UCL Institute of Ophthalmology

NEUR0017: Fundamentals of Psychophysics

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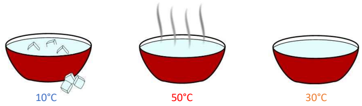

John Locke (1632 – 1704)

- 30°C water will feel HOT to a hand that was previously in 10°C water…
- …and will feel COLD to a hand that was previously in 50°C water.

- The water has a **physical** property: temperature (as measured in Celsius)
- And a perceived/**psychological** property: it's thermal quality (as described by 'hotness' or 'coldness')

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Temperature (°C)	Hotness
Sound intensity (dB_{SPL})	Loudness
Sound frequency (hz)	Pitch
Light intensity (cd/m^2)	Brightness
Chemical compounds (??)	Odour
Physical Size (cm)	Apparent Size

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Temperature (°C)	→ Hotness
Sound intensity (dB_{SPL})	→ Loudness
Sound frequency (hz)	→ Pitch
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Chemical compounds (??)	→ Odour
Physical Size (cm)	→ Apparent Size

Psychophysics deals with quantifying the relationship between physical stimuli and the perceptions they produce

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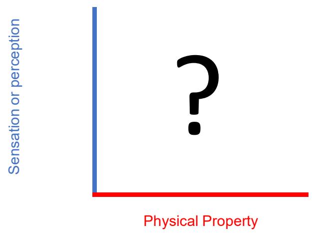

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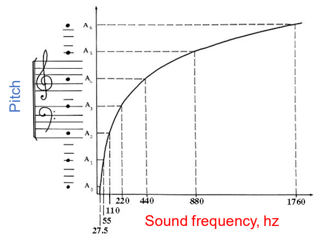

Psychophysics deals with quantifying the relationship between physical stimuli and the perceptions they produce

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Psychophysics is a way of answering questions about our senses

Often just one question:
- What's the smallest X you can detect/discriminate?

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Psychophysics is a way of answering questions about our senses

Often just one question:
- What's the smallest X you can detect/discriminate?
- **What's the smallest letter you can see?**

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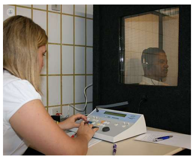
Psychophysics is a way of answering questions about our senses

Often just one question:
- What's the smallest X you can detect/discriminate?
- What's the smallest letter you can see?
- **What's the quietest tone you can hear?**



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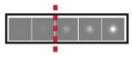
Psychophysics is a way of answering questions about our senses

Often just one question:
- What's the smallest X you can detect/discriminate?
- What's the smallest letter you can see?
- What's the quietest tone you can hear?
- **What's the dimmest light you can see?**



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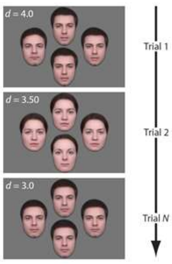
Psychophysics is a way of answering questions about our senses

Often just one question:
- What's the smallest X you can detect/discriminate?
- What's the smallest letter you can see?
- What's the quietest tone you can hear?
- What's the dimmest light you can see?
- **What's the smallest difference between two faces that you can tell apart?**



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In psychophysics these are all questions about 'Thresholds' (or '*Limens*')

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Psychophysics is a way of answering questions about our senses

Often just one question:
- What's the smallest X you can **detect/discriminate?**
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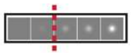

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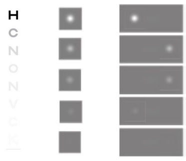
How to measure a threshold?

First we need to define some (any) task, that will allow us to present different stimulus levels, and see whether the observer sees the stimulus (i.e., responds correctly)

E.g., to measure contrast sensitivity thresholds, we could present targets of different luminance (light intensity), and ask the observer:
- To read the letter aloud (*identification paradigm*)
- Say 'yes' if they see it (*yes/no paradigm*)
- Say whether the target was on the left or the right (*two-alternative forced-choice [2AFC] paradigm*)



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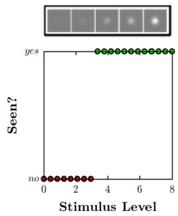
How to measure a threshold?

With an **ideal observer** we would present each and every possible stimulus level once…



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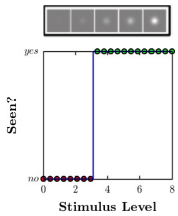
How to measure a threshold?

With an **ideal observer** we would present each and every possible stimulus level once…

…and find the point where they start responding correctly. This is their threshold.

The blue line is their **psychometric function**, and for the ideal observer is a step function.



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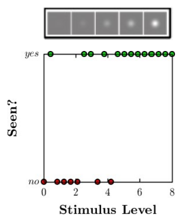
How to measure a threshold?

Unfortunately, real observers are not ideal. Their data will often look more like this (*right*).

It is not possible to draw a meaningful step function through these data.

Why are the data so messy?



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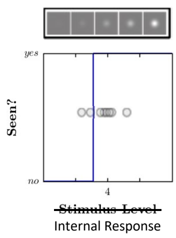
How to measure a threshold?

Real observers do not respond consistently because perceptual judgments are intrinsically noisy:
- External noise (e.g., literal noise, passing traffic, jitter)
- Internal noise (e.g., stochastic neural processes, heartbeat, fluctuations in concentration)

This noise means that even if we present the exact same stimulus level multiple times, the **internal response** in the brain will be slightly different each time



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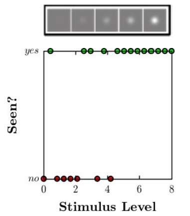

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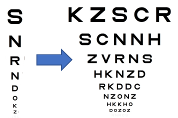
How to measure a threshold?

To deal with this noise, the solution is to present every stimulus more than once, and find the **proportion** of the correct responses, *P*(Seen).



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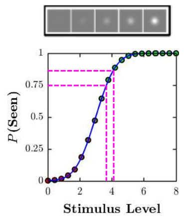
How to measure a threshold?

To deal with this noise, the solution is to present every stimulus more than once, and find the **proportion** of the correct responses, *P*(Seen).

What you typically obtain is a smooth, **sigmoidal** psychometric function (where the slope is proportional to the magnitude of internal noise)

You can then read across and down to find their **threshold**.

Any 'threshold level' (e.g., 75% correct, 82.5% correct, 93.33% correct) is valid, so be careful when comparing across papers/methods!



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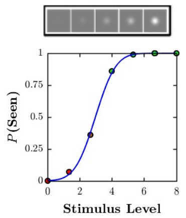
How to measure a threshold?

Real experiments tend to test fewer stimulus levels (e.g., 5 – 9), for practical reasons.



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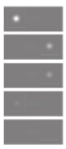
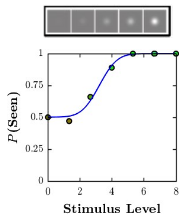
How to measure a threshold?

Real psychometric functions often don't tend to start at zero, but at a higher value. (In psychophysics language: "the **lower asymptote** > 0".)

This is because the guess rate (chance of a **false positive** response) is often > 0. E.g., 50% in the case of a 2AFC design.

Higher guess rates also makes the data at all stimulus levels noisier (less reliable/precise) for the same number of trials.





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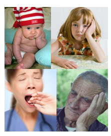
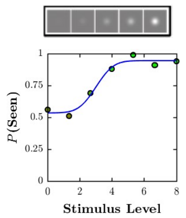
How to measure a threshold?

Real psychometric functions often don't tend to end at 1, but at a lower value. (In psychophysics language: "the **upper asymptote** < 1".)

This is because people get bored, tired, and distracted, and make mistakes (**false negative** responses)

Again, also adds noise. Plus need to be careful to actually fit the right function to the data, and not just assume that it goes up to 1.





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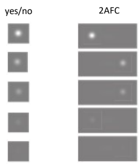
How to measure a threshold?

As well as internal noise, guesses, and lapses, also need to be aware of **response bias** (“*criterion effects*”).

Some people might prefer one response over another, and might differ in how confident they feel is necessary before responding. If you’re not careful this can cause **sensitivity** to be underestimated.

Can try to minimize this bias by using paradigms like 2AFC, rather than yes/no (e.g., since people tend to have no strong feelings about ‘1’ vs ‘2’, whereas don’t like saying ‘yes’ and being wrong).



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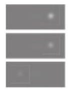
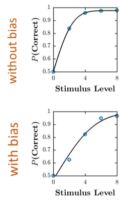
How to measure a threshold?

As well as internal noise, guesses, and lapses, also need to be aware of **response bias** (“*criterion effects*”).

But can never eradicate bias altogether. And, depending on how you plot the data, the bias isn’t always obvious in the psychometric function. Be careful!





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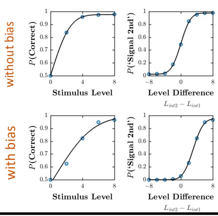

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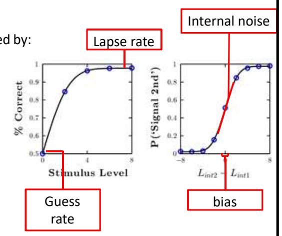
Interim Summary:

Unlike an **ideal observer** human beings are limited by:

1. Internal noise
2. Lapses (or *‘inattentiveness’*)
3. Response Bias

Because of these limitations, we have to treat detection/discrimination as a **probabilistic** process.

Each trial/stimulus is repeated many times, and a **psychometric function** then **fitted** to the data (‘Method of Constant Stimuli’)



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What I’ve described so far (the “Method of Constant Stimuli”) is the **gold standard.** But it doesn’t always work in the real world, for practical reasons:

1. Limited time
2. Non-stationary observers

Is there a faster alternative if we don’t want to characterise the whole psychometric function? (i.e., just want to know the Threshold)

Yes – adaptive methods

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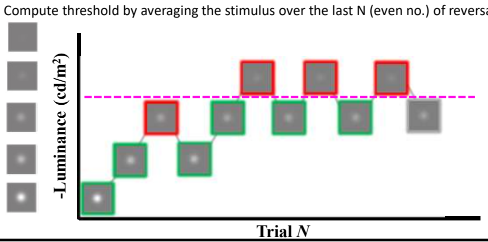
Simple up-down staircase: Increase the stimulus by +1 unit after a correct response, ✓ and by -1 unit after a incorrect response, ×.

Compute threshold by averaging the stimulus over the last N (even no.) of reversals.



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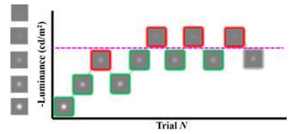
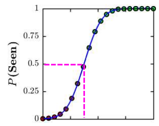
Simple up-down staircase: Increase the stimulus by +1 unit after a correct response, ✓ and by -1 unit after a incorrect response, ×.

Compute threshold by averaging the stimulus over the last N (even no.) of reversals.

This value corresponds to the point on the psychometric function where the probability of responding correctly, P(✓), is equal to the probability of answering incorrectly P(×).

i.e., the "50% detection/discrimination threshold"





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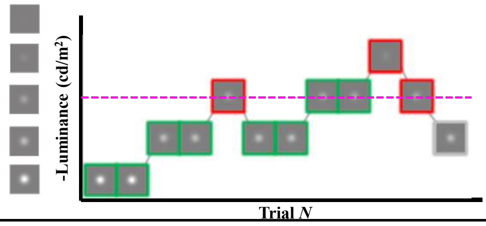
2-Up-1-Down (70.7%) transformed staircase (Levitt, 1971). Increase the stimulus by +1 unit after 2 correct responses, ✓✓, and by -1 unit after 1 incorrect response, ×.

Compute threshold by averaging the stimulus over the last N (even no.) of reversals.



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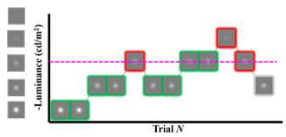
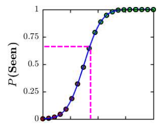
2-Up-1-Down (70.7%) transformed staircase (Levitt, 1971). Increase the stimulus by +1 unit after 2 correct responses, ✓✓, and by -1 unit after 1 incorrect response, ×.

Compute threshold by averaging the stimulus over the last N (even no.) of reversals.

This targets the 70.7% correct point on the psychometric function:

P(×) $= P$(✓✓)
$P(0.5) = P(x^2)$
$P(0.5) = P(0.707^2)$





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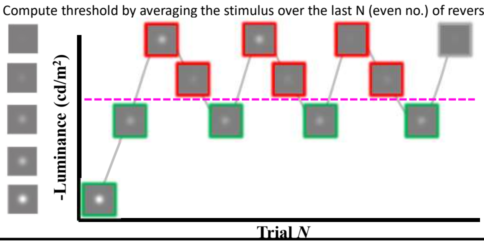
Up-2-Down-1 (33%) weighted staircase (Kaernbach, 1991) Increase the stimulus by +2 unit after 1 correct responses, ✓, and by -1 unit after 1 incorrect response, ×.

Compute threshold by averaging the stimulus over the last N (even no.) of reversals.



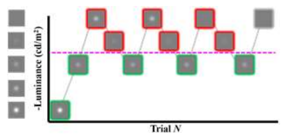
34

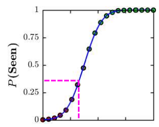
Up-2-Down-1 (33%) weighted staircase (Kaernbach, 1991) Increase the stimulus by +2 unit after 1 correct responses, ✓, and by -1 unit after 1 incorrect response, ×.

Compute threshold by averaging the stimulus over the last N (even no.) of reversals.

By varying the step size weighting, $\omega_\uparrow$, can targets any point on the psychometric function:

$[1-P(✓)]/P(✓) = \omega_\uparrow$
$[1-0.333]/0.333 = \omega_\uparrow$
$[1-0.333]/0.333 = 2$





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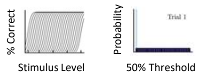
In recent years, staircases have started to be replaced by more efficient **Maximum Likelihood** methods (e.g., *QUEST+, psi, qCSF*).

These posit a number of **hypotheses**, and compute the likelihood that each fits the data.



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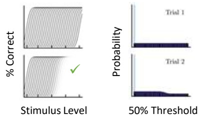

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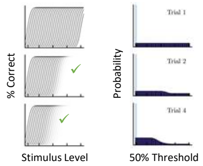

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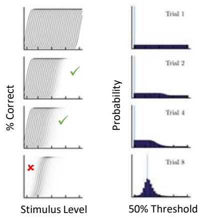

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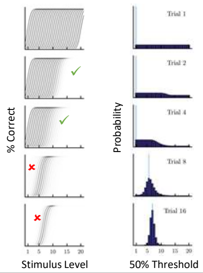
In recent years, staircases have started to be replaced by more efficient **Maximum Likelihood** methods (e.g., *QUEST+, psi, qCSF*).

These posit a number of **hypotheses**, and compute the likelihood that each fits the data.

They can also be used to determine the most **informative** stimulus to present next.

Can posit any, arbitrarily complex model.



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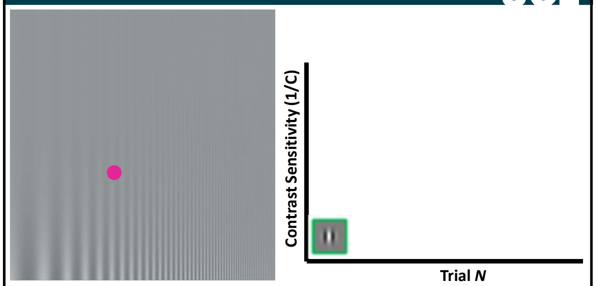

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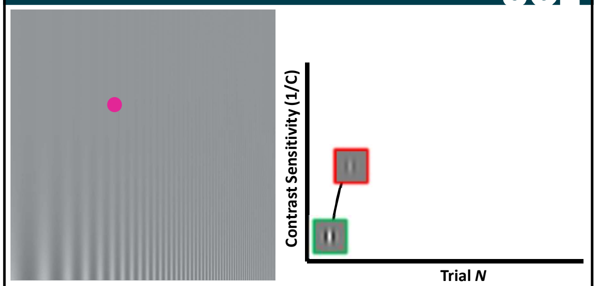

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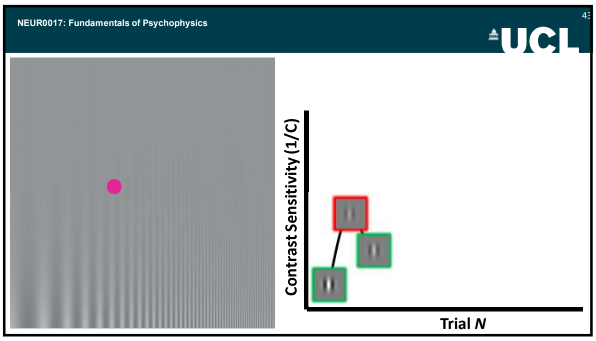

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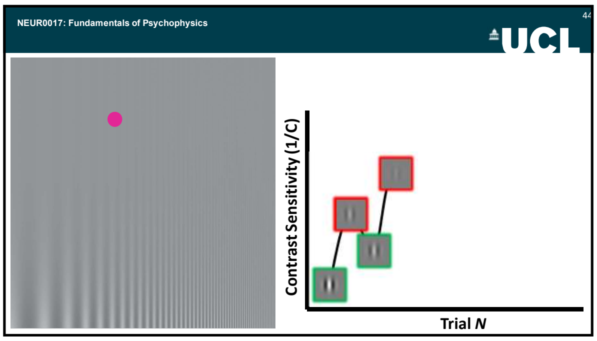

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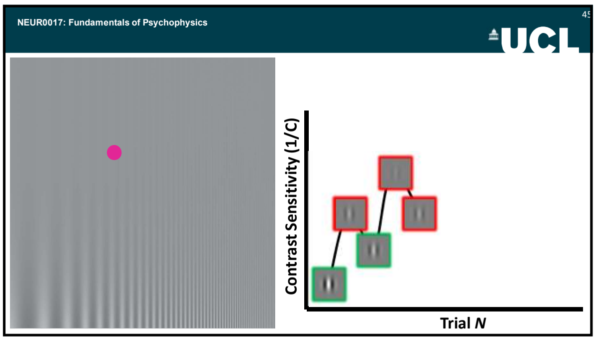

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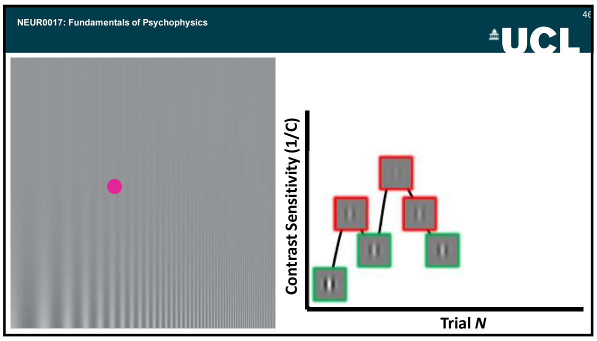

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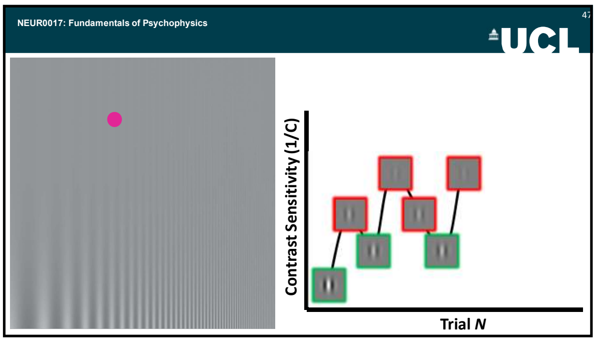

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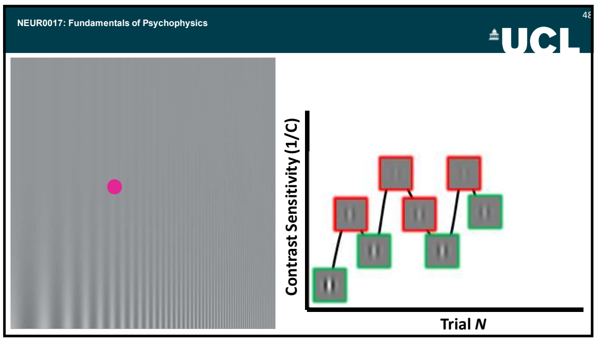

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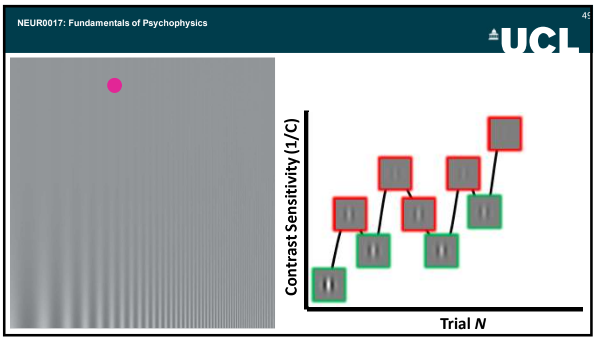

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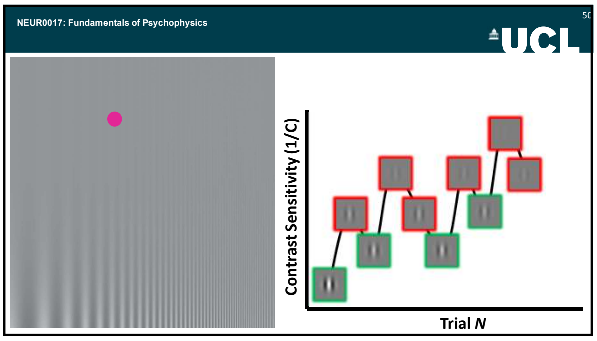

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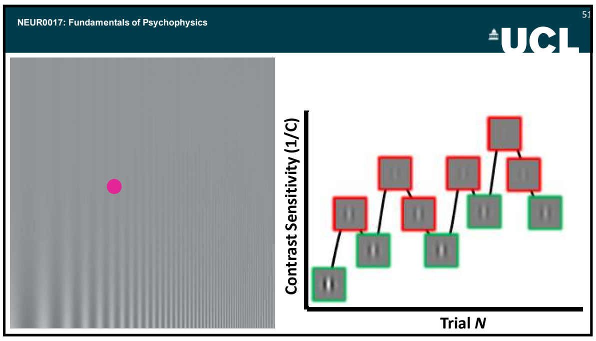

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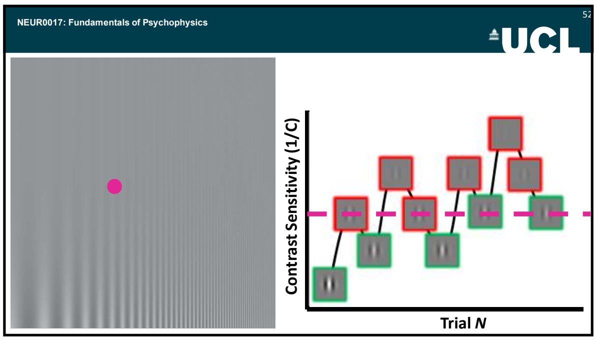

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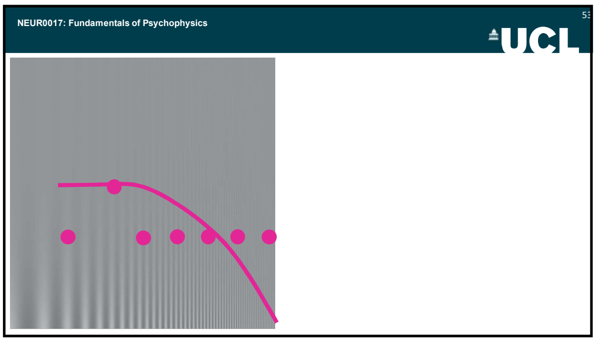

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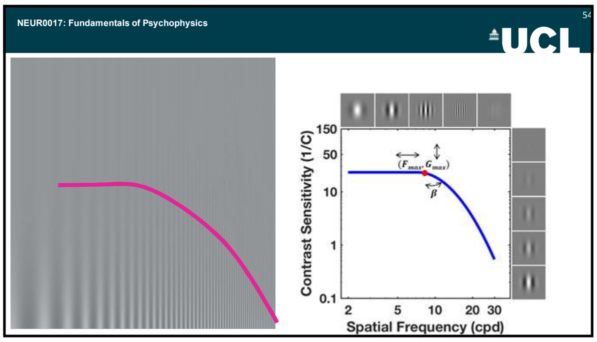

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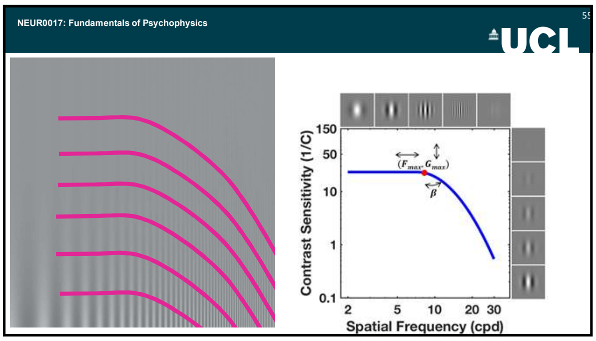

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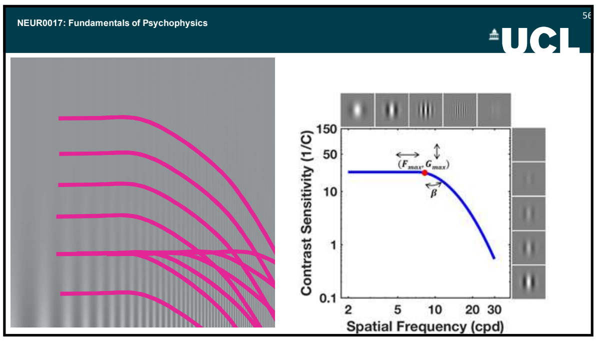

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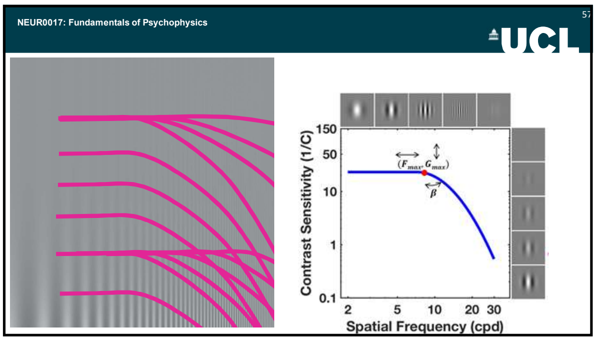

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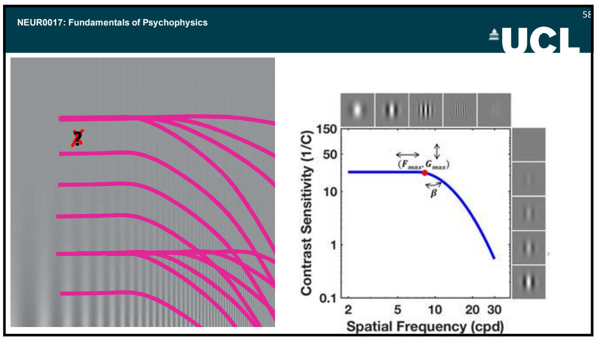

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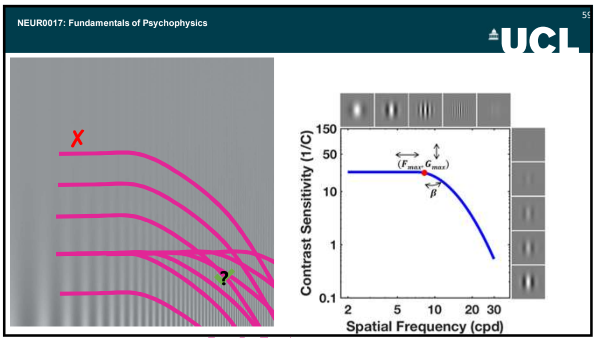

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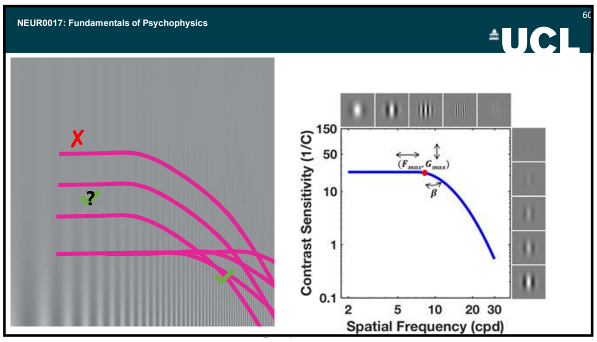

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NEUR0017: Fundamentals of Psychophysics

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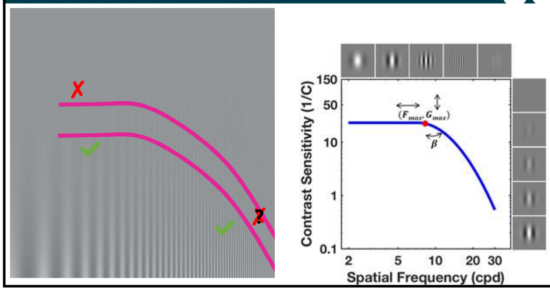

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Interim Summary:

Thresholds can be measured by:

1. Using fixed stimuli, and fitting a whole psychometric function (Method of Constant Stim)
   - Pros: Gold standard. Can analyse the data post-hoc and find the best fitting model
   - Cons: Slow. Potentially lots of redundant trials
2. Using an adaptive staircase
   - Pros: Fast
   - Cons: Can be affected by bias, lapses, etc.
3. Using a Maximum Likelihood adaptive procedure
   - Pros: Fastest
   - Cons: A complex method that requires lots of mathematical assumptions

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Assorted key terms:

- Threshold (*limen*)
- Ideal observer
- Signal Detection Theory
- Internal noise (*intrinsic noise*)
- External noise
- Internal response
- Psychometric function
- Slope
- Guess rate (*chance rate*)
- Lapse rate
- Response bias (*criterion effect*)
- Method of Constant Stimuli
- Stationarity
- Adaptive staircase
- Transformed staircase
- Weighted staircase
- Maximum Likelihood (*Bayes*)
- Prior
- m-Alternative Forced choice paradigm
- yes/no paradigm

Reading:

[**Detailed background theory**] Macmillan NA & Creelman CD. Detection theory: A user's guide. In: Mahwah, New Jersey: Lawrence Erlbaum Associates; 2005:1-495.

[**Primer on background theory**] Wickens TD. Elementary signal detection theory. In: New York, New York: Oxford University Press (USA); 2002:114-118.

[A **practical guide to making psychophysical measurements**] Kingdom FAA & Prins N. *Psychophysics: A Practical Introduction*. 1st ed. Elsevier Academic Press; 2010.

[An **even more practical guide to running experiments in general**] Lu Z-L. & Dosher, B. *Psychophysics: From laboratory to theory*. MIT Press; 2013.

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