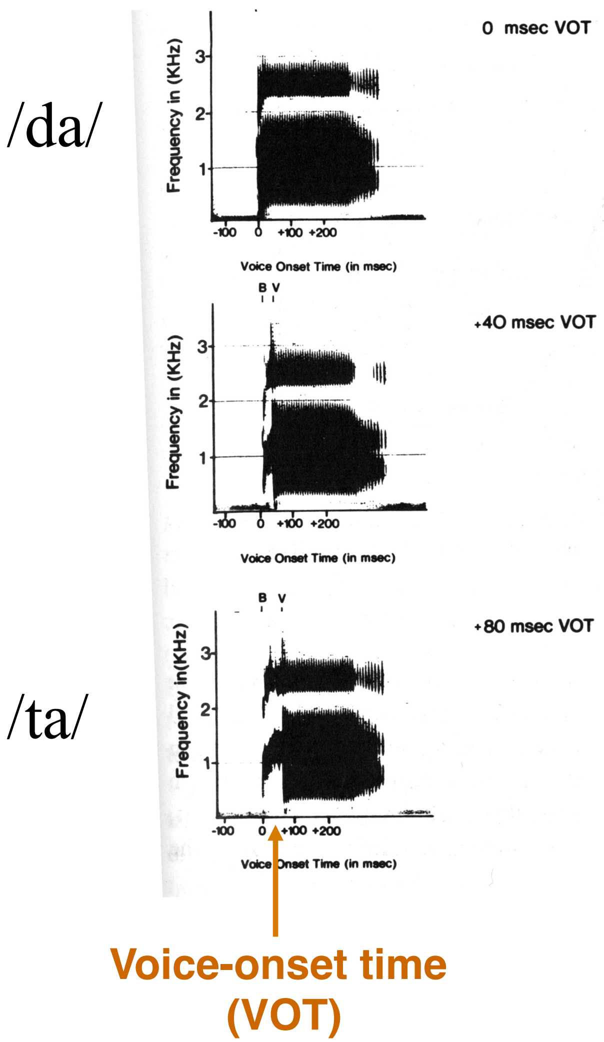
Perception is brain’s interpretation of the external world

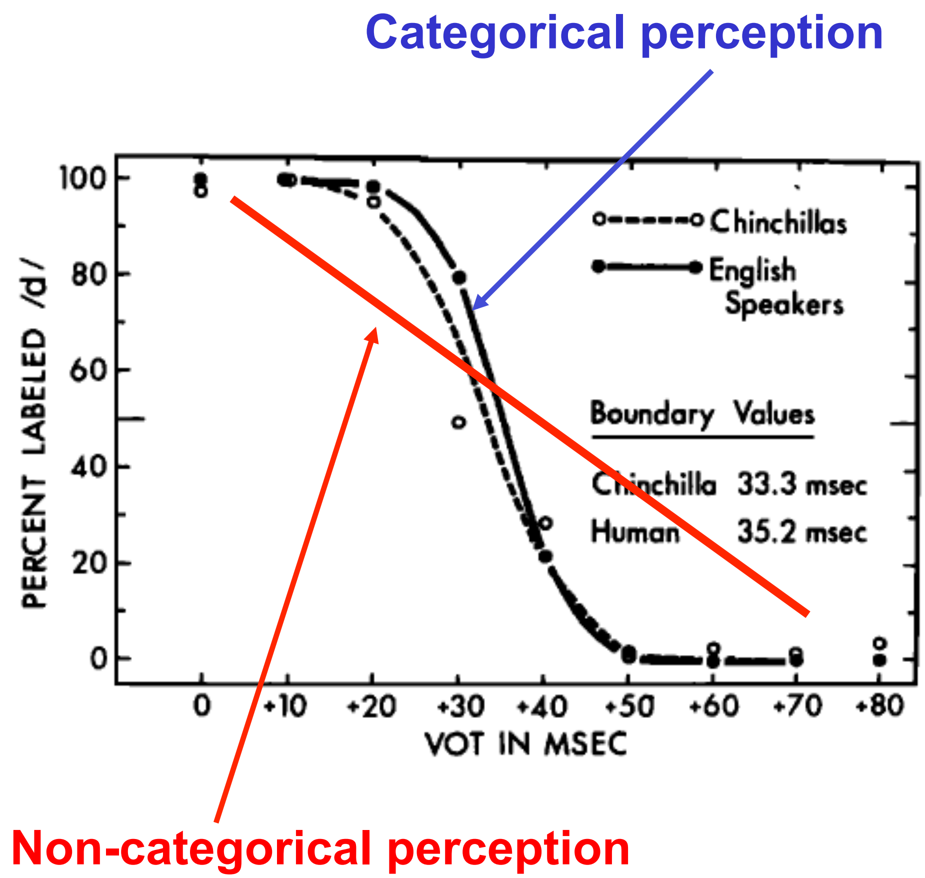
Perception ≠ Sensation

Categorical perception of speech.

(*left plot*) Stimuli from a voiced-voiceless continuum varying in voice onset time (VOT). Humans perceive the 0-msec VOT stimulus as /da/, whereas the +40-msec VOT and +80-msec VOT stimuli are perceived as /ta/. The onset of voicing (V) and the onset of the burst (B) are marked.

(*right plot*) Humans' and animals' identification functions for two series ranging from a voiced to a voiceless phonetic unit (/d/ to /t/ and /g/ to /k/) showing that animals' perceptual boundaries correspond to humans' phonetic boundaries. .



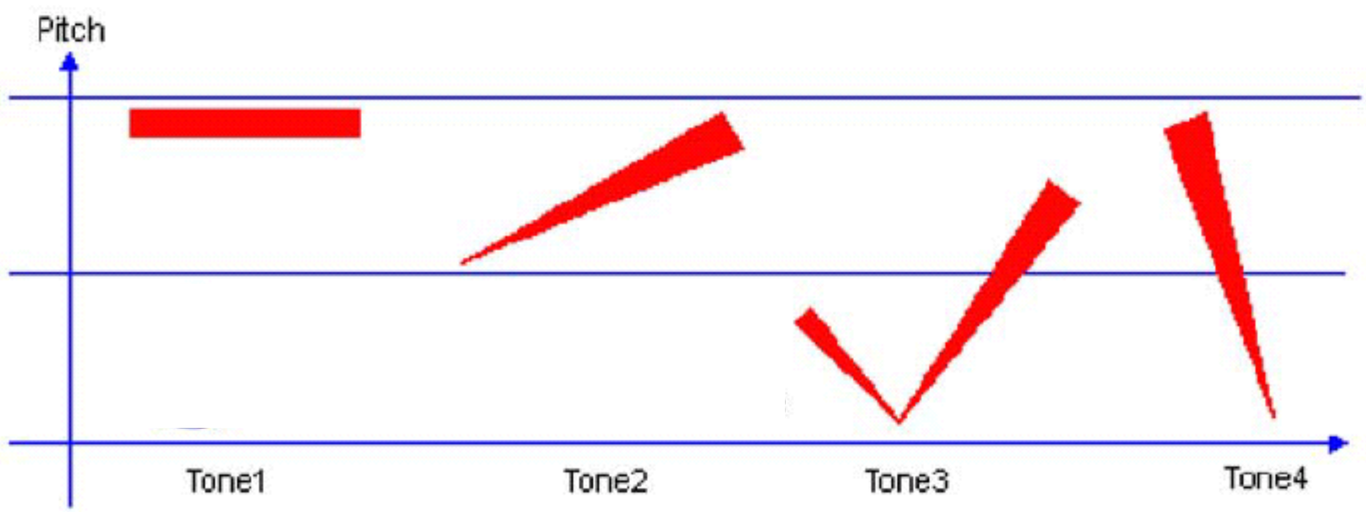


Kuhl PK, Miller JD. Speech perception by the chinchilla: identification function for synthetic VOT stimuli. J Acoust Soc Am. 63(3):905-917, 1978.

Categorical Perception of Four Chinese Tones

"Wang"

汪（vast)　　王（King)　　网（net)　　忘（forget)



McGurk-effect
An auditory-visual illusion

Now close your eyes. What do you hear?

Courtesy of Prof. Arnt Maasø of University of Oslo
http://www.youtube.com/watch?v=aFPtc8BVdJk

McGurk-effect
An auditory-visual illusion

Seeing and hearing together:

- Most adults (98%) think they are hearing /da/

- In reality, you are hearing the sound /ba/, while seeing the lip movement of /ga/

Hearing alone: /ba/

Suggested readings:

- “Signal Detection Theory” lecture notes by Professor David Heeger of NYU:

  http://www.cns.nyu.edu/~david/handouts/sdt/sdt.html

- Kuhl PK, Miller JD. Speech perception by the chinchilla: identification function for synthetic VOT stimuli. *J Acoust Soc Am*. 1978 Mar;63(3):905-17