PSY-2007S

Auditory Experimentation

week 5 – Signal Detection Theory

Signal Detection Theory

Internal noise
Hits and false alarms
Sensitivity
D'
Bias

Detecting stimuli in noise: Signal Detection Theory (SDT)

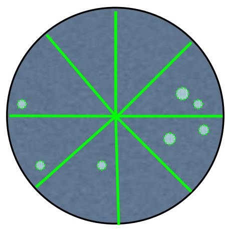
- How stimuli are detected/discriminated against background noise
- How to make good decisions from bad information
- SDT explains why shape of psychometric function varies with noise
- SDT explains how a subject's *criterion* (response bias) affects decisions and how to measure it
- SDT allows measurement of *sensitivity* (ability to make correct responses/decisions) regardless of criterion/bias

Origin of SDT: WW2 radar and sonar

Task: warn of incoming aircraft or submarines

Are the blobs enemy aircraft?
Or just noise (clouds)?

Radar screen



Decision depends on *subjective* criterion: how big must a blob be to count as aircraft

Decision has consequences:
- If you miss an aircraft, people might get killed
- If you mistake noise for aircraft, fuel, manpower & resources are wasted

Decision outcomes & consequences

SIGNAL: are the blobs real enemy subs?

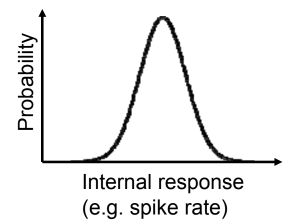
DECISION: should you shoot?

DECISION \ SIGNAL	*yes*	*no*
yes	Hit	False alarm
no	Miss	Correct reject

Signal Detection Theory

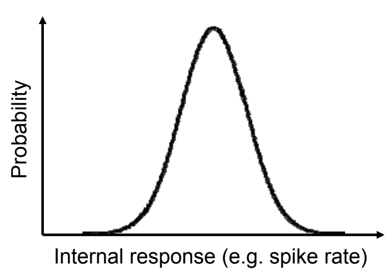
Important idea: Treat the stimulus as a probability

For a certain stimulus…
…how much sound reaches the ear?
…how much hair cells are activated?
…spikes are generated?

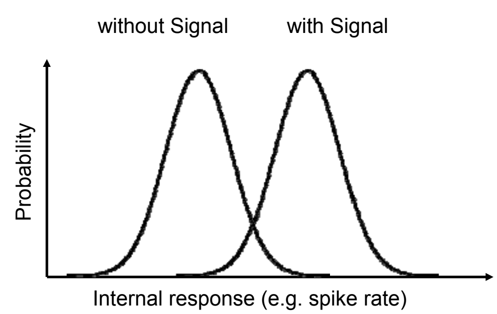


Signal Detection Theory

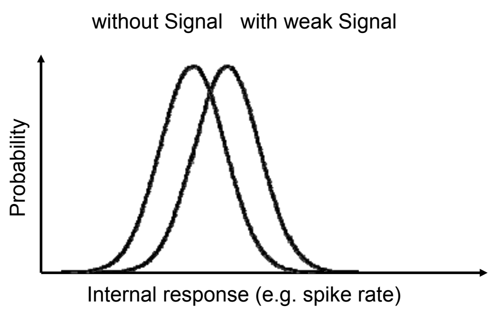
Important concept:
Internal response probability density functions



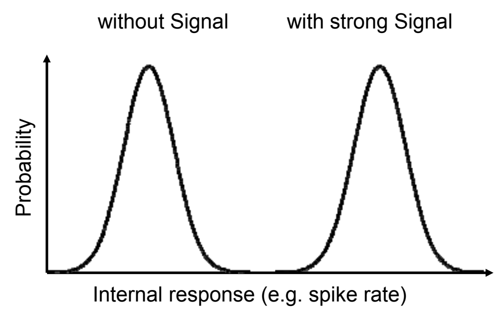
Signal Detection Theory



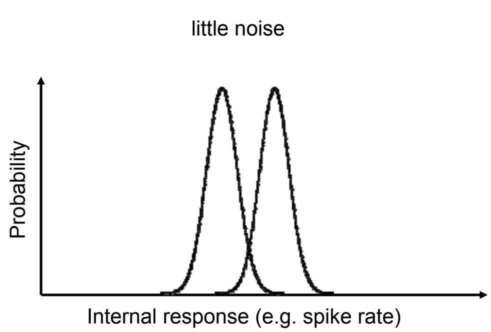
Signal Detection Theory



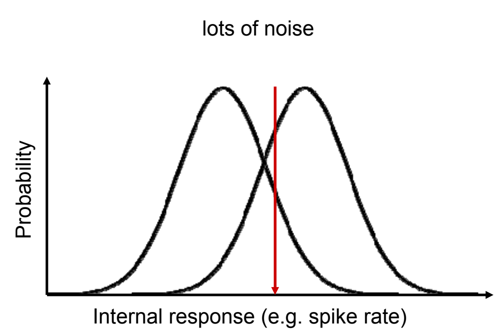
Signal Detection Theory



Signal Detection Theory

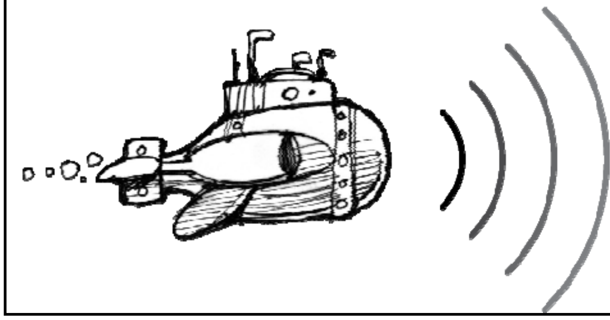


The Response Criterion

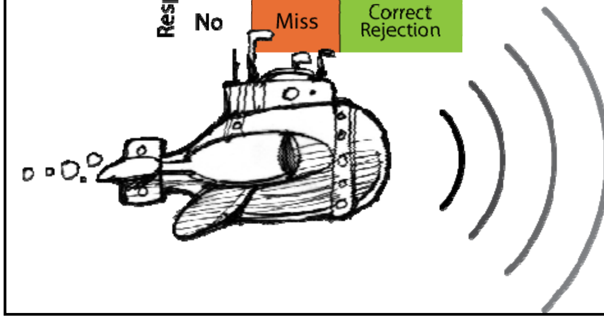


Signal Detection Theory

Two factors determine the response:
Ability to detect the signal and response bias

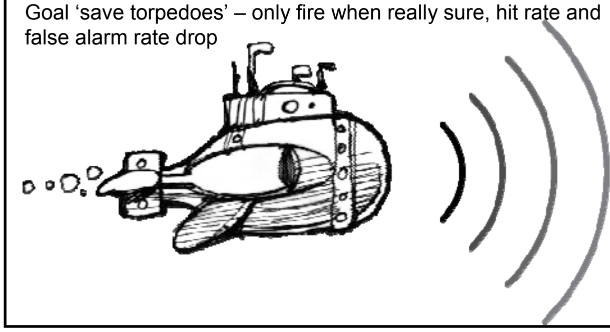


		Signal present? Yes	Signal present? No
Response	Yes	Hit	False Alarm
Response	No	Miss	Correct Rejection

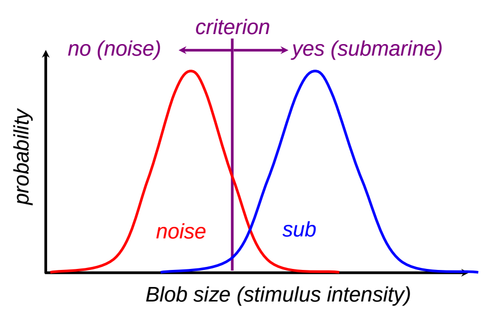


Response bias will influence the decision that is made independent of the detection.

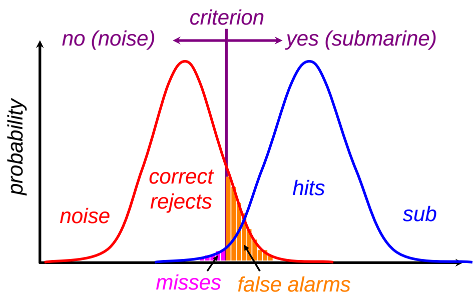
Goal ‘get all subs’ – more likely to fire, increase hit rate (also more false alarms)
Goal ‘save torpedoes’ – only fire when really sure, hit rate and false alarm rate drop



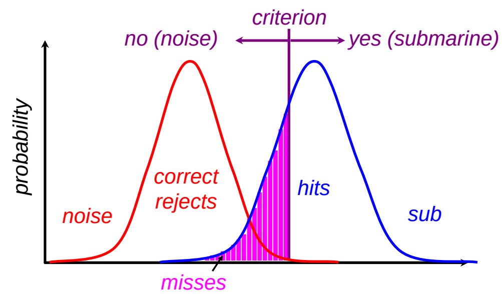
Effect of response criterion



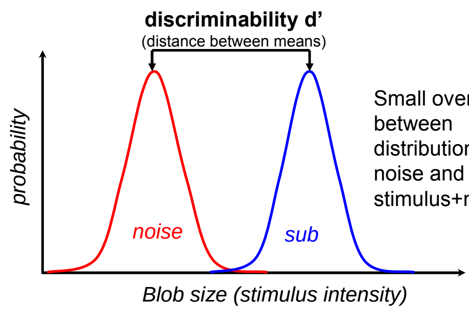
Effect of response criterion (low)



Effect of response criterion (high)

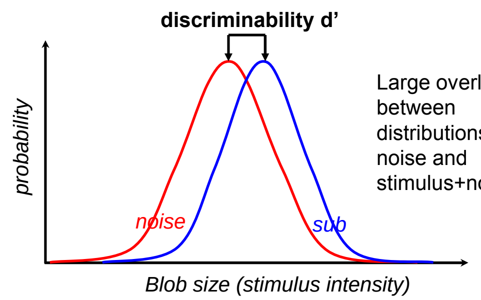


Low *noise*: high discriminability & sensitivity (few misses & false alarms)



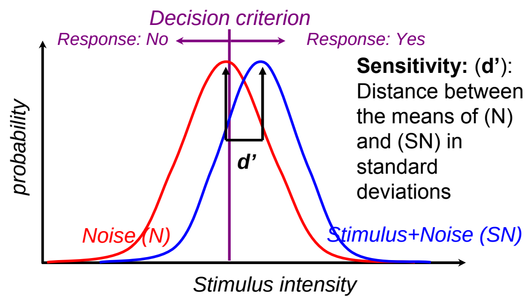
Small overlap between distributions of noise and stimulus+noise

High *noise*: low discriminability & sensitivity (many misses & false alarms)



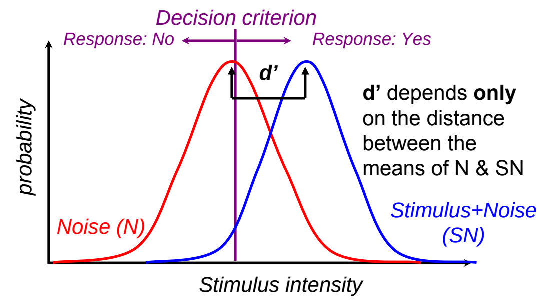
Large overlap between distributions of noise and stimulus+noise

SDT & psychophysics



Sensitivity: (**d'**): Distance between the means of (N) and (SN) in standard deviations

d' is independent of criterion



d' depends **only** on the distance between the means of N & SN

How do we measure d'?

d': difference between the *means* of the noise and stimulus+noise distributions, in units of *standard deviations*:

$$d' = [\mu_{SN} - \mu_N] / \sigma_N$$

But these distributions are not usually known!

d' can be estimated from the *hit rate* and the *false alarm rate*: Convert rates (probabilities) to *z* scores:

$$d' = z(H) - z(FA)$$

z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.7	.7580	.7611	.7642	.7673	.7704	.7734	.7764	.7794	.7823	.7852
0.8	.7881	.7910	.7939	.7967	.7995	.8023	.8051	.8078	.8106	.8133
0.9	.8159	.8186	.8212	.8238	.8264	.8289	.8315	.8340	.8365	.8389
1.0	.8413	.8438	.8461	.8485	.8508	.8531	.8554	.8577	.8599	.8621
1.1	.8643	.8665	.8686	.8708	.8729	.8749	.8770	.8790	.8810	.8830
1.2	.8849	.8869	.8888	.8907	.8925	.8944	.8962	.8980	.8997	.9015
1.3	.9032	.9049	.9066	.9082	.9099	.9115	.9131	.9147	.9162	.9177
1.4	.9192	.9207	.9222	.9236	.9251	.9265	.9279	.9292	.9306	.9319
1.5	.9332	.9345	.9357	.9370	.9382	.9394	.9406	.9418	.9429	.9441
1.6	.9452	.9463	.9474	.9484	.9495	.9505	.9515	.9525	.9535	.9545
1.7	.9554	.9564	.9573	.9582	.9591	.9599	.9608	.9616	.9625	.9633
1.8	.9641	.9649	.9656	.9664	.9671	.9678	.9686	.9693	.9699	.9706
1.9	.9713	.9719	.9726	.9732	.9738	.9744	.9750	.9756	.9761	.9767
2.0	.9772	.9778	.9783	.9788	.9793	.9798	.9803	.9808	.9812	.9817
2.1	.9821	.9826	.9830	.9834	.9838	.9842	.9846	.9850	.9854	.9857

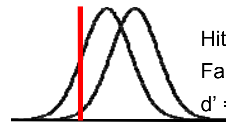
Interpreting d’

Low *d’* means SN and N distributions are overlapping.

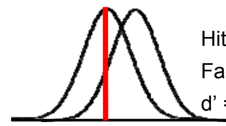
d’ = 0 means hit rate and false alarm rate are the same, thus SN and N are identical stimulus = chance level performance

High *d’* means SN and N distributions are far apart.

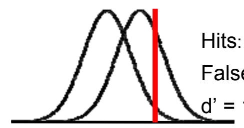
d’ = 1: moderate performance
d’ = 4.65: “optimal” (H = 0.99, FA = 0.01)



Hits: 97.7%
False Alarms: 84%
d’ = 1



Hits: 84%
False Alarms: 50%
d’ = 1



Hits: 50%
False Alarms: 16%
d’ = 1

Example

Performance on sound detection before drinking alcohol:
H = 0.7, FA = 0.2

Performance after drinking alcohol:
H = 0.8, FA = 0.3

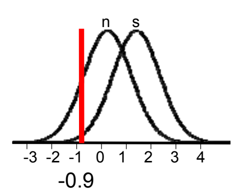
Did performance or sensitivity improve?

Before: *d’* = z(H) - z(FA) = 0.542 - (-0.842) = 1.366
After: *d’* = z(H) - z(FA) = 0.842 - (-0.542) = 1.366

Alcohol did not improve performance (*d’*), but lowered the response criterion (more tendency to say yes).

Measuring the bias

The strategy of the participant is expressed via the choice of the threshold. The position of the threshold can also be given relative to the signal or the noise distribution:



The most popular way of expressing the location of the threshold is relative to what is called the ideal observer.

Measuring the bias

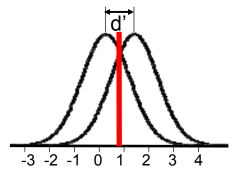
Sensitivity is a relatively stable property of the sensory process, but the decision criterion can vary widely from task to task and from time to time.

The decision criterion is influenced by three factors:
-the instructions to the observer
-the relative frequency of signal trial and no-signal trails
-and the payoff matrix (the relative cost of making the two types of errors and the relative benefit of making the two types of correct responses

If the proper index of sensitivity is not used, changes in the decision criterion will be incorrectly interpreted as changes in sensitivity.

Measuring the bias

The ideal observer (ideal strategy if the cost of all errors is the same): threshold halfway between noise and signal.



The value of *C* is the distance from the actual threshold to the ideal observer, it can computed as *C* = *threshold − d'* or estimated as

$$C = -\frac{z(HR) + z(FA)}{2}$$

The sign of *C* reveals the participant's strategy: when *C* = 0, we have the ideal observer; when *C* is negative the participant is *libéral* (*i.e.,* responds Yes more often than the ideal observer); when *C* is positive the participant is *conservative* (*i.e.,* responds No more often than the ideal observer).

Another example – wine tasting

	DECISION: (TASTER'S RESPONSE)		
REALITY	Yes (Gamay)	No (Pure Pinot)	Σ
Signal Present	Hit	Miss	
(Gamay)	#{Hit}=9 Pr{Hit}=.9	#{Miss}=1 #{Miss}=.1	10 1
Signal Absent	False Alarm (FA)	Correct Rejection	
(Pure Pinot)	#{FA}=2 Pr{FA}=.2	#{Correct Rejection}=8 Pr{Correct Rejection}=.8	10 1

The performance of a wine taster trying to identify Gamay in a Pinot Noir wine.

Another example – wine tasting

	DECISION: (TASTER'S RESPONSE)		
REALITY	Yes (Gamay)	No (Pure Pinot)	Σ
Signal Present	Hit	Miss	
(Gamay)	#{Hit}=9 Pr{Hit}=.9	#{Miss}=1 #{Miss}=.1	10 1
Signal Absent	False Alarm (FA)	Correct Rejection	
(Pure Pinot)	#{FA}=2 Pr{FA}=.2	#{Correct Rejection}=8 Pr{Correct Rejection}=.8	10 1

$$d' = Z_H - Z_{FA} = Z_{.9} - Z_{.2} = 1.28 - (-.84) = \underline{2.12}$$

$$C = -\frac{1}{2}[Z_H + Z_{FA}] = -[Z_{.9} + Z_{.2}] = -\frac{1}{2}[1.28 - .84] = \underline{-.22}$$

Another example – wine tasting

$$d' = Z_H - Z_{FA} = Z_{.9} - Z_{.2} = 1.28 - (-.84) = 2.12$$

$$C = -\frac{1}{2}[Z_H + Z_{FA}] = -[Z_{.9} + Z_{.2}] = -\frac{1}{2}[1.28 - .84] = -.22$$

How to interpret these results? The taster is clearly (but not perfectly) discriminating between Pinots and tempered Pinots (as indicated by a d′ of 2.12), this taster is also liberal (in case of doubt the taster will rather say that the wine has been tempered rather than not).

Vocabulary

Internal noise
Hits,
False alarms
Correct rejections
Misses
Sensitivity (D')
Bias (C)
Z distribution