Review questions

- What are the four dimensions of attention resources as stated in multiple resource theory?
  - Stages
  - Processing codes
  - Perceptual modality
  - Focal (fovea) vs. ambient (peripheral) vision field

- What are the potential negative effects of task switching on performance?
  - Task switch time cost
  - Forget to resume OT (original task) promptly
  - Miss some steps of OT
  - Confuse between OT and IT (interrupting task)

Check previous lecture slides to find the answers.

SYDE 543
Cognitive Ergonomics

Signal Detection Theory

Professor Shi Cao
Systems Design Engineering

UNIVERSITY OF WATERLOO

Overview of today's lecture

- Signal detection problems
- Signal detection theory
  - Quantify operator capability by sensitivity
  - Explain decision preference by response criterion
- Computation examples

Examples of signal detection problems

- Email spam filter
- Medical diagnosis
- Weather forecast
- Food inspection
- Product line quality inspection
- Airport security screening
- … …

Signal detection example (binary)

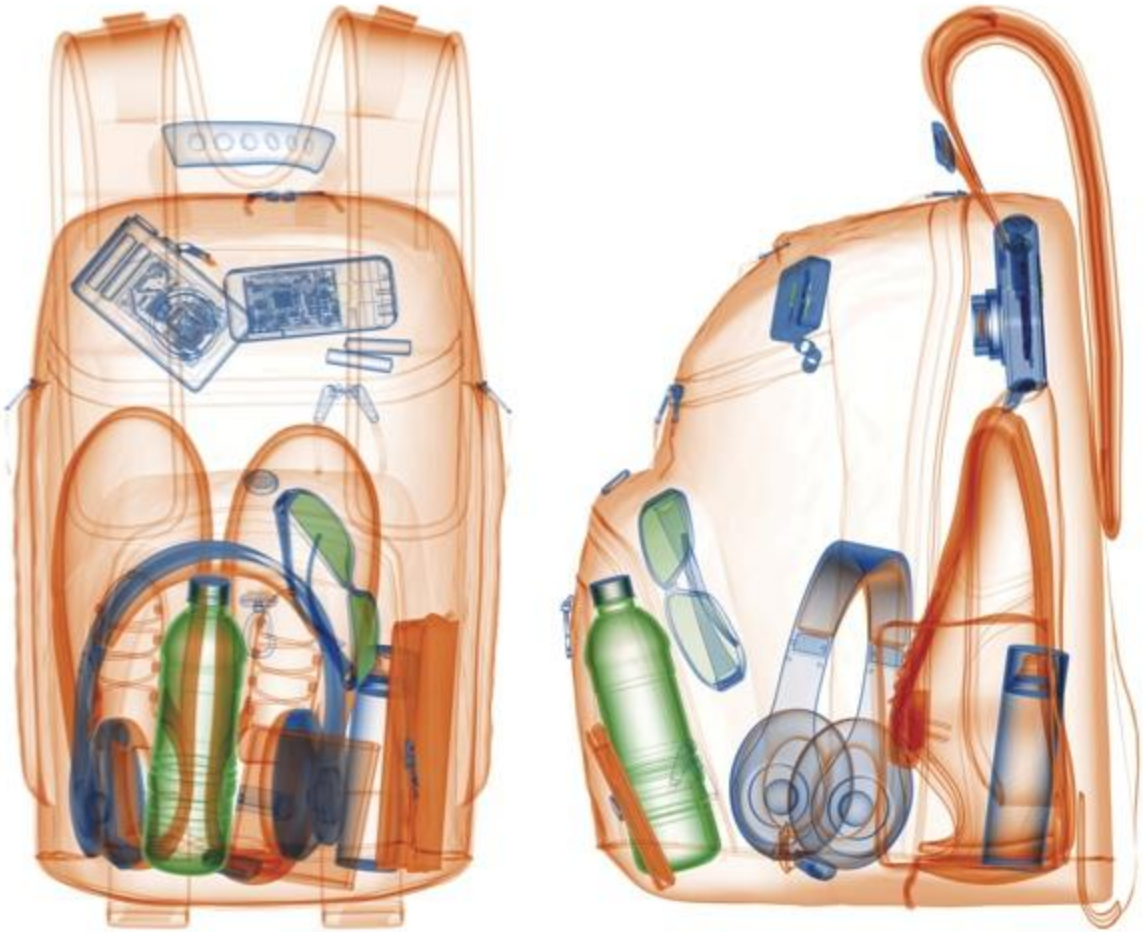
- Airport security screening
- Task: detect suspicious passengers (target)

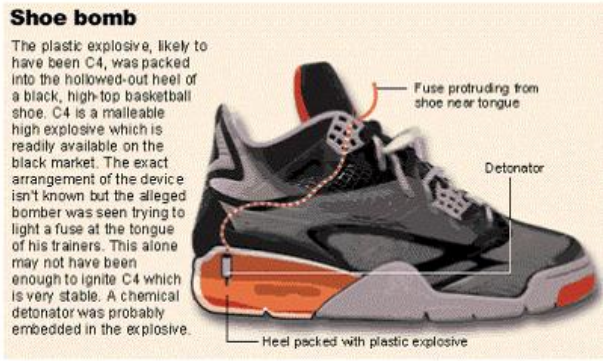
- Airport security check
- Task: detect forbidden items (target)

THE SHOE BOMBER

- **Date: December 21 –22, 2001**
  - Aftermath of September 11
  - 1 month after crash of AA 587 at JFK
- **Airplane: Boeing 767**
- **Flight: American Airlines 63 (8:30 am),**
  - Paris to Miami

Airport X ray scanners





Signal detection error in this case

- Airport security check
- Task: detect forbidden items (target)
- Error: failed to detect (missed the target)

Suspicious bag prompts airport lockdown

BY KELLY ROCHE, OTTAWA SUN

FIRST POSTED: SUNDAY, MAY 13, 2012 04:14 PM EDT | UPDATED: SUNDAY, MAY 13, 2012 04:20 PM EDT

The Ottawa International Airport is looking for more money from the taxi industry for exclusive customer access. File photo (DARREN BROWN/QMI AGENCY)

A false alarm prompted a lockdown at the Ottawa Airport Sunday morning after a suspicious bag was spotted by airport security screeners.

"We thought it was an explosive device of some sort," said Ottawa police acting Staff Sgt. Jamie Harper.

"It turned out to be nothing like that."

Cops were called at 9:22 a.m.

The luggage of concern was on an outbound flight, causing headaches for Mother's Day travellers.

"We just didn't have the ability to process any bags, so that's what caused the delays," said airport authority spokeswoman Krista Kealey, noting a dozen flights were affected.

Police cleared out at 12:26 p.m.

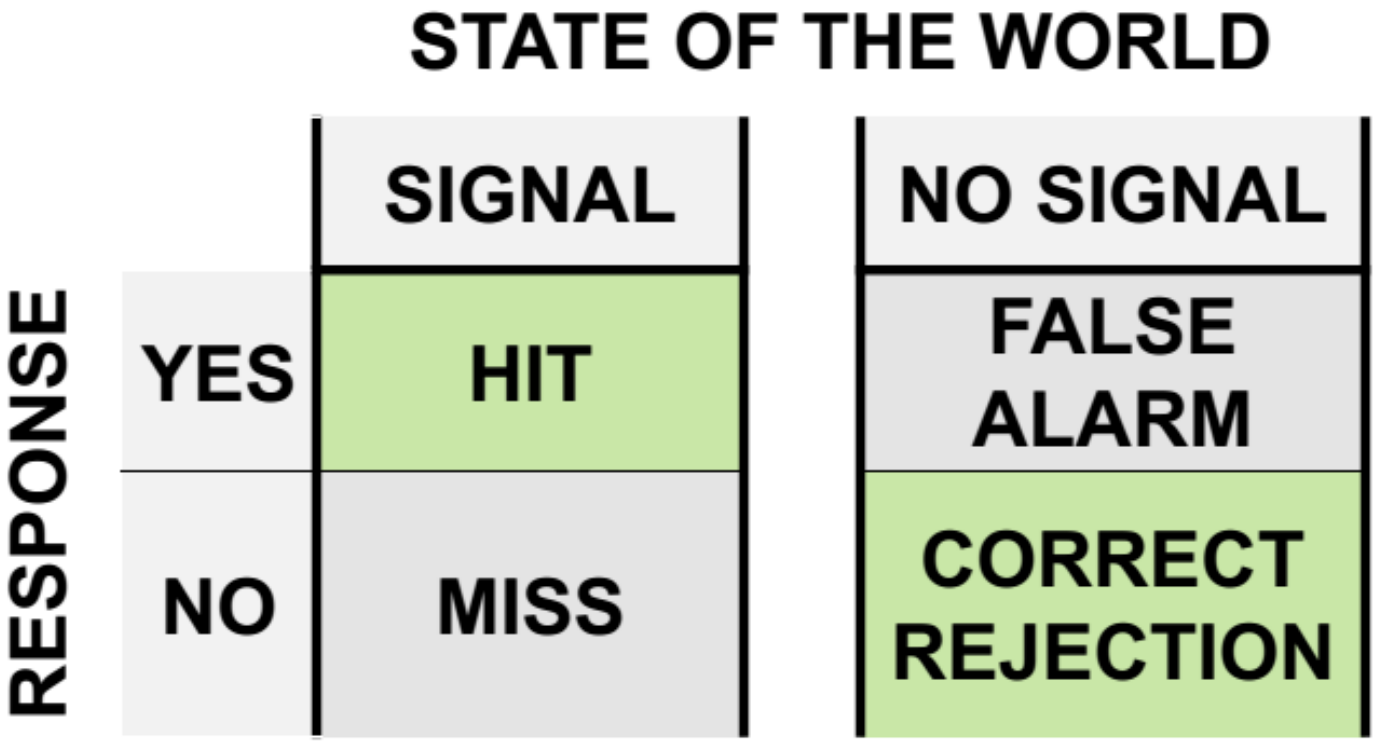
"Once we got the all-clear from the Ottawa police...everything resumed very quickly," said Kealey.

Signal detection error in this case

- Airport security check
- Task: detect forbidden items (target)
- Also: let normal items pass
- Error: mistakenly identified a normal item as forbidden (false alarm)

Signal detection problem

- Item: **signal** or **no signal** (noise)
- Response: "**yes, it is a signal**" or "**no, it is not a signal**"
- 4 possible outcomes



Signal detection example (binary)

- Sandwich bun production line quality control
- Task: visually separate irregular buns (too large) from regular buns
- An intern operator was given 1010 buns to inspect
  - 1000 regular and 10 irregular
- Signal: irregular buns (too large)
- Non-signal (noise): other good buns

http://gtresearchnews.gatech.edu/images/bakery.jpg

- P(S) = 10 / 1010 = 0.99%
- P(N) = 1000 / 1010 = 99.01%

1

- P(Hit) = 8 / 10 = 80%
- P(Miss) = 2 / 10 = 20%

1

- P(CR) = 990 / 1000 = 99%
- P(FA) = 10 / 1000 = 1%

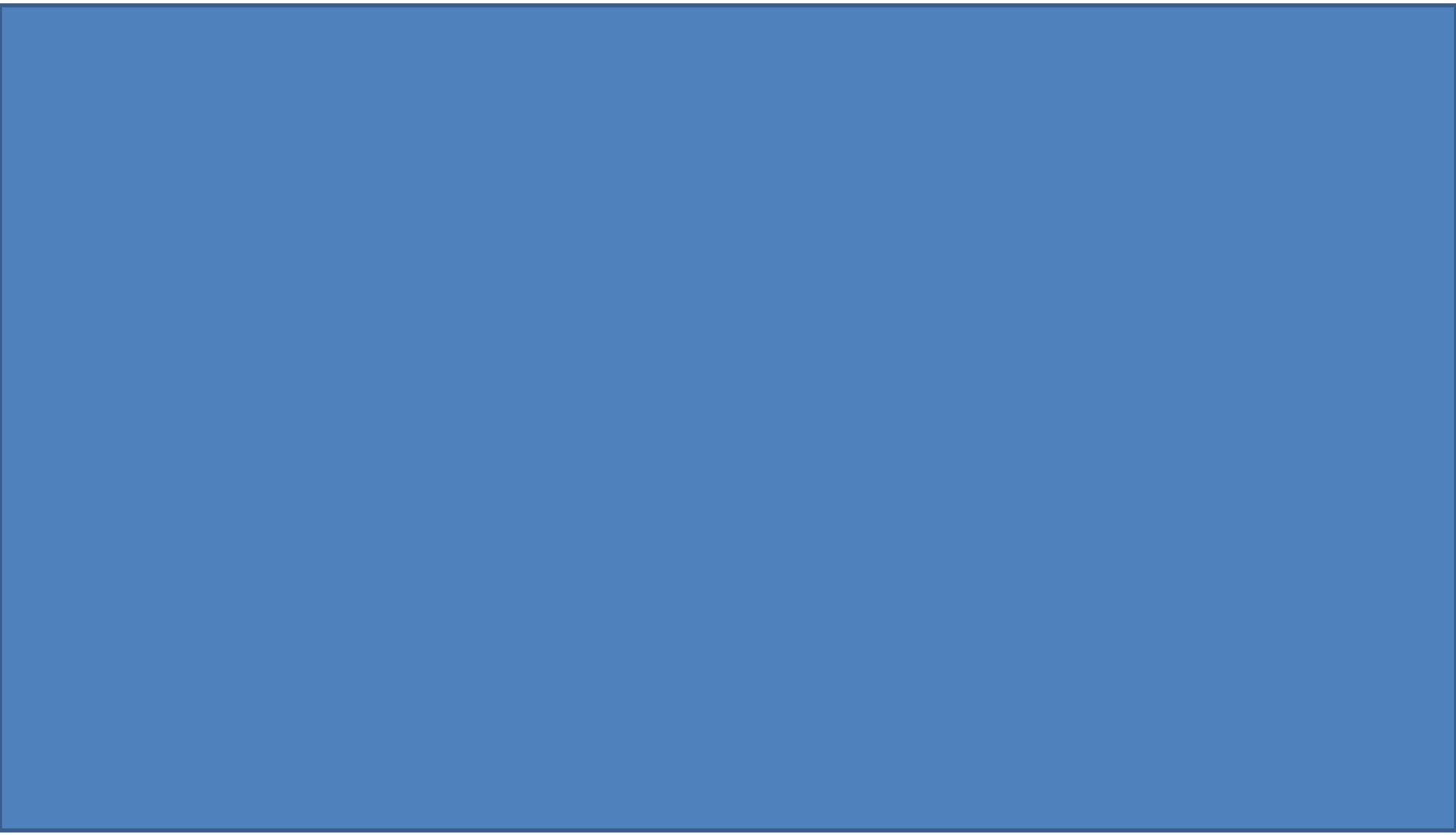
1

RESPONSE	STATE OF THE WORLD: SIGNAL (10)	STATE OF THE WORLD: NO SIGNAL (1000)	
YES	HIT 8	FALSE ALARM	10
NO	MISS 2	CORRECT REJECTION	990

SDT practice

Part A

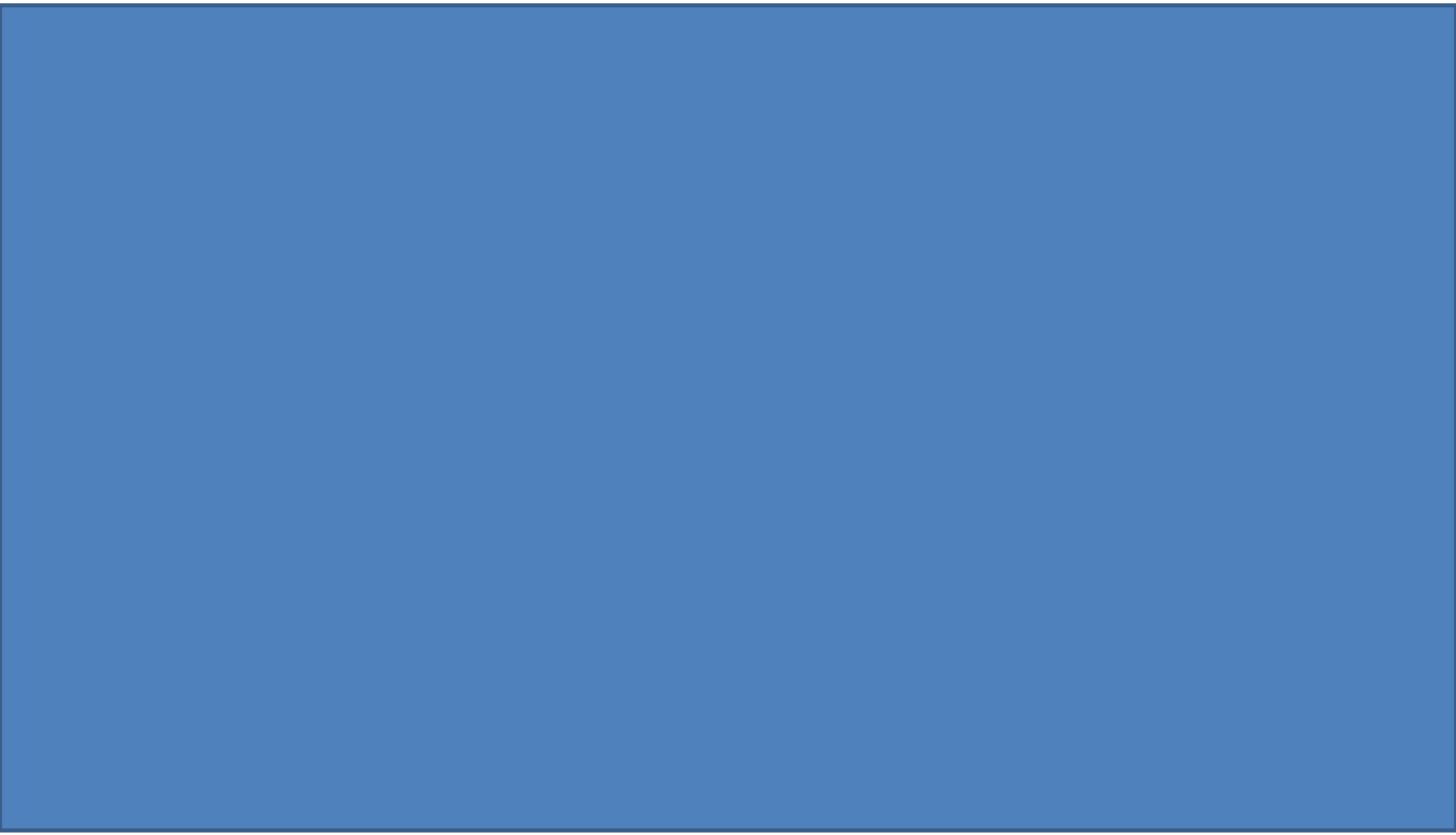
SDT practice solution



SDT practice

Part B

SDT practice solution



Signal detection problem

		STATE OF THE WORLD: SIGNAL	STATE OF THE WORLD: NO SIGNAL
RESPONSE	YES	HIT	FALSE ALARM
	NO	MISS	CORRECT REJECTION

- Hit and correct rejection are good outcomes.
- Miss and false alarm are bad outcomes (errors).
- **How to evaluate and compare operators' performance?**

HIT .70	FALSE ALARM .30
MISS .30	CORRECT REJECTION .70

vs.

HIT .95	FALSE ALARM .80
MISS .05	CORRECT REJECTION .20

Signal detection theory

Separate between

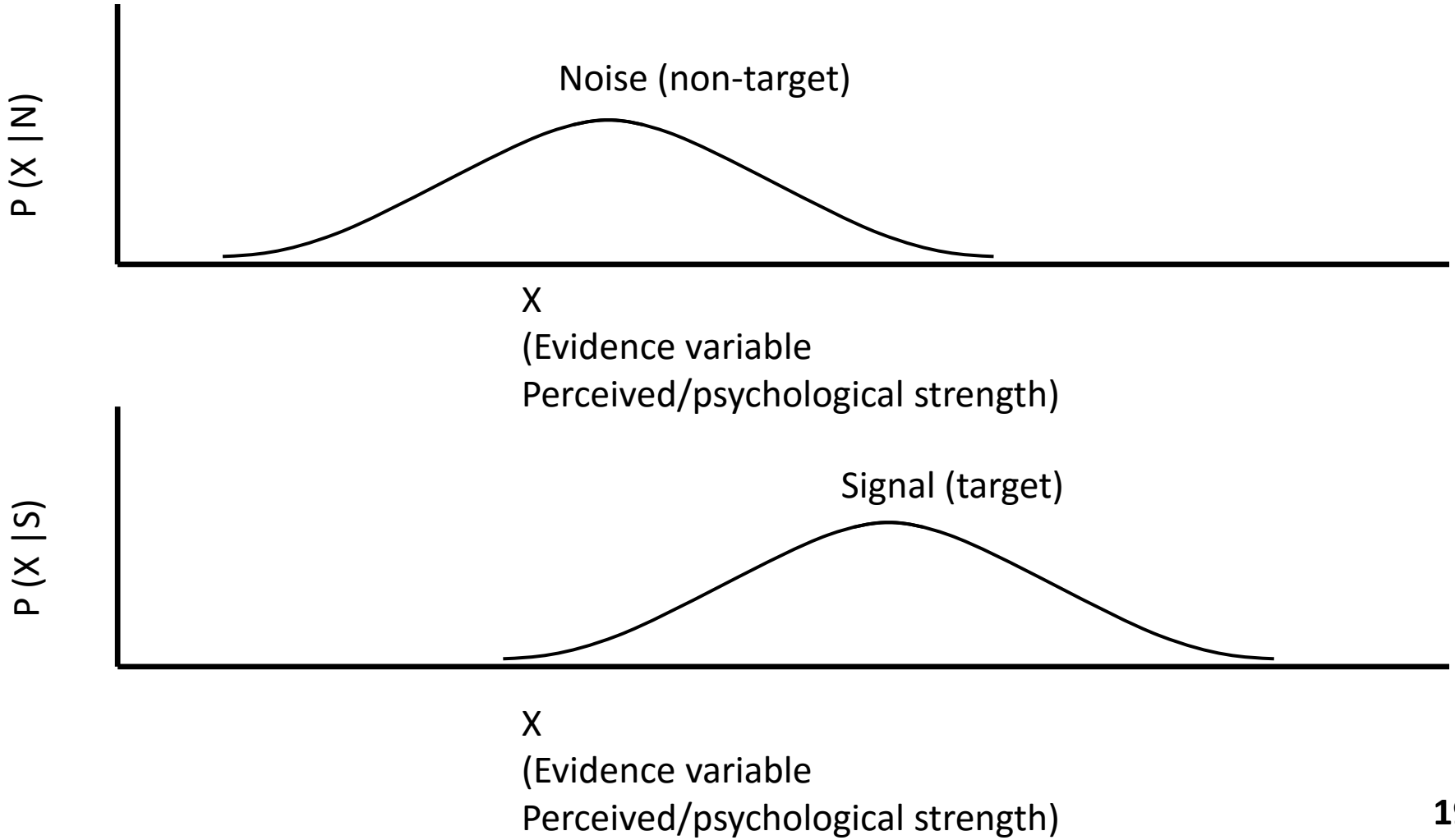
- **Sensitivity**: underlying ability to discriminate signals from noise

- **Decision criterion (bias)**: preference in trade-off types of errors (being risky or conservative)

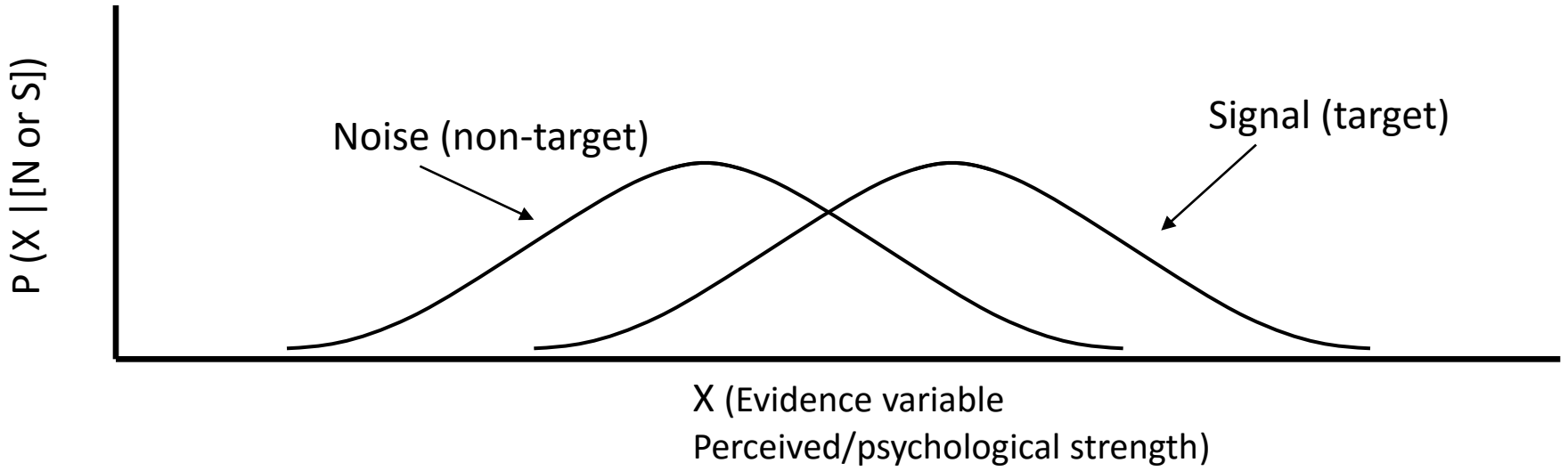
Assumptions:

1. Normal distribution of both perceived signal and noise strengths
2. Equal standard deviation (or variance) of both perceived signal and noise strength distributions

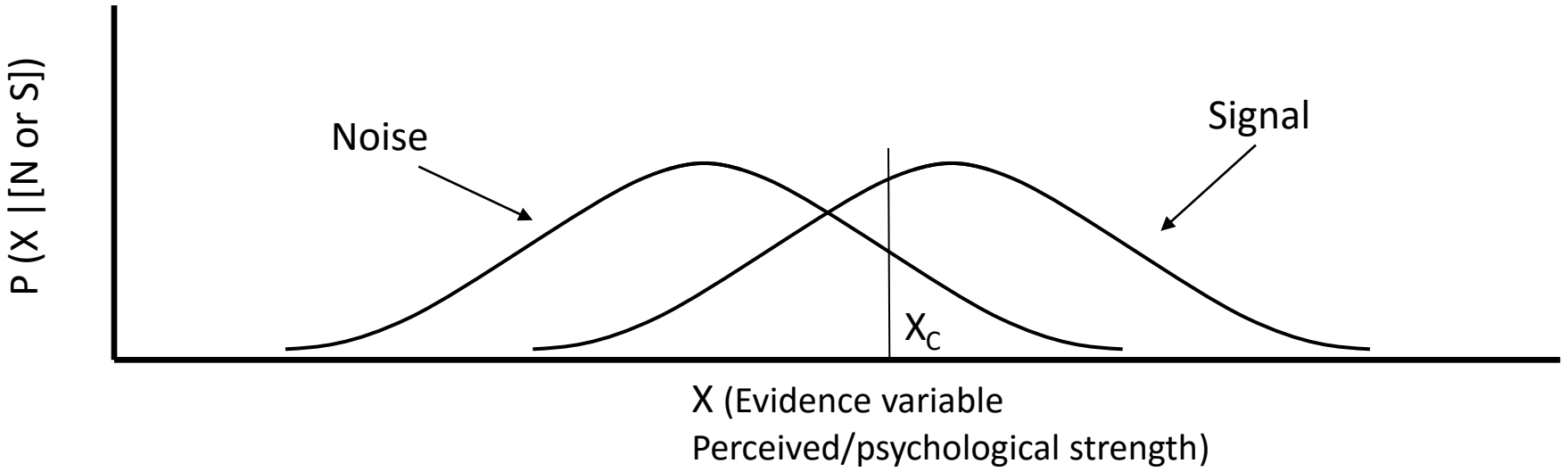
E.g., an irregular bun is usually perceived as larger than regular, but not always.



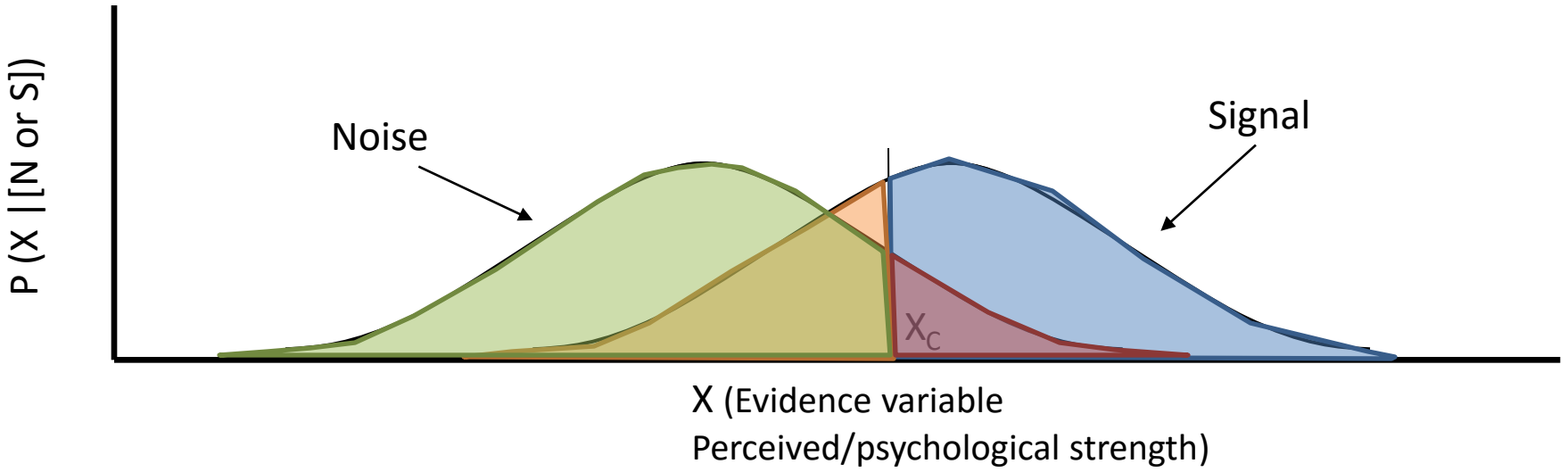
- Since the noise distribution and the signal distribution overlap, when an operator perceives value x, it may be from noise or signal (uncertainty).



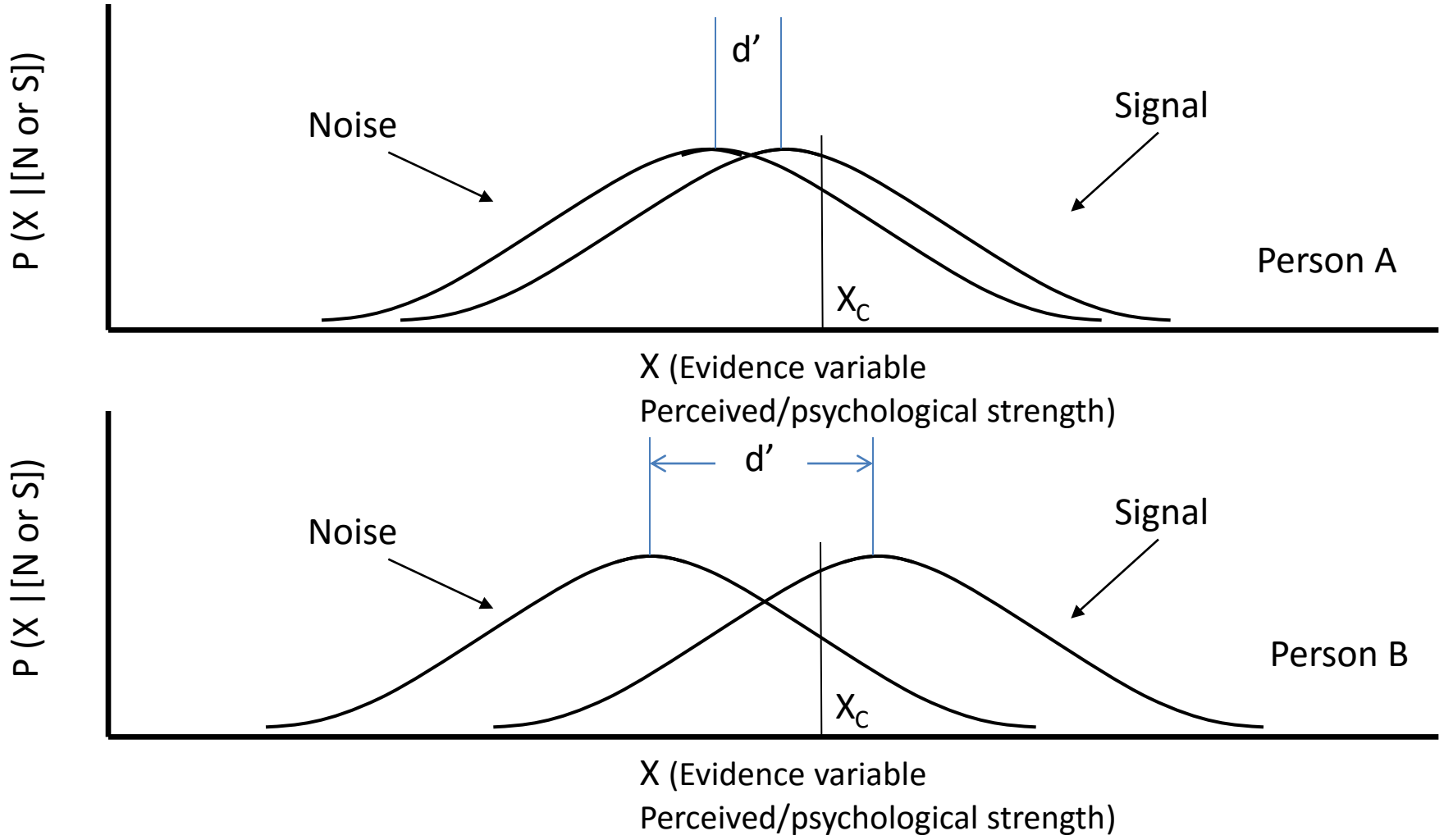
- How do we decide whether a perceived signal strength was from a signal or noise?
  - Establish a criterion, Xc
  - If x <= Xc, respond: it is not a signal
  - If x > Xc, respond: it is a signal



- Outcome probabilities
  - P(Hit): P(X > Xc | S)
  - P(Miss): P(X <= Xc | S)
  - P(FA): P(X > Xc | N)
  - P(CR): P(X <= Xc | N)



- For the same detection task, operators with better **sensitivity (d')** have larger separation between the two distributions.



Signal detection theory

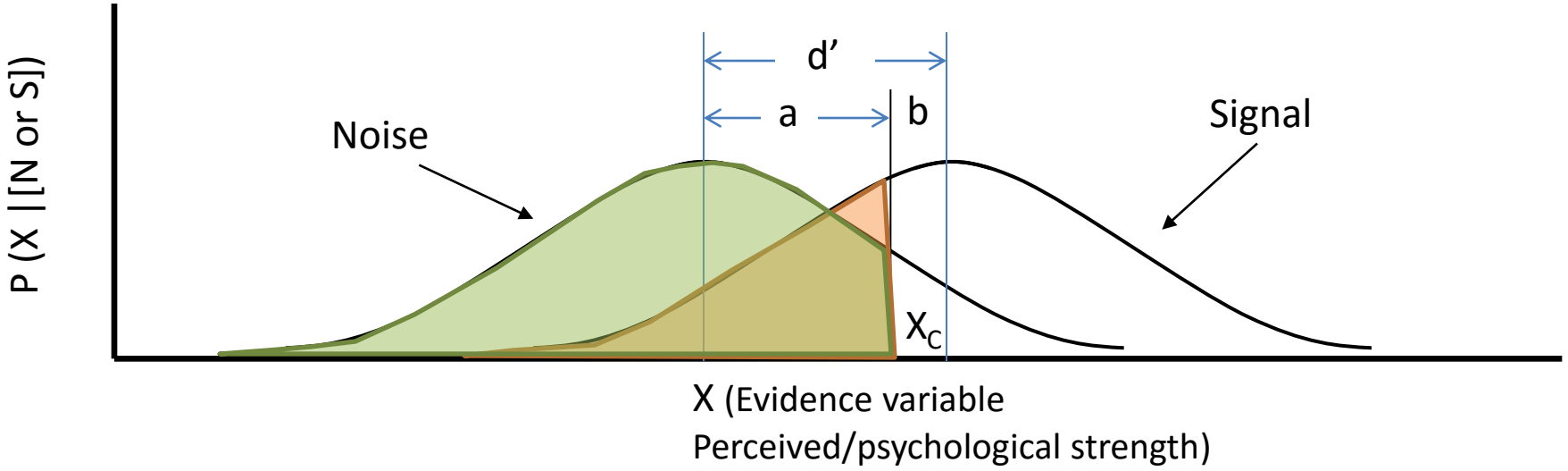
- Compute **sensitivity (d')**
- d' = a + b
  = Z(CR) + (- Z(Miss))

Since Z(CR) = - Z(FA), Z(Miss) = - Z(Hit),
d' also = Z(Hit) - Z(FA)

Tables of the Normal Distribution

Probability Content from -oo to Z

z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07
0.0	0.5000	0.5040	0.5080	0.5120	0.5160	0.5199	0.5239	0.527
0.1	0.5398	0.5438	0.5478	0.5517	0.5557	0.5596	0.5636	0.567
0.2	0.5793	0.5832	0.5871	0.5910	0.5948	0.5987	0.6026	0.606
0.3	0.6179	0.6217	0.6255	0.6293	0.6331	0.6368	0.6406	0.644



Example

HIT .70	FALSE ALARM .30
MISS .30	CORRECT REJECTION .70

vs.

HIT .95	FALSE ALARM .80
MISS .05	CORRECT REJECTION .20

For P(Hit) = 0.70, Z(Hit) = 0.52
For P(FA) = 0.30, Z(FA) = -0.52

d' = Z(Hit) - Z(FA)
= 0.52 – (-0.52)
= 1.04

For P(Hit) = 0.95, Z(Hit) = 1.65
For P(FA) = 0.80, Z(FA) = 0.84

d' = Z(Hit) - Z(FA)
= 1.65 – 0.84
= 0.81

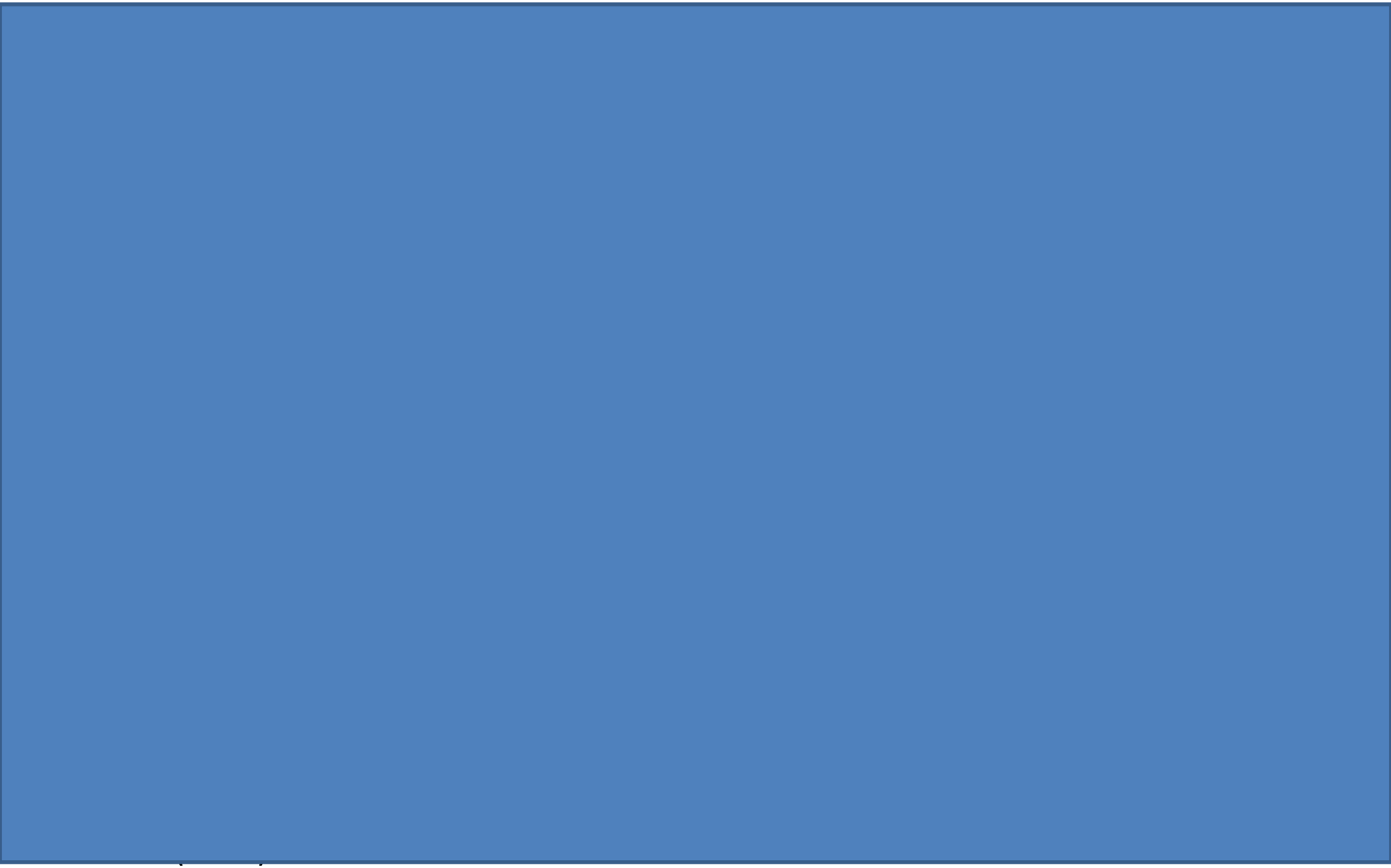
TABLE A
z scores and ordinate values (O) of the normal distribution corresponding to proportions (*p*)

p	z	O	p	z	O	p	z	O	p	z	O
.01	−2.33	.026	.26	−.64	.325	.51	.03	.399	.76	.71	.310
.02	−2.05	.049	.27	−.61	.331	.52	.05	.398	.77	.74	.303
.03	−1.88	.068	.28	−.58	.337	.53	.08	.398	.78	.77	.297
.04	−1.75	.086	.29	−.55	.343	.54	.10	.397	.79	.81	.287
.05	−1.65	.102	.30	−.52	.348	.55	.13	.396	.80	.84	.280
.06	−1.56	.118	.31	−.50	.352	.56	.15	.394	.81	.88	.271
.07	−1.48	.133	.32	−.47	.357	.57	.18	.393	.82	.92	.261
.08	−1.41	.148	.33	−.44	.362	.58	.20	.391	.83	.95	.254
.09	−1.34	.163	.34	−.41	.367	.59	.23	.389	.84	.99	.244
.10	−1.28	.176	.35	−.39	.370	.60	.25	.387	.85	1.04	.232
.11	−1.23	.187	.36	−.36	.374	.61	.28	.384	.86	1.08	.223
.12	−1.18	.199	.37	−.33	.378	.62	.31	.380	.87	1.13	.211
.13	−1.13	.211	.38	−.31	.380	.63	.33	.378	.88	1.18	.199
.14	−1.08	.223	.39	−.28	.384	.64	.36	.374	.89	1.23	.187
.15	−1.04	.232	.40	−.25	.387	.65	.39	.370	.90	1.28	.176
.16	− .99	.244	.41	−.23	.389	.66	.41	.367	.91	1.34	.163
.17	− .95	.254	.42	−.20	.391	.67	.44	.362	.92	1.41	.148
.18	− .92	.261	.43	−.18	.393	.68	.47	.357	.93	1.48	.133
.19	− .88	.271	.44	−.15	.394	.69	.50	.352	.94	1.56	.118
.20	− .84	.280	.45	−.13	.396	.70	.52	.348	.95	1.65	.102
.21	− .81	.287	.46	−.10	.397	.71	.55	.343	.96	1.75	.086
.22	− .77	.297	.47	−.08	.398	.72	.58	.337	.97	1.88	.068
.23	− .74	.303	.48	−.05	.398	.73	.61	.331	.98	2.05	.049
.24	− .71	.310	.49	−.03	.399	.74	.64	.325	.99	2.33	.026
.25	− .67	.319	.50	.00	.399	.75	.67	.319			

SDT practice

Part C

SDT practice solution



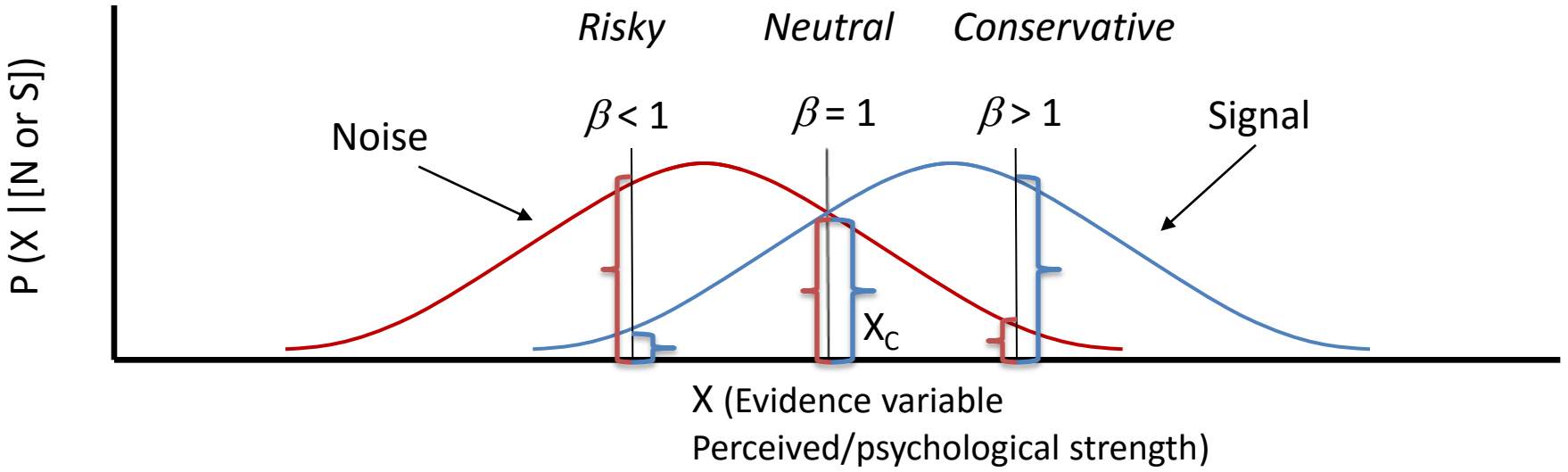
Signal detection theory

- Compute **decision criterion**
- Quantified by

$$\beta = \frac{P(X \mid S)}{P(X \mid N)} = \frac{Ordinate(P(Hit))}{Ordinate(P(FA))}$$

β: ratio of signal probability density to noise probability density at Xc.

  - X_C moves left, β decreases, more risky (liberal), say more "yes, it is a signal"
  - X_C moves right, β increases, more conservative, say less "yes, it is a signal"



Example

HIT .70	FALSE ALARM .30
MISS .30	CORRECT REJECTION .70

For P(Hit) = 0.70, O(Hit) = 0.348
For P(FA) = 0.30, O(FA) = 0.348

β = O(Hit) / O(FA)
= 0.348 / 0.348
= 1

TABLE A
z scores and ordinate values (O) of the normal distribution corresponding to proportions (*p*)

p	z	O	p	z	O	p	z	O	p	z	O
.01	−2.33	.026	.26	−.64	.325	.51	.03	.399	.76	.71	.310
.02	−2.05	.049	.27	−.61	.331	.52	.05	.398	.77	.74	.303
.03	−1.88	.068	.28	−.58	.337	.53	.08	.398	.78	.77	.297
.04	−1.75	.086	.29	−.55	.343	.54	.10	.397	.79	.81	.287
.05	−1.65	.102	.30	−.52	.348	.55	.13	.396	.80	.84	.280
.06	−1.56	.118	.31	−.50	.352	.56	.15	.394	.81	.88	.271
.07	−1.48	.133	.32	−.47	.357	.57	.18	.393	.82	.92	.261
.08	−1.41	.148	.33	−.44	.362	.58	.20	.391	.83	.95	.254
.09	−1.34	.163	.34	−.41	.367	.59	.23	.389	.84	.99	.244
.10	−1.28	.176	.35	−.39	.370	.60	.25	.387	.85	1.04	.232
.11	−1.23	.187	.36	−.36	.374	.61	.28	.384	.86	1.08	.223
.12	−1.18	.199	.37	−.33	.378	.62	.31	.380	.87	1.13	.211
.13	−1.13	.211	.38	−.31	.380	.63	.33	.378	.88	1.18	.199
.14	−1.08	.223	.39	−.28	.384	.64	.36	.374	.89	1.23	.187
.15	−1.04	.232	.40	−.25	.387	.65	.39	.370	.90	1.28	.176
.16	−.99	.244	.41	−.23	.389	.66	.41	.367	.91	1.34	.163
.17	−.95	.254	.42	−.20	.391	.67	.44	.362	.92	1.41	.148
.18	−.92	.261	.43	−.18	.393	.68	.47	.357	.93	1.48	.133
.19	−.88	.271	.44	−.15	.394	.69	.50	.352	.94	1.56	.118
.20	−.84	.280	.45	−.13	.396	.70	.52	.348	.95	1.65	.102
.21	−.81	.287	.46	−.10	.397	.71	.55	.343	.96	1.75	.086
.22	−.77	.297	.47	−.08	.398	.72	.58	.337	.97	1.88	.068
.23	−.74	.303	.48	−.05	.398	.73	.61	.331	.98	2.05	.049
.24	−.71	.310	.49	−.03	.399	.74	.64	.325	.99	2.33	.026
.25	−.67	.319	.50	.00	.399	.75	.67	.319			

SDT practice

Part D

SDT practice solution

SDT practice

Part E

SDT practice solution