

Aims

- *To understand the concept of thresholds*
- *To understand how decisions and threshold readings are influenced by non-sensory factors*
- *To understand a tool/theory (Signal Detection theory) that allows to determine sensory sensitivity in the presence of confounding factors*

Proceedings

- *What are thresholds?*
- *How can they be measured? What are possible confounds? How can these confounds be influenced? How can they be quantified?*
- *If confounds exist, is there a way out, i.e. can we nevertheless determine sensory sensitivity? Yes we can, but we must understand the basics of Signal Detection theory.*
- *How does signal detection theory relate to experimental findings? How does it allow calculation of absolute sensitivity?*

Psychophysics and Sensitivity

- **Psychophysics** is the scientific study of the relation between stimulus and sensation
- **Sensory threshold**: when stimuli are so weak that they can just about be detected
- **Absolute threshold**: smallest amount of stimulus energy that elicits perception

- Thresholds are not absolute --- from trial to trial sensitivity varies
- Expectancy and payoffs influence detection rates

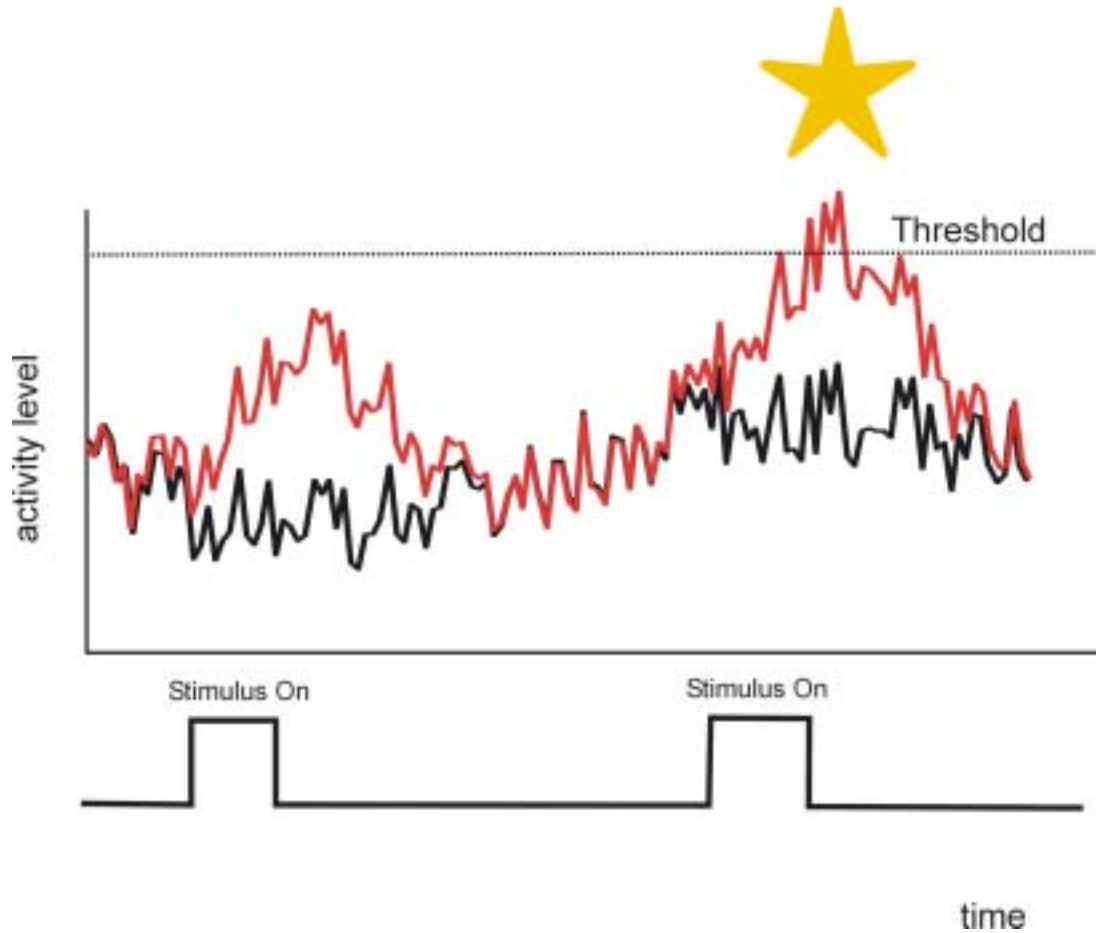
Why does sensitivity vary from trial to trial?

It's the noise

What noise?

Neural noise

Why does sensitivity vary from trial to trial?



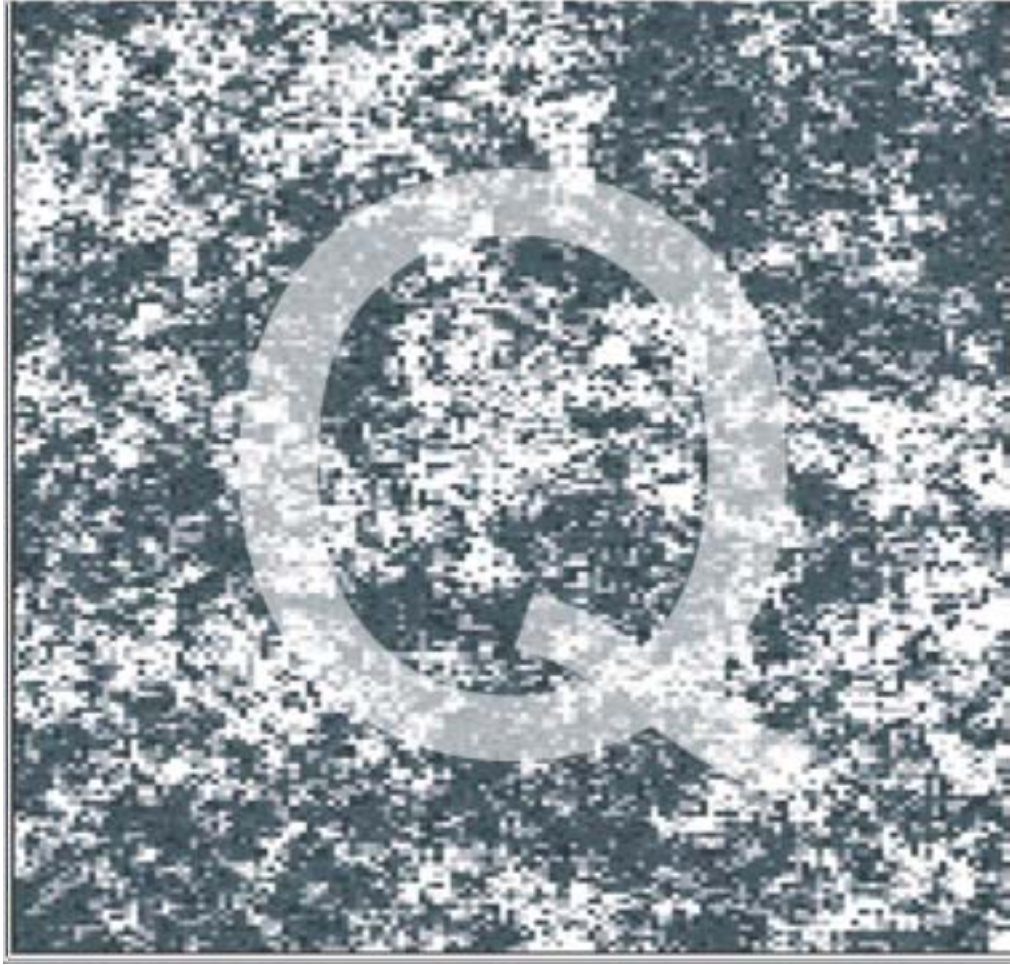
Today's experiment (brief overview)

- **Method of constant stimuli:** *Allows to determine psychophysical threshold.*

In 50% of the trials a stimulus is presented (letter detection task, 'Q').

We add some **external** noise to the stimulus to make detection more difficult

Today's experiment (example)



Today's experiment (brief overview)

The added noise level will vary in 5 steps. We want to determine at what noise level you are just about able to detect the presence of the letter.

You count the number of 'yes' (letter present) and 'no' (letter not present) responses.

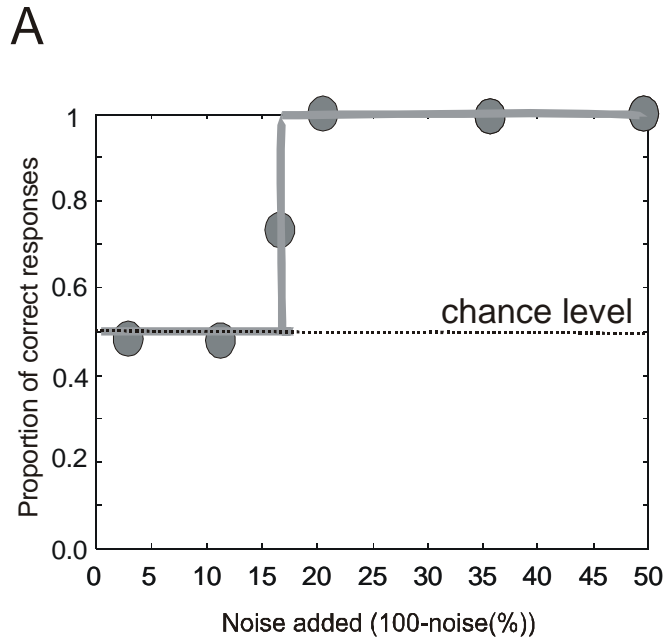
From these you can calculate your **performance**, i.e. the probability that you get it correct for a given noise level.

Threshold determination

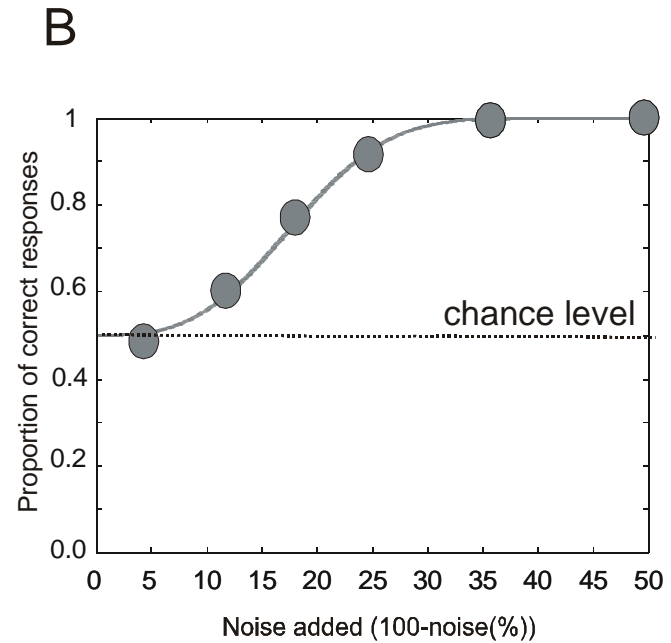
- Various stimulus/noise ratios are generally presented
- Many measurements are made for each stimulus/noise ratio.
- These repeated measurements are then averaged

Performance as a function of noise level

Idealized situation



real situation





Take home message: internal noise (biological factor) influences performance

What influences the decision?

1. internal noise (beyond our control, always present)
2. Stimulus probability (can be controlled by us)
3. **Payoffs** (can be controlled by us – used in today's experiment)

Possible outcomes in the detection situation

2x2 table	<i>Response '(yes)'</i>	<i>Response '(no)'</i>
<i>stimulus</i> 	<p>Hit correct</p>	<p>Miss error</p>
<i>No stimulus</i> 	<p>False alarm error</p>	<p>Correct rejection correct</p>

What happens when the criterion changes?

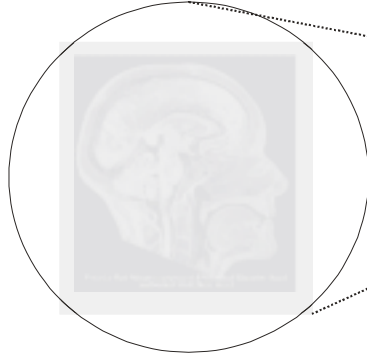
Is there anything
or not: **Yes**



Is there anything or not?
Oh well, what the heck,
they pay me 1 £ for every
hit

What happens when the criterion changes?

Is there anything or
not: **No**

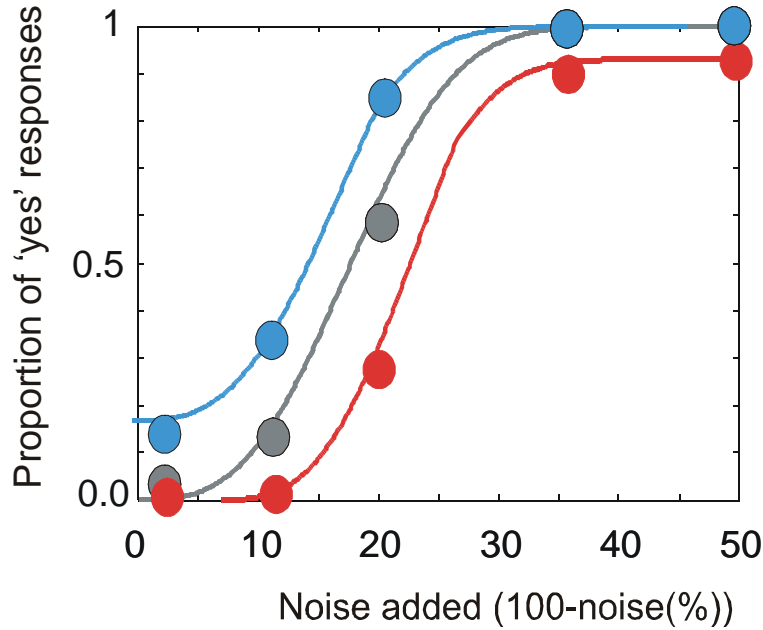


Is there anything or not?
Well, I better be cautious,
they'll make me pay 1 £
for every false positive

1 bottle of Champagne for the winner

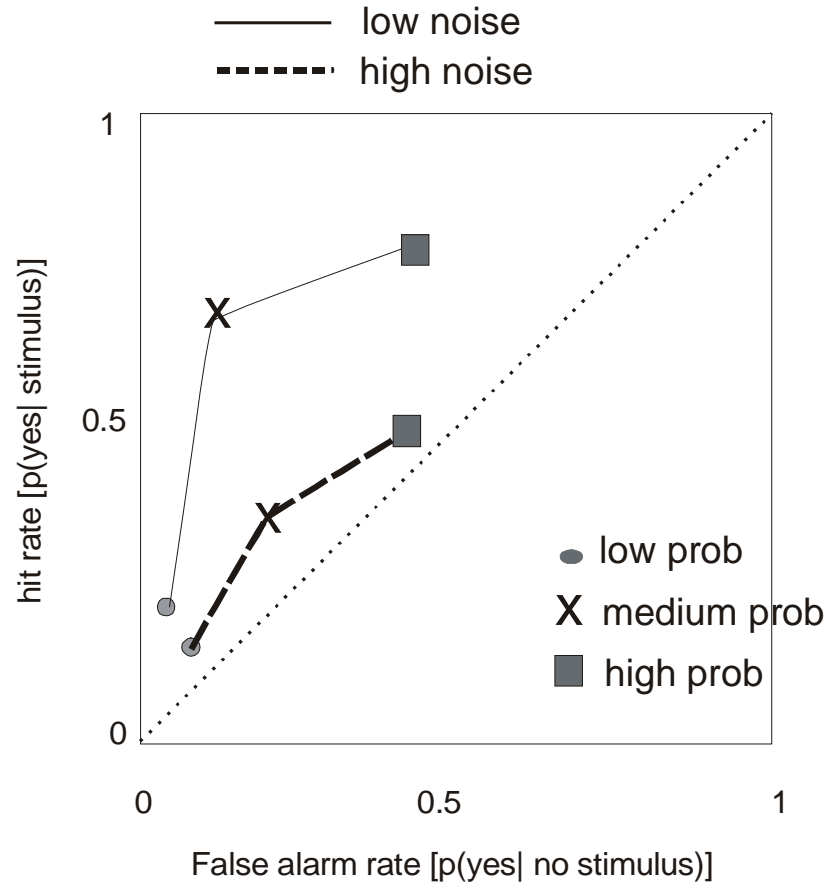


What happens when payoffs change?



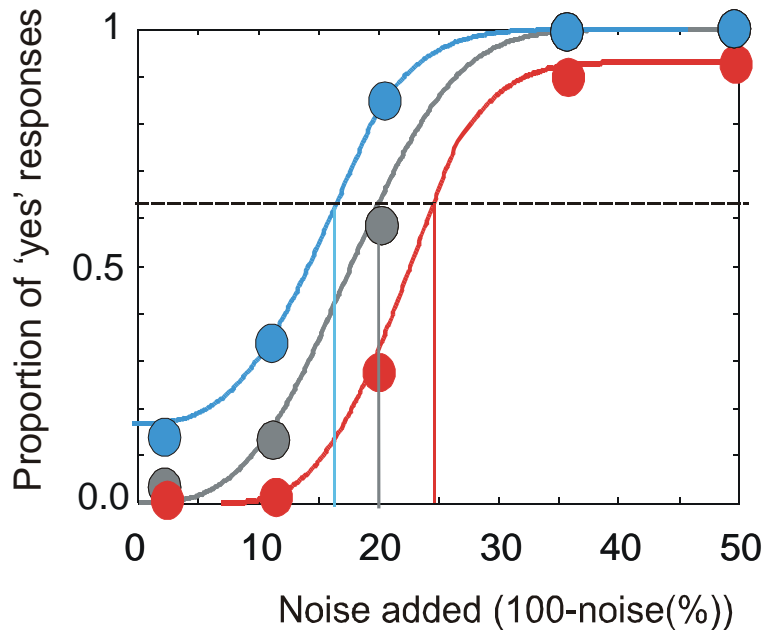
Low cost 'false alarm'
Neutral cost 'false alarm'
High cost 'false alarm'

Receiver Operating Characteristics



Receiver operating characteristics are calculated from the proportion of **hits** vs. the proportion of **false alarms**

Do payoffs change thresholds?



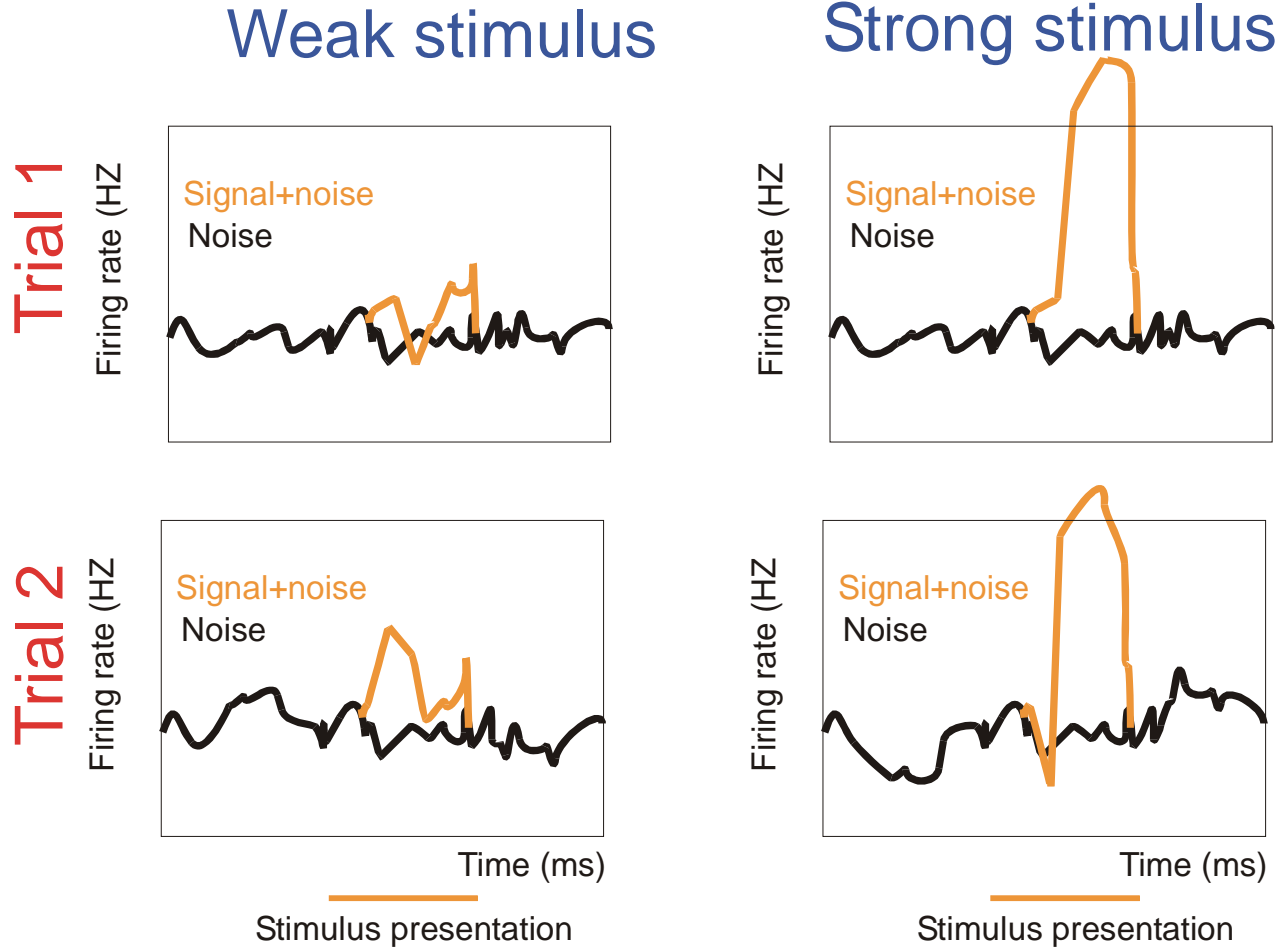
Low cost 'false alarm'
Neutral cost 'false alarm'
High cost 'false alarm'

No (most likely not)! This is a misleading graph. The criterion changes, and therefore the sensory threshold appears to shift. (But nobody knows for sure)

Is it possible to determine the sensitivity nevertheless (I)?

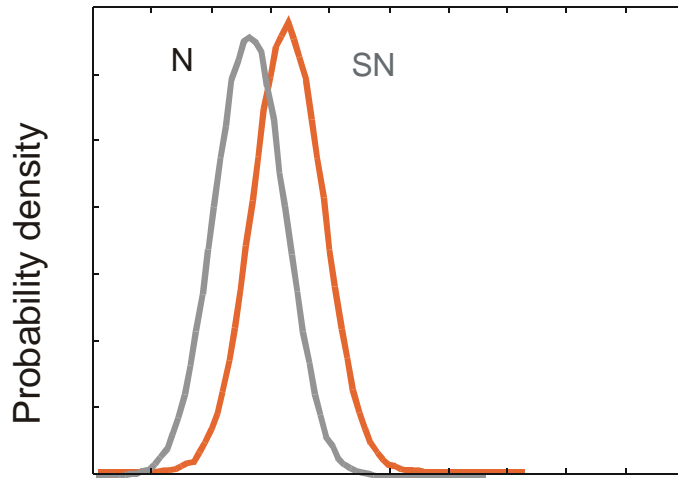
Yes, this is where **Signal Detection Theory** becomes important

How are stimuli represented in the brain?



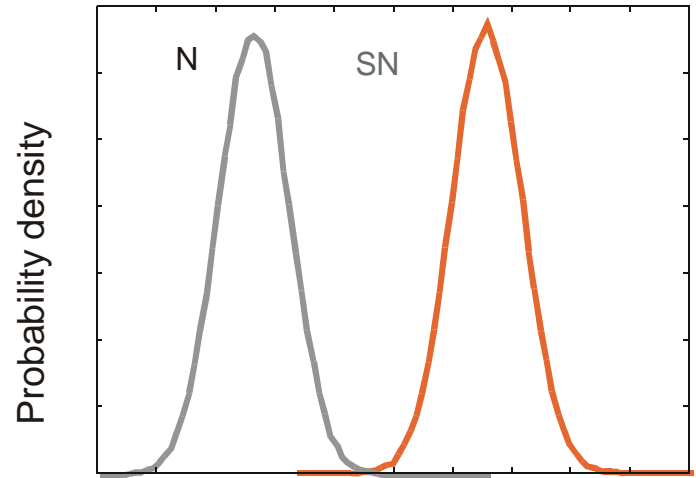
What is the probability density function of stimulus evoked responses?

Weak stimulus



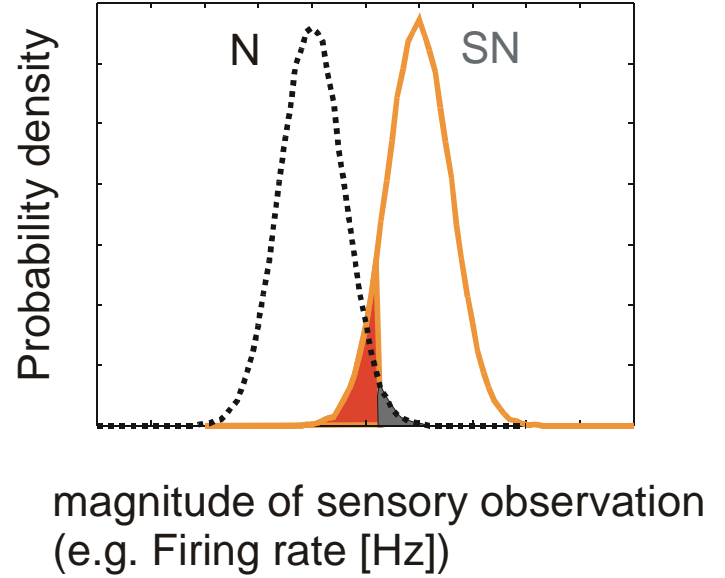
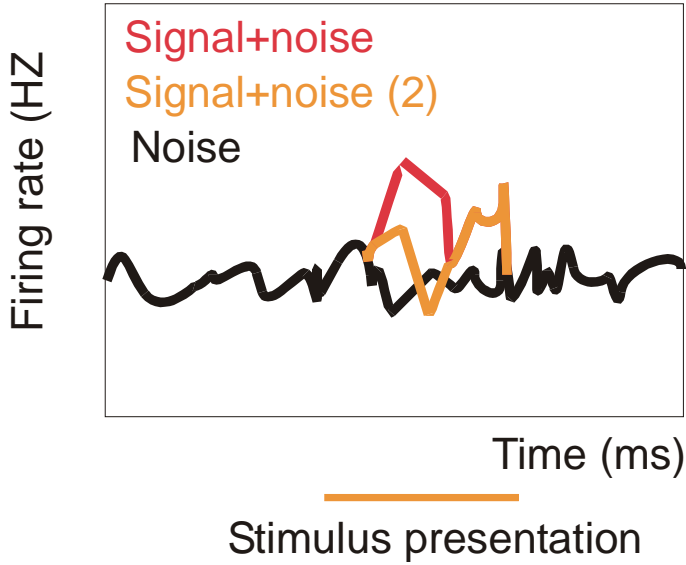
magnitude of sensory observation
(e.g. Firing rate [Hz])

Strong stimulus



magnitude of sensory observation
(e.g. Firing rate [Hz])

Is it possible to determine the sensitivity nevertheless (II)?



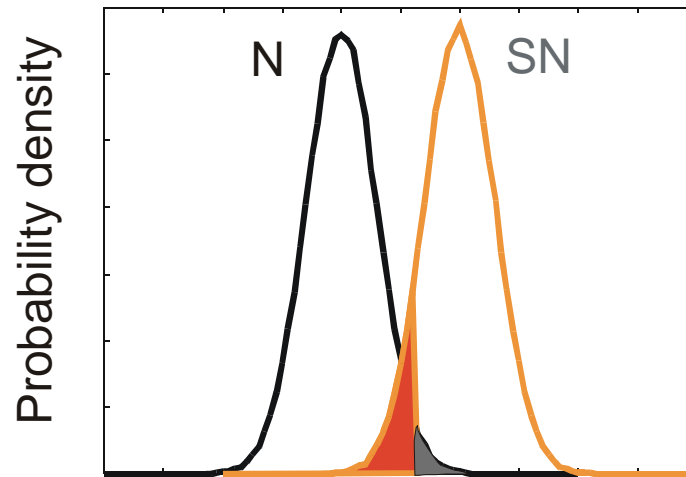
Signal Detection theory is based likelihood ratios

Likelihood: On any given trial the observer must decide whether a signal was present or not. He/she does it based on the likelihood that the neural activity arose by chance, or by the likelihood that it arose by impact from an external signal.

Signal Detection theory is based likelihood ratios

Likelihood ratio $I(x)$:

$I(x) = \text{probability of signal+noise} / \text{probability of noise}$

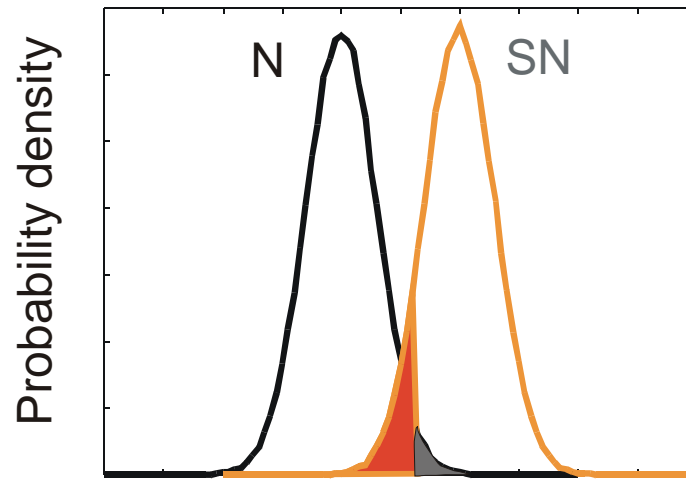


magnitude of sensory observation
(e.g. Firing rate [Hz])

Signal Detection theory is based likelihood ratios

Any decision criterion is based on a likelihood ratio $l(x)$

e.g.: $l(x) = 1.3$ high risk – yes
med risk – yes
low risk – no



magnitude of sensory observation
(e.g. Firing rate [Hz])

What have we had so far ?

- Decisions are influenced by **internal noise** and **external variables** (stimulus probability or payoffs)
- These external variables influence the our **criterion**, they make it more (or less) likely that an observer says 'yes' when no stimulus is present.
- The different criteria can be visualized using a **Receiver operating characteristics** graph (this graph has very powerful prediction, and we'll get to that)

What have we had so far ?

- The **noise** and the **Signal plus noise** are not identical from trial to trial.
frequency distribution
- A **decision criterion** is based on a likelihood that the signal occurred by chance or not. It is identical to a likelihood ratio $l(x)$.

What is all this good for ?

We want to know what the real **sensitivity** is!

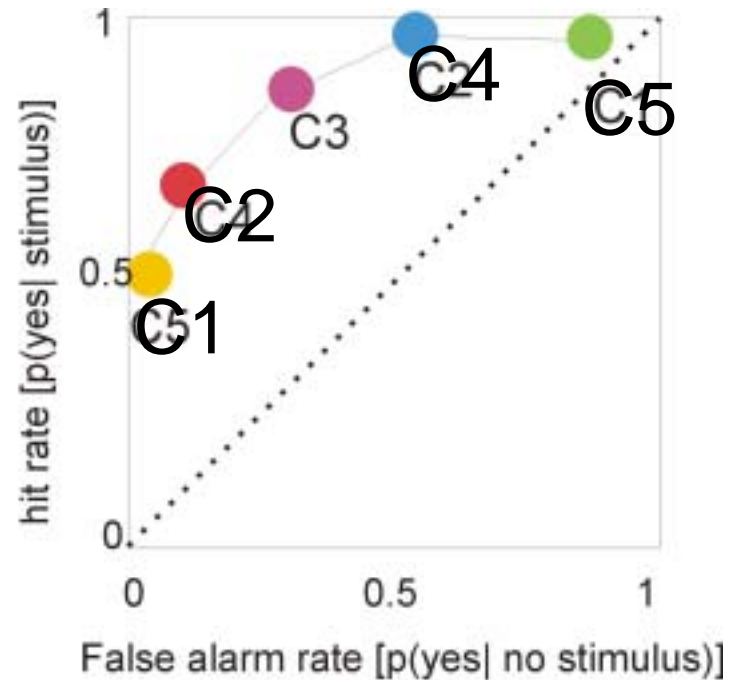
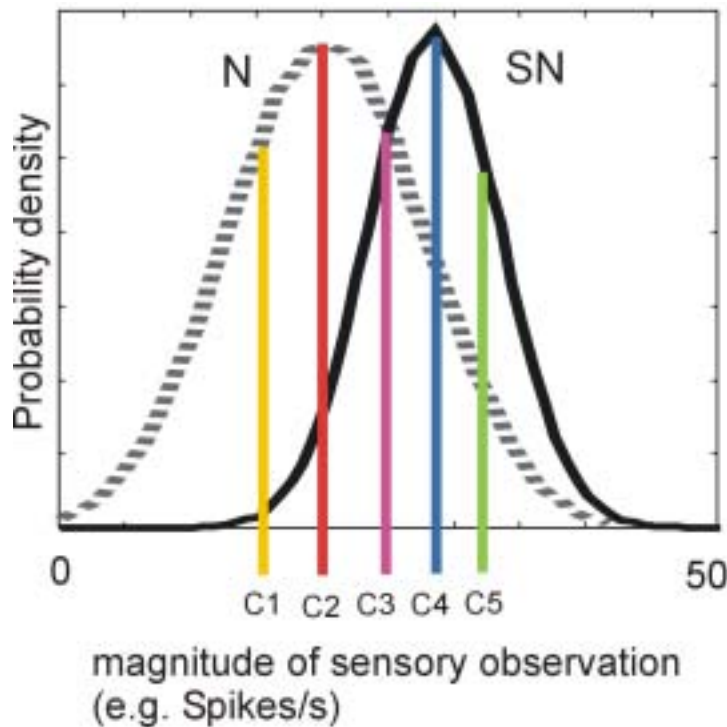
Thus we somehow need to get rid of the
confounds.

Why is Signal Detection theory cool (I)?

SDT allows to determine the observers criterion, the SN, and N distributions from just the hit and false alarm rate!

Sounds almost like a miracle, how can that be achieved?

All that is needed is to systematically vary the observer's criterion.



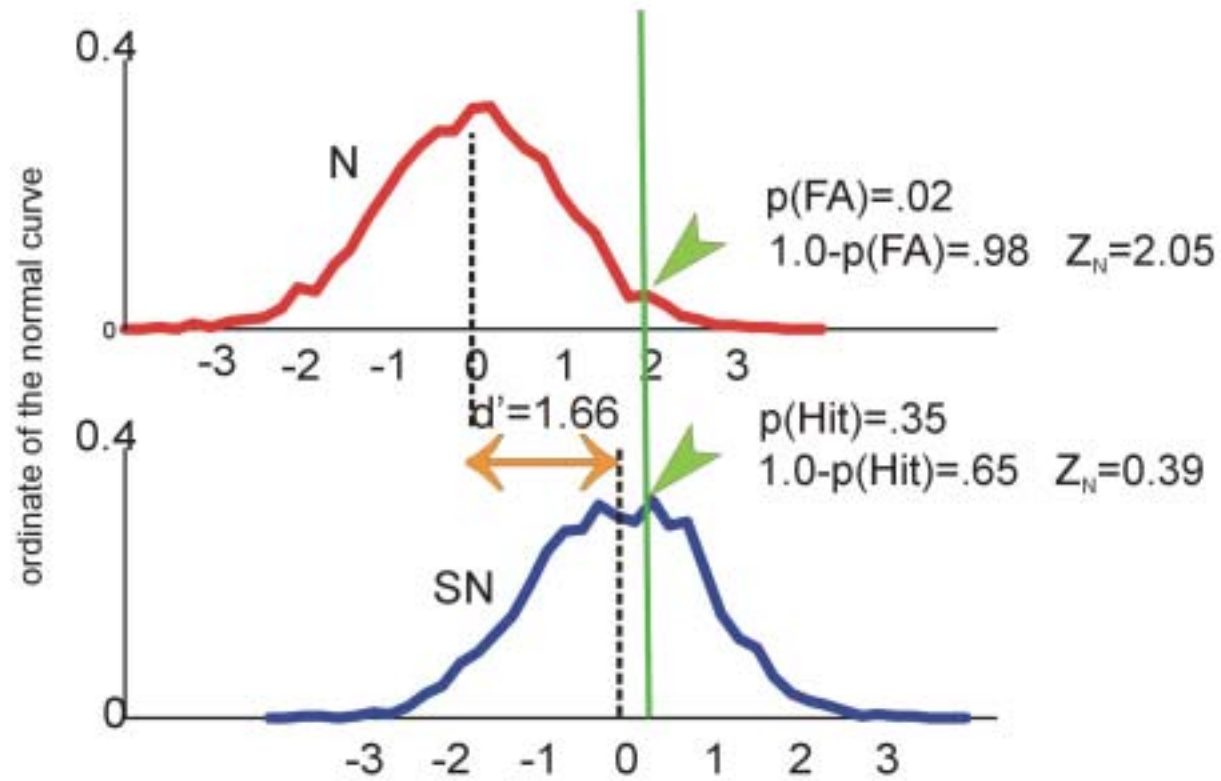
Why is Signal Detection theory cool (II)?

SDT allows to determine the observers sensitivity in the presence of confounding factors!

$$d' = \frac{M(SN) - M(N)}{\sigma(N)}$$

How can this theoretical concept of signal detectability be measured?

Fortunately there is an easy shortcut



$$d' = Z_N - Z_{SN} = 2.05 - 0.39 = 1.66$$

Easy shortcut to absolute sensitivity

Sensitivity can be derived from just the **hit** and **false** alarm rate

$$1.0 - p(\textit{false.alarm}) \longrightarrow Z(N)$$

$$1.0 - p(\textit{hit}) \longrightarrow Z(SN)$$

$$D' = Z(N) - Z(SN)$$

Why is Signal Detection theory cool (III)?

Taking the ideal observer approach. The area under the curve of an ROC corresponds to absolute detectability. An ideal observer would maximize his/her performance by establishing a criterion at a likelihood ratio of 1 (to be precise, he/she uses a maximum rule, which yields slightly different results, but for the sake of comprehensiveness we assume the above).

It can be mathematically shown, that an ideal observer approach is the best possible. Performance cannot be increased by any other approach.

Thus SDT in combination with an ideal observer approach is literally
as good as it gets

Summary

1. Psychophysical results are often contaminated by the observers' criterion
2. Signal detection theory allows to determine sensitivity independent of the observers' criterion.