Multisensory integration

Mind, **B**rain, and **M**odels 22/23

Tentative schedule

Week		Lec	Lecturer	Lecture topic	Workshop topic
	1			Preparation	Matlab
08-Feb	2	1	Max	Models	2IFC experiment
15-Feb	3	2	Max	Bayesian	Distributions
22-Feb	4	3	Max+Min Li	Multisensory	Causal inference
01-Mar	5	4	Max	Control Theory	Inverted
08-Mar	6	5	Dietmar Heinke	Agent based	Social
15-Mar	7	6	Alan Wing	Synchronization	Clapping
22-Mar	8	7	Joe Galea	Cerebellum	Learning
19-Apr	9	8	Max	Touch	Fibers
26-Apr	10	9	Howard	Neural fields	Dynamics
03-	11	10	Max	Visual	Convolution
9-May	12	11	Max	Project	Your choice

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15-Mar	7	6		***TOUCH?***	
22-Mar	8	7	Joe Galea	Cerebellum	Learning
19-Apr	9	8		SYNCH?	
26-Apr	10	9	Howard	Neural fields	Dynamics
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Food for thought

- Does the brain actually use Bayesian rules or are Bayesian models mere approximate descriptions of behaviour?
- Irrationality in cognition
- Implausibly uniform view of the mind
- Near-trivial due to their many degrees of freedom
- Relationship between perception, cognition, rationality, and consciousness
- Priors can be used to accommodate discrepancies
- Often constructed in a post-hoc manner
- Theoretical motivation of Bayesian theories is often unclear

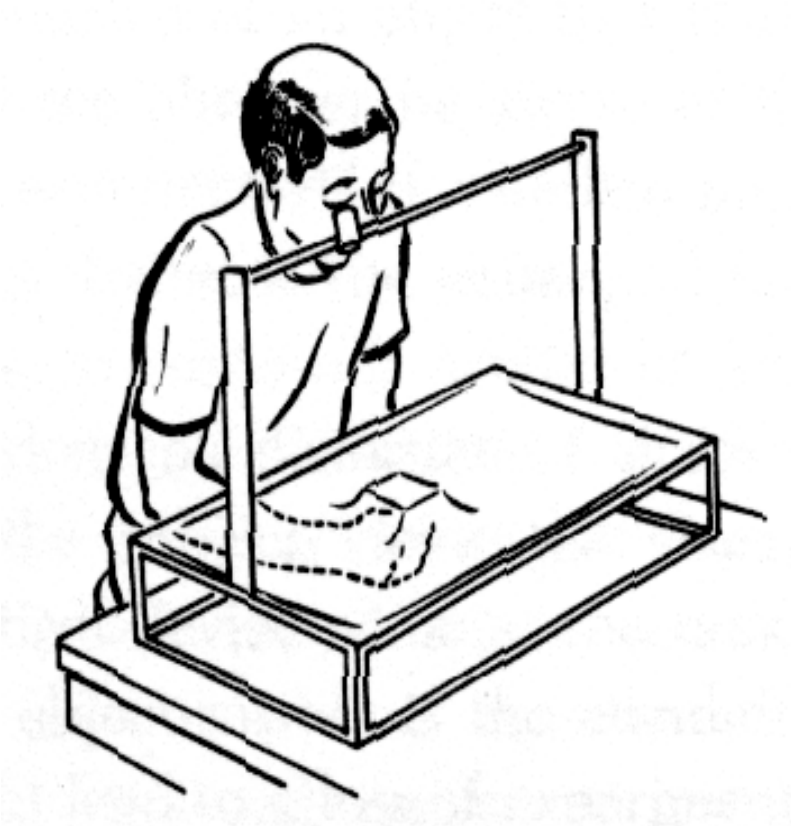
(From lecture 2)

#blueandblack **#whiteandgold**

Image available at
https://web.archive.org/web/20150227014959/http://swiked.tumblr.com/post/112073818575/guys-please-help-me-is-this-dress-white-and

Rock & Victor (Science, 1964)

Looking at an object through a distortion lens
while touching the object.



Discrepancy between visual and haptic form.
Which form is perceived?

Double-flash illusion

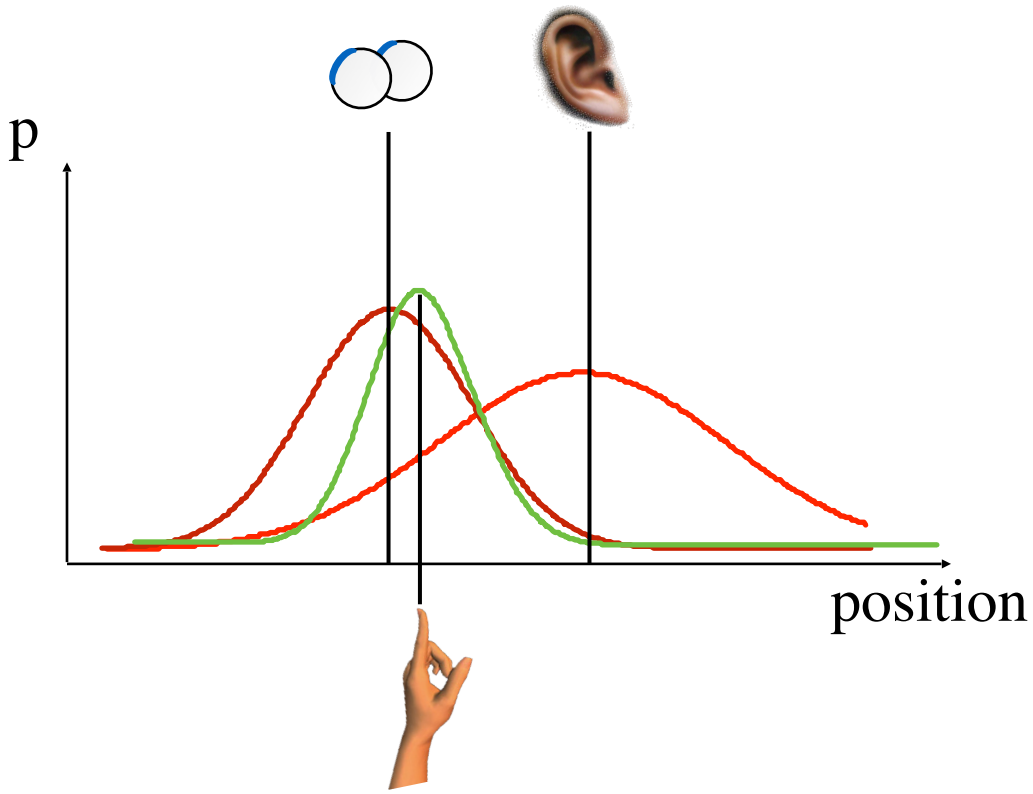
Shams, Kamitani, & Shimojo (2000)

Modality appropriateness hypothesis

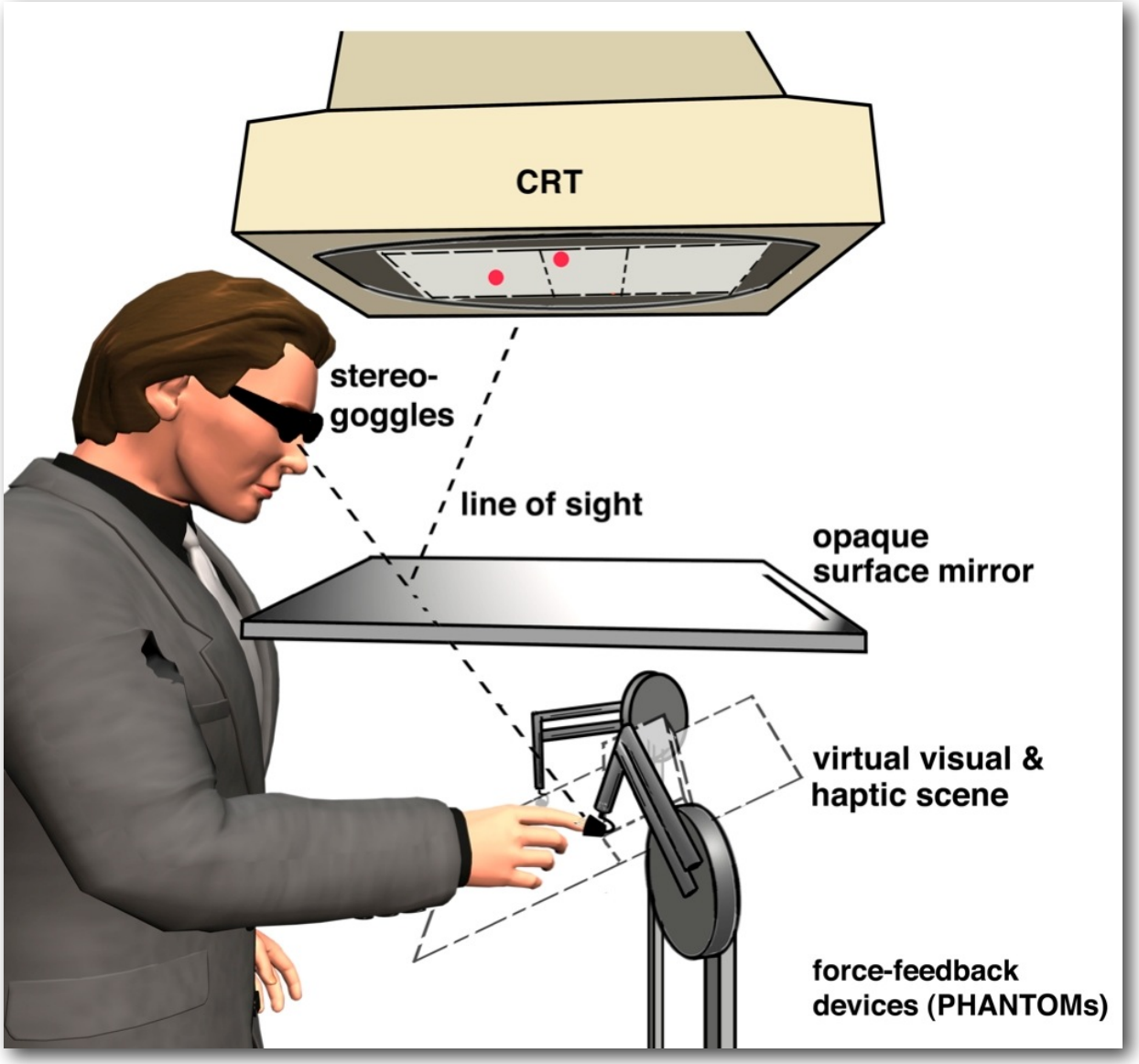
- Preference is given to the sensory modality that provides the more reliable task-relevant information for efficient performance of the actual task
- Welch and Warren, 1980

Ventriloquist

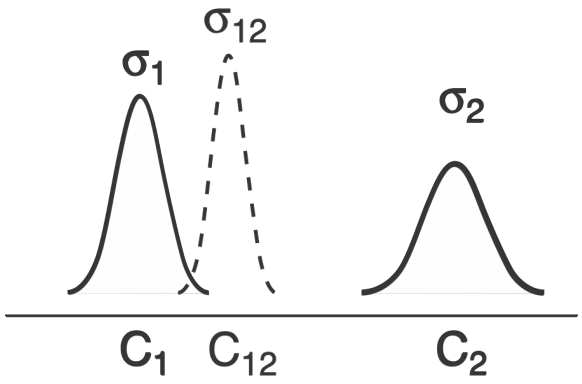
Ventriloquist

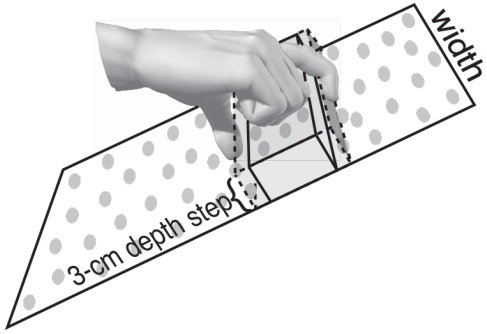


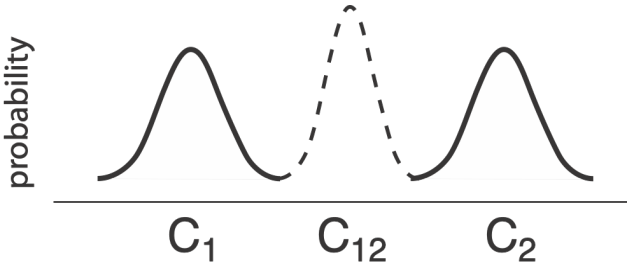
Visual-haptic Setup



Multisensory Integration





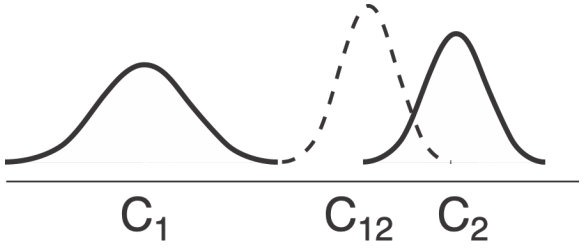


reliability

$$r_i = \frac{1}{\sigma_i^2}$$

weights

$$w_i = \frac{r_i}{\sum r_j}$$



weighted sum

$$C_{12} = w_1 C_1 + w_2 C_2$$

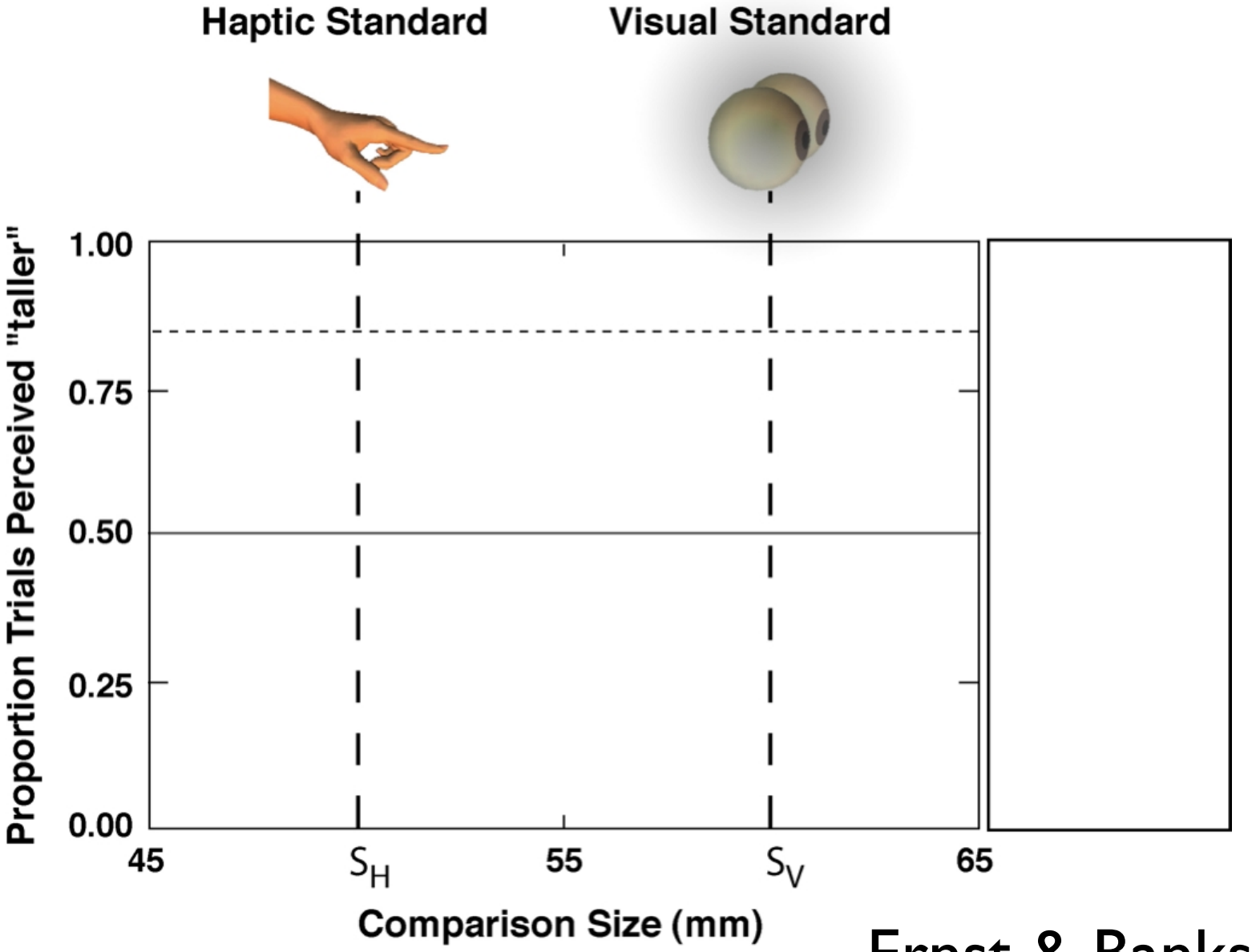
combined reliability

$$r_{12} = r_1 + r_2$$

„ideal observer“ approach

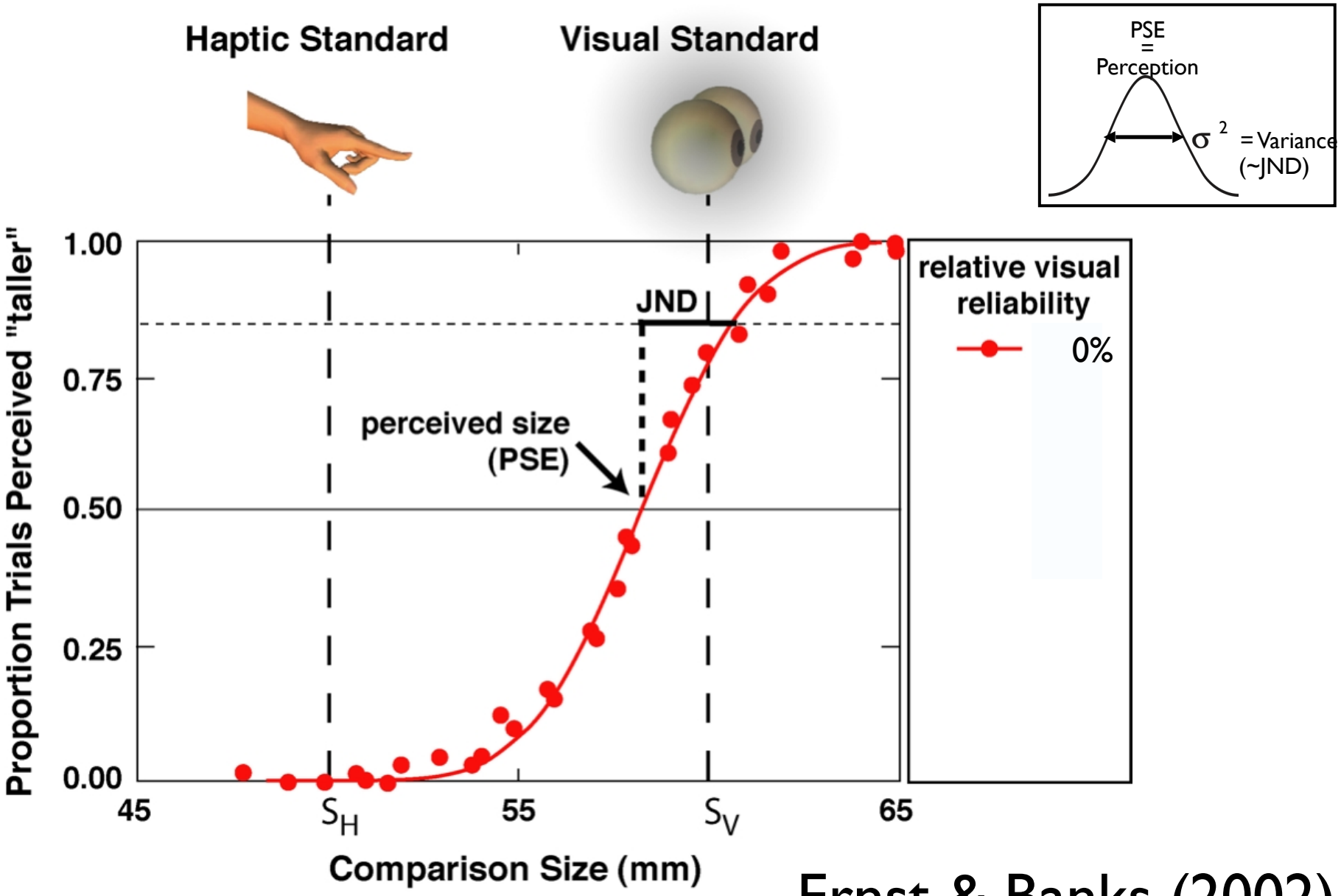
Ernst & Banks, 2002

Visual-Haptic Integration



Ernst & Banks (2002)

Visual-Haptic Integration



Ernst & Banks (2002)

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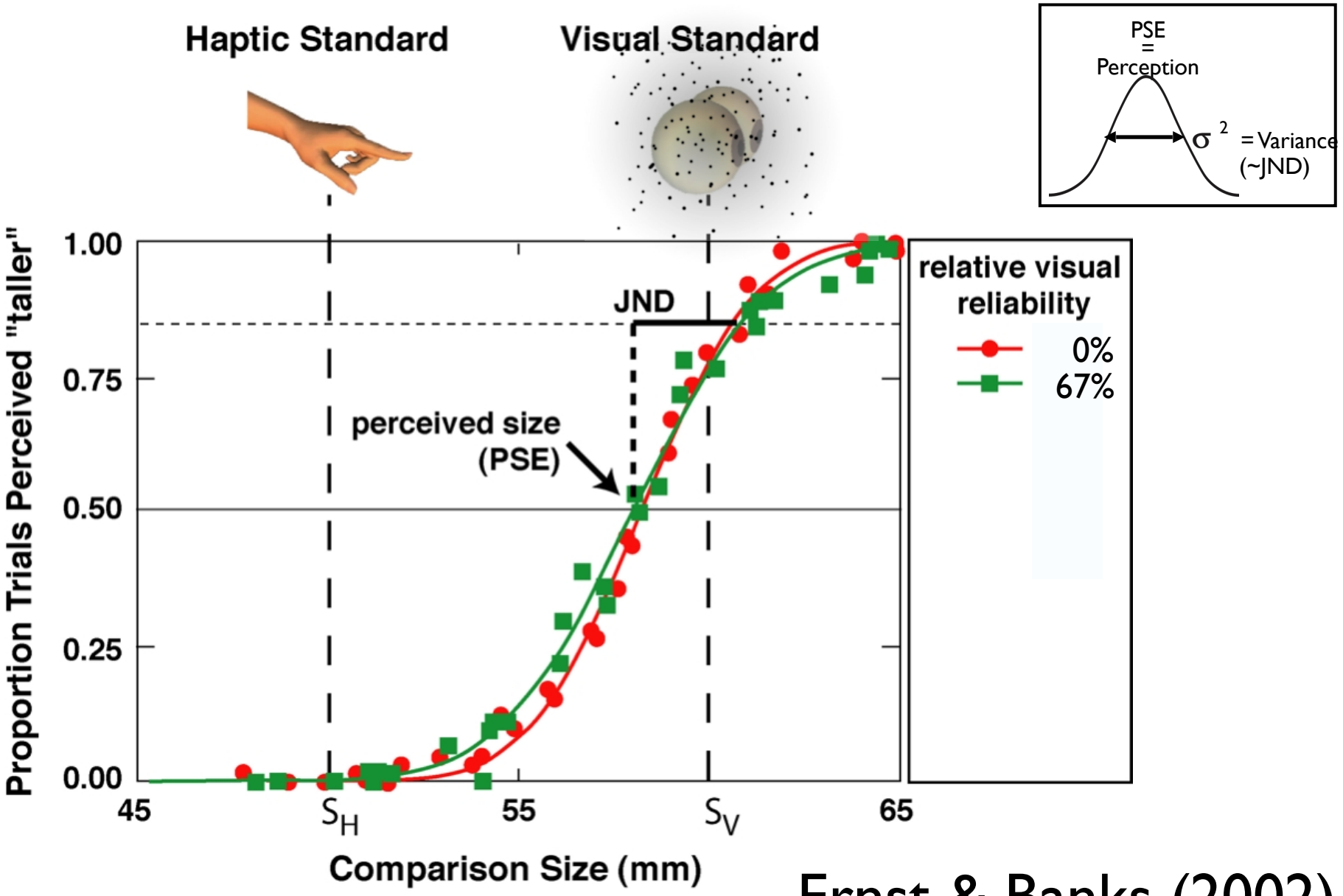
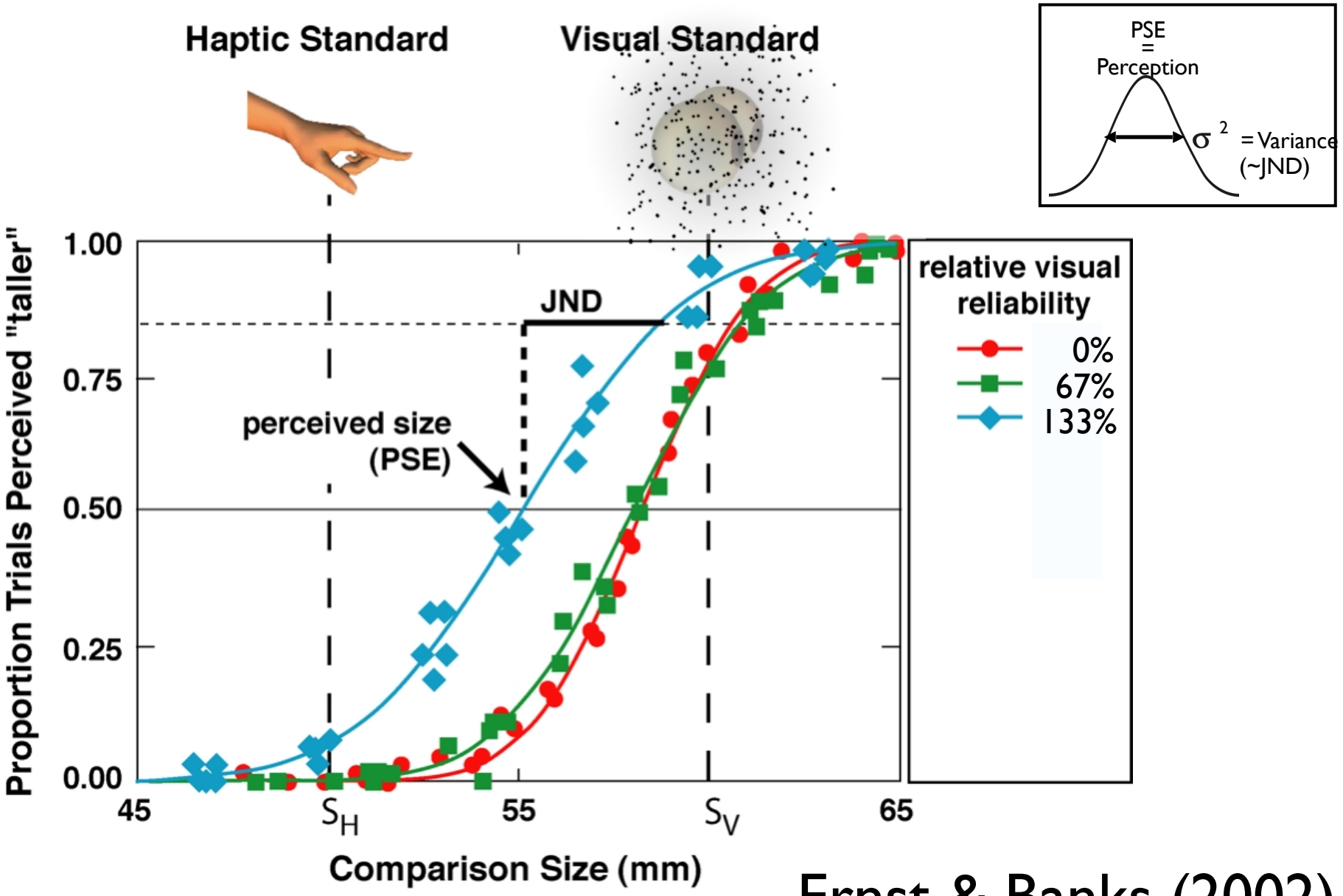


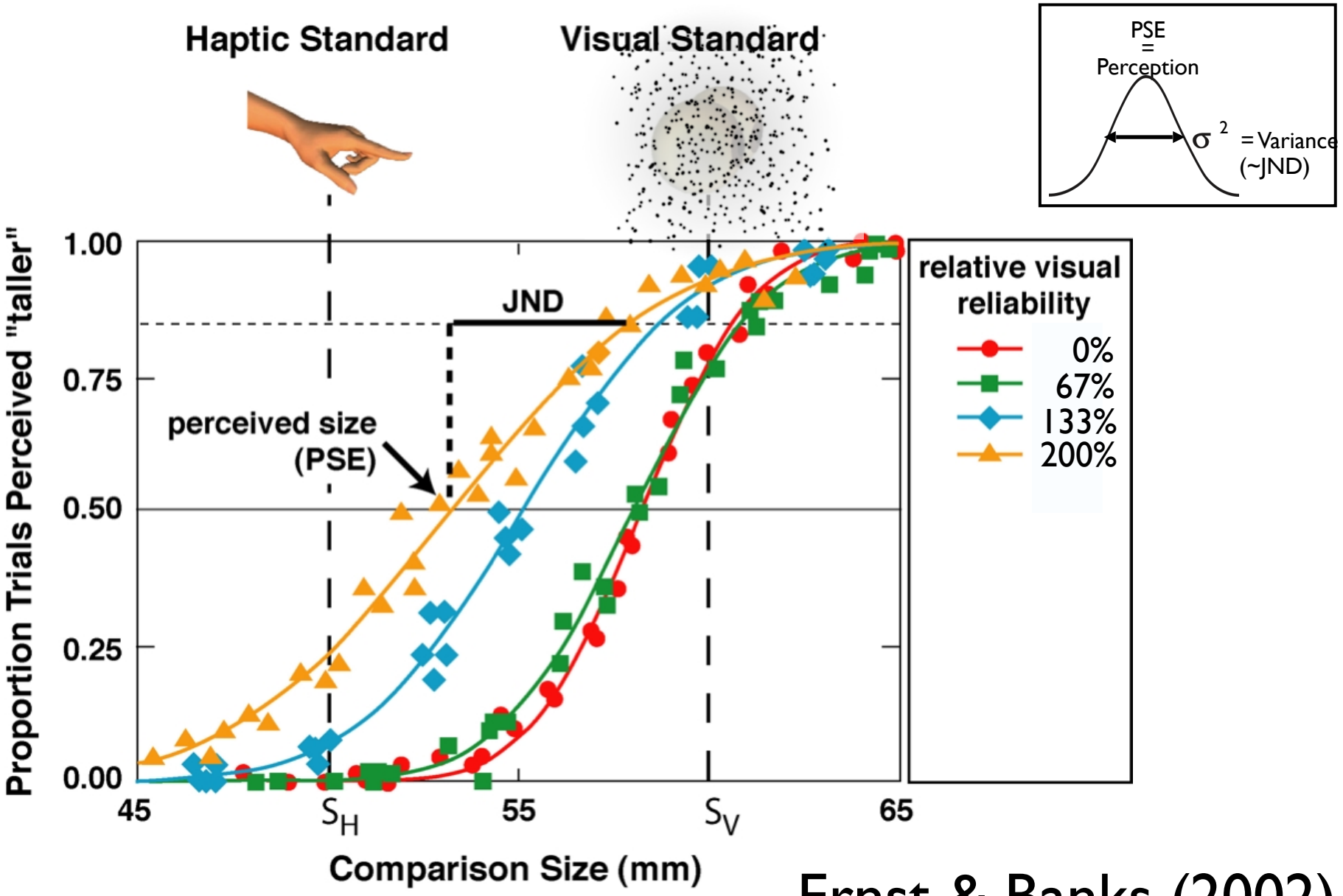
Ernst & Banks (2002)

Visual-Haptic Integration



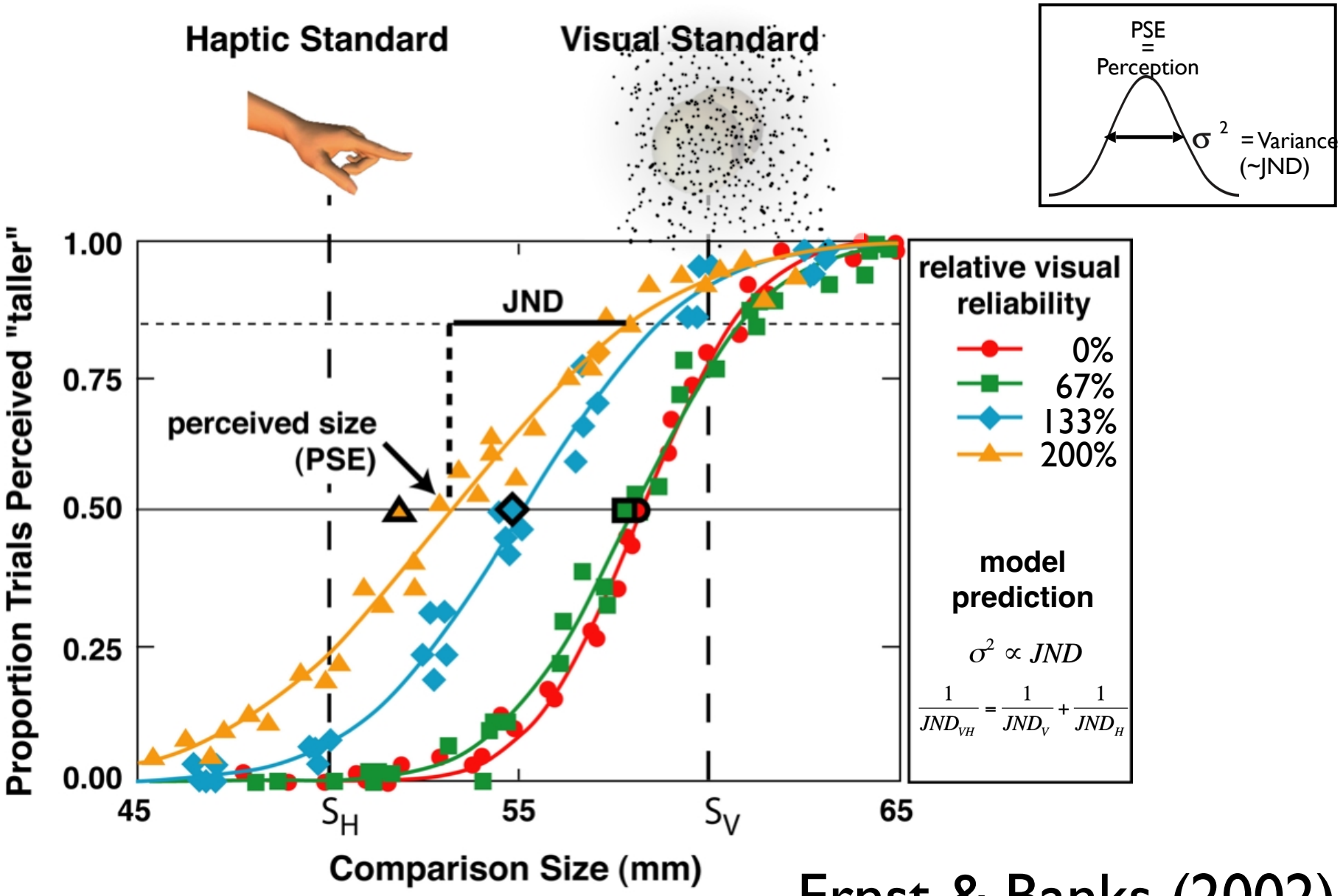
Ernst & Banks (2002)

Visual-Haptic Integration



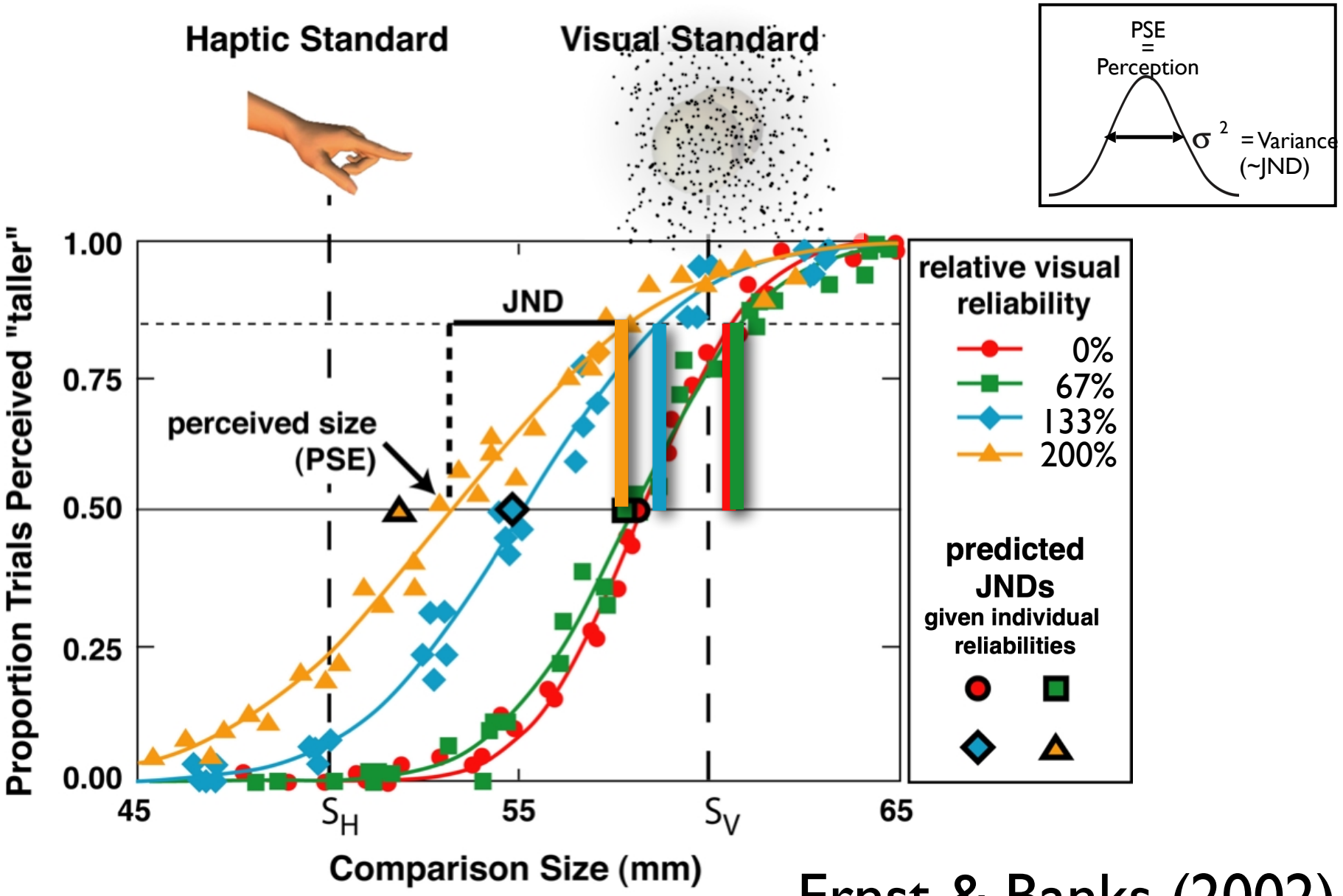
Ernst & Banks (2002)

Visual-Haptic Integration



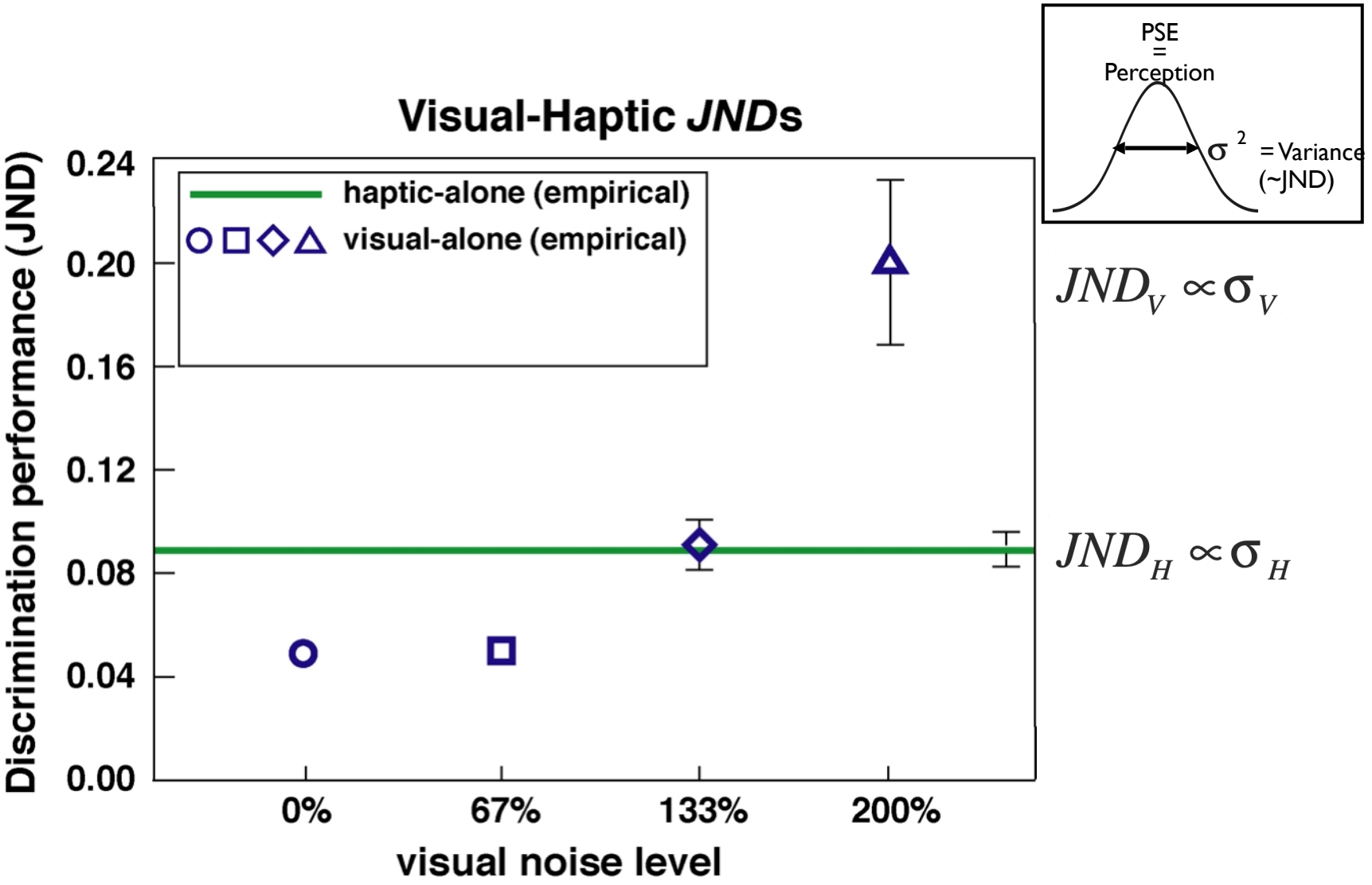
Ernst & Banks (2002)

Visual-Haptic Integration



Ernst & Banks (2002)

Combined Performance (JNDs)



Ernst & Banks (2002)

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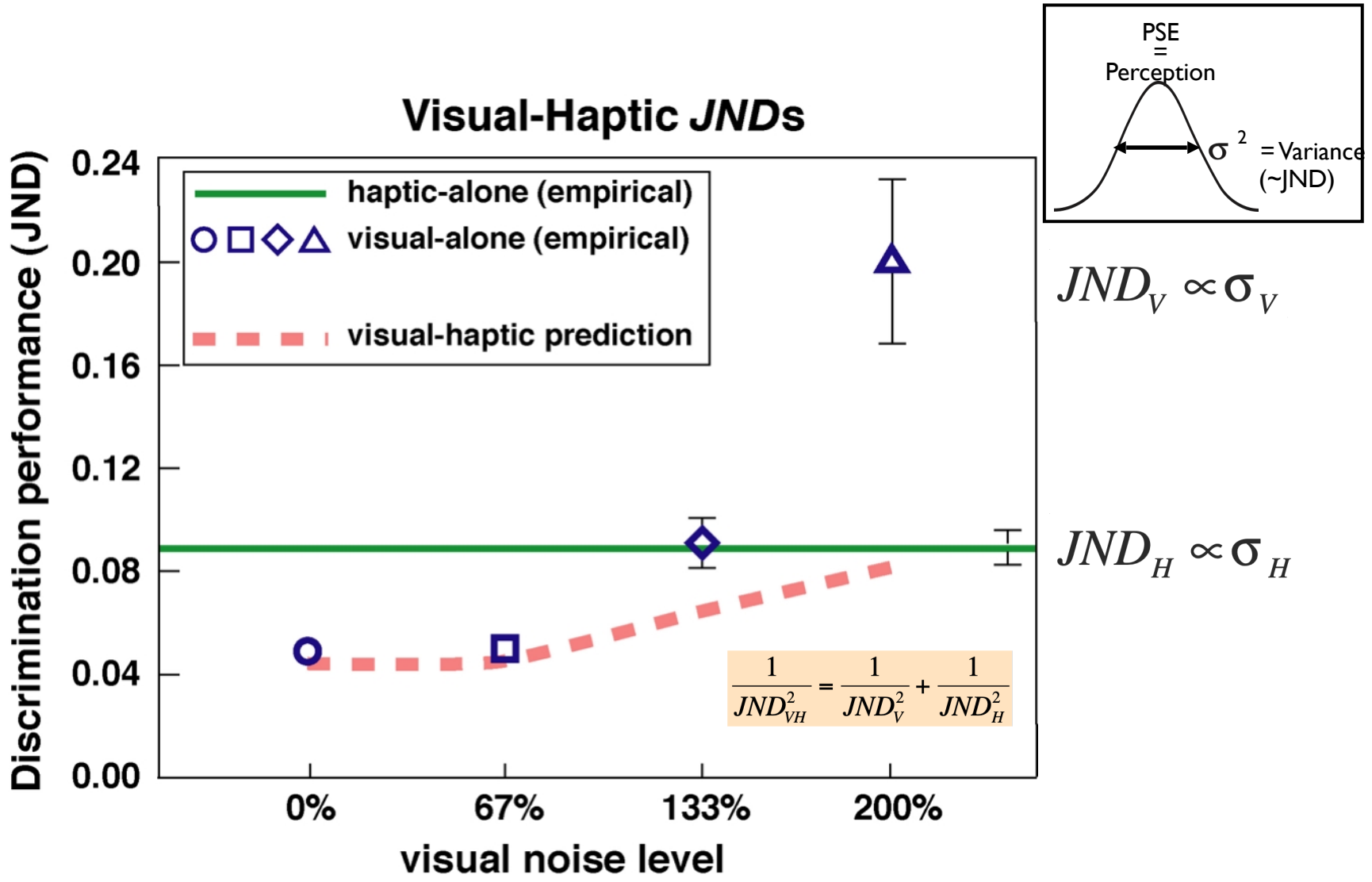

Ernst & Banks (2002)

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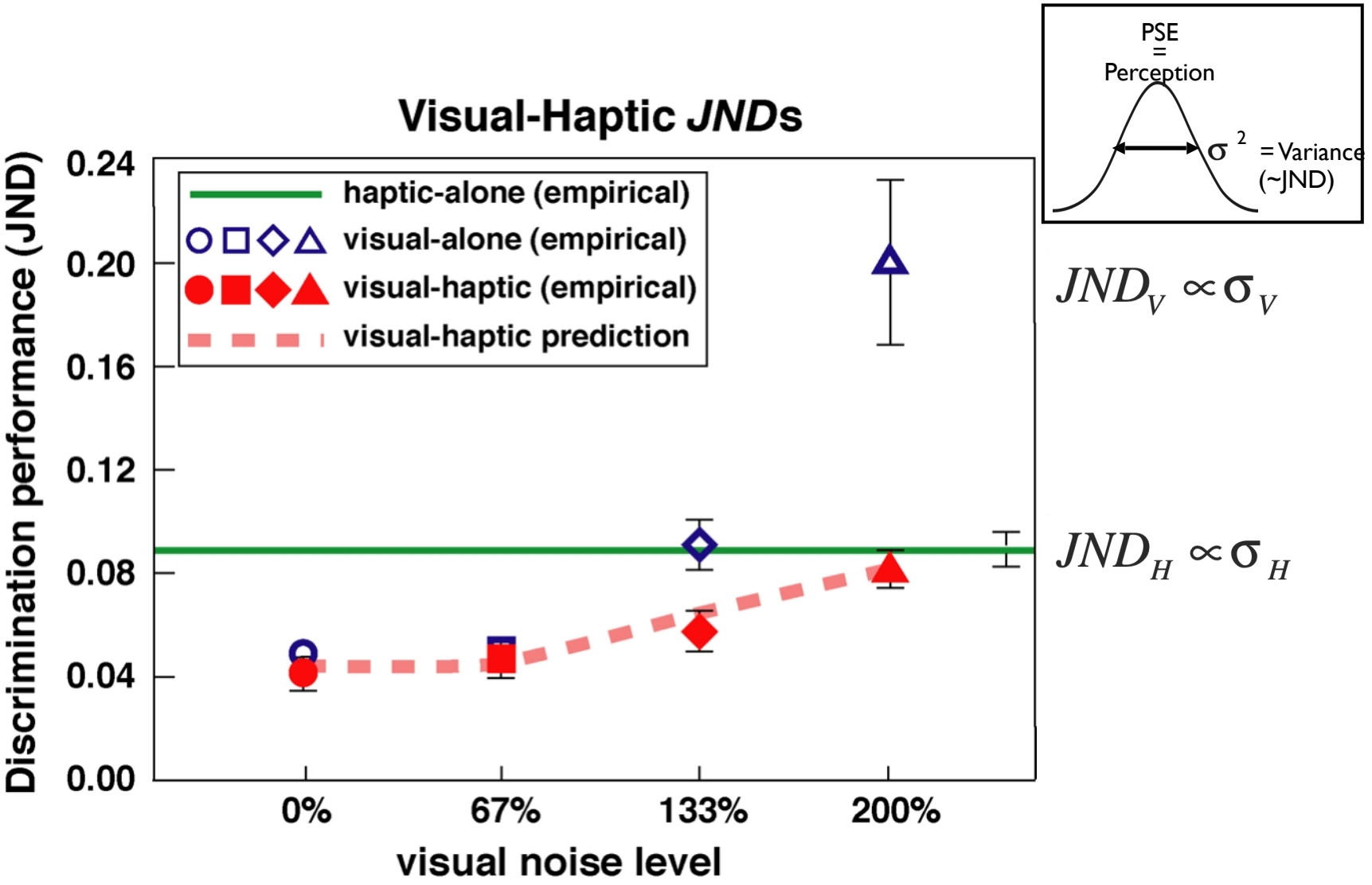
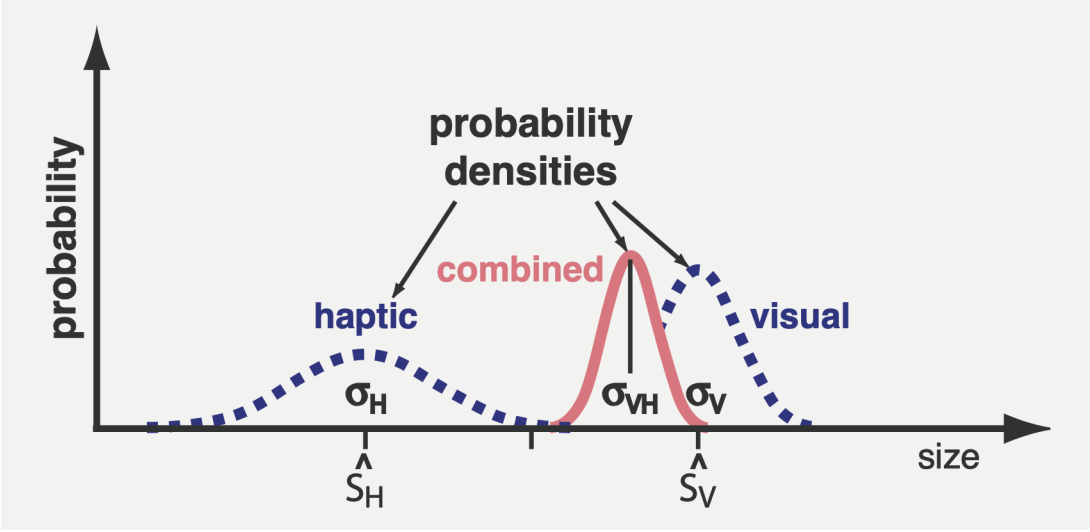


Ernst & Banks (2002)

Maximum Likelihood Estimation

$$\text{Reliability} = 1 / \sigma^2$$

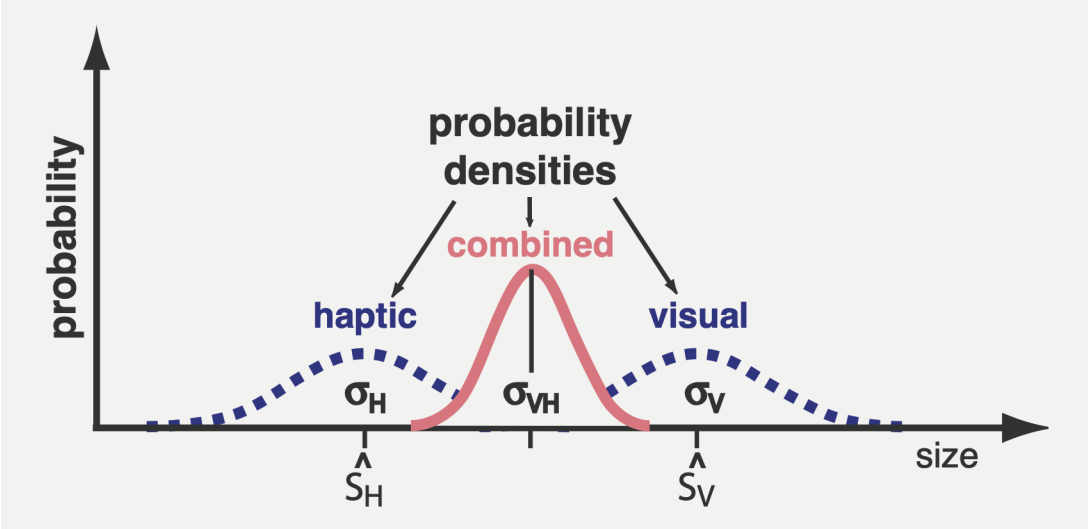


$$S_{VH} = w_V S_V + w_H S_H$$

$$w_V = \frac{\sigma_H^2}{\sigma_V^2 + \sigma_H^2}$$

$$\frac{1}{\sigma_{VH}^2} = \frac{1}{\sigma_V^2} + \frac{1}{\sigma_H^2}$$

Maximum Likelihood Estimation



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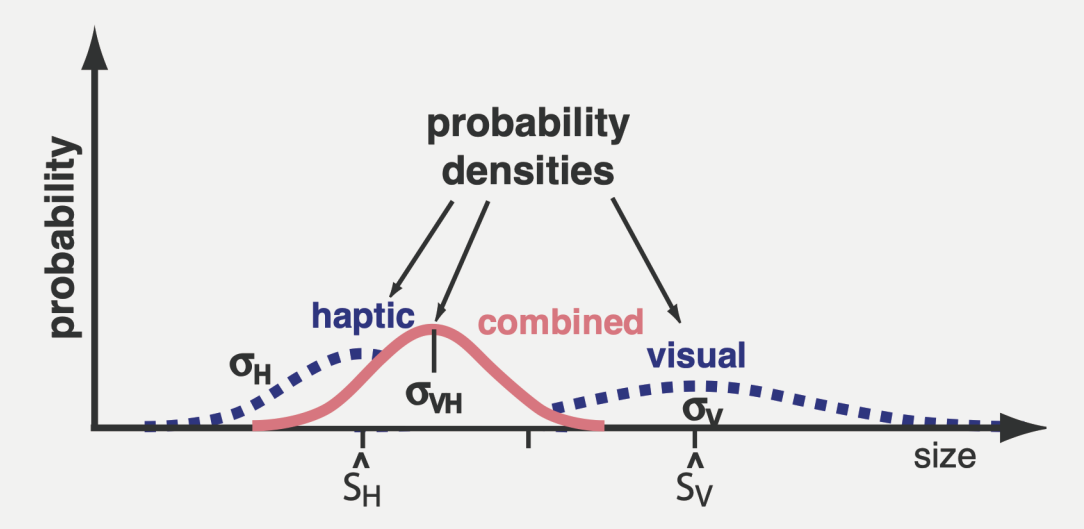
Optimal Integration



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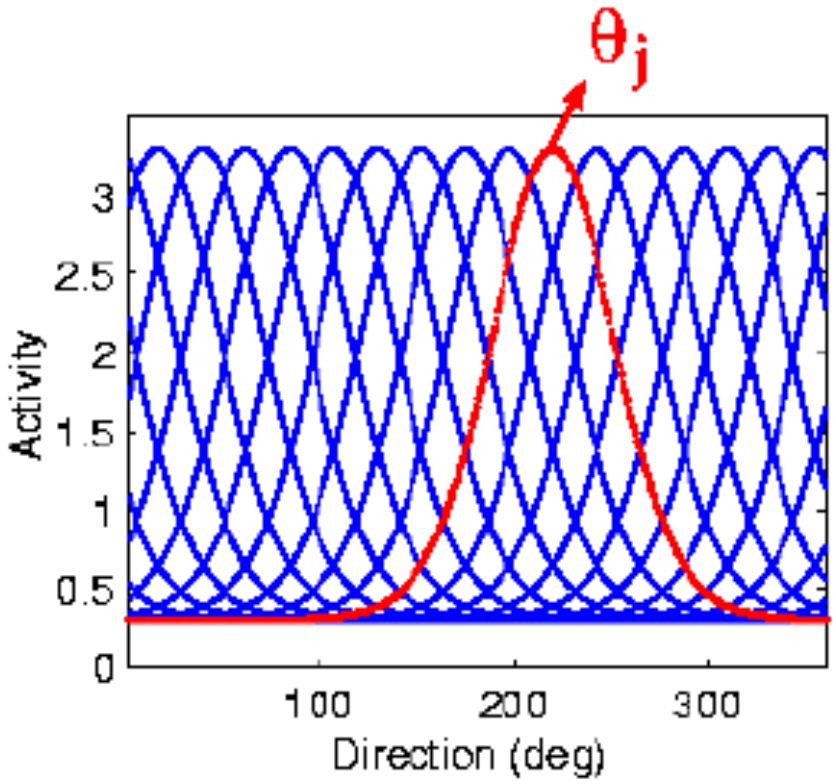
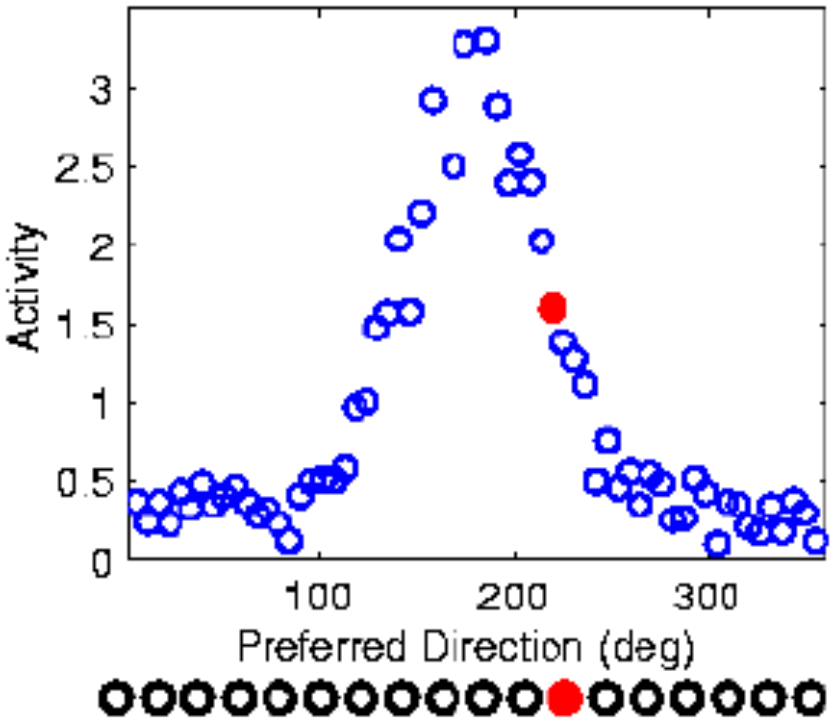
Population Code





Tuning Curves

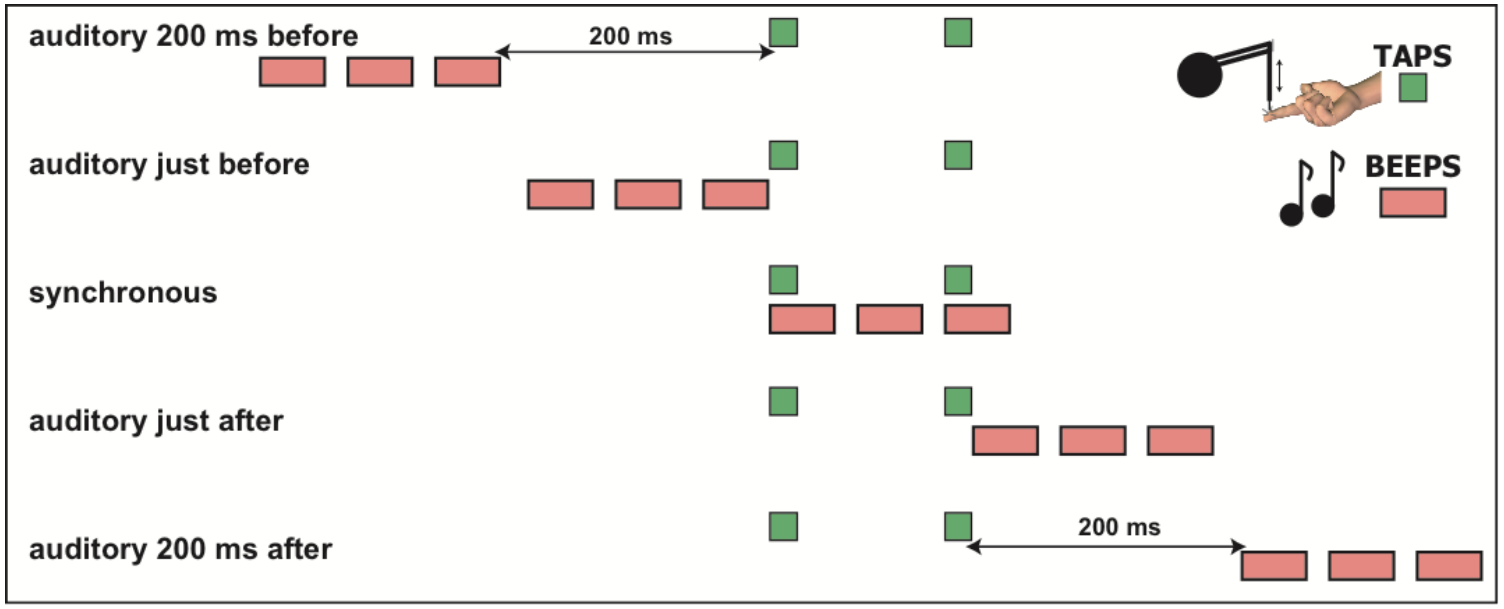
Pattern of activity (A)

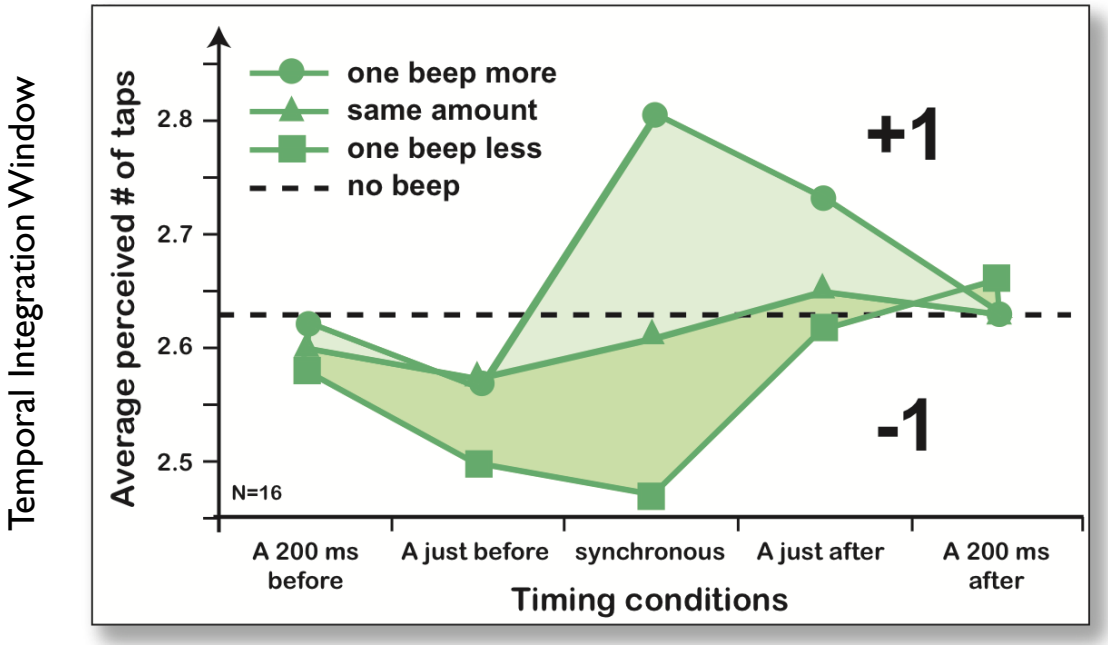
(Preview to lecture 9)

Breakdown of integration

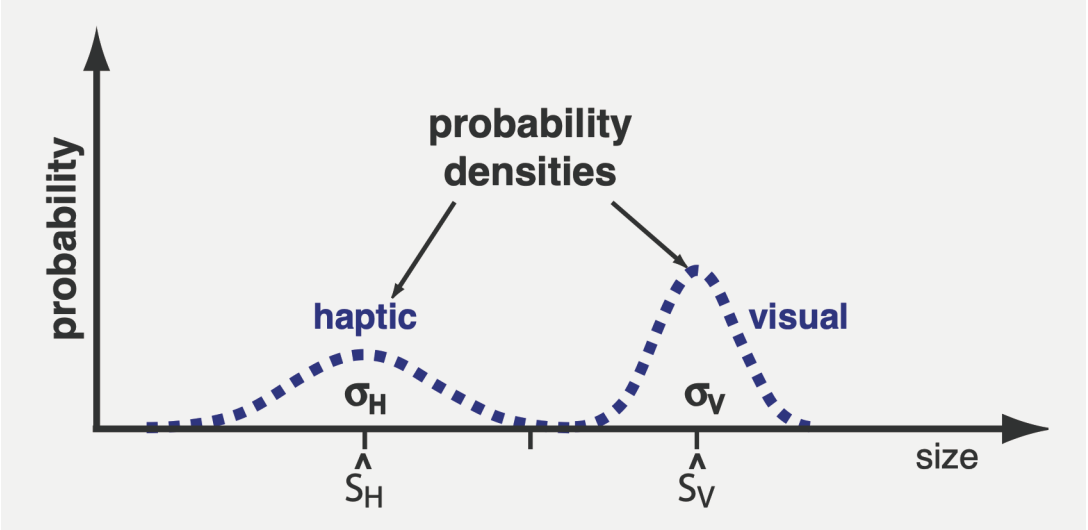
Correspondence Problem

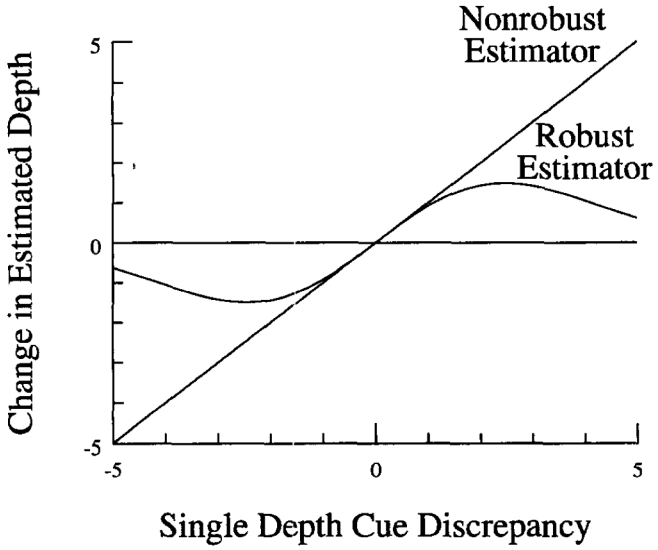
- Co-location
- Simultaneity/ temporal order
- Synesthetic congruency

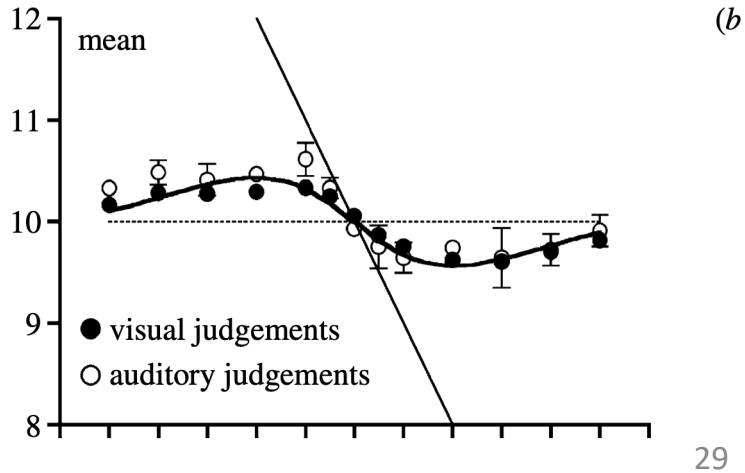




Mandatory fusion vs robust estimation



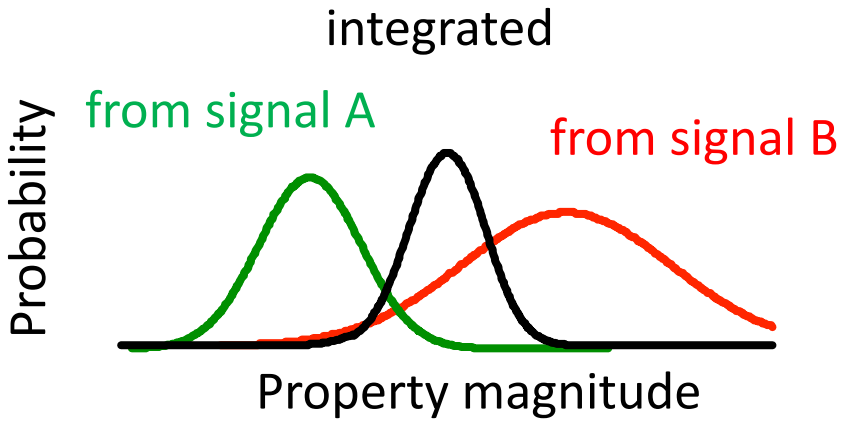




Roach et al. (2007)

- Strength of coupling
- Heavy tails
- Causal inference

Bivariate distributions to model multisensory integration



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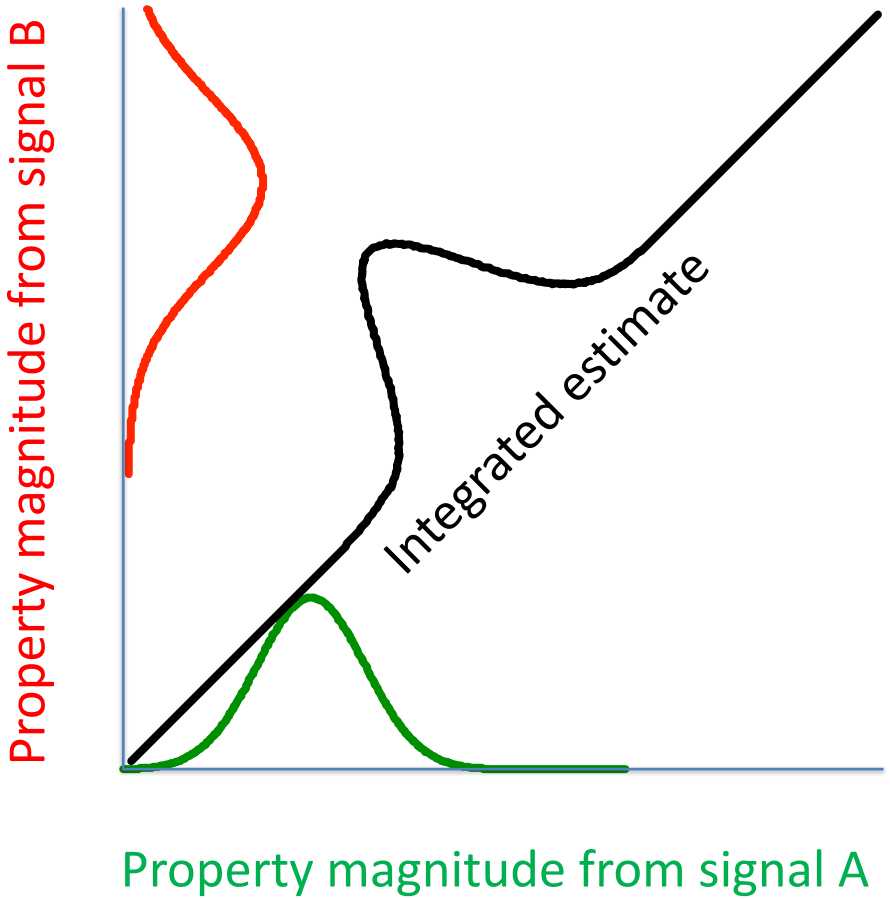

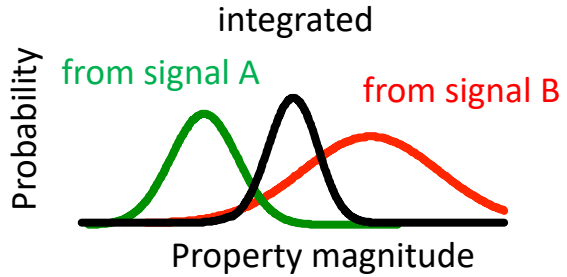

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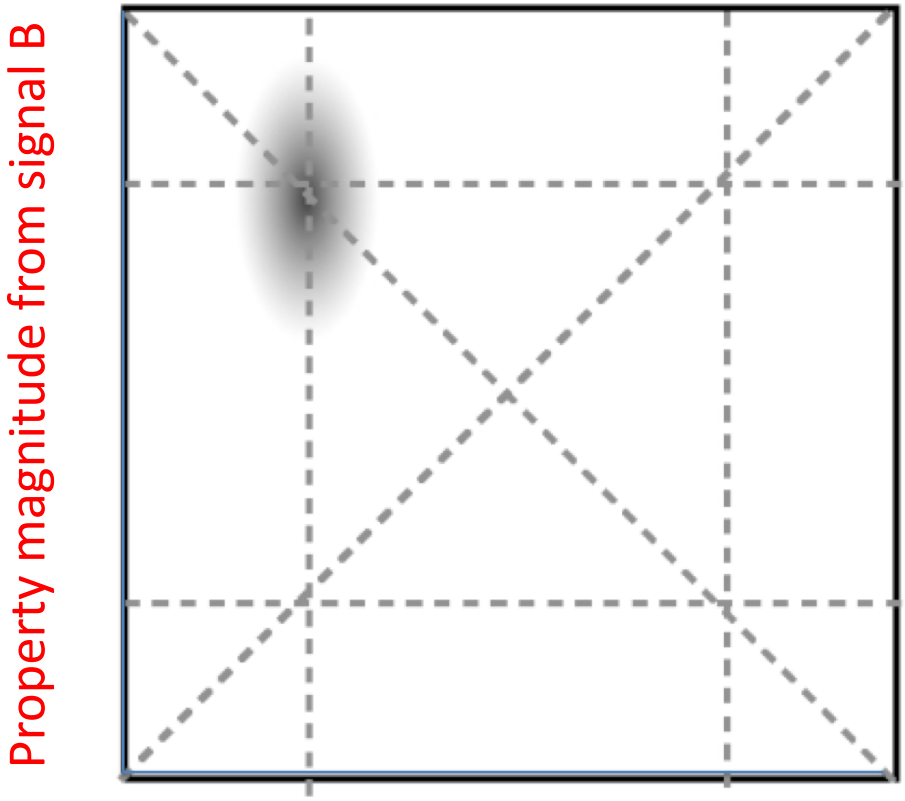
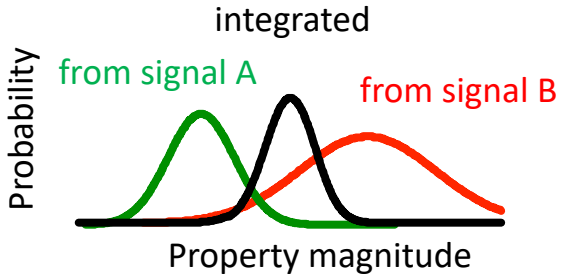
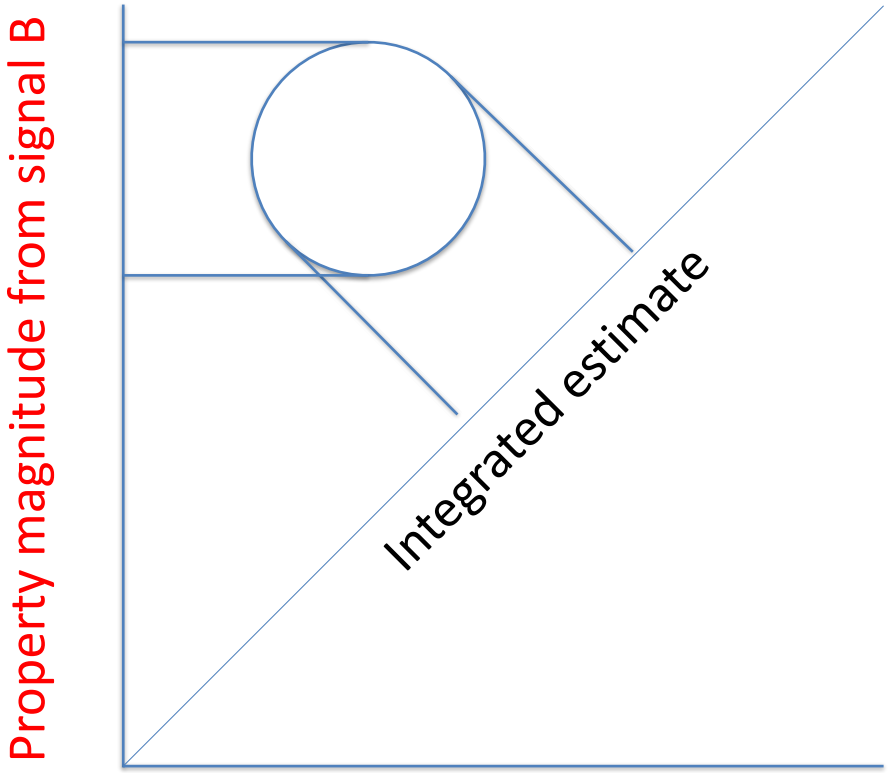
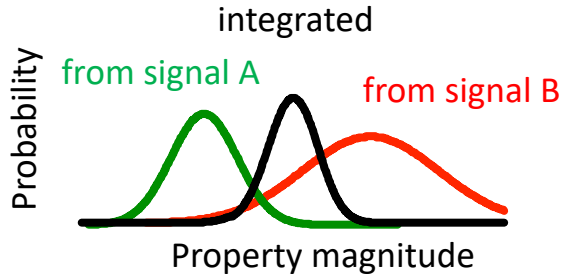
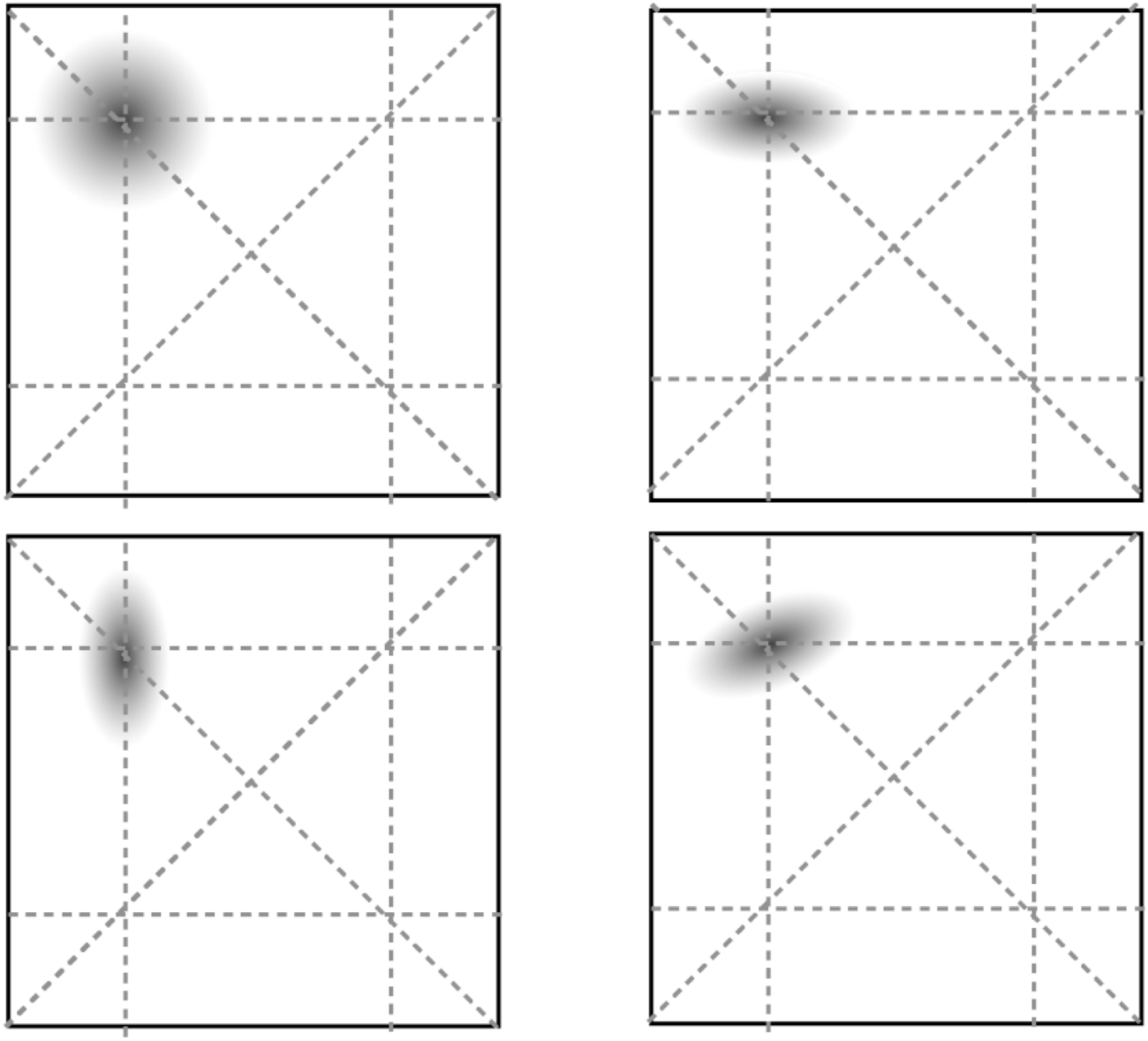




Bivariate distributions to model multisensory integration



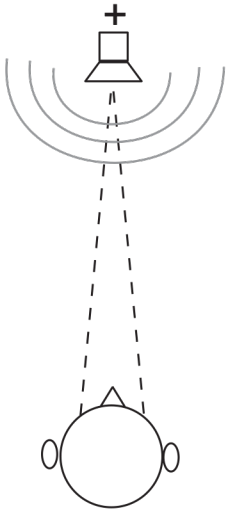


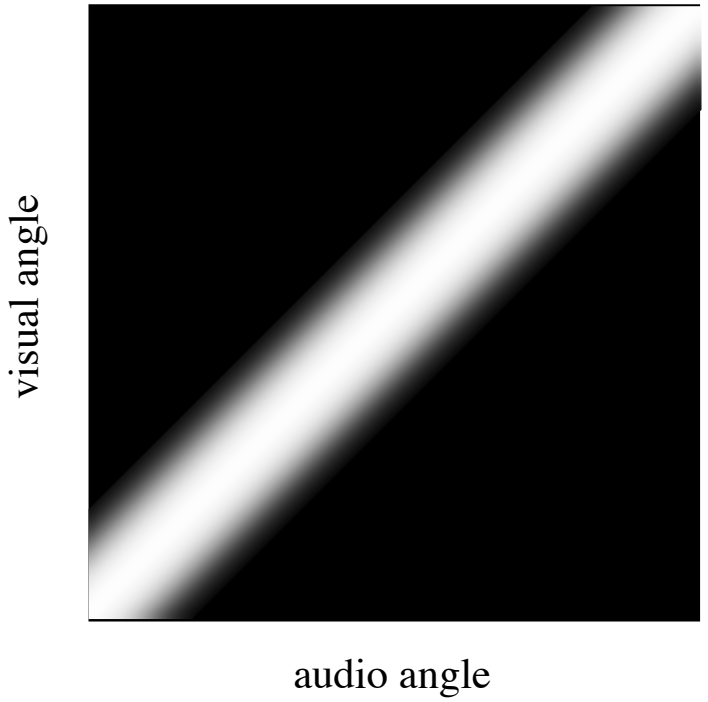


Ernst (2005)

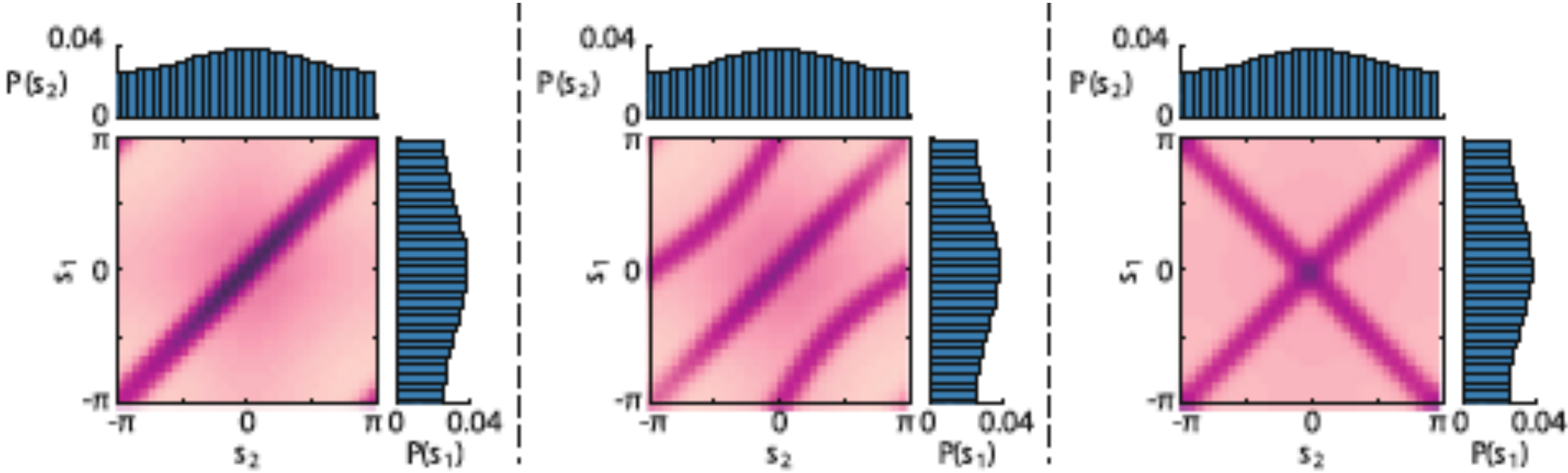
Coupling prior

- Statistics of spatio-temporal co-occurrence of stimuli

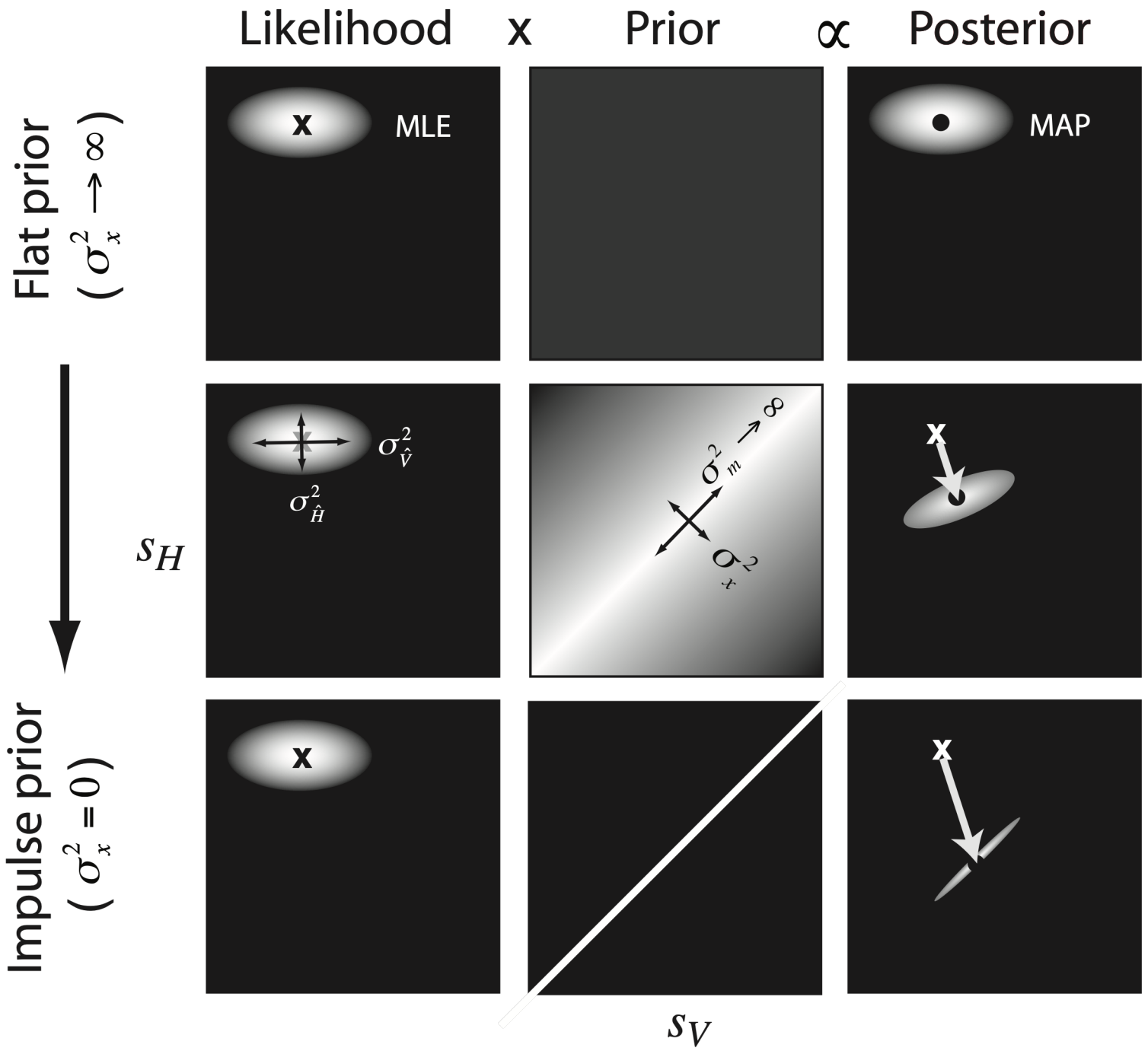


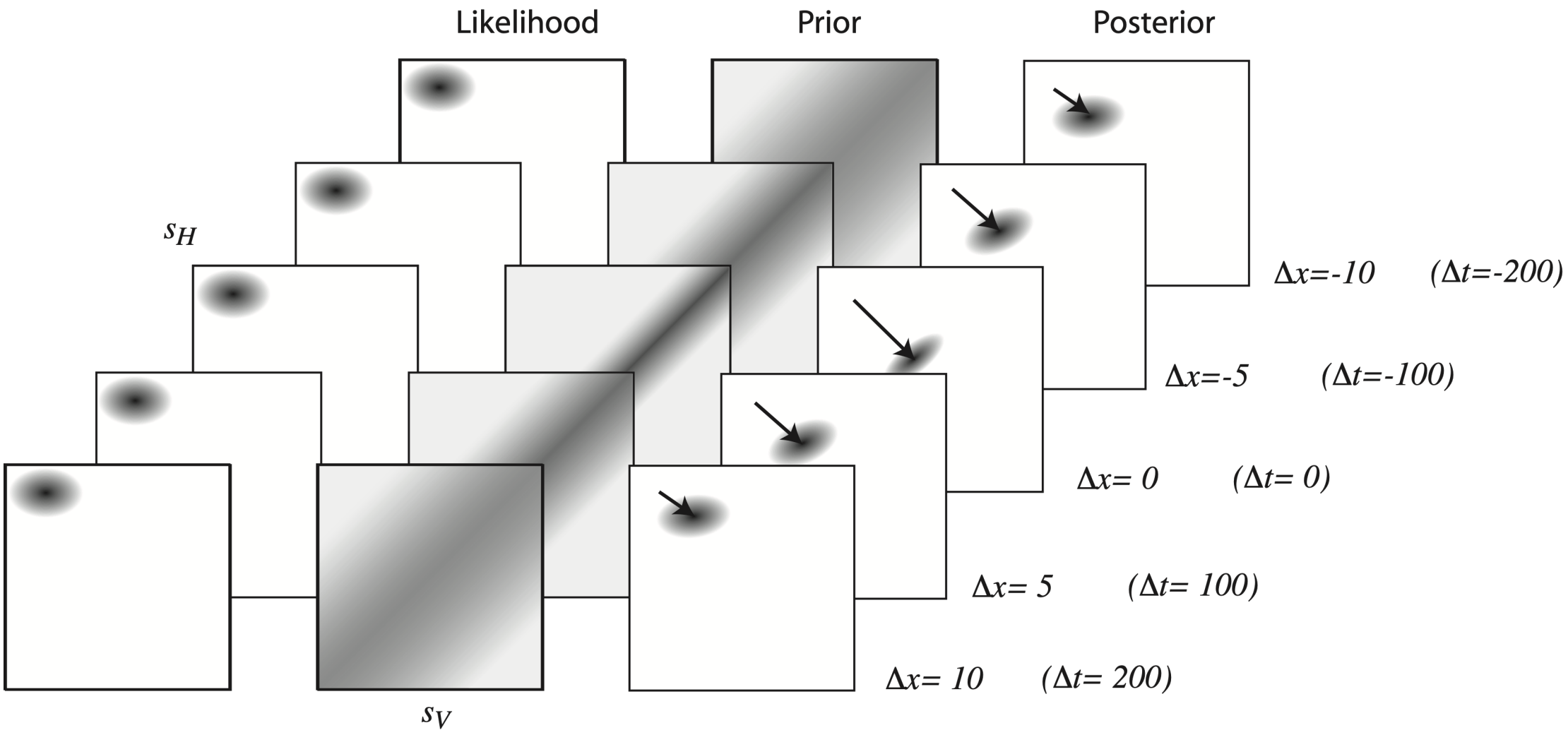


Ernst (2005)

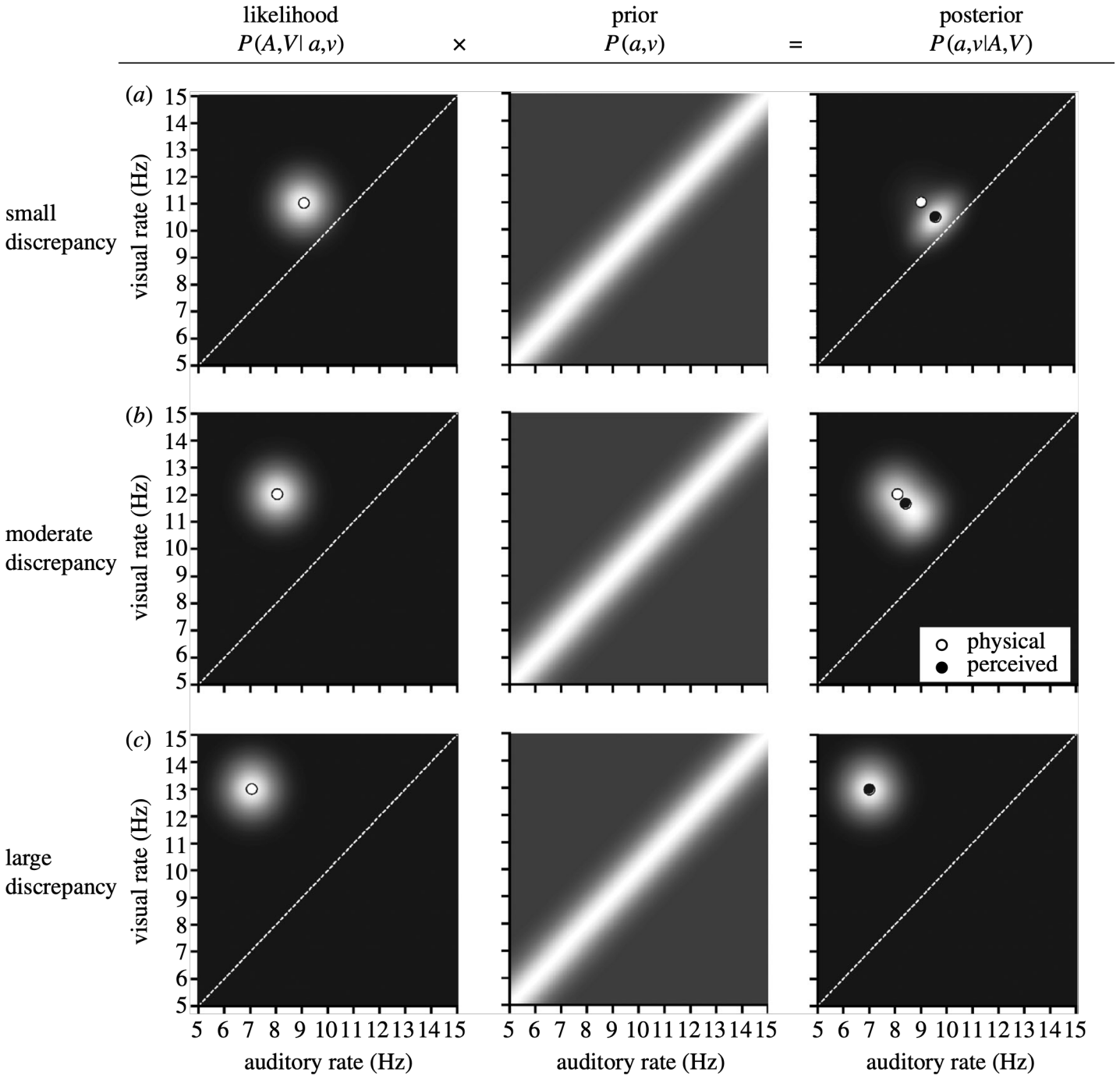


Wang et al (2017)


Likelihood
x
Prior
∝
Posterior
Flat prior
($\sigma_x^2 \to \infty$)
Impulse prior
($\sigma_x^2 = 0$)
x
MLE
MAP
$\sigma_{\hat{V}}^2$
$\sigma_{\hat{H}}^2$
$\sigma_m^2 \to \infty$
σ_x^2
s_H
s_V

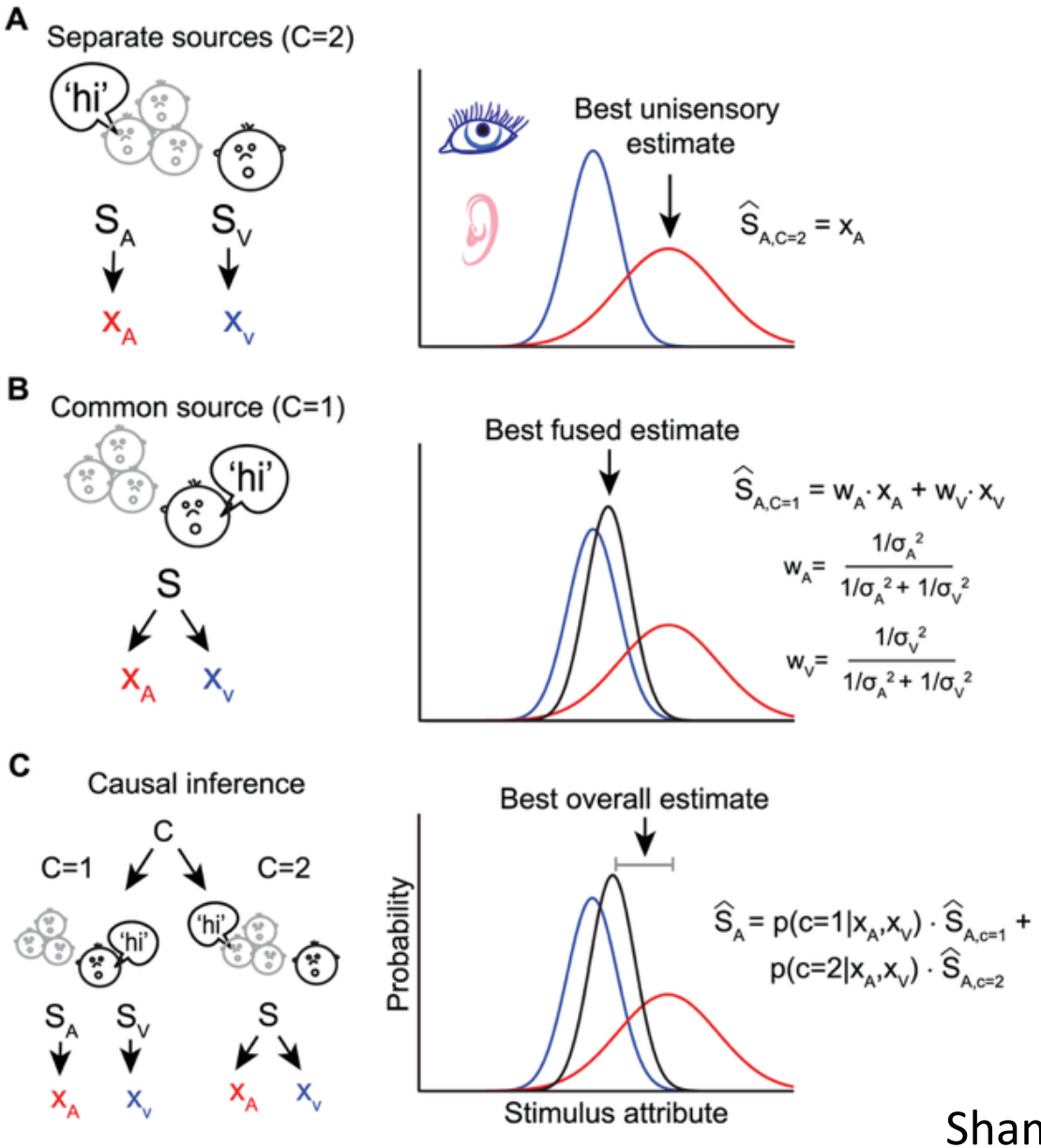


Ernst (2005), Bresciani et al (2007)



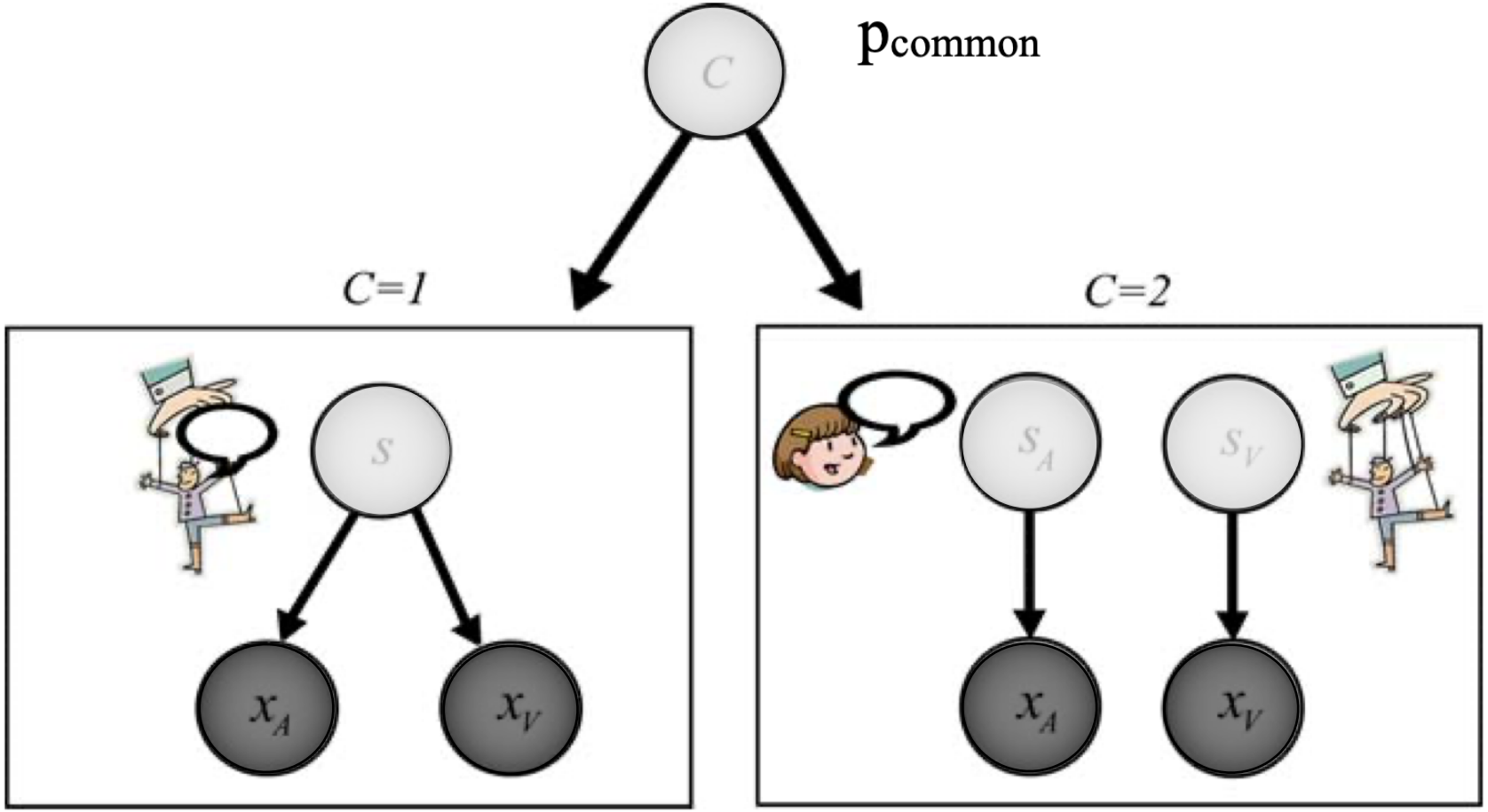
Roach et al. (2007)

Bayesian Causal Inference



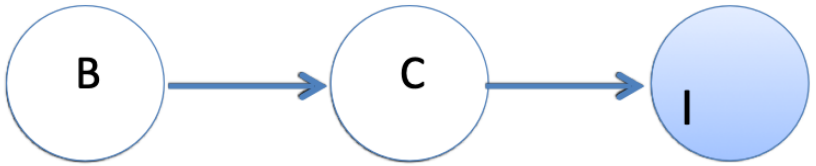
Shams and Beierholm, 2010

Bayesian Causal Inference



Shams Beierhom 2011

Causal Markov assumption = The screening off property



Bronchitis predicts insomnia

But is observed, bronchitis is no longer relevant to predicting insomnia

In probabilistic setting:

Marginal dependence: P(Insom | Br) > P(Insom)

Conditional independence: P(Insom | Br&Cough) = P(Insom | Cough)

Explaining Away

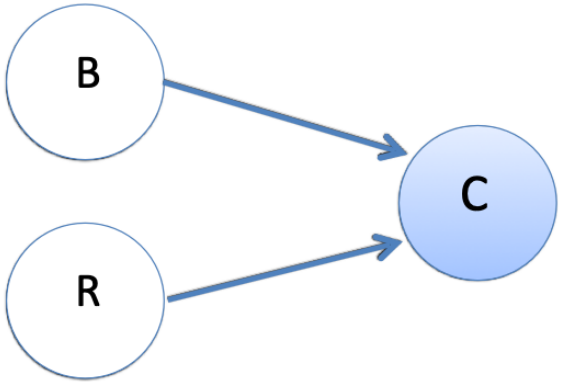
Two causes, one effect:

Marginal independence:

P(Rhinovirus | Bronchitis) = P(Rhinovirus)

Conditional dependence:

P(Rhinovirus | Bronchitis & Cough) < P(Rhinovirus | Cough)



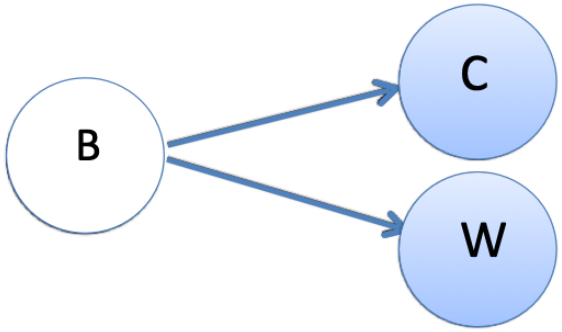
Common cause

Marginal independence?

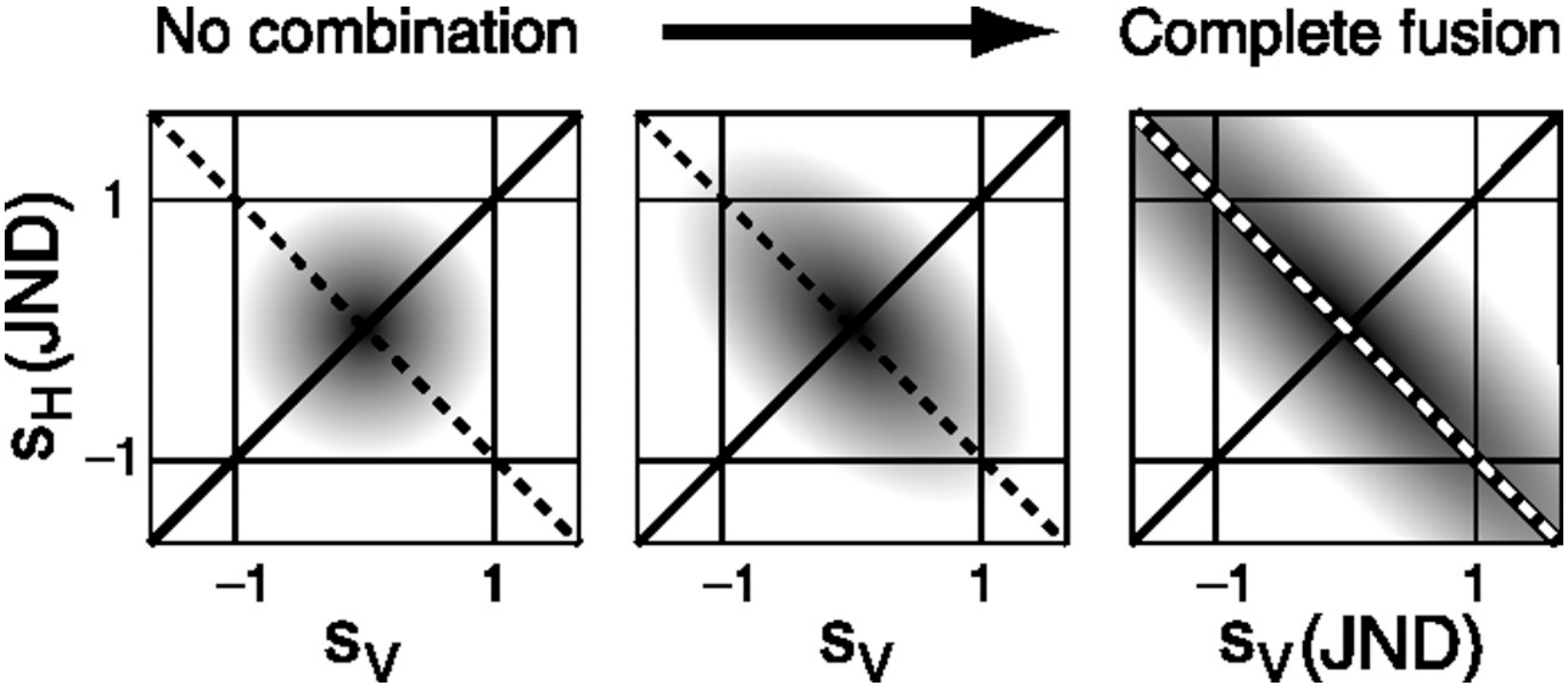
P(Cough | Wheezing) ? P(Cough)

Conditional independence?

P(Cough | Wheezing & Bronch) ? P(Cough | Bronch)

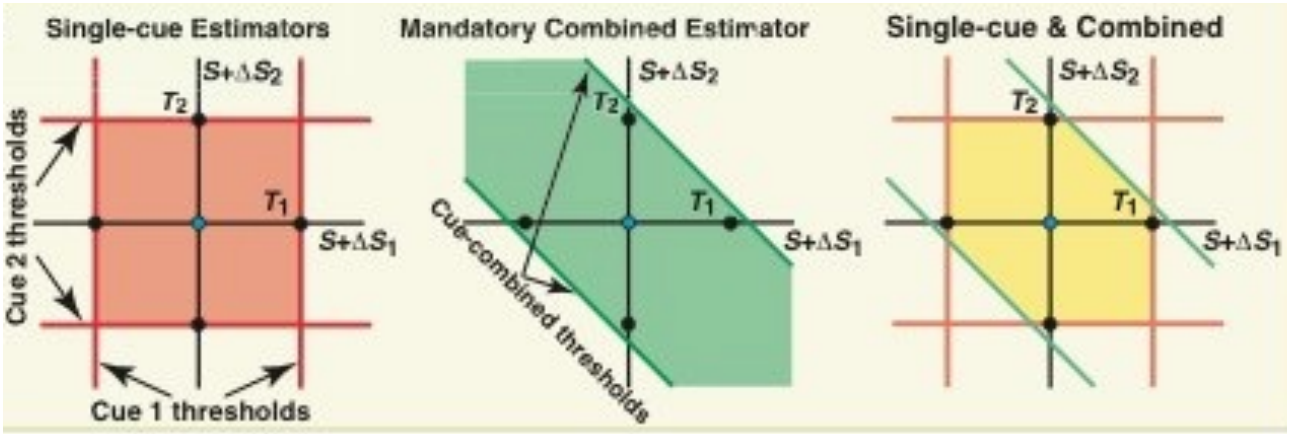


Integration vs fusion



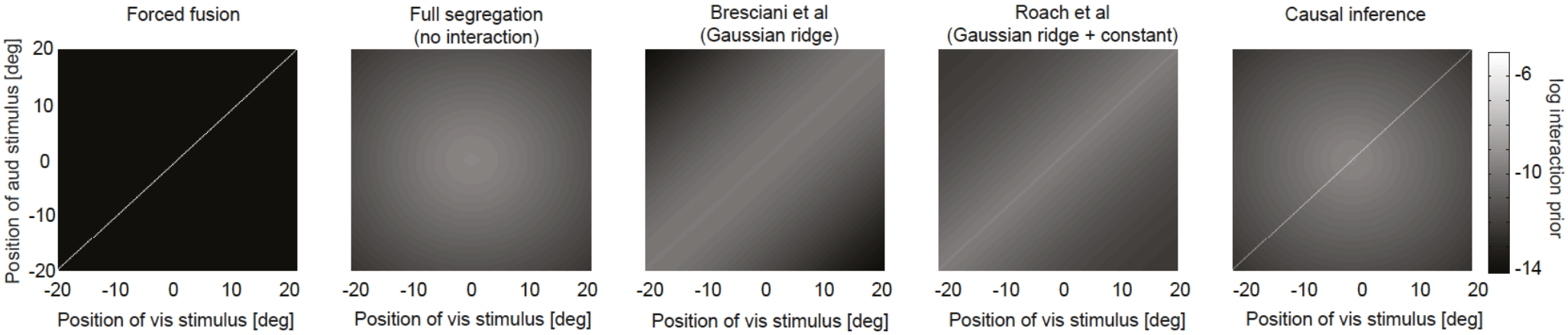
Hillis et al. (2002)

Integration vs fusion

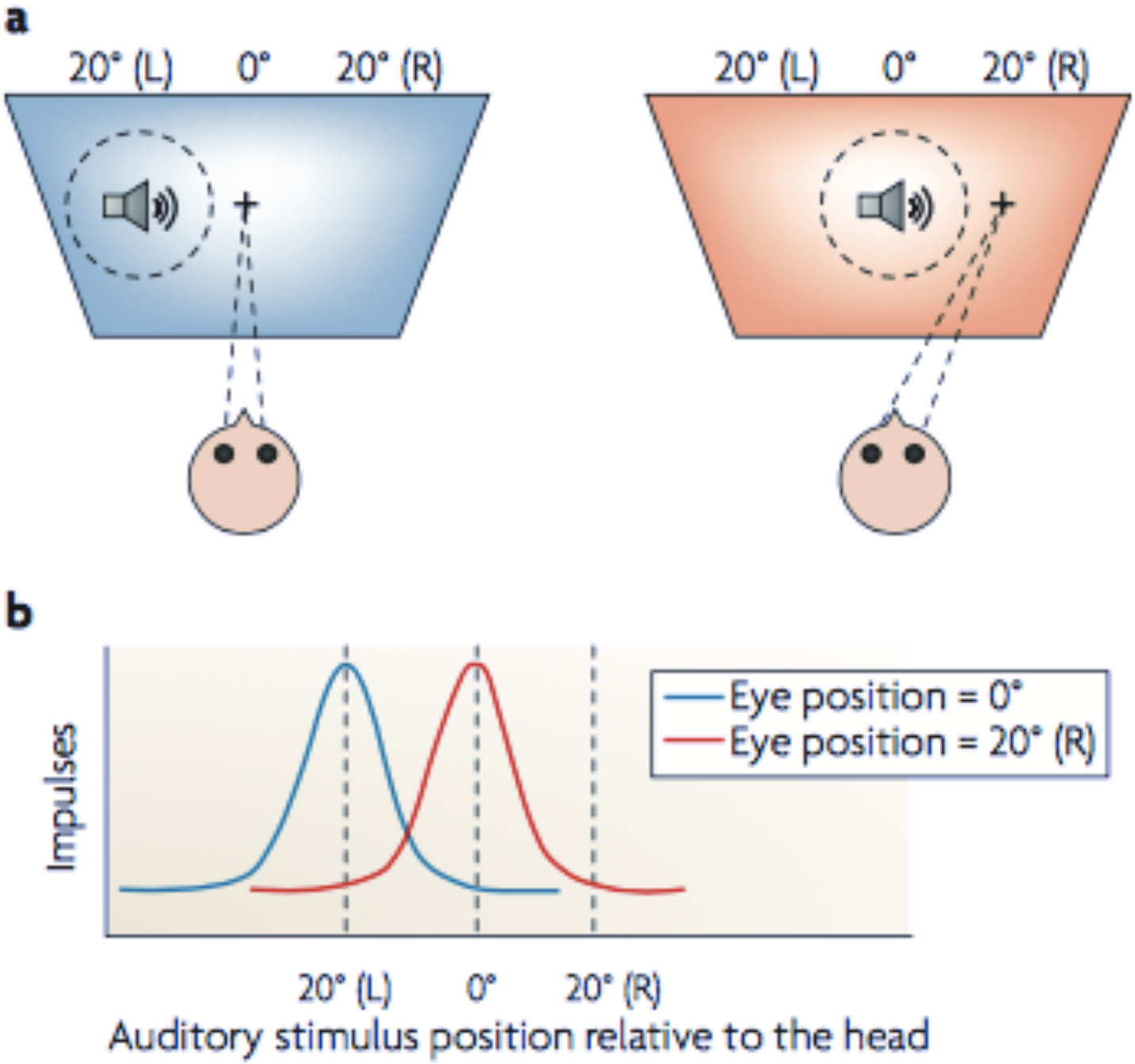


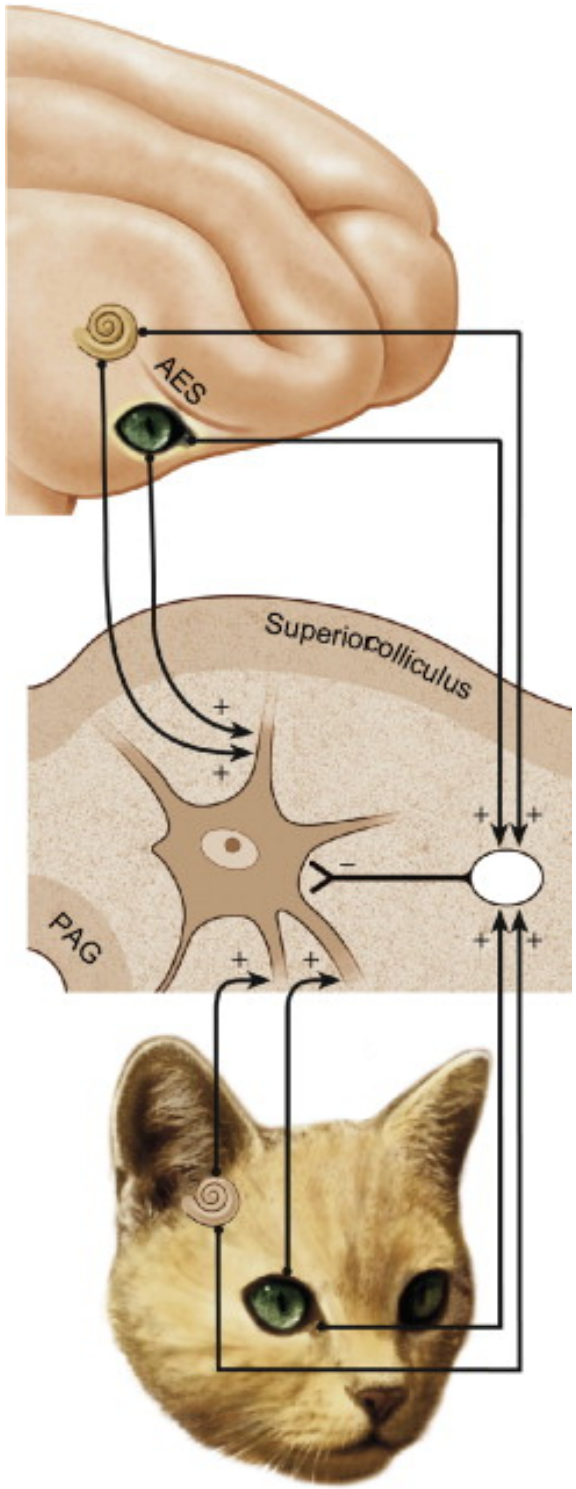
Hillis et al. (2002)

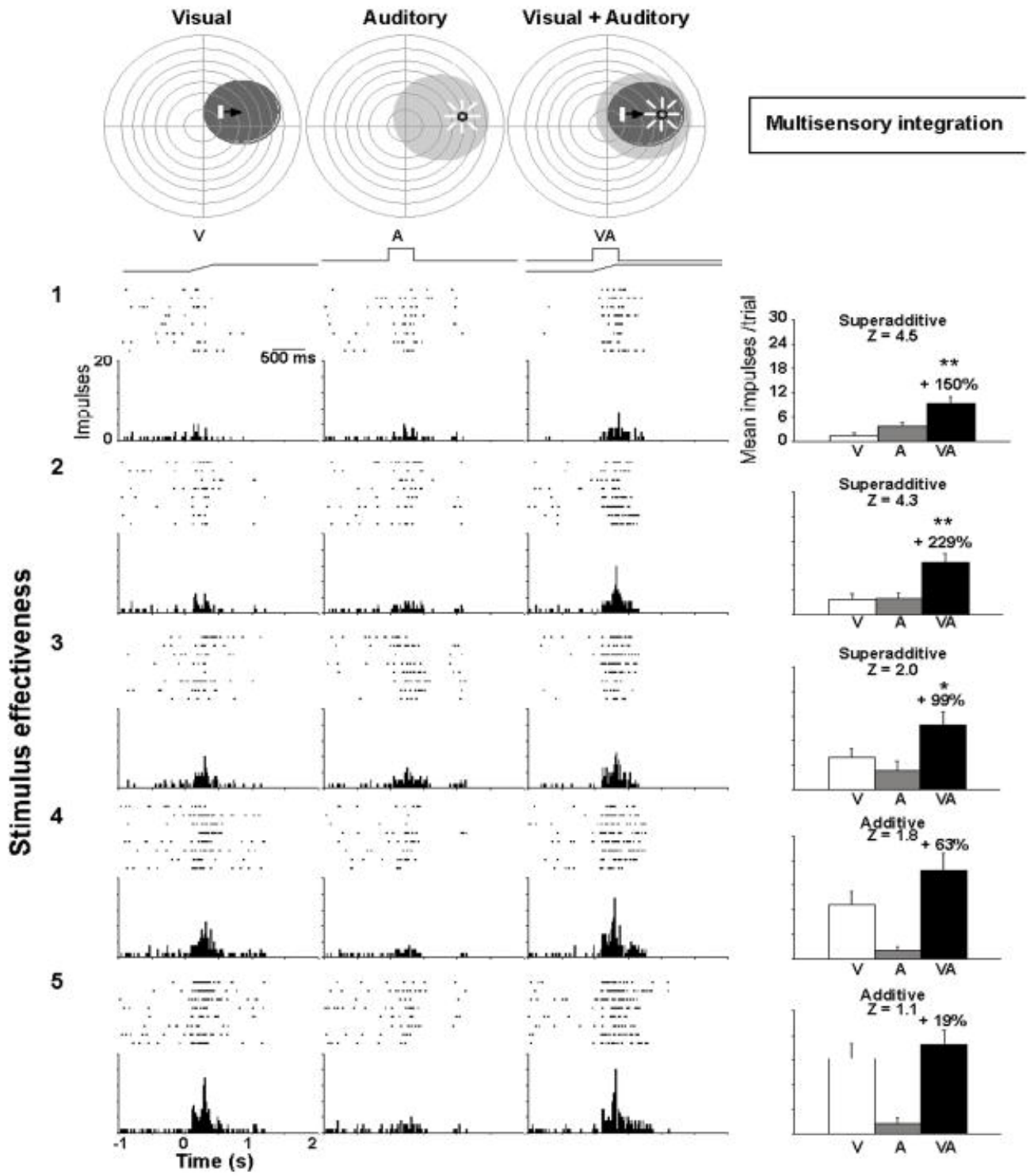
- Strength of coupling
  - Sigma determines amount of fusion
- Heavy tails
  - Conflict determines amount of fusion
- Causal inference
  - Conflict history determines amount of fusion



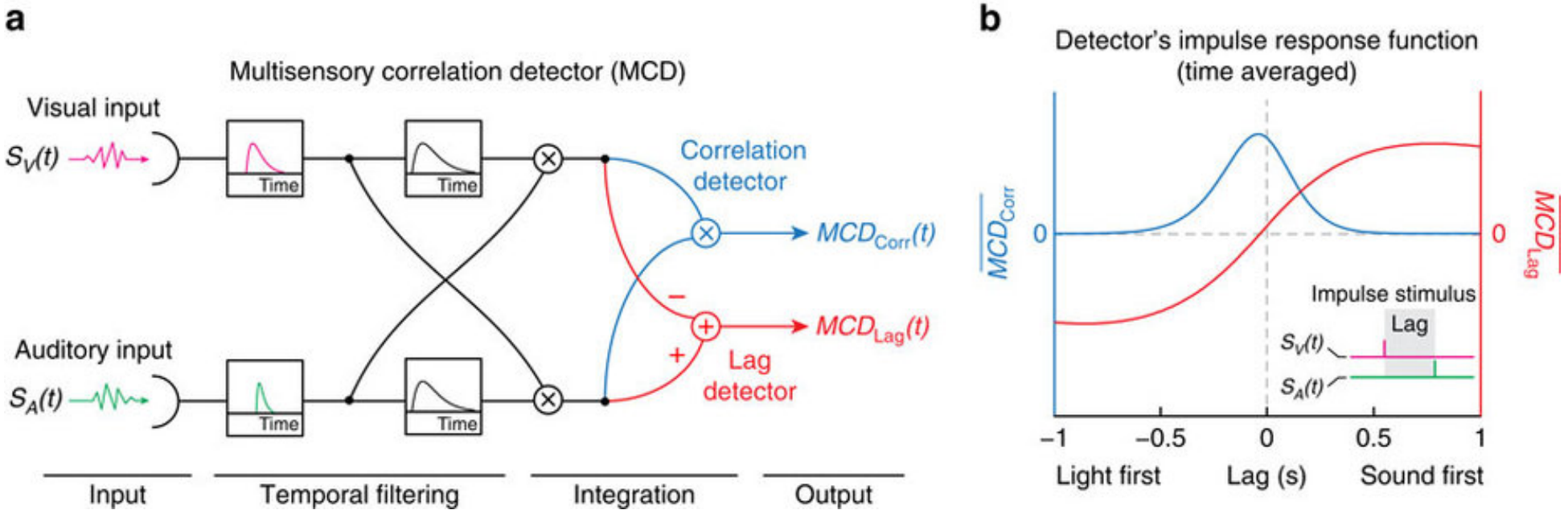
Neurons

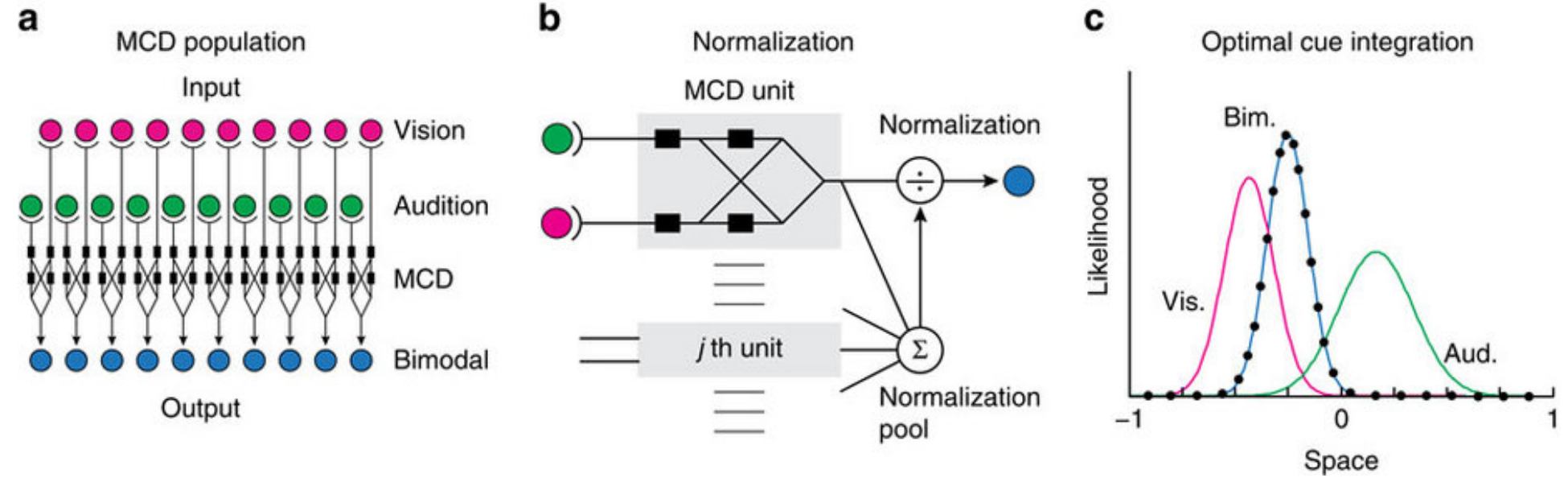

a
20° (L)
0°
20° (R)
20° (L)
0°
20° (R)
b
Impulses
Eye position = 0°
Eye position = 20° (R)
20° (L)
0°
20° (R)
Auditory stimulus position relative to the head


AES
Superior colliculus
PAG



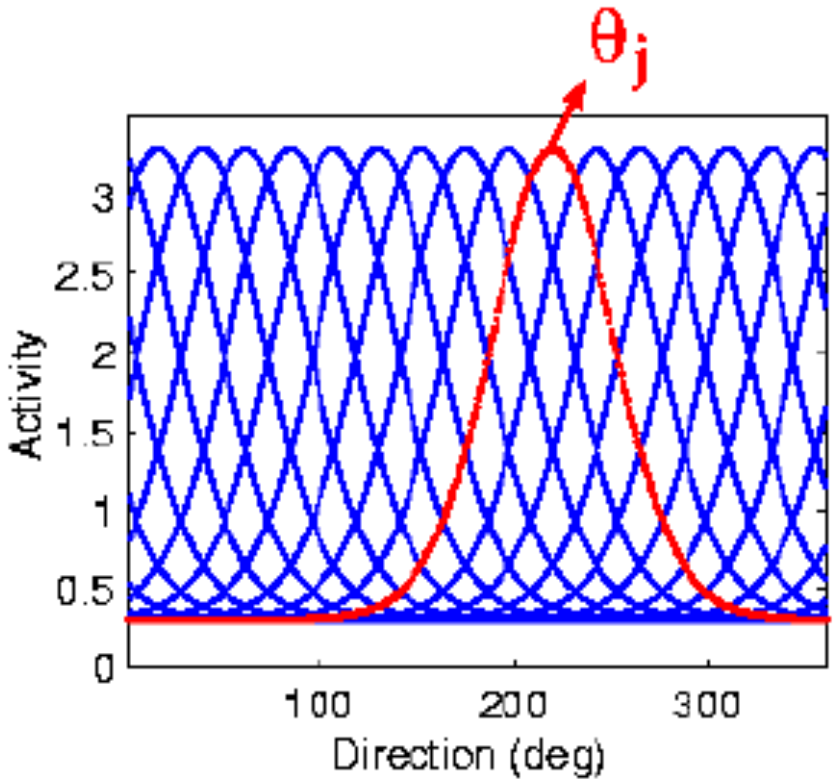
Stein, Stanford Rowland 2009

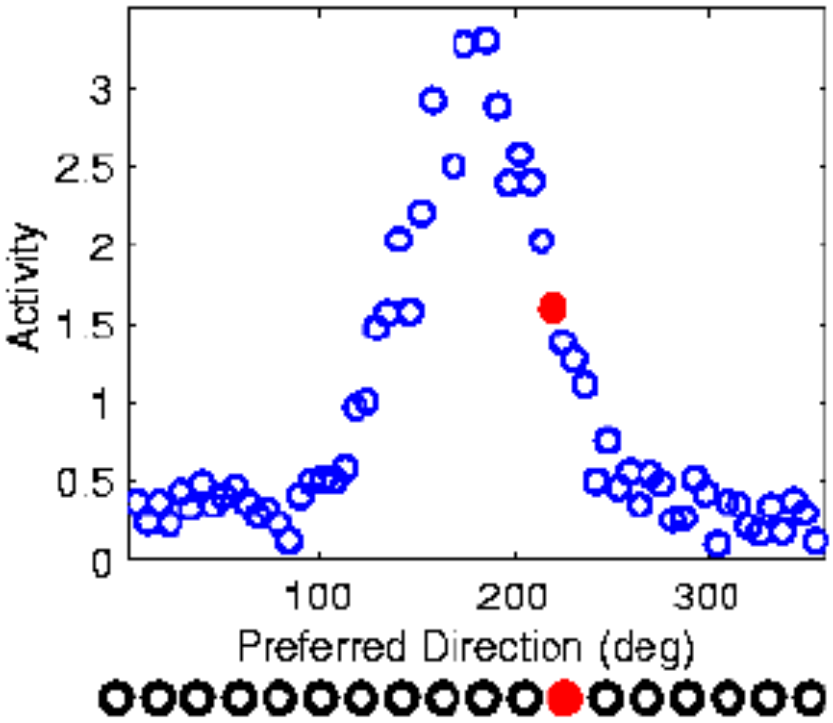




Parise & Ernst 2016

Population Code





Tuning Curves

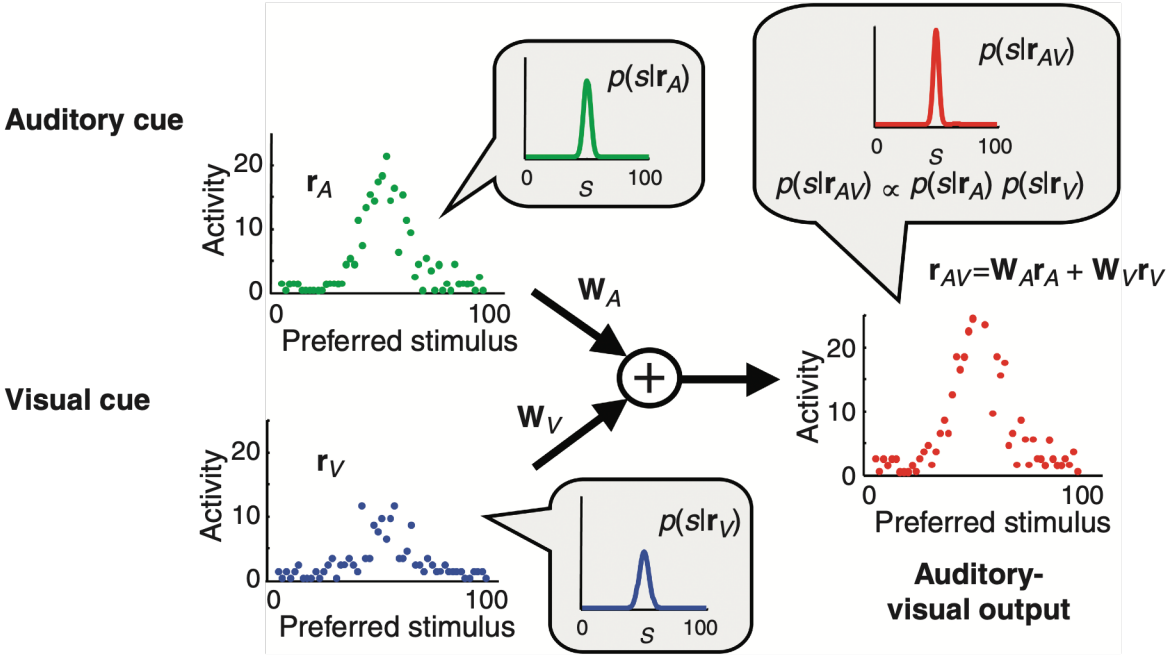
Pattern of activity

(Again)

Implementation in neurons

$$\log(P(r_1 \mid X) * P(r_2 \mid X)) = \log(P(r_1 \mid X)) + \log(P(r_2 \mid X))$$

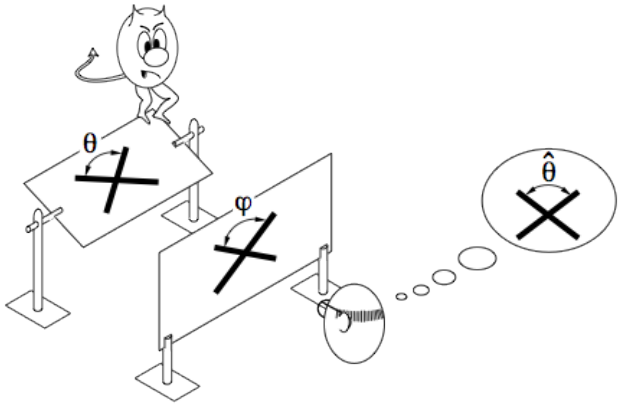
Assumes neural firing modulated by noise from the exponential family (e.g. Poisson)



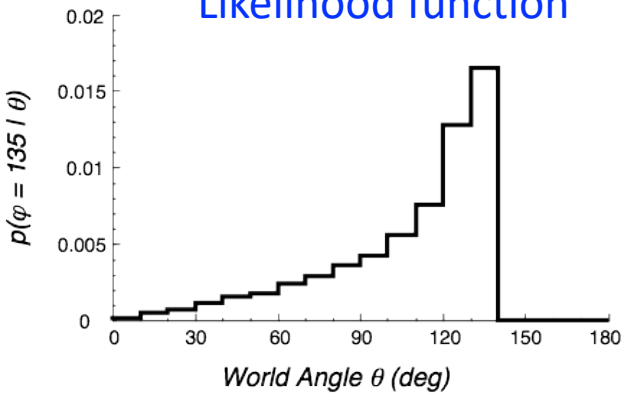
(Again)

Ma et al 06

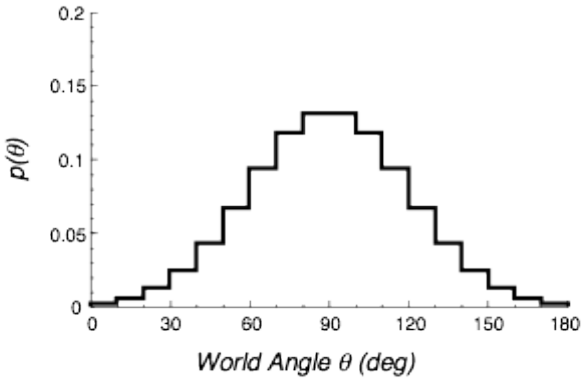
Bayesian Inference

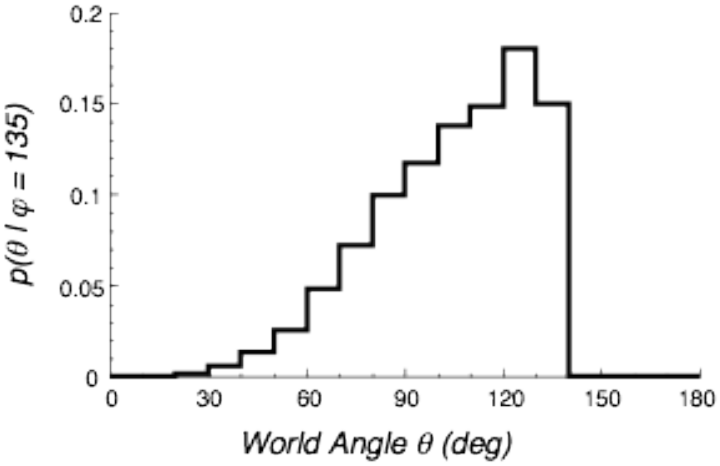


Likelihood function



Prior distribution





Posterior distribution

$$p(\theta \mid \varphi) = p(\varphi \mid \theta) \times p(\theta)/p(\varphi)$$

Likelihood

Prior

Posterior

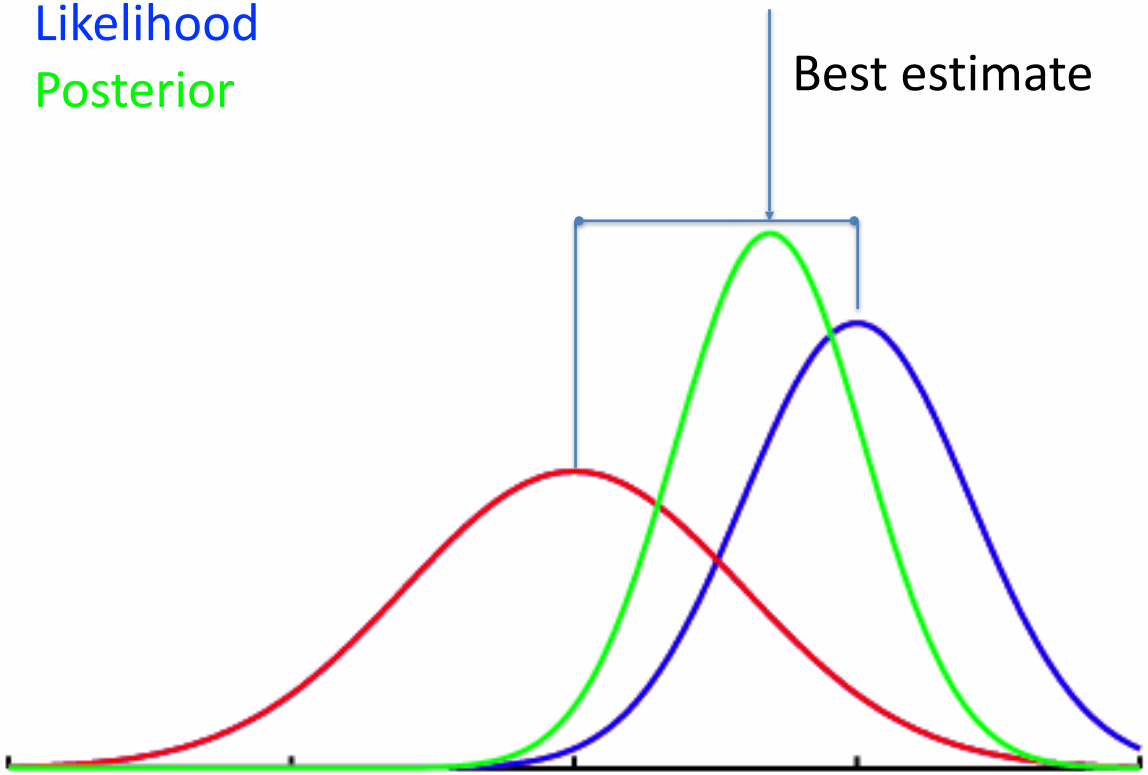
$$P(X \mid r) = \frac{P(r \mid X)P(X)}{P(r)}$$

(Again)

Mamassian Landy Maloney (2002)

Optimal estimate

Prior
Likelihood
Posterior



$$\hat{X} = w_1 \hat{X}_{Like} + w_2 \hat{X}_{Prior}$$

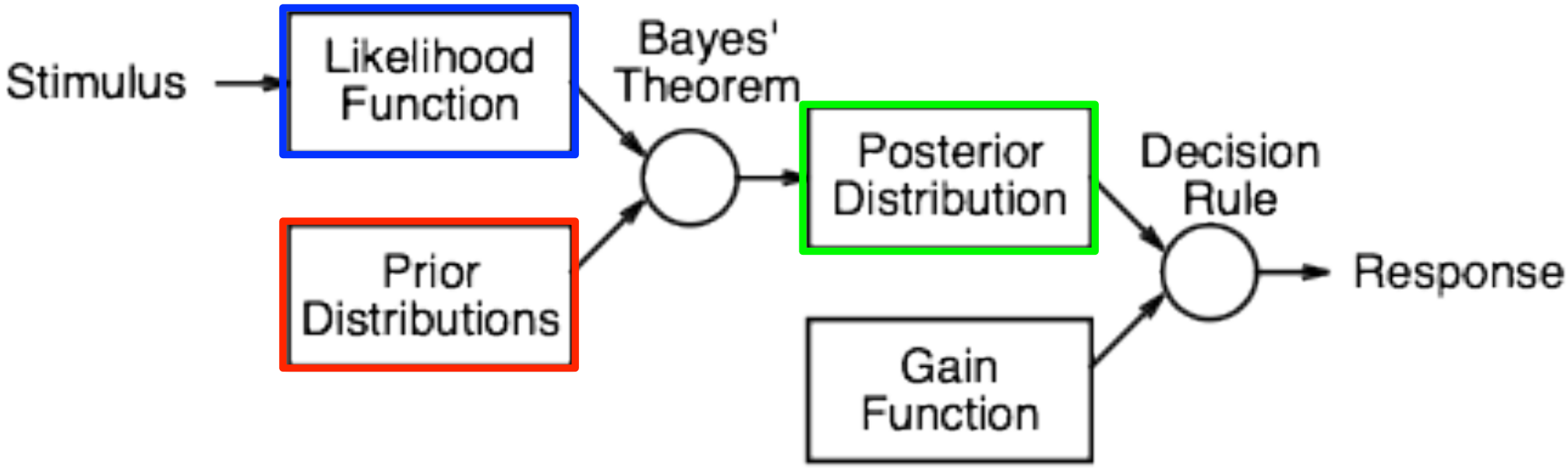
$$w_1 = \sigma_{Prior}^{\ 2} / (\sigma_{Like}^{\ 2} + \sigma_{Prior}^{\ 2})$$

$$w_2 = \sigma_{Like}^{\ 2} / (\sigma_{Like}^{\ 2} + \sigma_{Prior}^{\ 2})$$

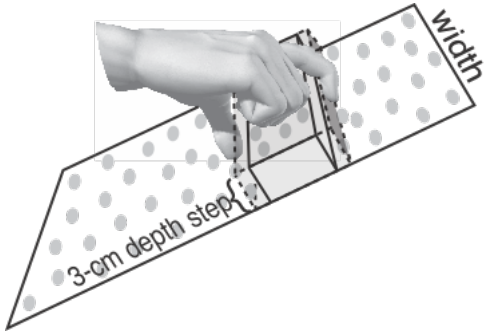
$$P(X \mid r) = \frac{P(r \mid X) P(X)}{P(r)}$$

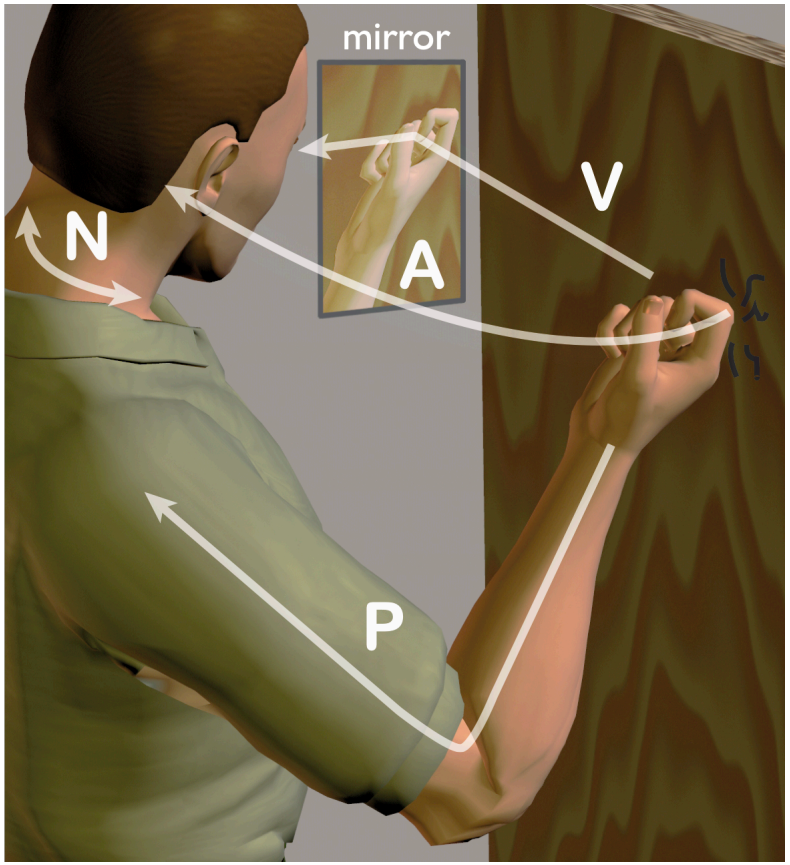
(Again)

Implementation in behaviour
Decision and action



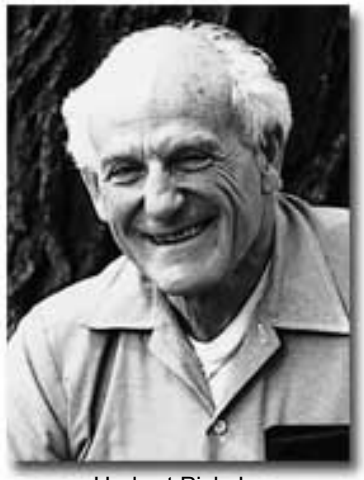
Recalibration



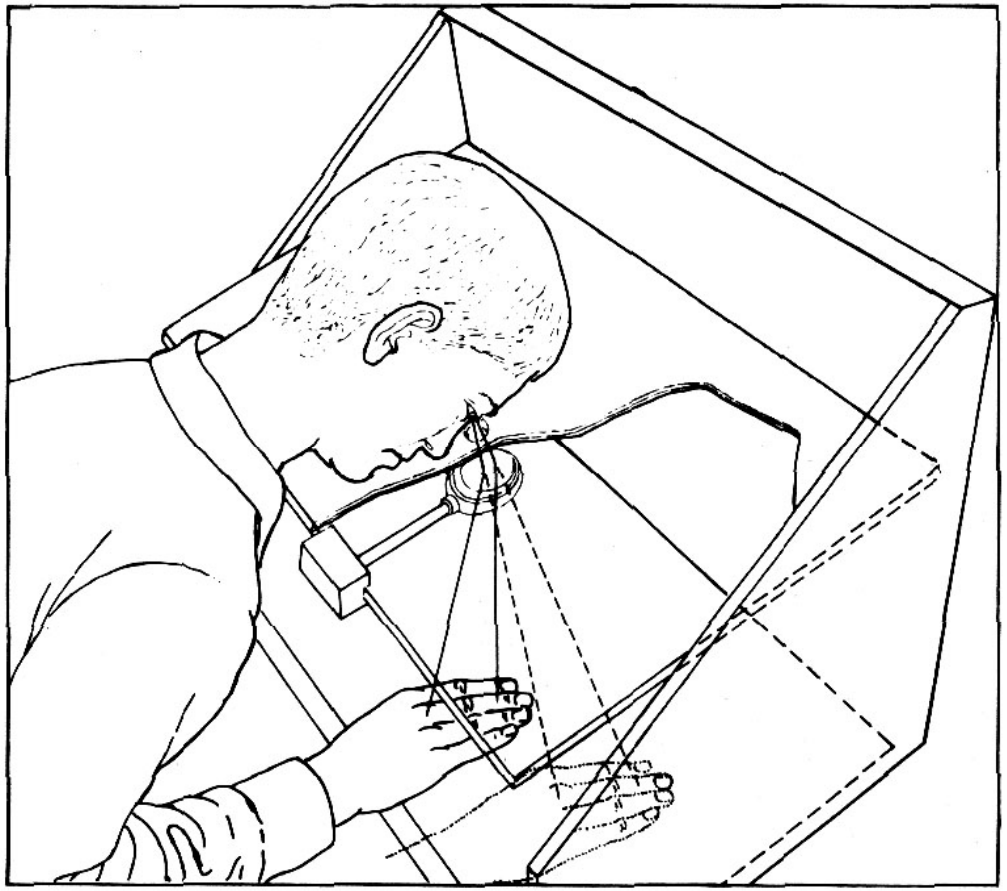


Visuomotor Adaptation

Hermann von Helmholtz
(1821-1894)



Herbert Pick Jr.

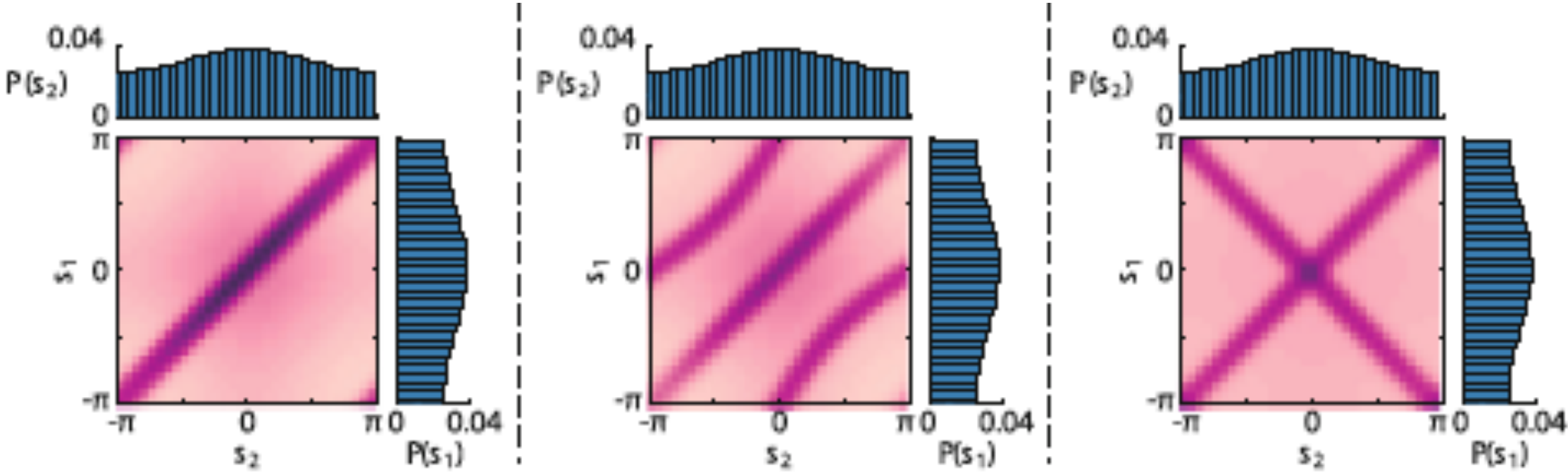


Seeing the hand through a distortion lens

- Visual and proprioceptive representation in conflict!
- How to adapt this systematic error?

(Preview to lecture 7)

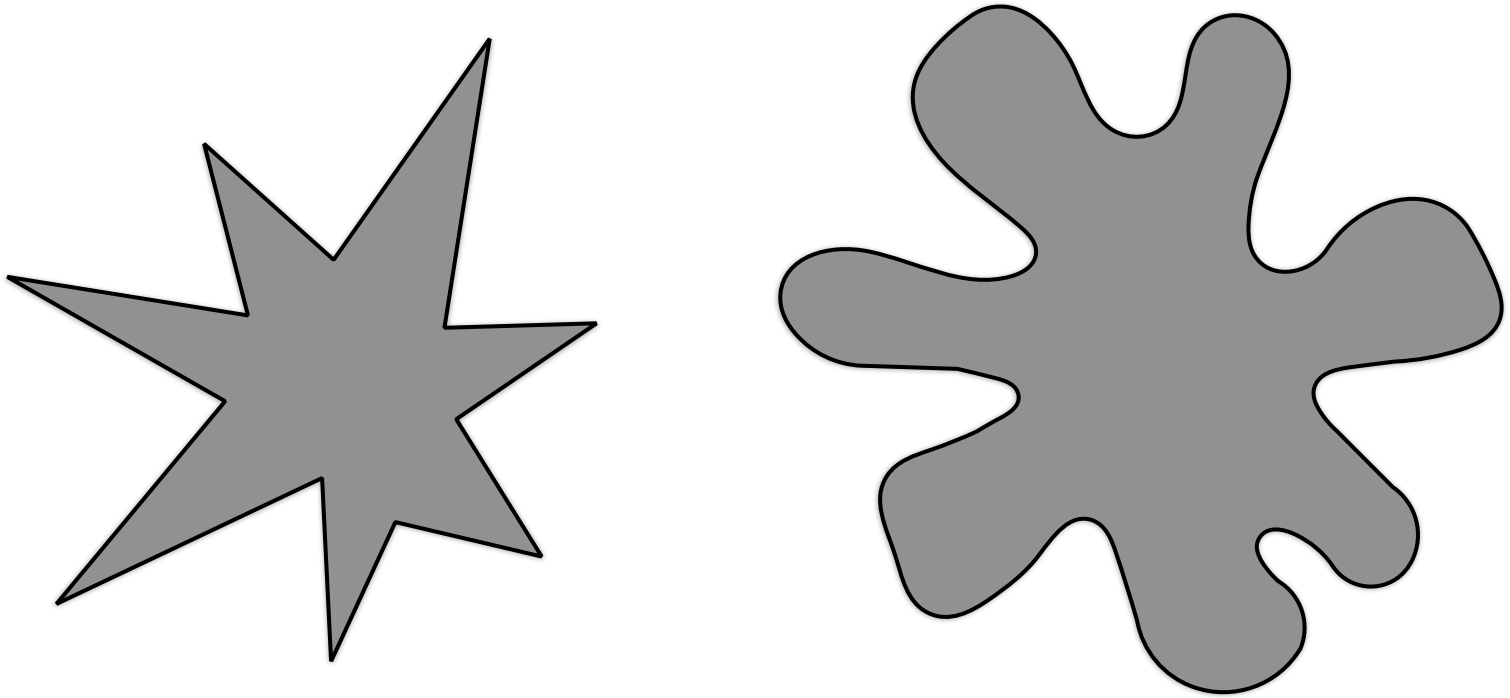
What mappings?



Wang et al (2017)

(Again)

Intrinsic mapping



Takete / Maluma
Kiki / Bouba

(Again)

Köhler (1929)

SYNESTHESIA

0123456789