How do we extract signal from noise?

Readings for today

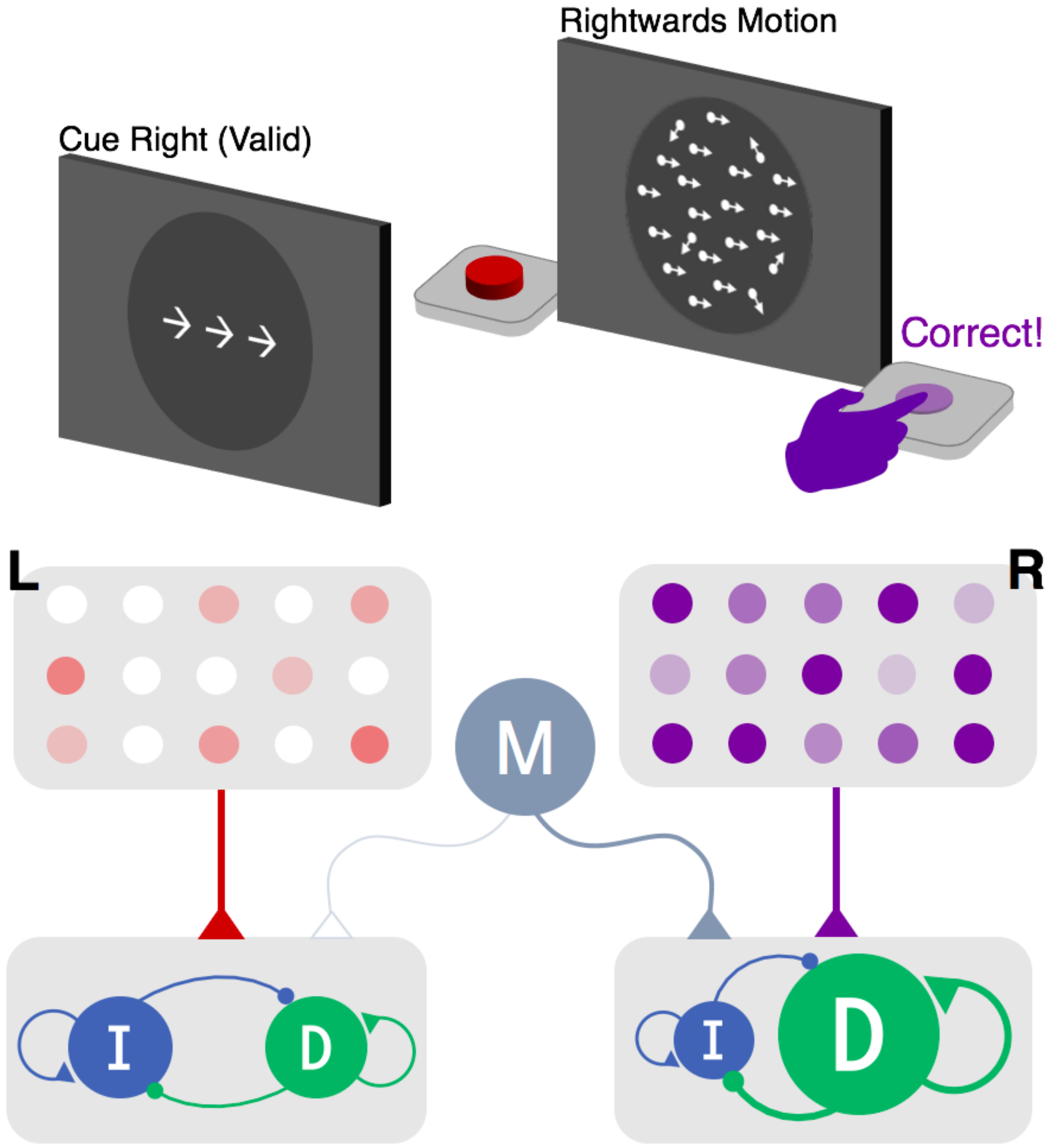
- Abdi, H. (2007). Signal detection theory (SDT). Encyclopedia of measurement and statistics, 886-889.

Topics

- Origins of your signal
- How to discern a signal from noise

Origins of your signal

The cued dot motion task



Task:

- Cue primes attention to one direction.
- Moving dots are displayed.
- Motion of the dots indicate response direction.
- Coherence of the dots (% of dots moving in the common direction) determines the signal-to-noise.
    - More coherence = ↑ signal-to-noise
    - Less coherence = ↓ signal-to-noise

What exactly is the signal then in this task?

(Dunovan & Verstynen, 2016; adapted from Seiderman & Newsome, 1999)

Signal detection theory

- "A general framework to describe and study decisions that are made in uncertain or ambiguous situations." - Wickens, *Elementary Signal Detection Theory*
- “Signal Detection Theory (often abridged as SDT) is used to analyze data coming from experiments where the task is to categorize ambiguous stimuli which can be generated either by a known process (called the signal) or be obtained by chance (called the noise in the sdt framework)... The goal of signal detection theory is to estimate two main parameters from the experimental data.” - Abdi, *Signal detection theory (SDT). Encyclopedia of measurement and statistics.*

Origins of the problem

Context:
- World War II
- Sonar relies on emitting a sound pulse and listening for echos from objects.

Problem:
- What is an echo vs. what is a directed sound?
- What is a ship vs. what is a whale?

How to discern a signal from noise

Did I just perceive that?

Task:
- Stimulus detection.
- Participants respond when they think a target stimulus (e.g., tone, visual stimulus, tactile event) has happened.
- A stimulus property (e.g., volume, intensity) is manipulated to determine threshold by which the stimulus becomes detectable.

Example: Is that your phone vibrating in your pocket?

(Stanislaw & Todorov, 1999; Abdi, 2007)

The basics of signal detection theory

	DECISION: (PARTICIPANT'S RESPONSE)	
REALITY	Yes	No
Signal Present	Hit	Miss
Signal Absent	False Alarm (FA)	Correct Rejection

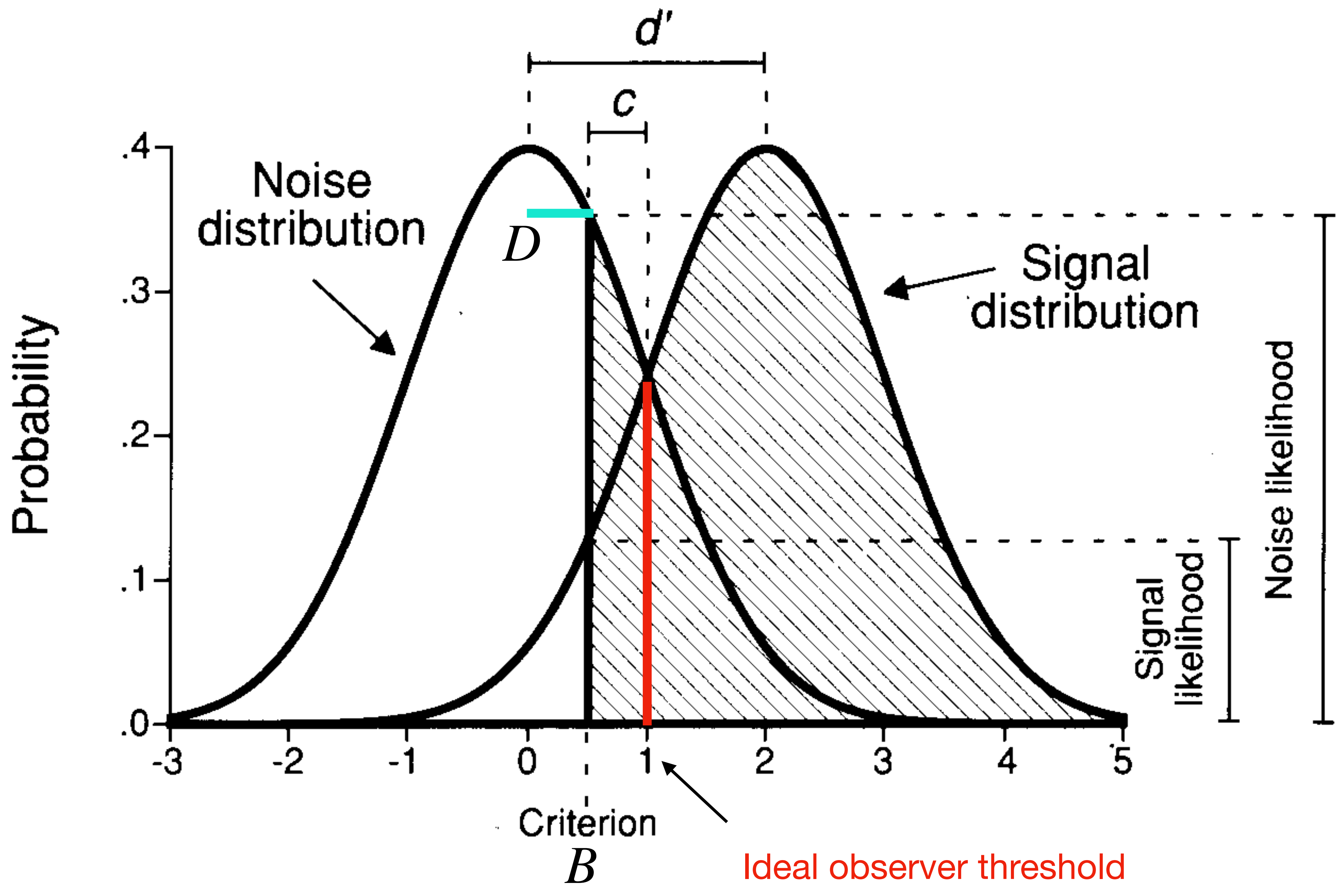
Signal Present: All responses are either Hit's or Misses

Signal Absent: All responses are either False Alarms or Correct Rejections

Therefore all the meaningful information is in the Hits vs. False Alarms!

(Stanislaw & Todorov, 1999; Abdi, 2007)

The basics of signal detection theory



Parameters:

$\underline{d'}$: Strength of the signal relative to the noise.

$\underline{B}$: Position of the threshold relative to the noise distribution. The criterion.

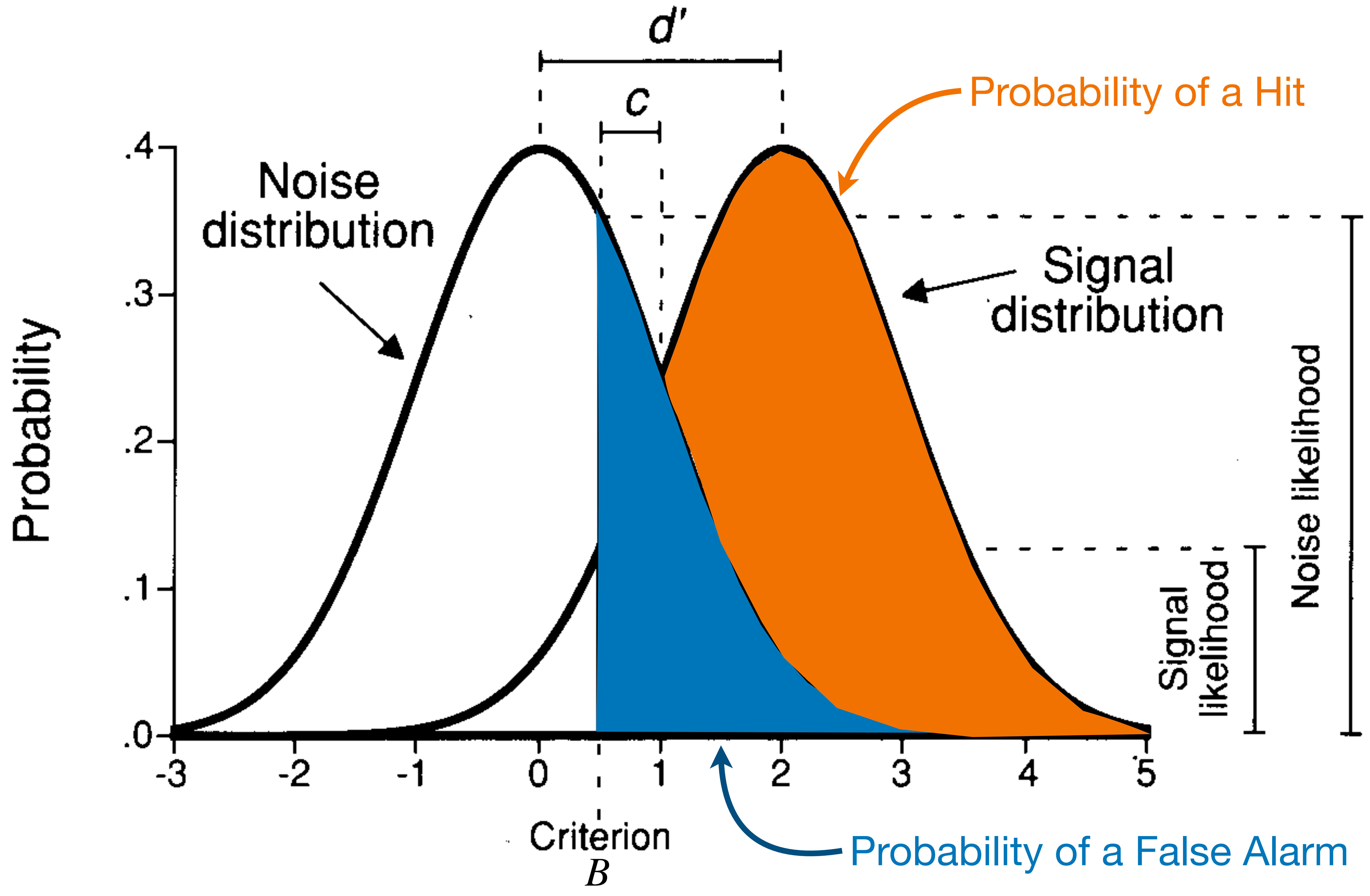
$\underline{C}$: The strategy of the participant relative to an ideal observer threshold.

$\underline{\beta}$: A variant of C. The ratio of the height of the signal distribution relative to the noise distribution for B.

$\underline{D}$: Separation between threshold (B) and d' (i.e., $D = B - d'$)

(Stanislaw & Todorov, 1999; Abdi, 2007)

The basics of signal detection theory



(Stanislaw & Todorov, 1999; Abdi, 2007)

Strategy: C (& β)

Response

	YES	NO
Present	100%	0%
Absent	100%	0%

Reality

Liberal agents will always respond that a signal is present, inflating both Hits & False Alarms.

(Stanislaw & Todorov, 1999; Abdi, 2007)

Strategy: C (& β)

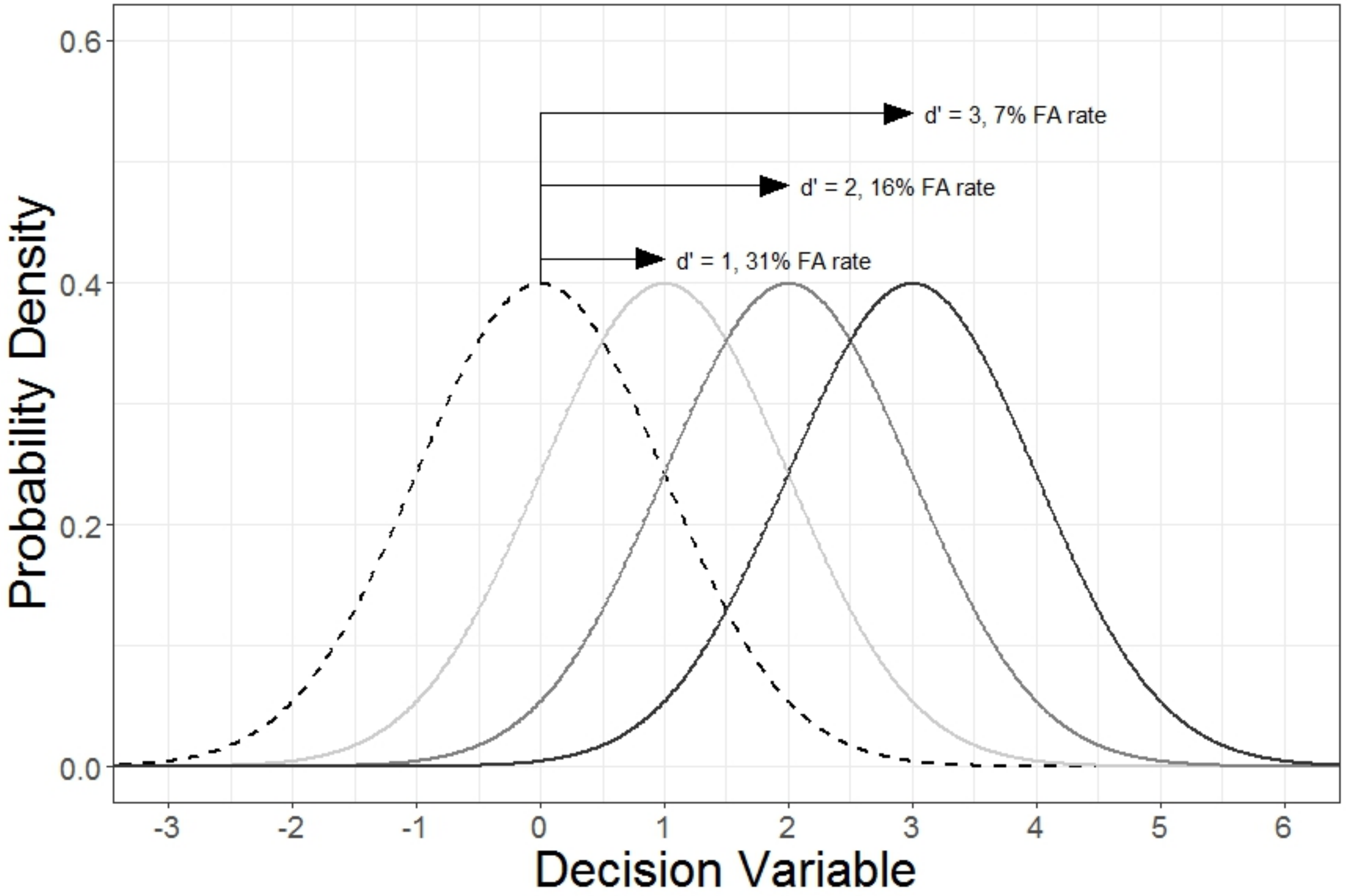
Response

		YES	NO
Reality	Present	0%	100%
	Absent	0%	100%

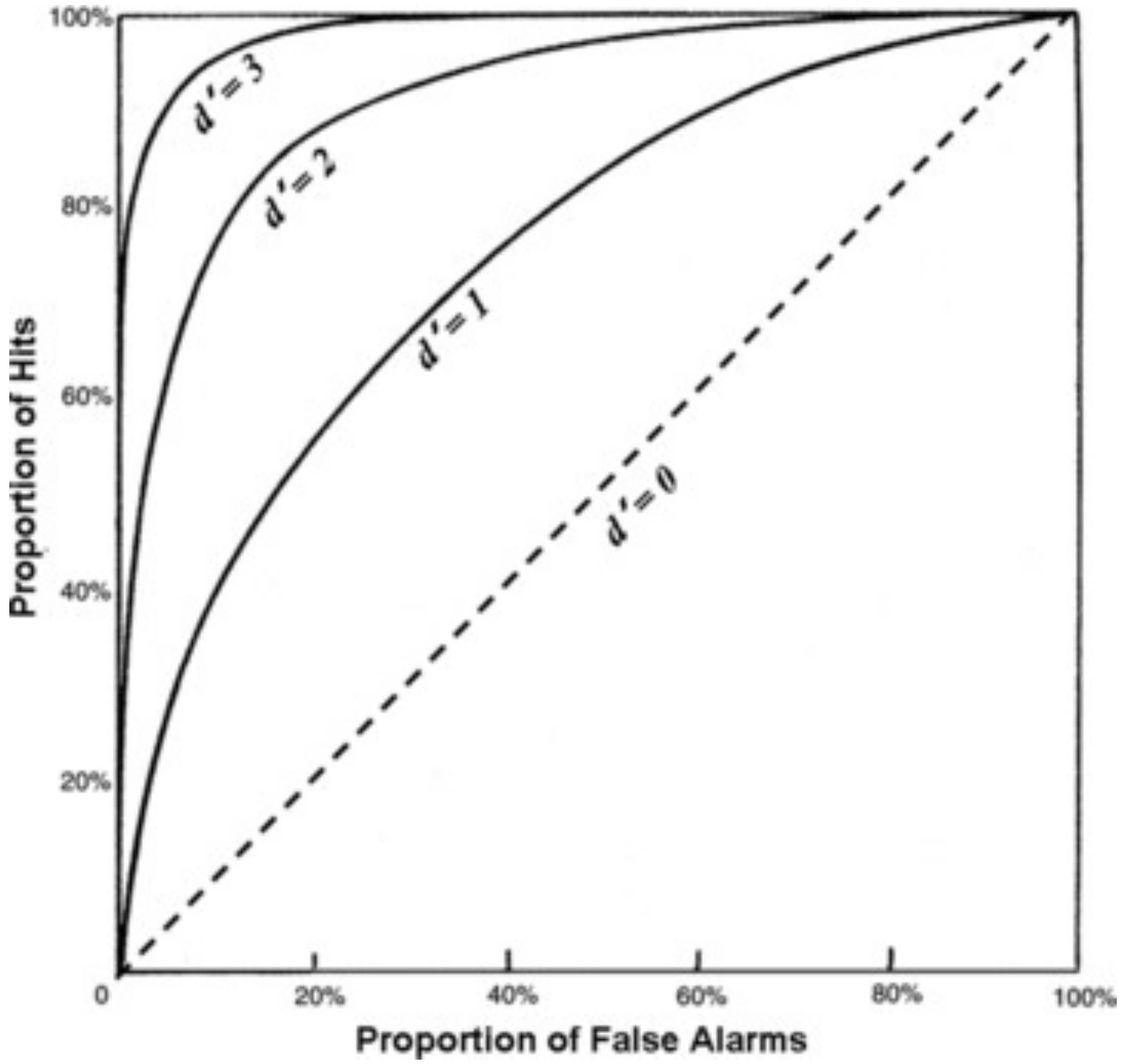
Conservative agents will never respond that a signal is present, inflating both Misses & Correct Rejections.

(Stanislaw & Todorov, 1999; Abdi, 2007)

Measuring difficulty: d'



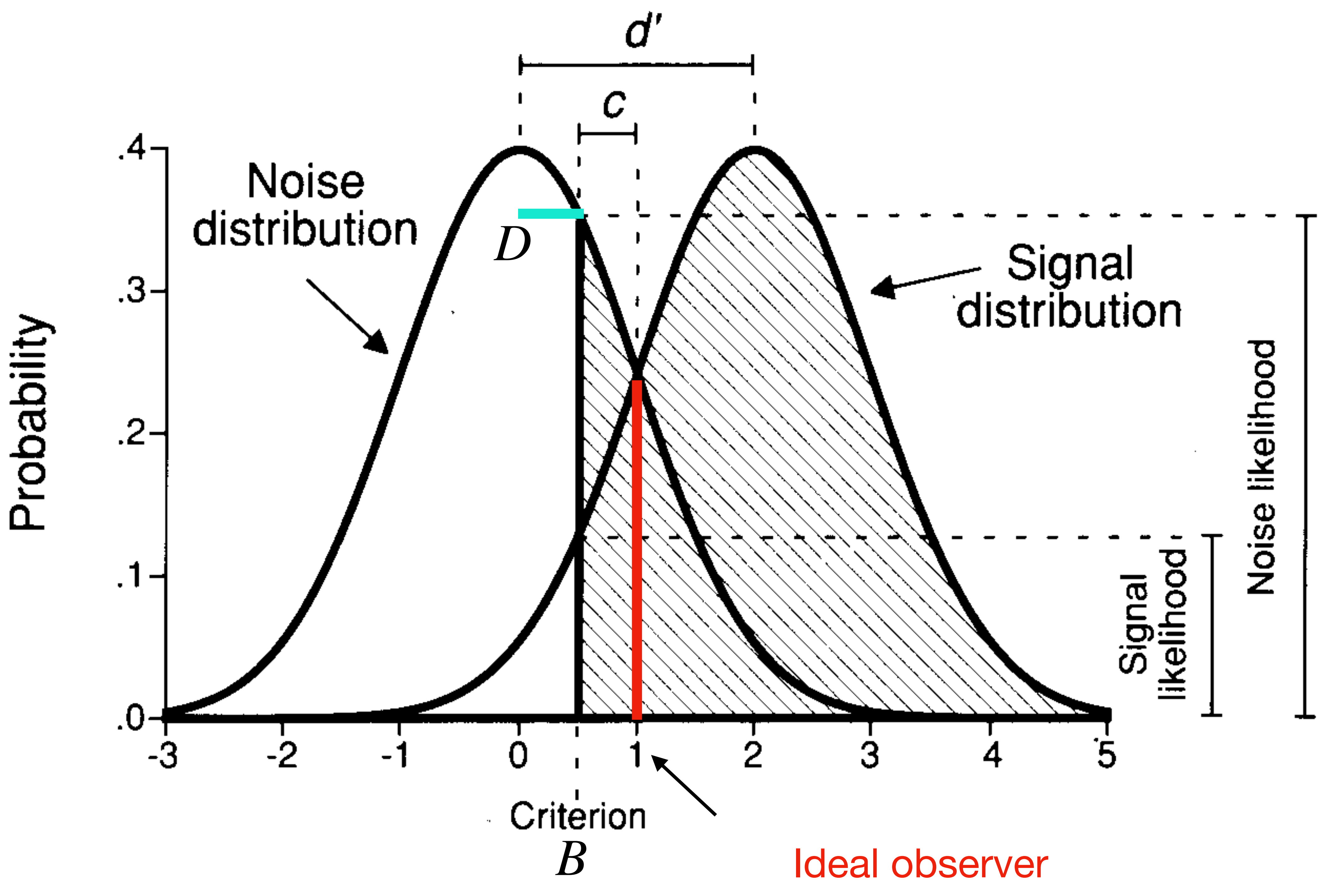
ROC Curve



As the signal-to-noise improves, the proportion of responses that are Hits begins to dominate over False Alarms.

(Stanislaw & Todorov, 1999; Abdi, 2007)

Measuring performance with SDT



1. Calculate d'

$$d' = Z_H - Z_{FA}$$

2. Calculate C

$$C = B - \frac{d'}{2}$$

3. Calculate β

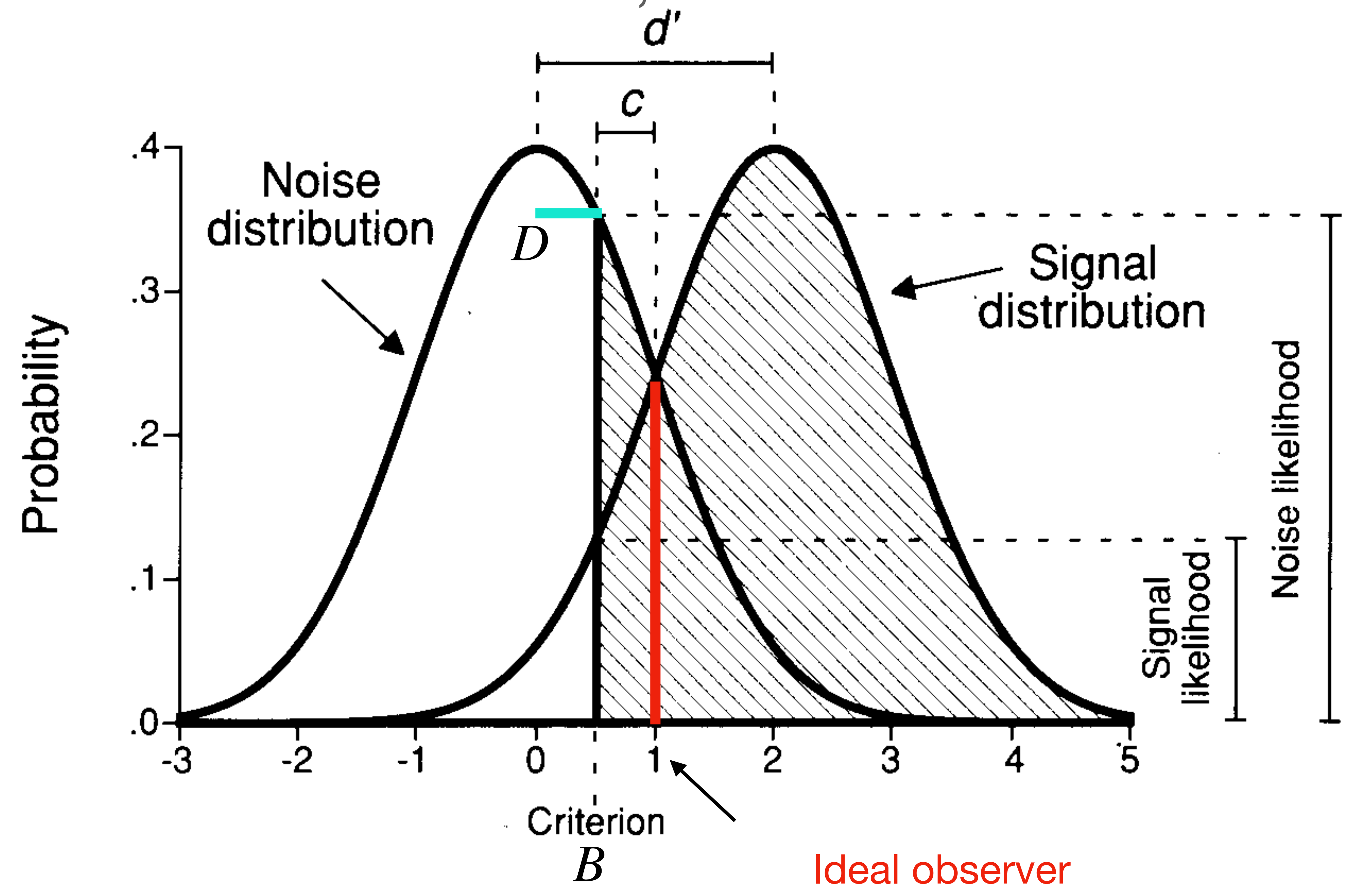
$$\beta = e^{d' \times C}$$

$$\ln \beta = d' \times C$$

(Stanislaw & Todorov, 1999; Abdi, 2007)

An example: wine tasting

Task: Wine taster (Pinot vs. Gamay).
Identify when it is Pinot.
90% hits, 20% false alarms



Conclusions:
- Taster can clearly discriminate between wines ($d' = 2.12$)
- Taster has a liberal criterion (i.e., more likely to say Pinot than not) ($C = -0.22, \beta = = 0.47$)

1. Calculate d'

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

2. Calculate C

$$C = -\frac{1}{2}[Z_H + Z_{FA}]$$
$$= -\frac{1}{2}[Z_{.9} + Z_{.2}]$$
$$= -\frac{1}{2}[1.29 - .84] = -.22$$

3. Calculate β

$$\ln \beta = d' \times C = 2.12 \times -.22 = -.47$$

$$\beta = e^{\ln \beta} = e^{-.47} = .63$$

(Stanislaw & Todorov, 1999; Abdi, 2007)

Take home message

- Signal detection theory offers a mathematical formalism for the process of detecting signals from noise.
- The detection of a signal relies not only on the distance of the signal from the noise, d', but also the information criterion that the perceiver uses.

Playing with signal detection theory

URL: https://danieldickison.github.io/sdt-visualization/

Task: Using the Spreadsheet template that was emailed to you, follow the link to the SDT widget. Run two tests as a group:

1. Vary the hit and false alarm rates in order to keep the d’ constant at ~1.5.

2. Vary the hit and false alarm rates in order to keep the C at ~0.200

Compare the 2 ROC plots. What does the behavior in the plots tell you about the relationship between d’ and C?