Fundamentals of Psychophysics

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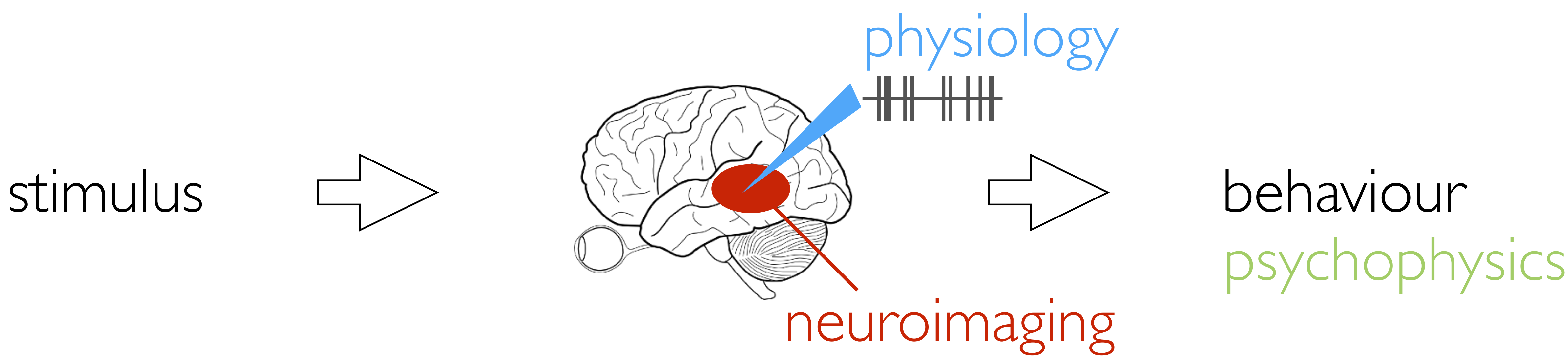
Visual neuroscience



- How do we see the world?
- The brain is a complex system with many different levels
- So we need approaches with different scales of analysis
  - Physiology, e.g. recording from individual neurons
  - Neuroimaging, e.g. fMRI scans to see the brain regions activated
  - Psychophysics: the system as a whole, e.g. reading, seeing colours

Today

- An overview of psychophysics and its methodological approaches

Stimulus
- Luminance patch
- Gabor
- etc.

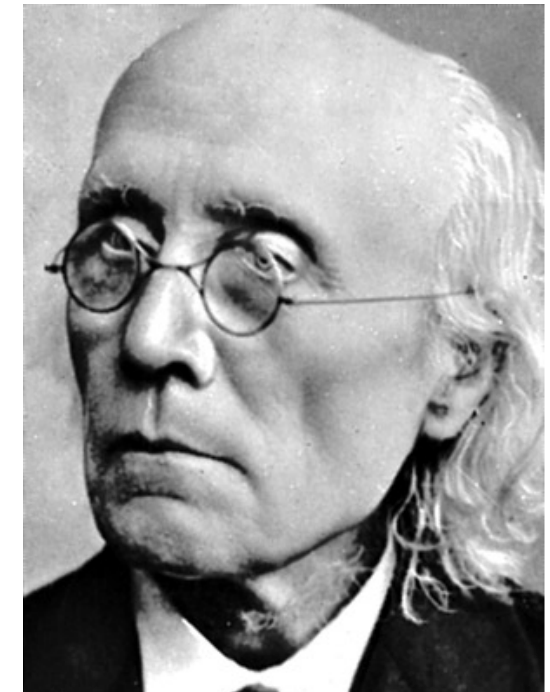
Task
- detection
  - yes/no
  - forced choice
- discrimination
  - yes/no
  - forced choice

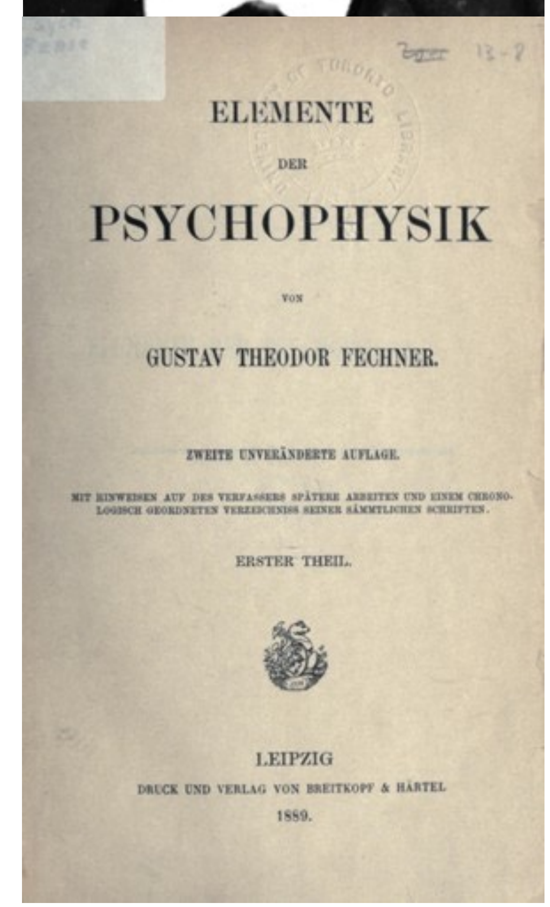
Method
- Limits
- Adjustment
- Constant stimuli
- SDT

Outcome
- performance
  - Reaction times
  - Percent correct
  - Thresholds
  - d’ and c
- appearance
  - Matching

Psychophysics

- Originates from Fechner (1860)
- Investigates the relationship between physical stimuli and psychological quantities ('psyche')
  - We can't measure the mind directly, so we measure behaviour
  - Requires **linking hypotheses** between subjective and objective phenomena
  - Requires precise control over physical stimuli and testing procedures
  - If you know the properties of a stimulus, and how a person responds to that stimulus, you can infer the underlying perceptual operations of the brain





ELEMENTE

DER

PSYCHOPHYSIK

VON

GUSTAV THEODOR FECHNER.

ZWEITE UNVERÄNDERTE AUFLAGE.

MIT HINWEISEN AUF DES VERFASSERS SPÄTERE ARBEITEN UND EINEM CHRONOLOGISCH GEORDNETEN VERZEICHNISS SEINER SÄMMTLICHEN SCHRIFTEN.

ERSTER THEIL.

LEIPZIG

DRUCK UND VERLAG VON BREITKOPF & HÄRTEL

1889.

From behaviour to function

- How can we infer neural processes from behaviour?

Stimulus

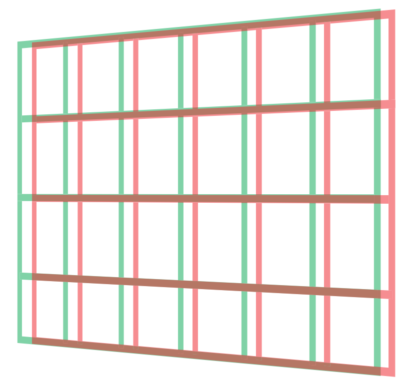
Task

Method

Outcome

The stimulus

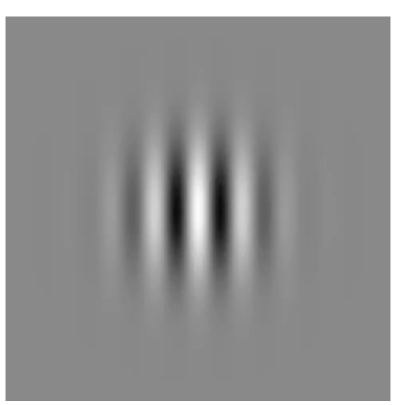
Luminance patch
For brightness or contrast perception



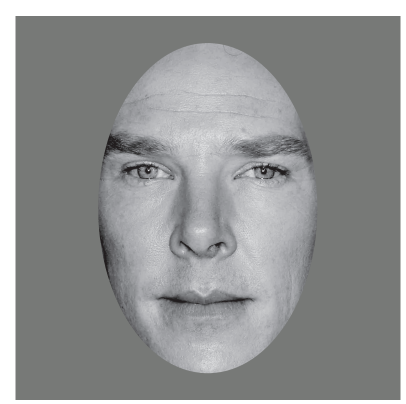
Stereoscopic stimuli
For depth perception

Oriented Gabor
For orientation perception/spatial vision

Letters
To study reading and/or acuity



Moving Gabor
For motion perception



Faces
For face vs. object recognition

From behaviour to function

- How can we infer neural processes from behaviour?

Stimulus
- Luminance patch
- Gabor
- etc.

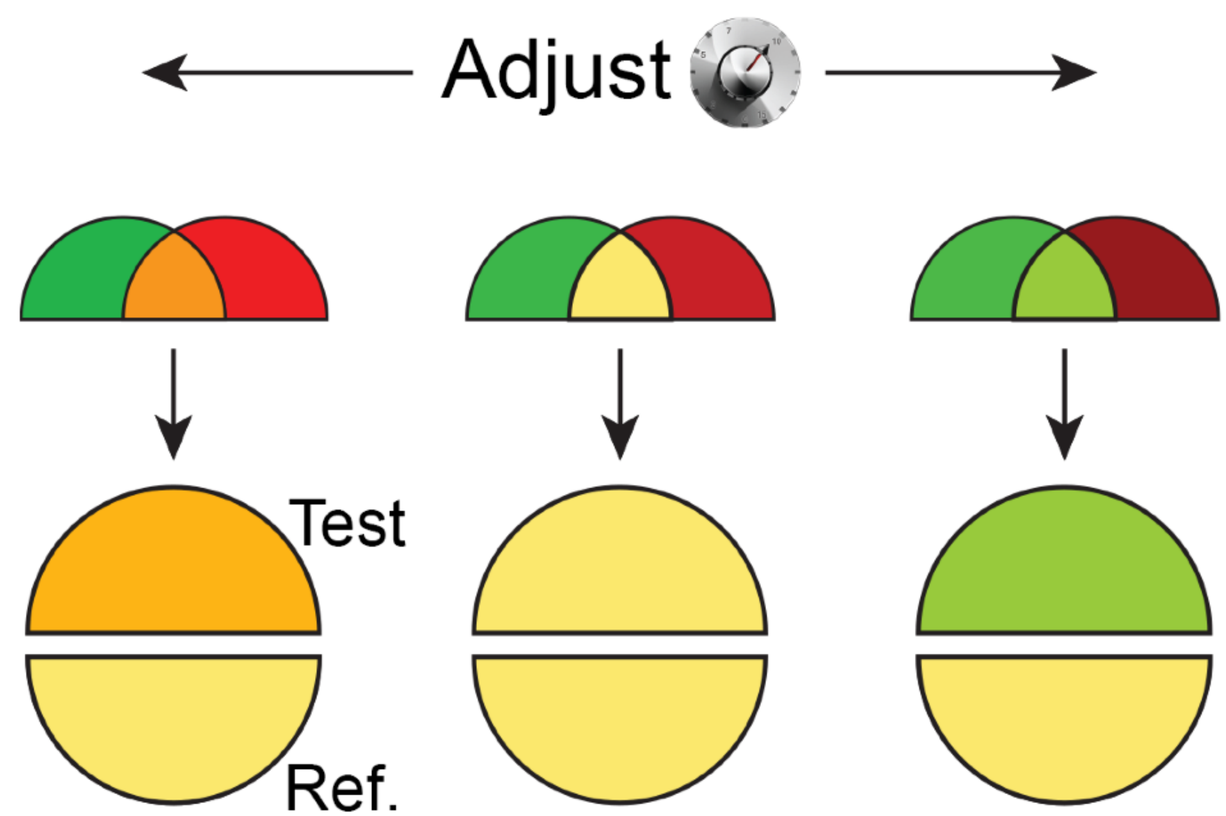
Task

Method

Outcome
- performance
- appearance — Matching

Appearance: matching

- A simple way to measure the perceived equivalence of two stimuli: ask observers to match their appearance
  - e.g. with two patches of colour: match the appearance of a narrowband yellow reference with a test patch made via superimposition of red & green lights
  - Allows the measurement of *metamers* - stimuli that are physically dissimilar but perceptually identical



From behaviour to function

- How can we infer neural processes from behaviour?

Stimulus
- Luminance patch
- Gabor
- etc.

Task
- detection
- discrimination

Method

Outcome
- performance
  - Reaction times
  - Percent correct
  - Thresholds
- appearance
  - Matching

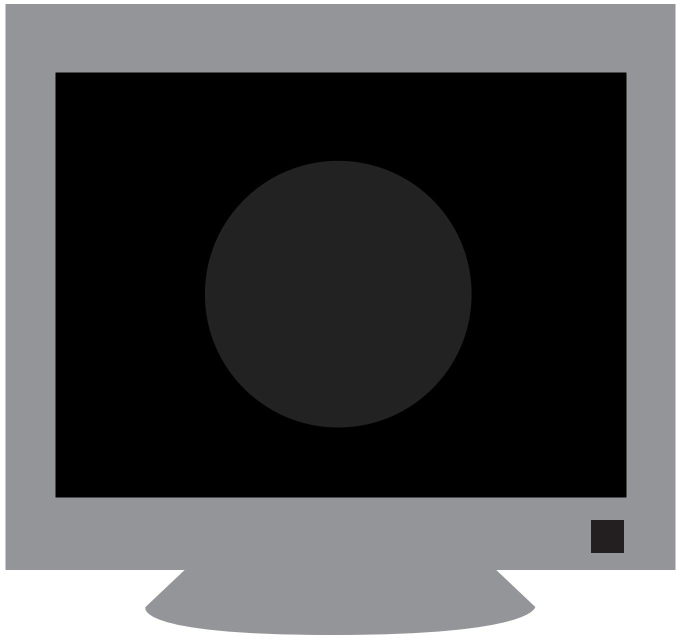
Thresholds

- A major concern of psychophysics: thresholds
  - The lowest stimulus quantity that can be reliably seen
  - e.g. for size, brightness/luminance, motion, etc.
- Thresholds measure sensitivity, which can be related to the tuning of a neural detector (our linking hypothesis)
- Two types of thresholds:
  - Absolute / detection thresholds
  - Difference / discrimination thresholds

Detection thresholds

- Definition: The minimum intensity at which a stimulus is "just detectable"

e.g. brightness



The lowest brightness value you can see

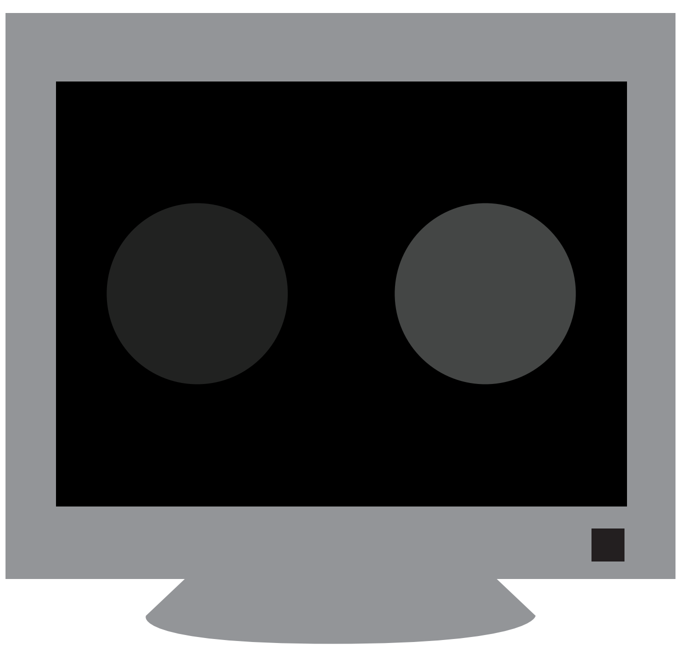
e.g. motion

The slowest speed that you can see

Discrimination thresholds

- The smallest *difference* in intensity that is just detectable
- Requires comparison between two or more stimuli, or between one stimulus quantity and a standard/reference

e.g. brightness



The lowest difference in brightness that you can see

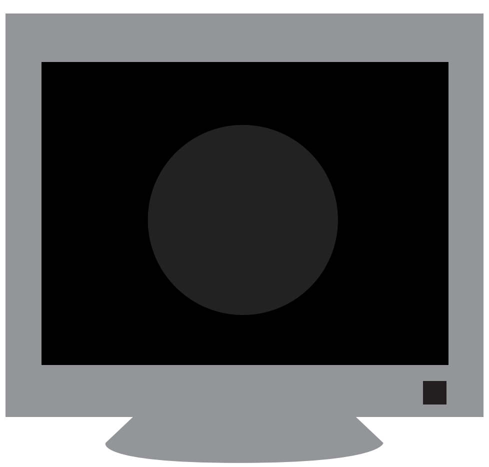
e.g. orientation

The smallest orientation offset from vertical that you can see

From behaviour to function

- How can we infer neural processes from behaviour?

Stimulus
- Luminance patch
- Gabor
- etc.



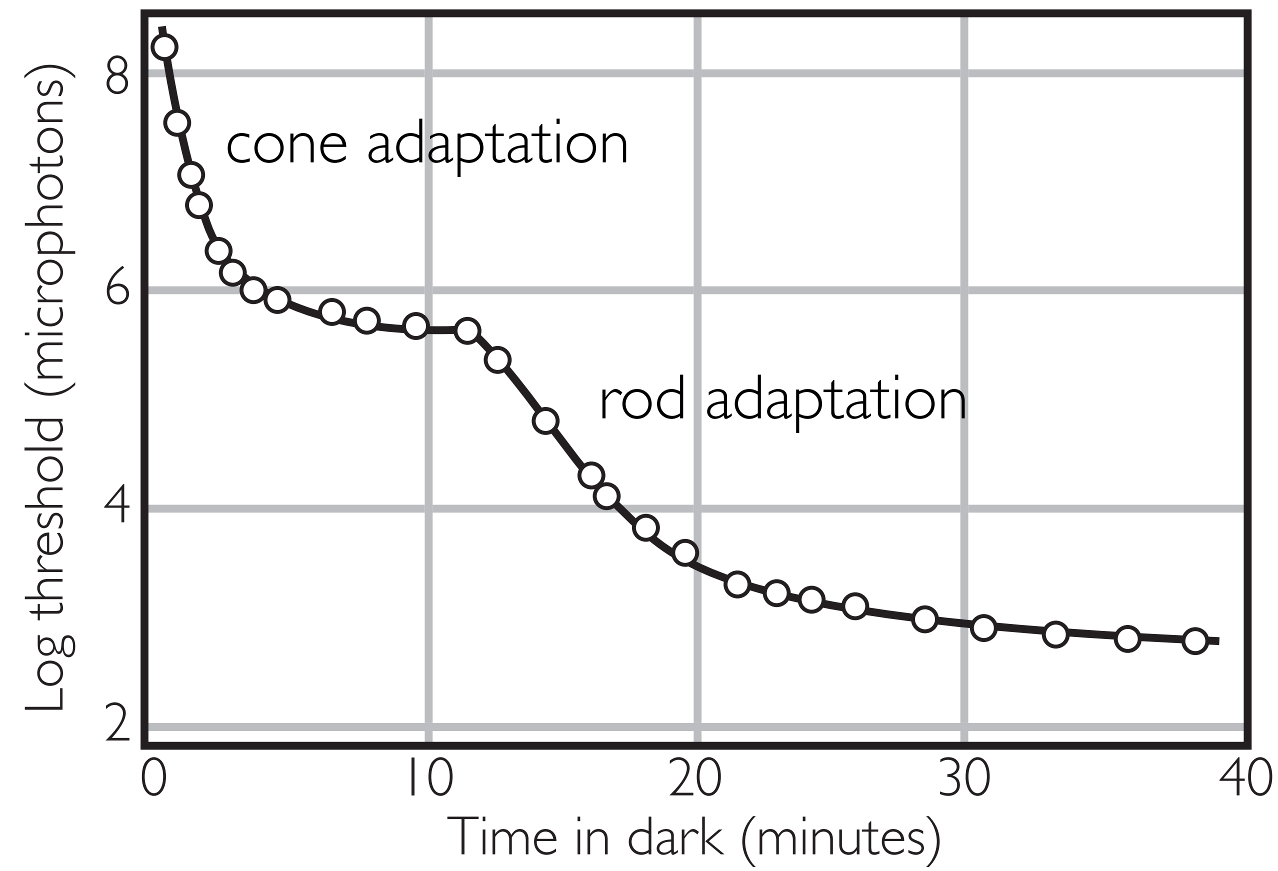
Method

Task
- detection
- discrimination

Outcome
- performance
  - Reaction times
  - Percent correct
  - Thresholds
- appearance — Matching

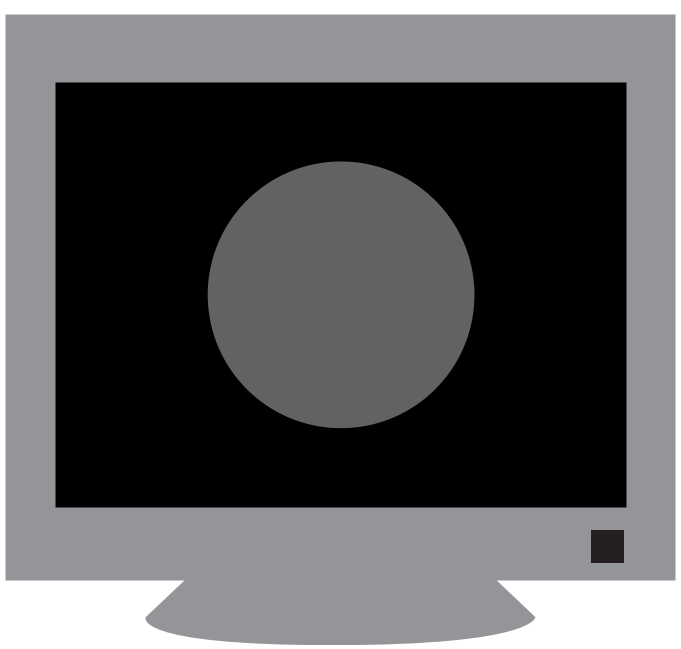
Task

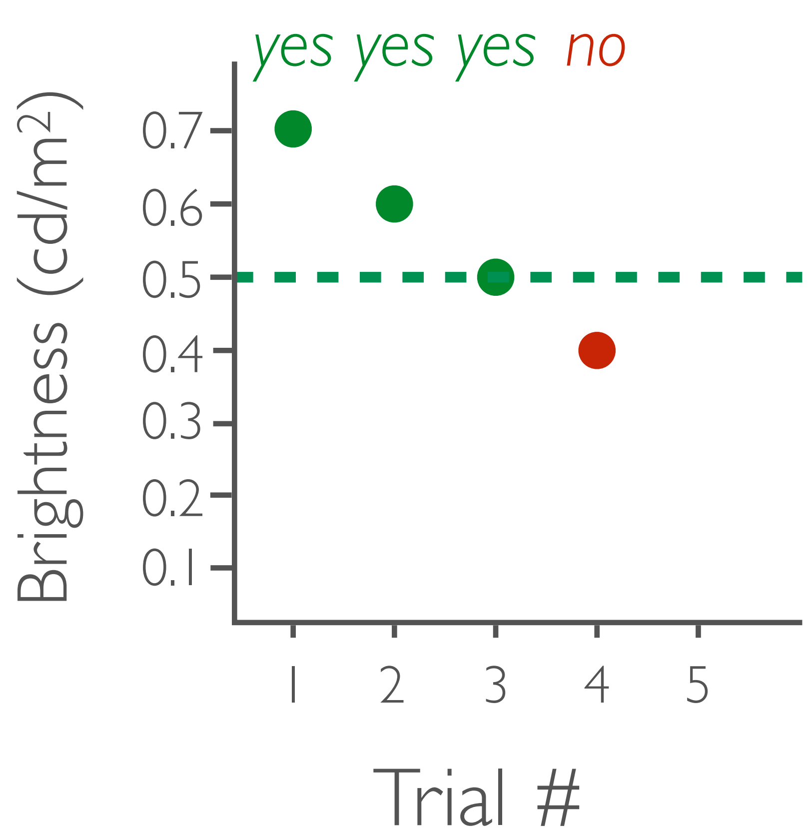
- Let's select detection thresholds for a luminance patch
  - Why do this? e.g. Hecht, Haig & Chase (1937)
  - Measured detection thresholds after different durations in the dark
- How do you ask the question?
  - Yes/no methods
    - e.g for detection:
      "Can you see it?"
      Yes / no



Method / sampling procedure

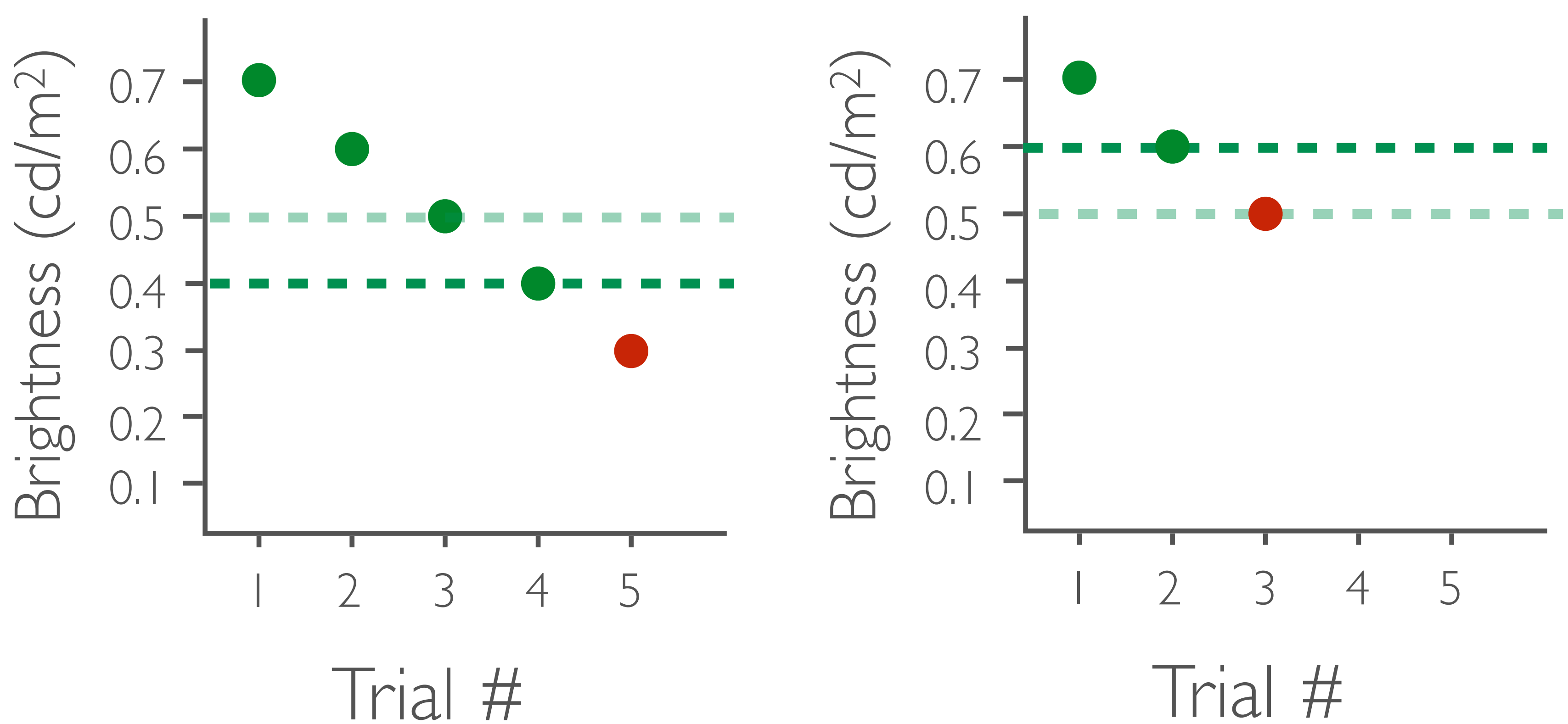
- On the range of intensity values, where do you select the ones to show the observer?
- Method of Limits
  - Intensity gradually increased/decreased until response changes





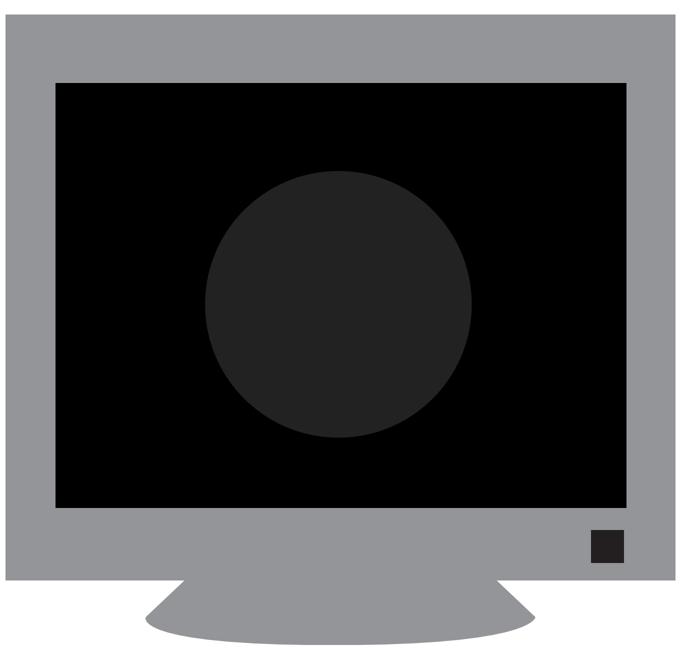
Method of limits

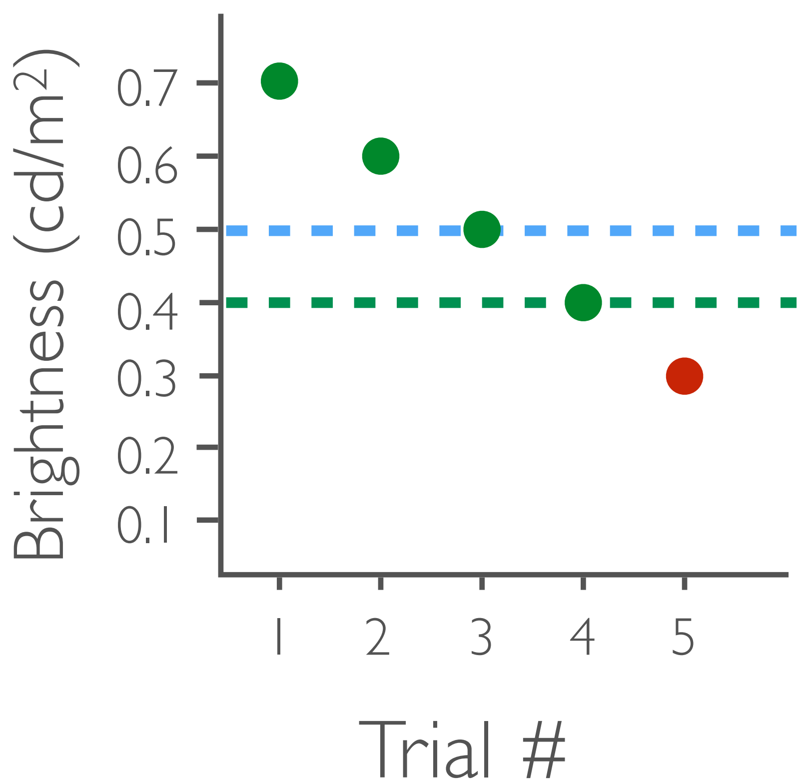
- Errors of habituation
  - Giving the same response continually and don't change
- Errors of anticipation
  - Know the threshold is coming and change response too soon

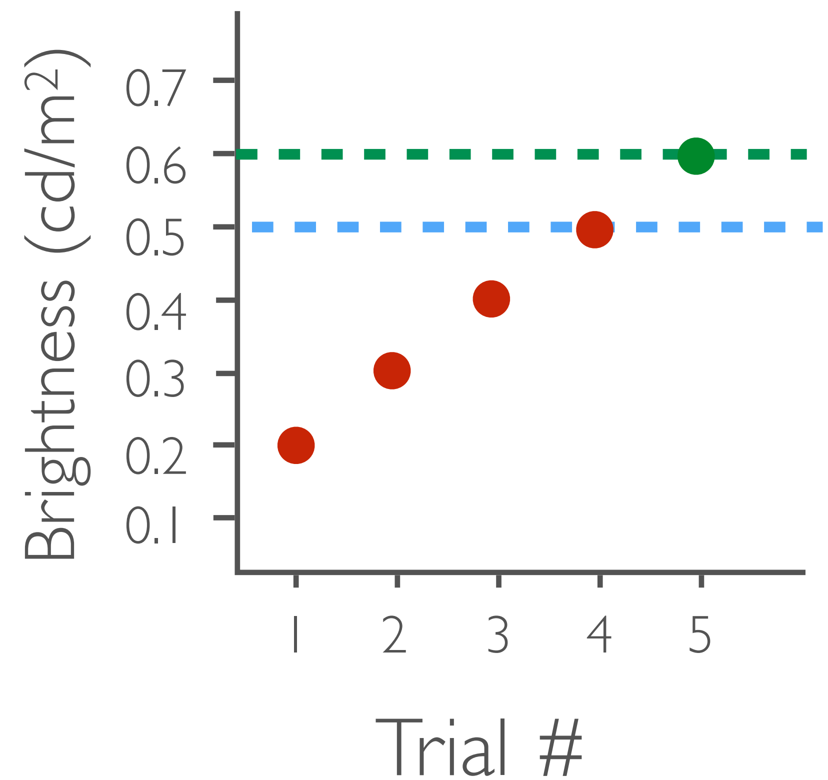


Method of limits

- Minimise these errors by approaching in both directions (∞ to 0, and 0 to ∞)
- Threshold is then the average of these measurements
  - performance measure: average setting = brightness threshold

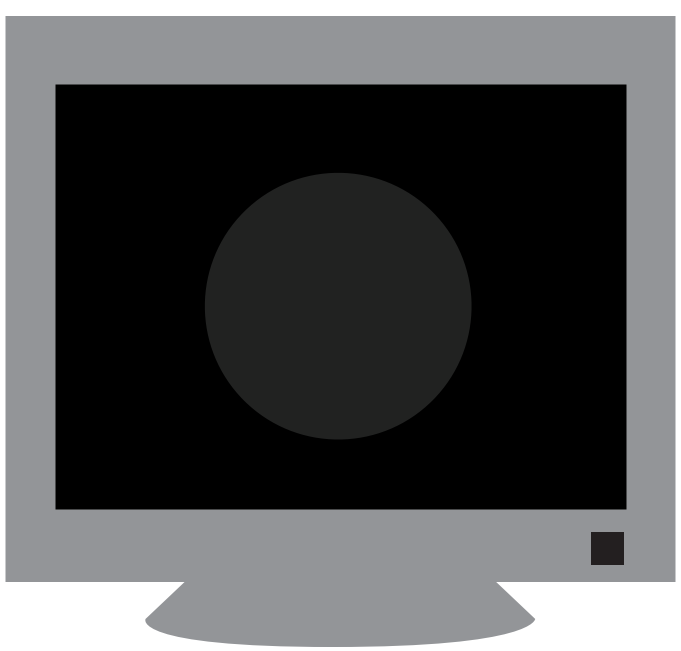


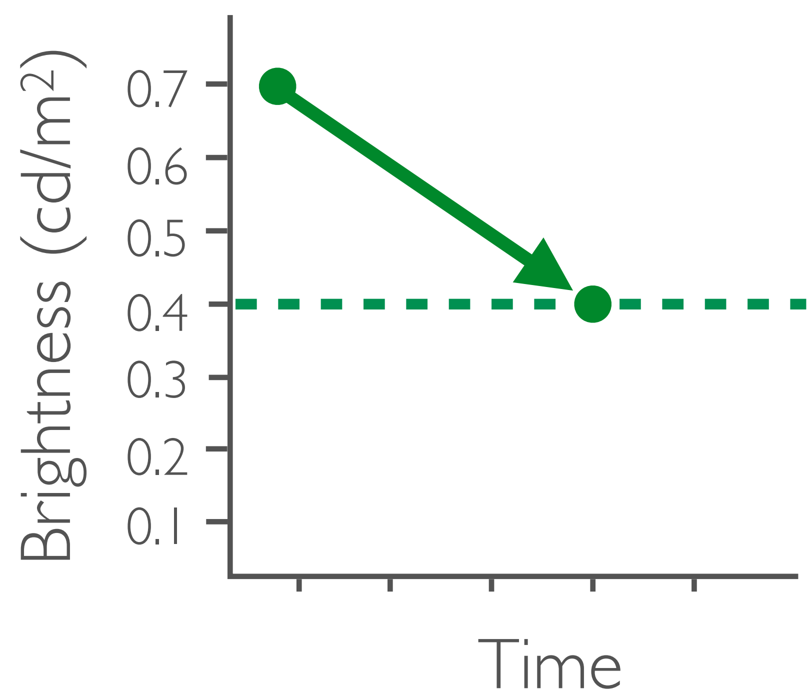




Method of adjustment

- As with the method of limits, but the observer adjusts the stimulus levels themselves until their report changes from visible to invisible or vice versa



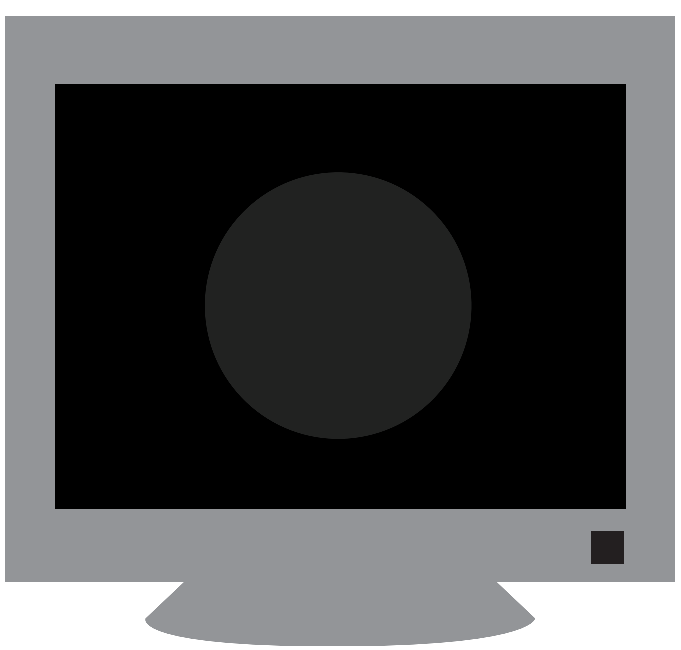


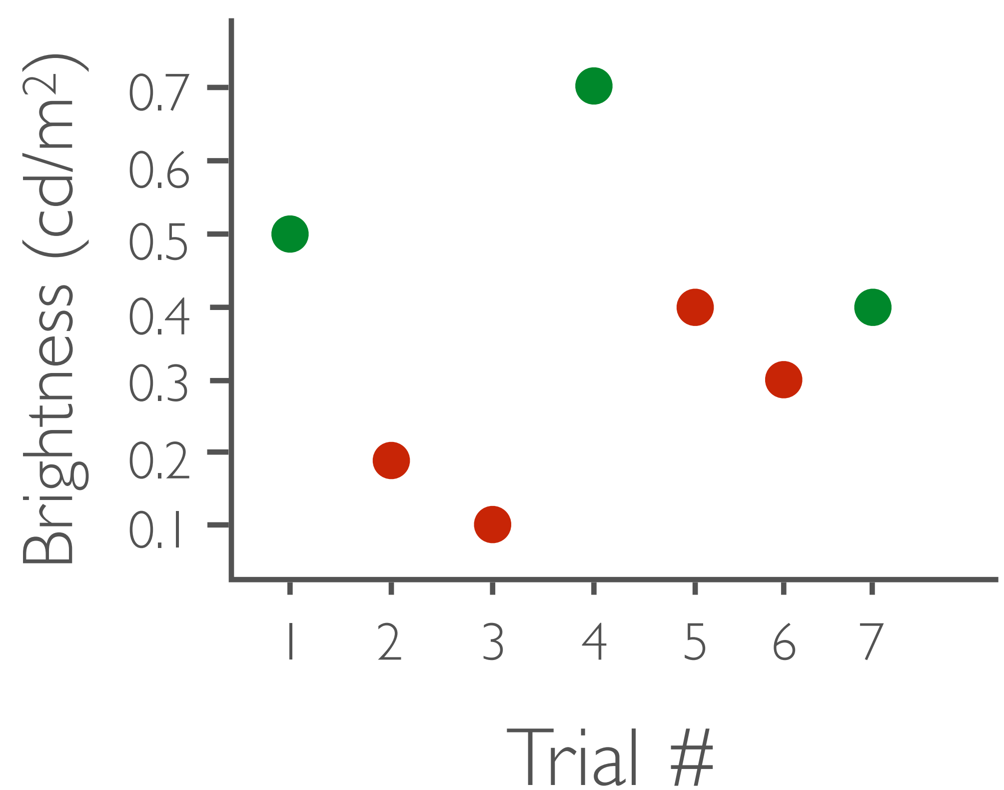
Issues with adjustment/limits

- Advantage of method:
  - Rapid estimation of threshold
- Disadvantage:
  - Errors of habituation and anticipation
  - Although these errors can be partly overcome with different directions of measurement, there is an alternative

Method of Constant Stimuli

- Intensities presented in a random order, with repeats
  - Removes issues of anticipation/habituation



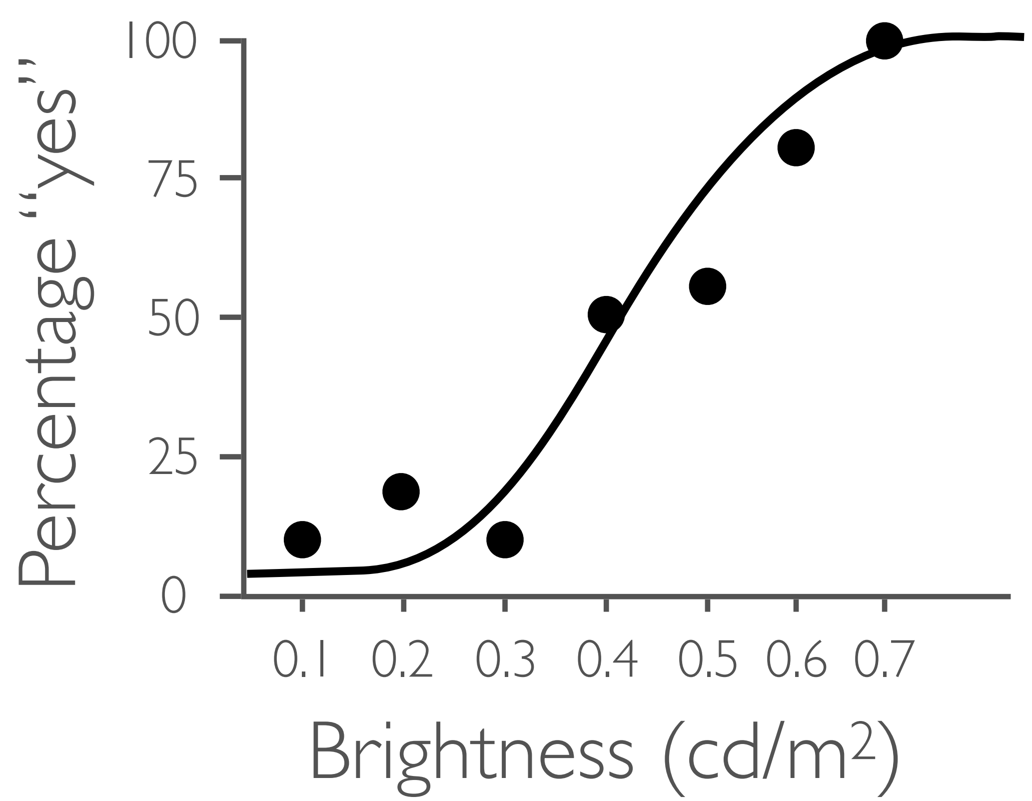


Tally

0.7	1
0.6	
0.5	1
0.4	1
0.3	0
0.2	0
0.1	0

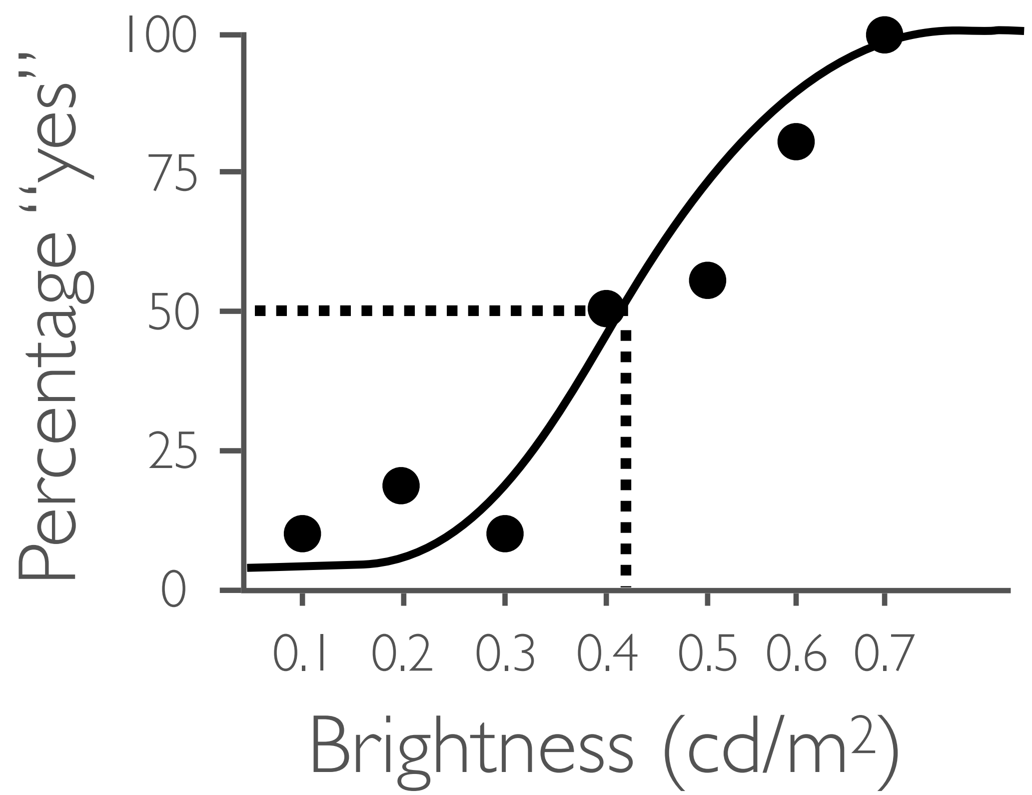
Method of Constant Stimuli

- But where is the threshold?
  - Performance varies from 0 to 100%
- Can fit a 'psychometric curve'
  - Cumulative form of a Gaussian function



Method of Constant Stimuli

- At what point do we call the threshold?
  - It should be above 0% (never seen) and below 100% (always seen)
  - The midpoint (50%) represents the 'tipping point' between predominantly "yes" and predominantly "no" (and the point with the fastest rate of change)



Issues with MCS

- Advantages:
  - Avoids issues of habituation/anticipation
- Disadvantages:
  - Slower estimation of threshold
  - Need to test a predetermined range of intensity values

From behaviour to function

- How can we infer neural processes from behaviour?

Stimulus
- Luminance patch
- Gabor
- etc.

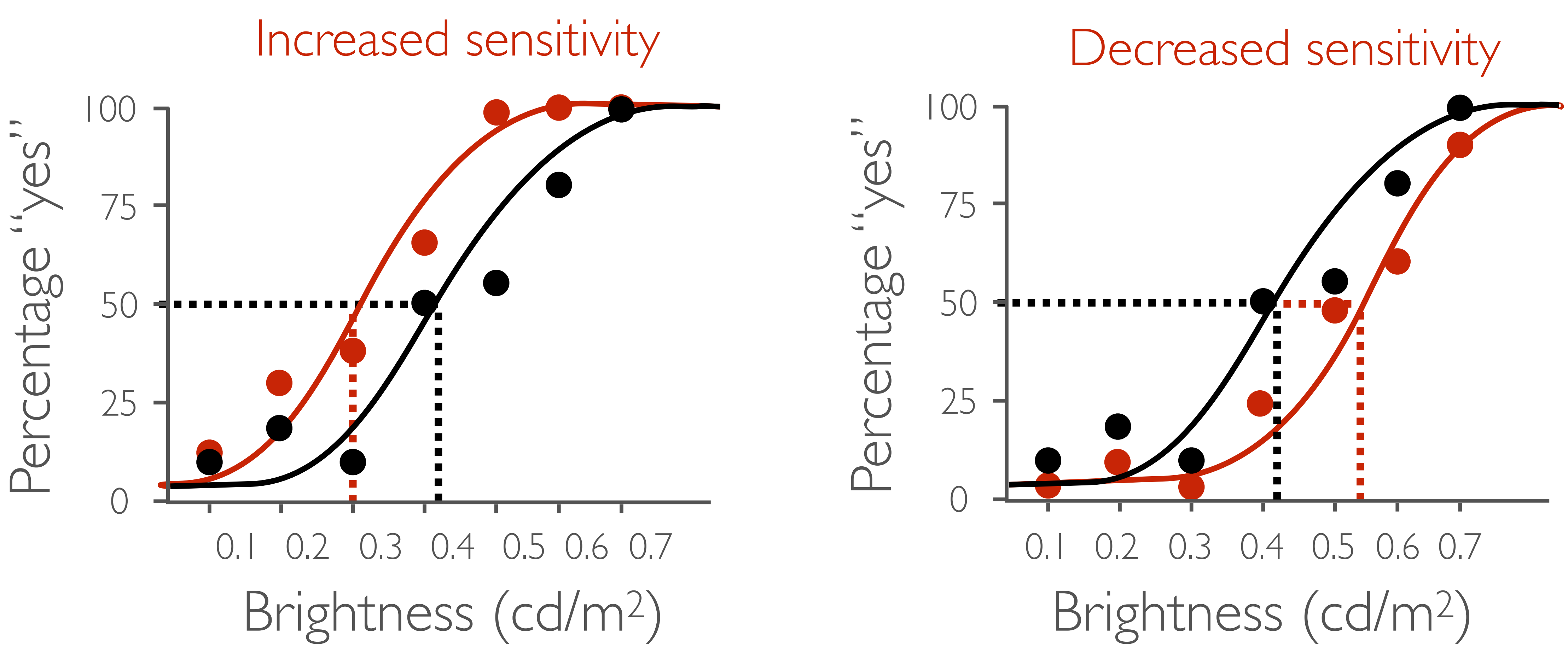
Task
- detection — yes/no
  - e.g. *"can you see it?"*
- discrimination — yes/no
  - e.g. *"are they different?"*

Method
- Limits
- Adjustment
- Constant stimuli

Outcome
- performance
  - Reaction times
  - Percent correct
  - Thresholds
- appearance — Matching

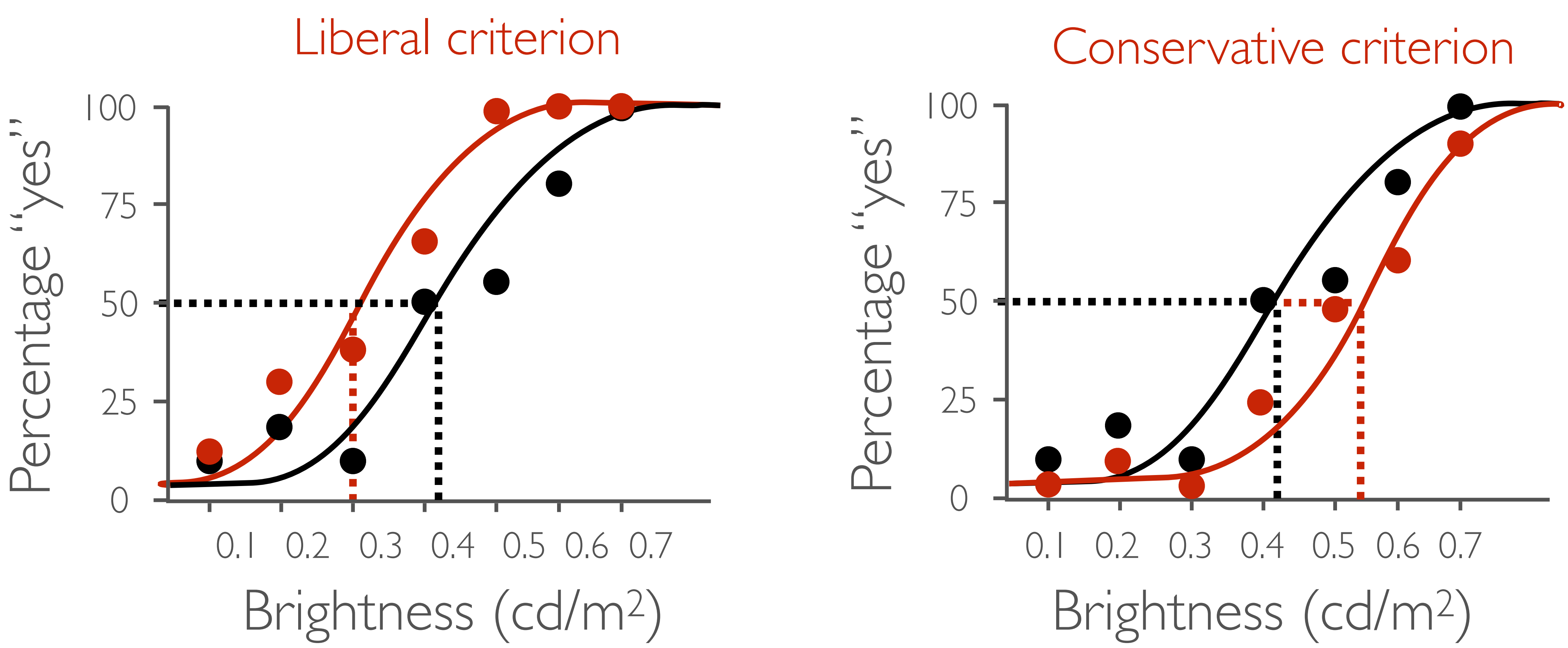
Threshold vs. criterion

- Yes/no procedures confound the threshold with the observer's subjective criterion
  - Consider the effect of increased sensitivity vs. decreased sensitivity



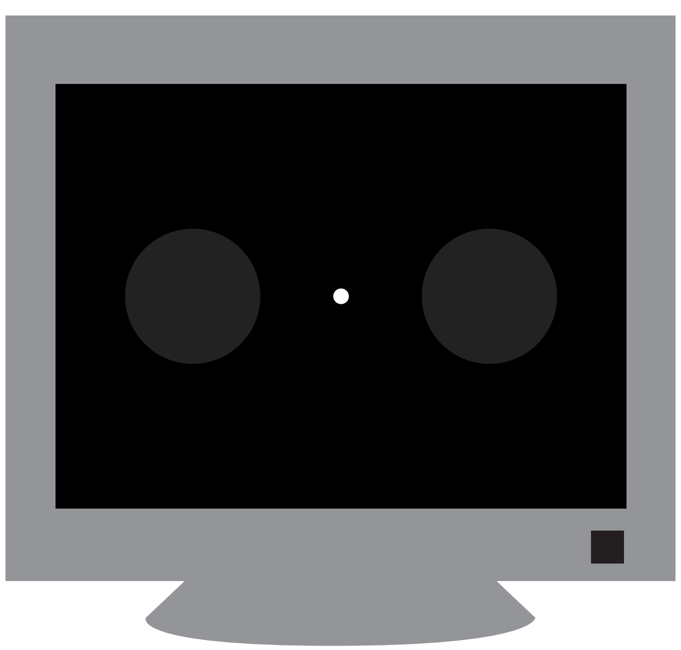
Threshold vs. criterion

- Now consider the effect of criterion differences
  - Someone eager to indicate "yes" (a liberal criterion) vs. someone reluctant to do so (conservative criterion)
- Impossible to distinguish from changes in sensitivity



Forced-choice measures

- Yes/no measures rely on a subjective criterion
- Forced-choice measures can minimise this influence
  - Force the observer to choose between 2 or more responses on each trial
  - Compare these judgements against an objective standard
  - e.g. two-alternative forced choice (2AFC)

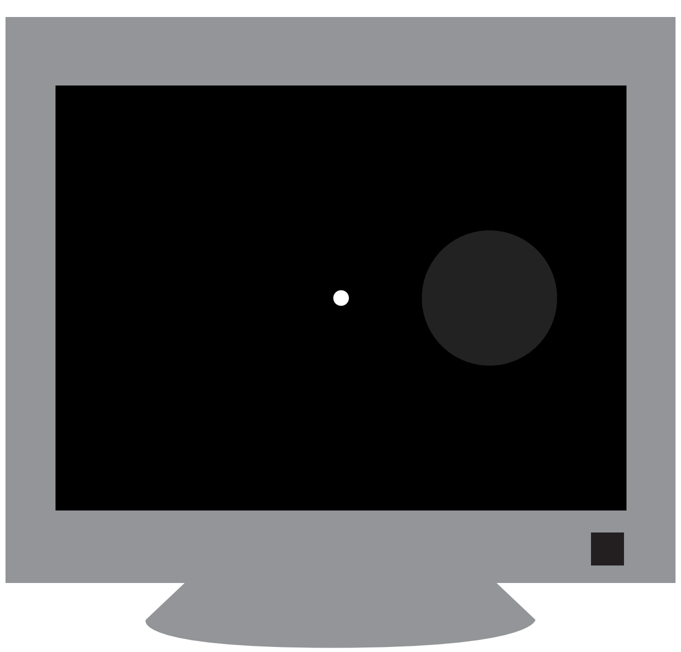


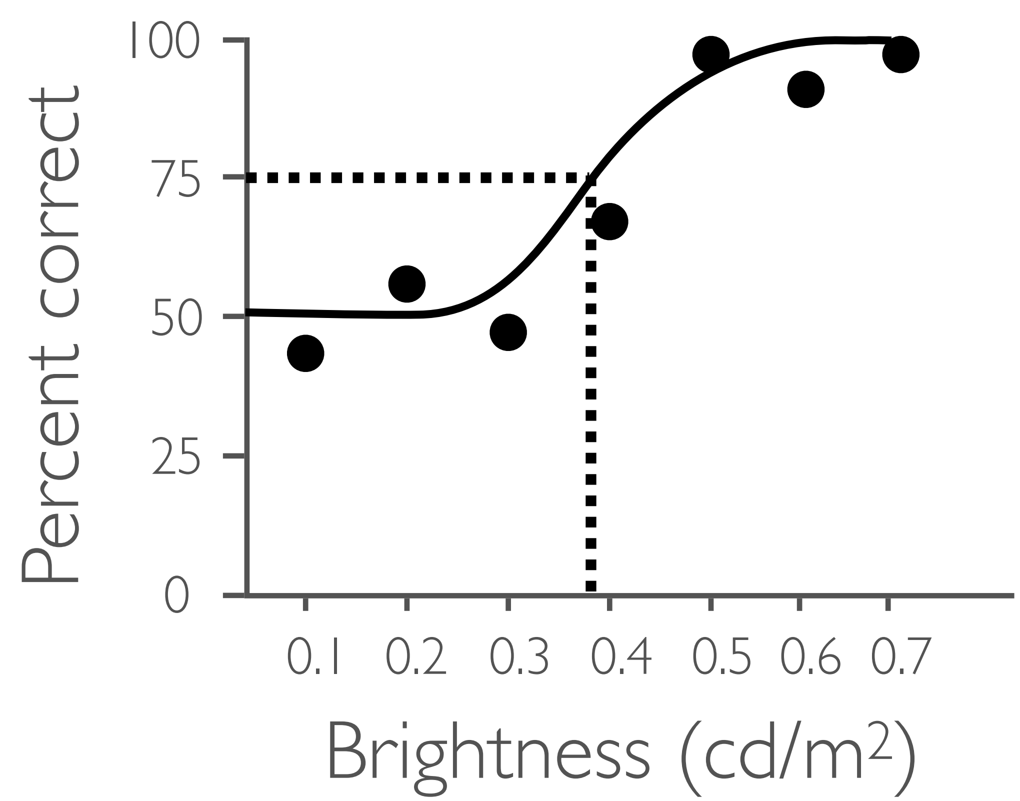
Was the patch to the left or right?

Was the motion to the left or right?

Forced-choice MCS

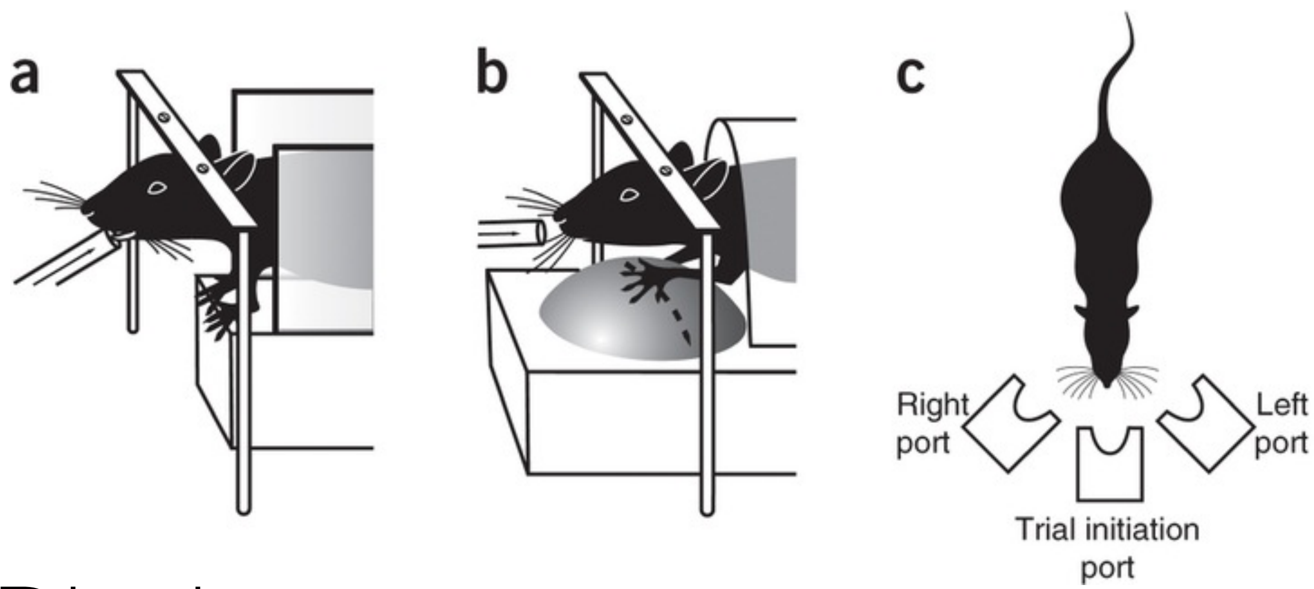
- What happens with the psychometric function?
  - e.g. the detection task for luminance/brightness
  - With a 2AFC design the guess rate is 50%
  - The midpoint (threshold) is now taken as 75% correct





Forced-choice issues

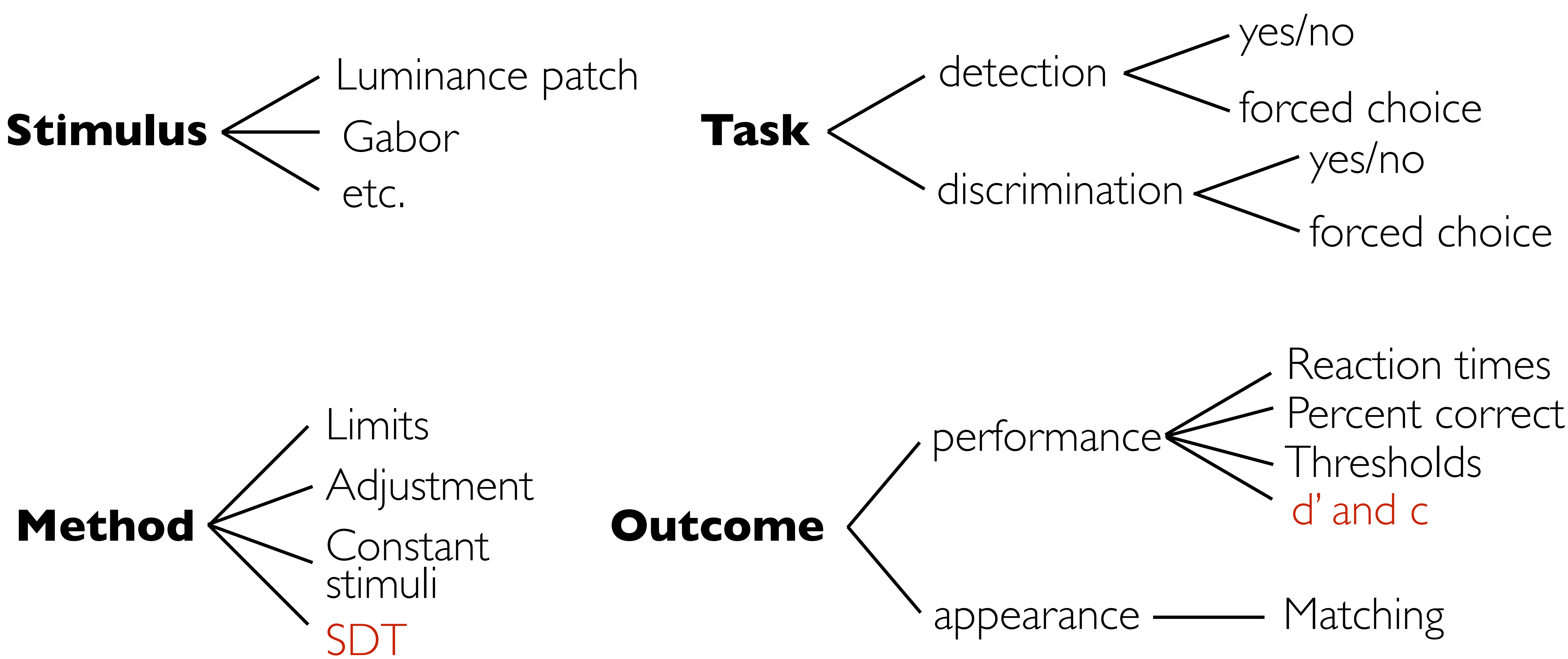
- Advantages
  - Avoids issues of subjective criterion
  - Can use to test perception in animals / pre-verbal children



from Carandini & Churchland (2013)

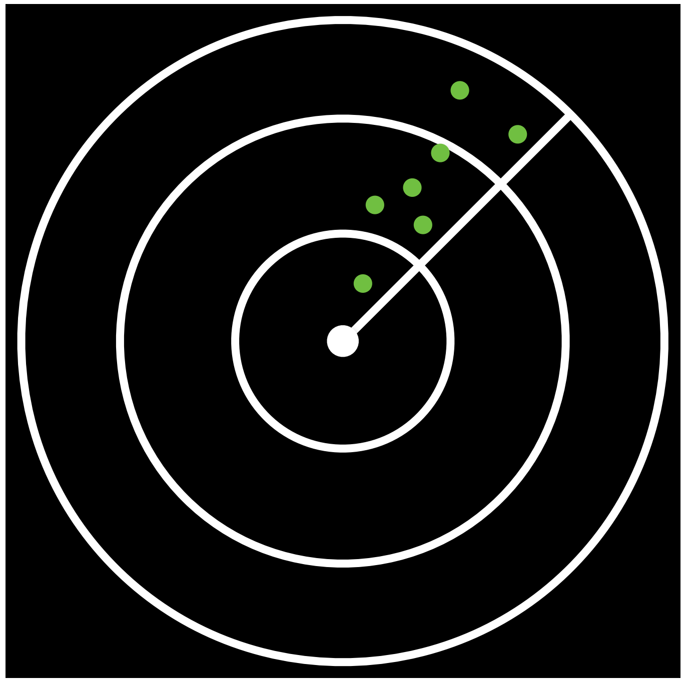
- Disadvantages
  - Not always possible to create 'objective' scoring

From behaviour to function



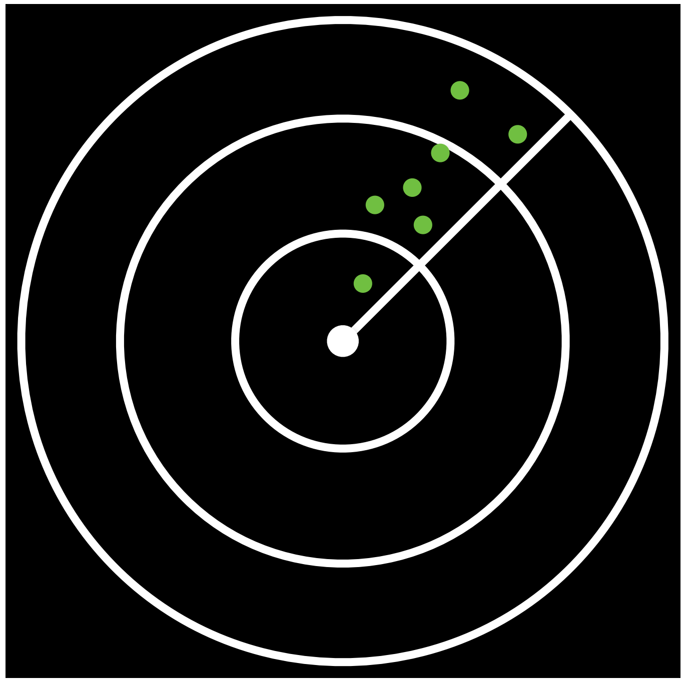
Signal Detection Theory

- Derives from radar operators during World War II
  - Radar antenna direction given by line
  - Dots trailing this visible only briefly and could arise from objects in environment, weather patterns, noise, or enemy aircraft
  - Upon seeing a dot: should you raise the alarm or not?



Signal Detection Theory

	Signal: Is it actually an enemy plane?	
Decision: Is there an enemy plane?	**Yes**	**No**
Yes	Hit	False Alarm
No	Miss	Correct Reject



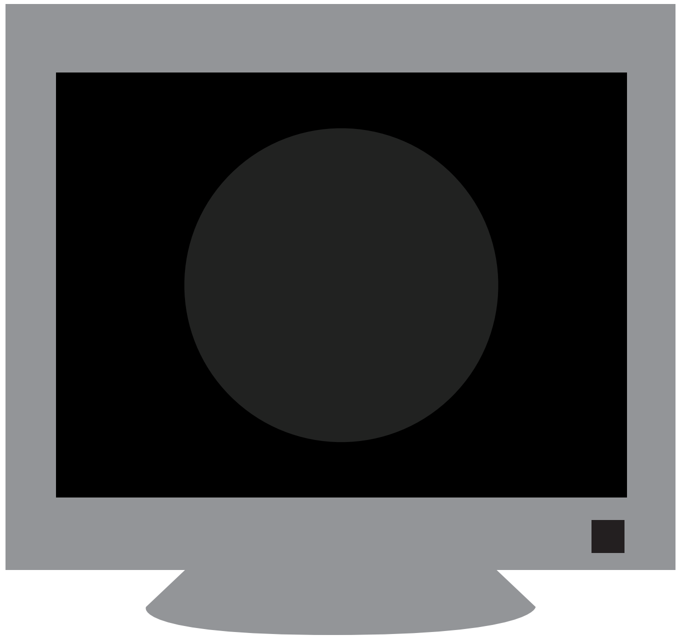
- Consequences:
  - **Hit:** Enemy are engaged and turned away
  - **Miss:** Enemy attack their target unscathed
  - **False alarm:** Aircraft take off for nothing, fuel wasted, pilots fatigued
  - **Correct rejection:** Crew able to rest and fuel is not wasted

SDT for brightness

Signal: Is there a luminance patch?

Decision: Is there a luminance patch?

	Yes	**No**
Yes	Hit	False Alarm
No	Miss	Correct Reject

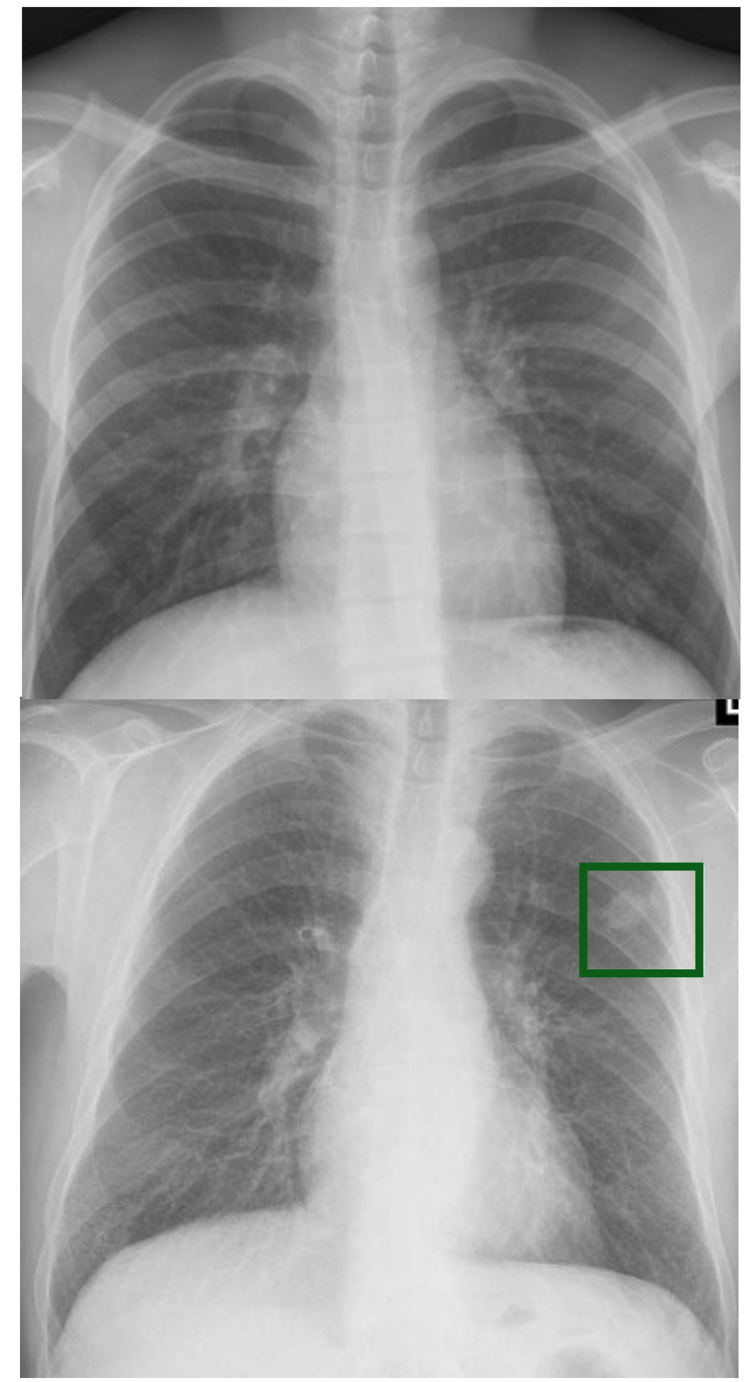


- Formalised for psychophysics by Green & Swets (1966)
- Easy to transpose this situation into a yes/no decision task, e.g. with our luminance patch
- Here we need two types of trials: signal present or absent
  - Decisions in each case: yes/no for each type of trial

SDT and X-ray diagnosis

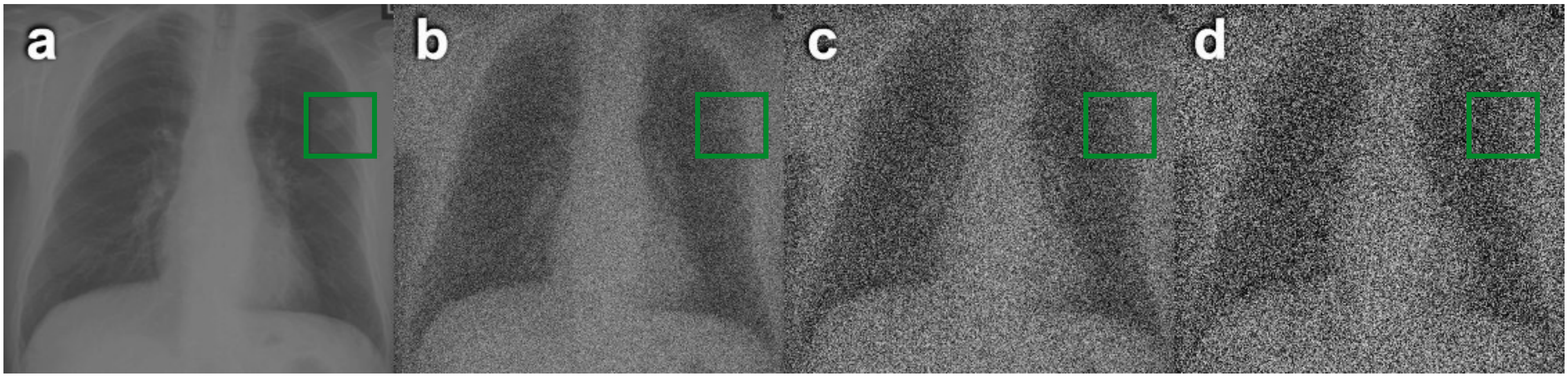
Signal: Is there a tumour?

Decision: Is there a tumour?	**Yes**	**No**
Yes	Hit	False Alarm
No	Miss	Correct Reject
	signal+noise	*noise*



- Radiologists examine chest x-rays and asked "is a tumour present or absent?" (Kundel & Nodine, 1975)
- What limits performance and how can we characterise this?

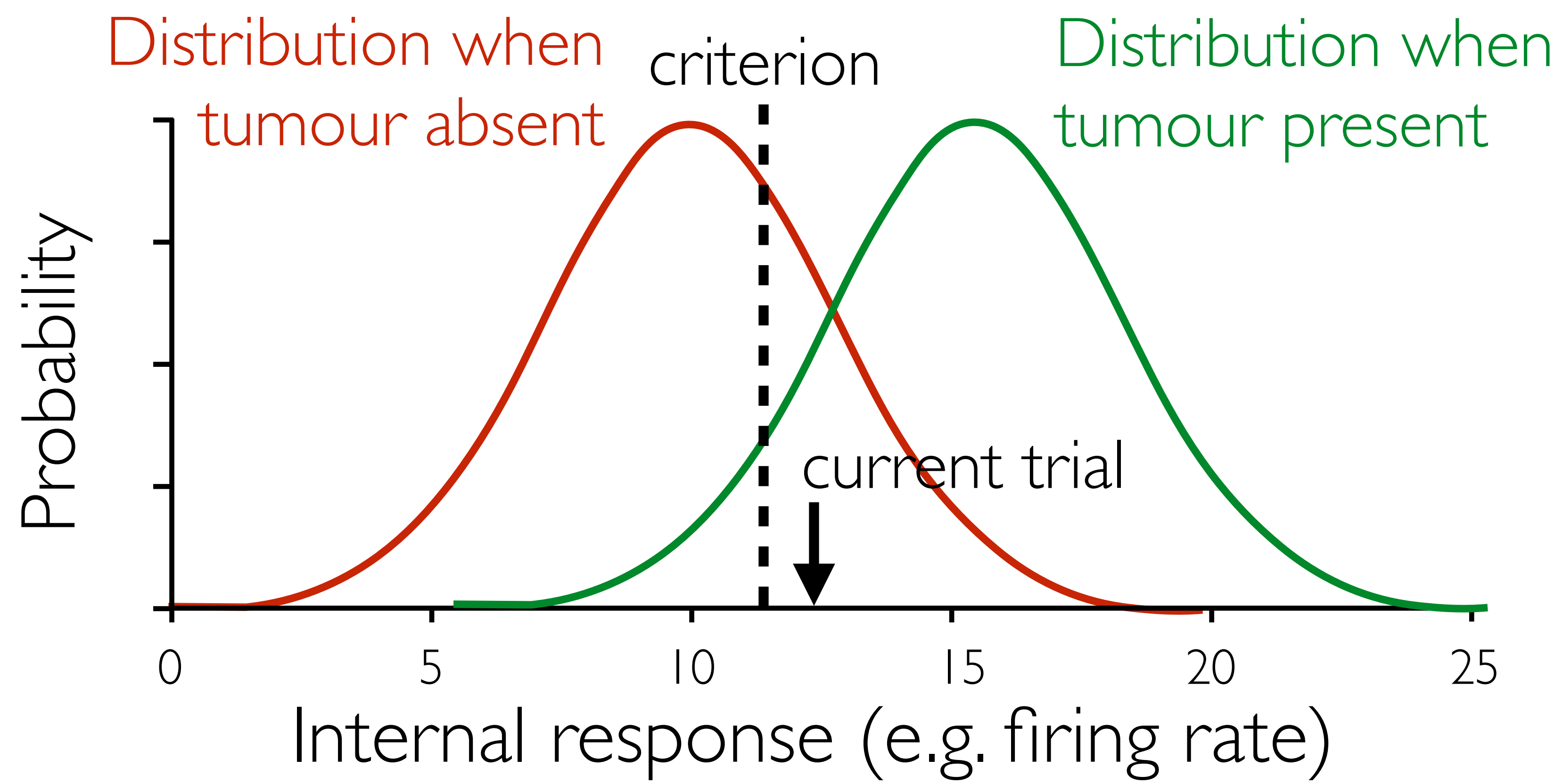
Noise



Increasing external noise →

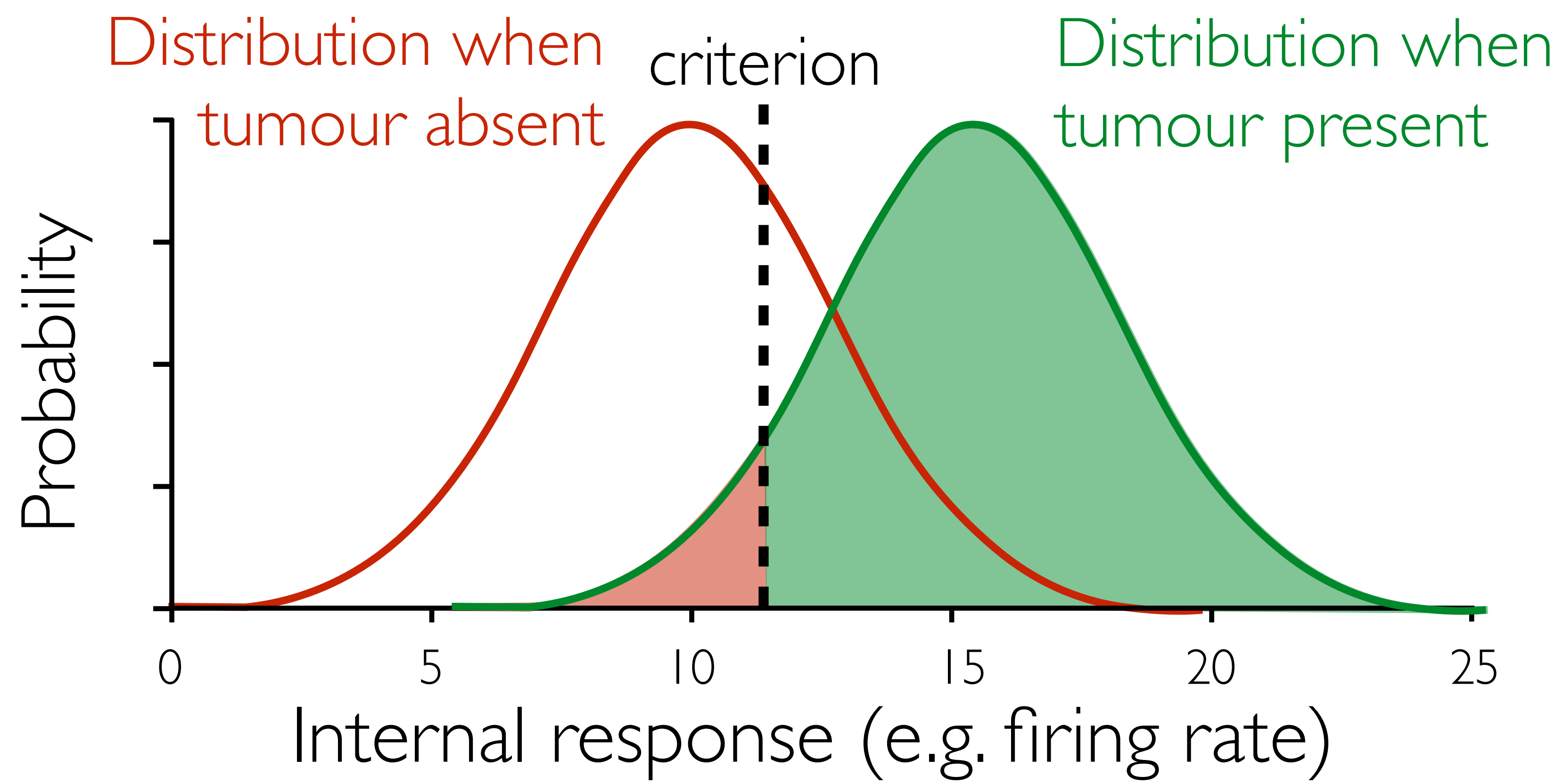
- Uncertainty on these tasks arises from two types of noise
- **External noise:** e.g. imaging errors, variation in lung tissue
- **Internal noise:** radiologist uses some neural response to detect a tumour - these responses are variable

Internal distributions



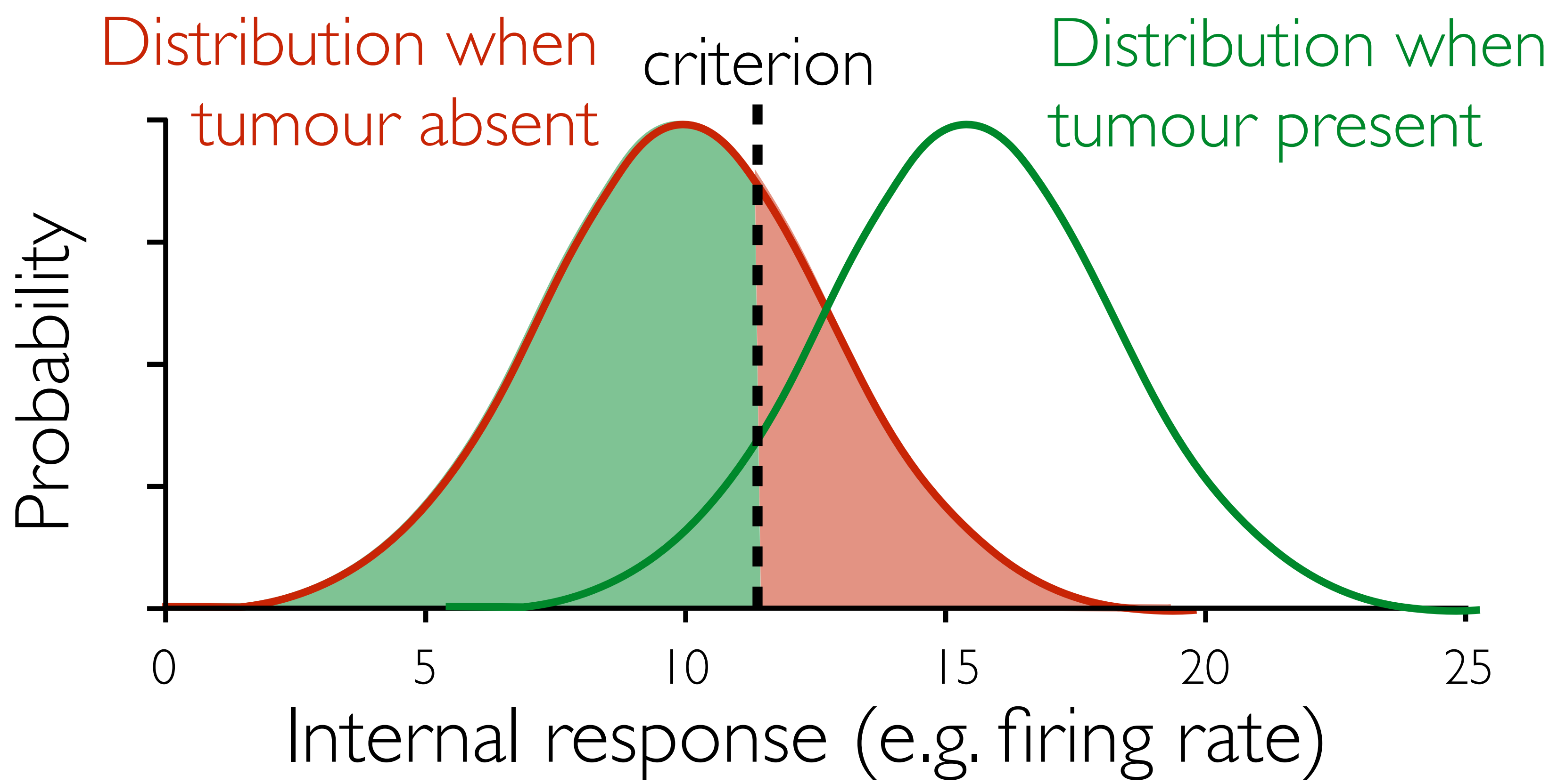
- Compare internal response probability of occurrence curves for noise alone vs. signal+noise trials
- Discriminability of the two possibilities set by separation/breadth of curves
- But decision also requires that we set a criterion value

Distributions to responses



- Signal present trials:
  - Response above the criterion = hit
  - Response below the criterion = miss

Distributions to responses

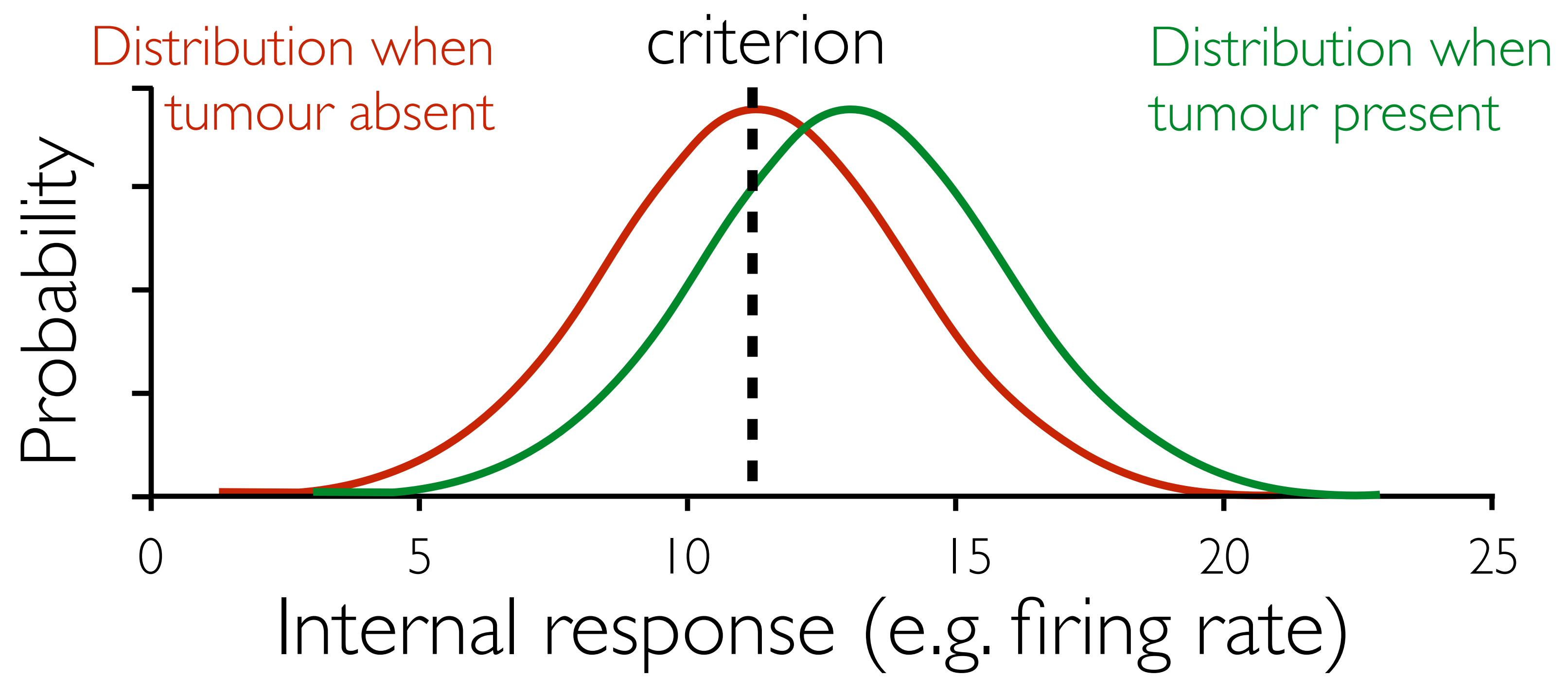


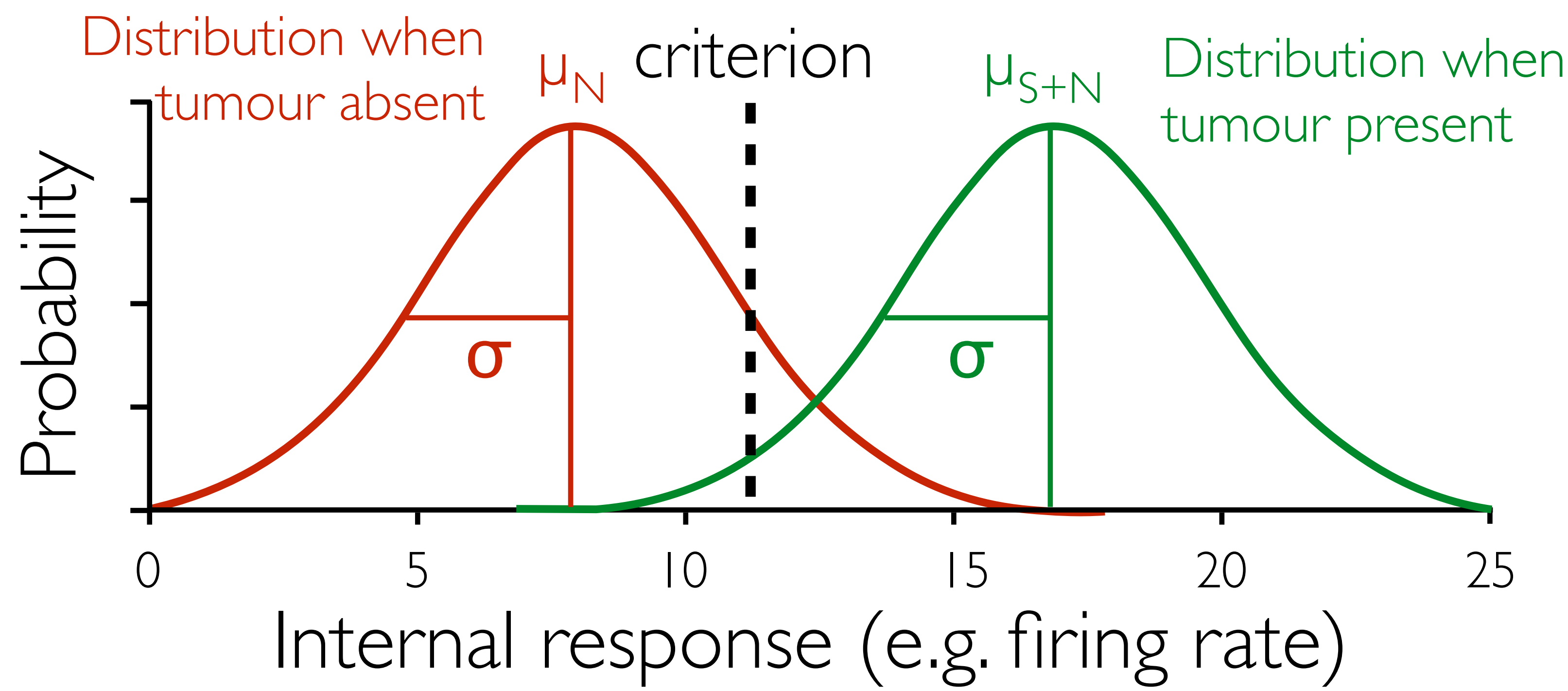
- Signal absent trials:
  - Response below the criterion = correct rejection
  - Response above the criterion = false alarm

Measuring sensitivity

- Sensitivity is characterised by d' (d prime)

$$d' = \frac{\mu_{S+N} - \mu_N}{\sigma}$$





Calculating d'

Signal:
Is there a tumour?

Decision: Is there a tumour?		**Yes**	**No**
	Yes	Hit	False Alarm
	No	Miss	Correct Reject
		signal+noise	*noise*

- Sensitivity is characterised by d' (d prime)

$$d' = \frac{\mu_{S+N} - \mu_N}{\sigma}$$

- d' = z(Hit) - z(FA)

d' examples

e.g. early stage tumour

Signal: Is there a tumour?

Decision: Is there a tumour?	**Yes**	**No**
Yes	0.84	0.50
No	0.16	0.50

e.g. late stage tumour

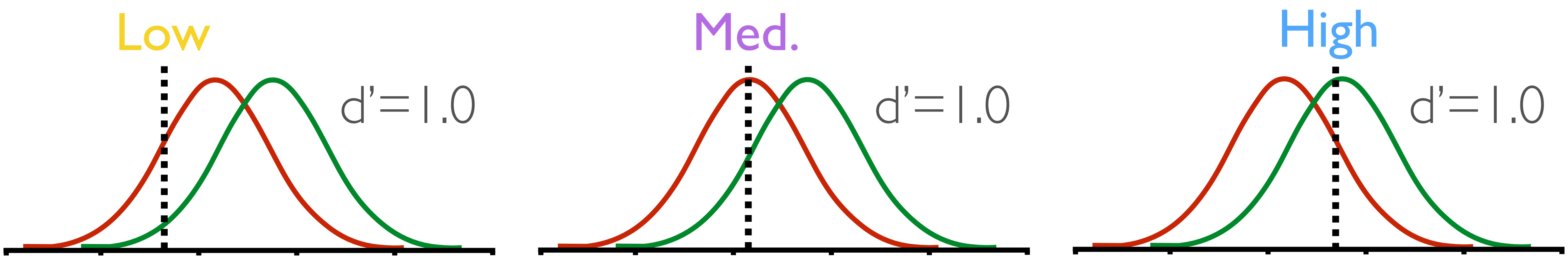
Signal: Is there a tumour?

Decision: Is there a tumour?	**Yes**	**No**
Yes	0.98	0.33
No	0.02	0.77

- Early stage tumour: d' = z(0.84) - z(0.5) = 1
- Late stage tumour: d' = z(0.98) - z(0.33) = 2.5

Criterion effects

- The criterion can also alter performance drastically
  - e.g. Radiologists may weigh errors differently - one considers missed diagnoses fatal, another minimises unnecessary procedures
  - Note there is no point that completely removes false alarms without missing many 'signal present' trials



Hits = 98%
False Alarms = 84%

Hits = 84%
False Alarms = 50%

Hits = 50%
False Alarms = 16%

Measuring the criterion

Low

Signal:
Is there a tumour?

Decision: Is there a tumour?		**Yes**	**No**
	Yes	0.98	0.84
	No	0.02	0.16

High

Signal:
Is there a tumour?

Decision: Is there a tumour?		**Yes**	**No**
	Yes	0.50	0.16
	No	0.50	0.84

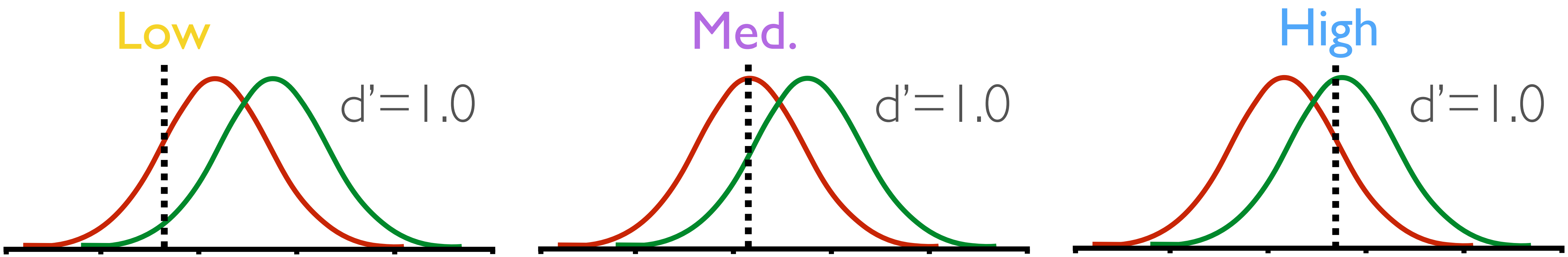
- Is there a way to characterise this criterion?

$$c = \frac{-(z(\text{Hit}) + z(\text{FA}))}{2}$$

- Negative means many 'yes' responses; positive means 'no'

Criterion examples

$$c = \frac{-(z(Hit) + z(FA))}{2}$$



Low	Med.	High
Hits = 98%	Hits = 84%	Hits = 50%
False Alarms = 84%	False Alarms = 50%	False Alarms = 16%
c = -1.5	c = -0.5	c = 0.5

SDT summary

- We can characterise performance using two values
  - d' - sensitivity
  - c - criterion
- Previously we sought to avoid the subjective criterion through the use of forced choice procedures
- SDT allows us to measure it
  - Through the separation of 'signal present' and 'signal absent' trials

Summary

Psychophysics provides tools to investigate the relationship between physical stimuli and psychological quantities

- **Stimulus**
  - Luminance patch
  - Gabor
  - etc.
- **Task**
  - detection
    - yes/no
    - forced choice
  - discrimination
    - yes/no
    - forced choice
- **Method**
  - Limits
  - Adjustment
  - Constant stimuli
  - SDT
- **Outcome**
  - performance
    - Reaction times
    - Percent correct
    - Thresholds
    - d’ and c
  - appearance
    - Matching

Summary

- With linking hypotheses we then make inferences about the mechanisms underlying our visual perception
  - We can divide psychophysical methods into four broad components: stimulus, method, task, and outcome
- In future lectures you'll go into more detail about specific visual dimensions
- Reading for this lecture:
  Chapter 1 of *Sensation & Perception* by either Goldstein or Wolfe *et al*