G89.2223 Perception

Sensory Cue Integration

Laurence T. Maloney

Visual Tasks

Constantine Brancusi

Size?
Shape?
Distance?

Material?
Weight?
Warmth?

Visual Tasks

Constantine Brancusi

Size?
Shape?
Distance?

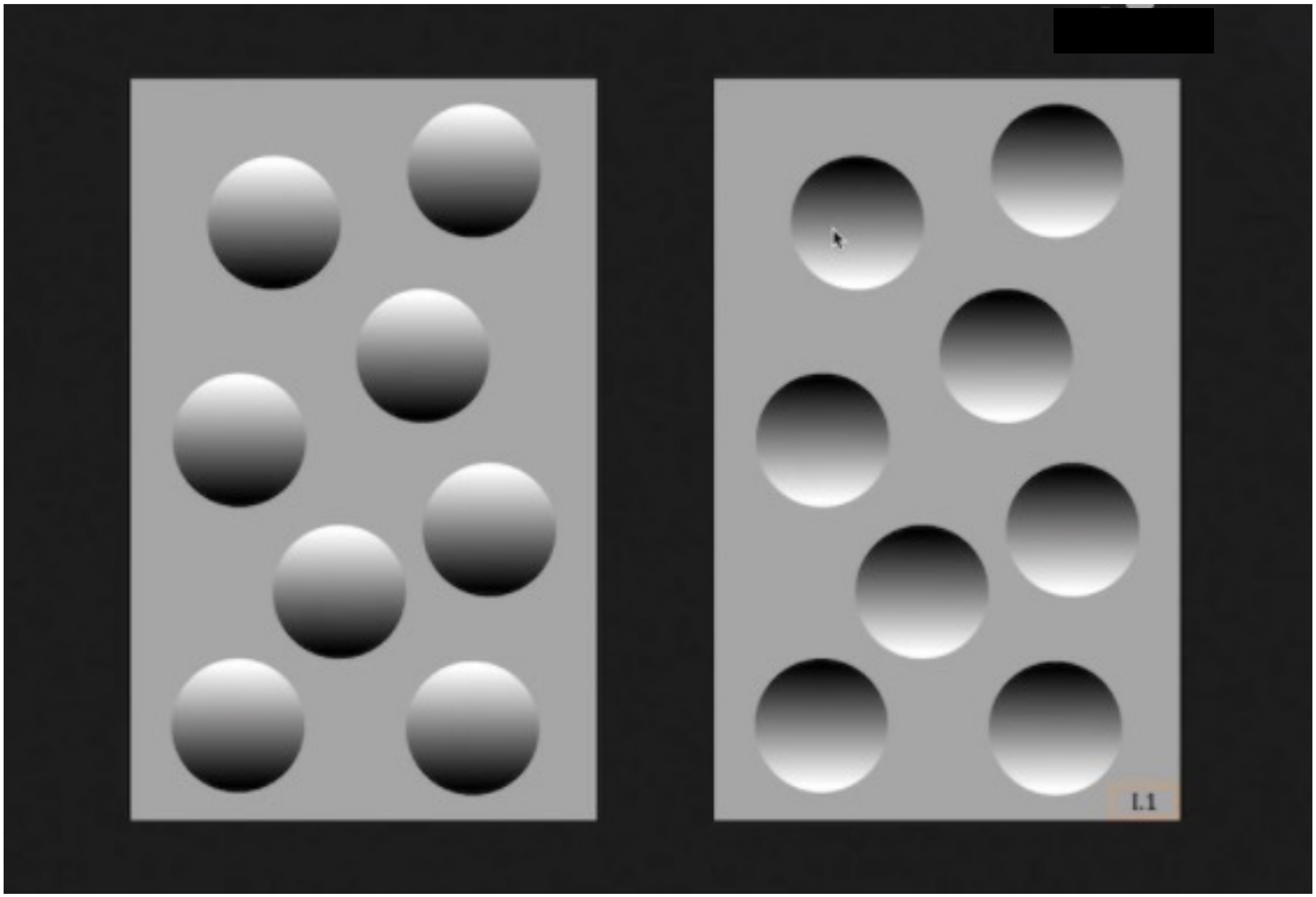
Material?
Weight?
Warmth?

There are typically multiple **cues** to depth/distance in a scene

Carlo Crivelli c. 1486

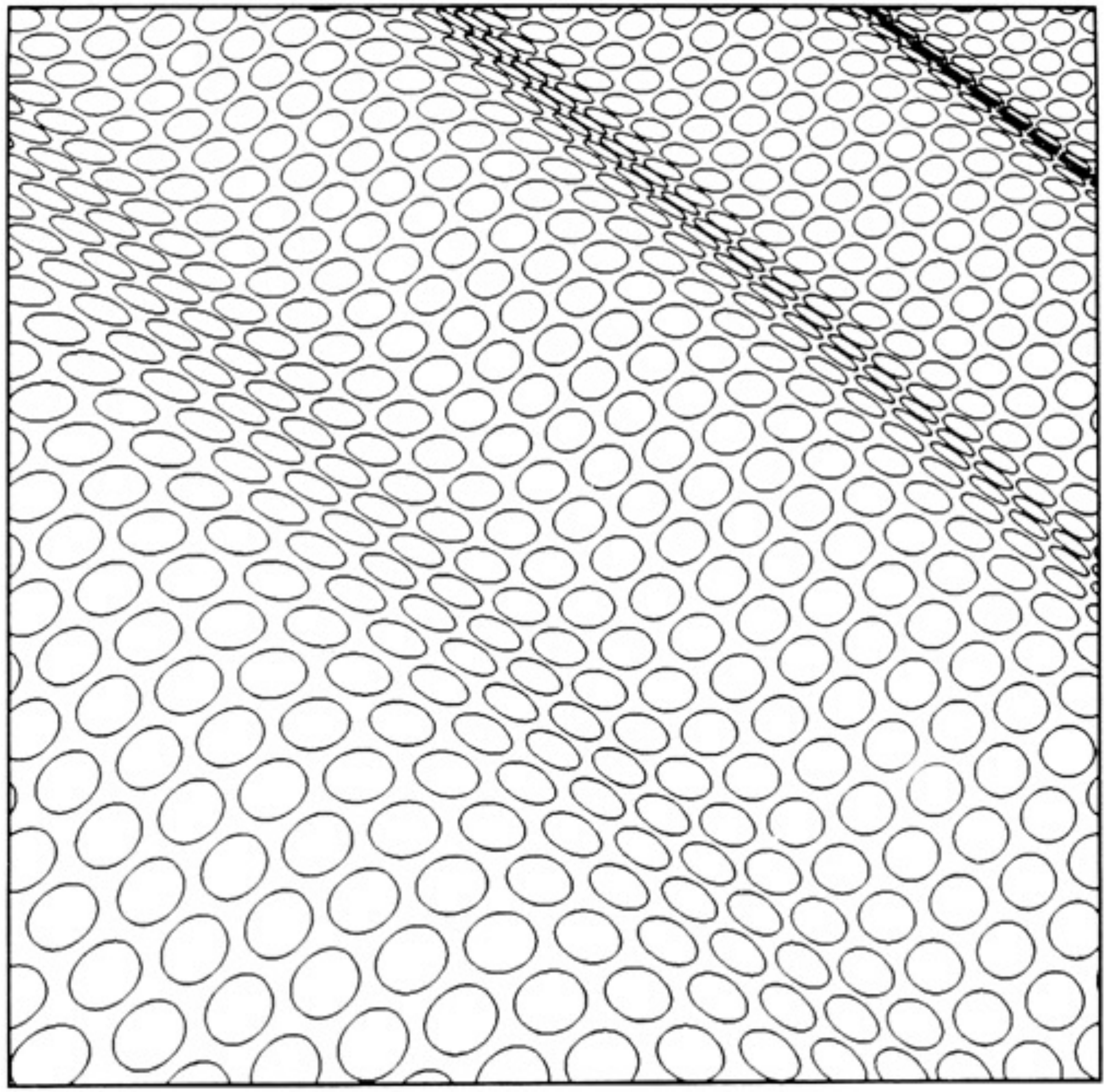
Some examples of cues to depth or shape

Shading

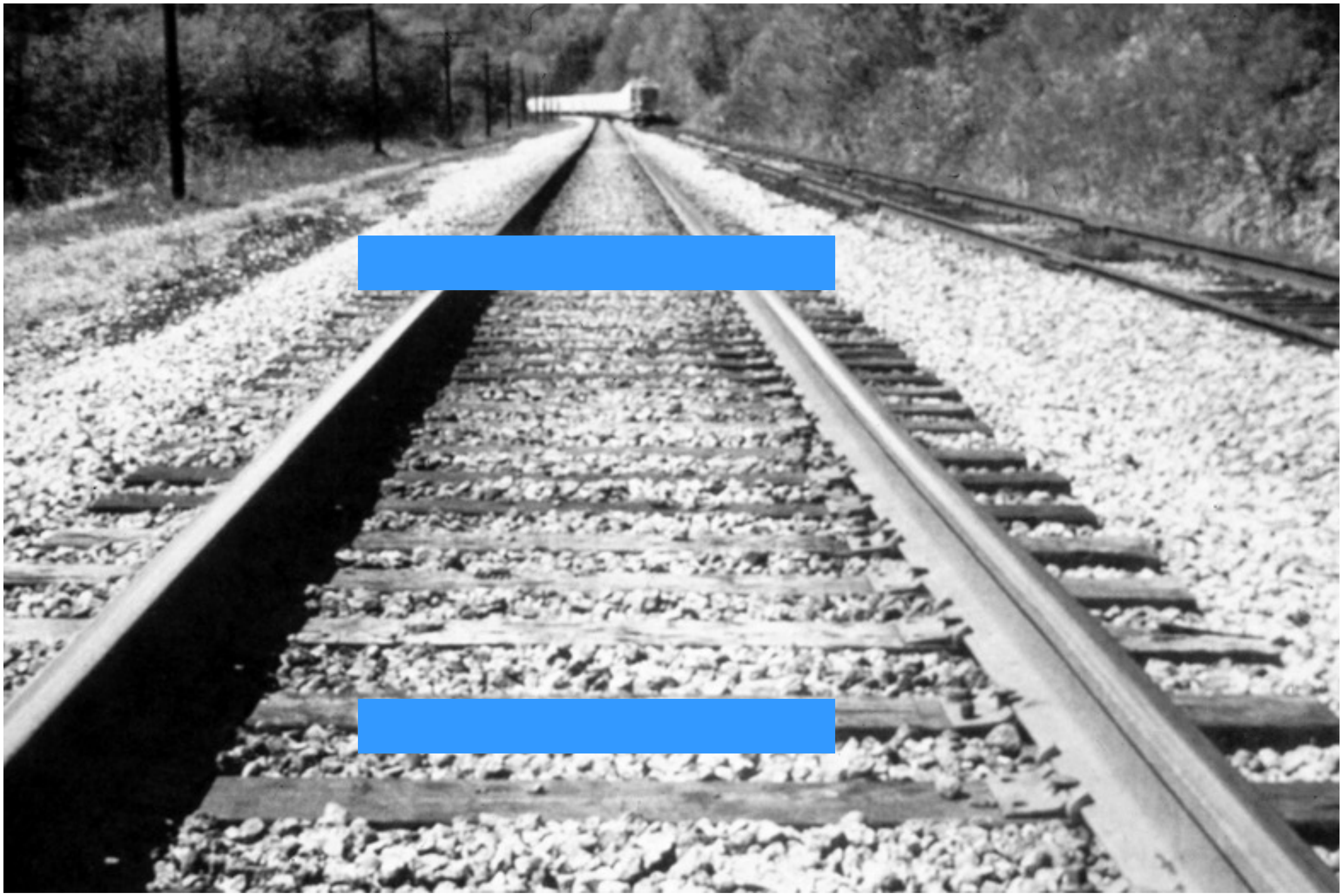


Texture Gradients

1. Density
2. Foreshortening
3. Size



Linear perspective



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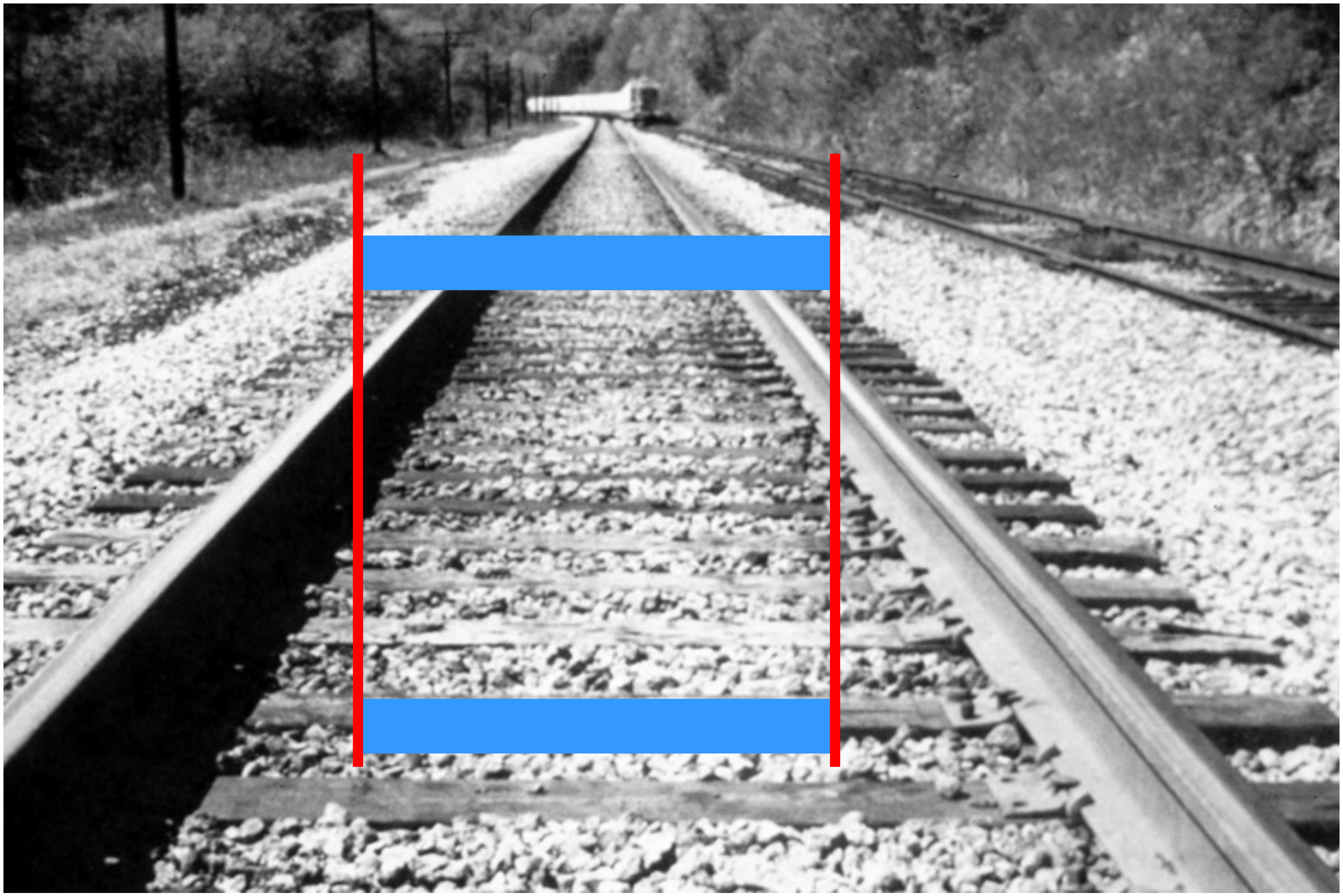
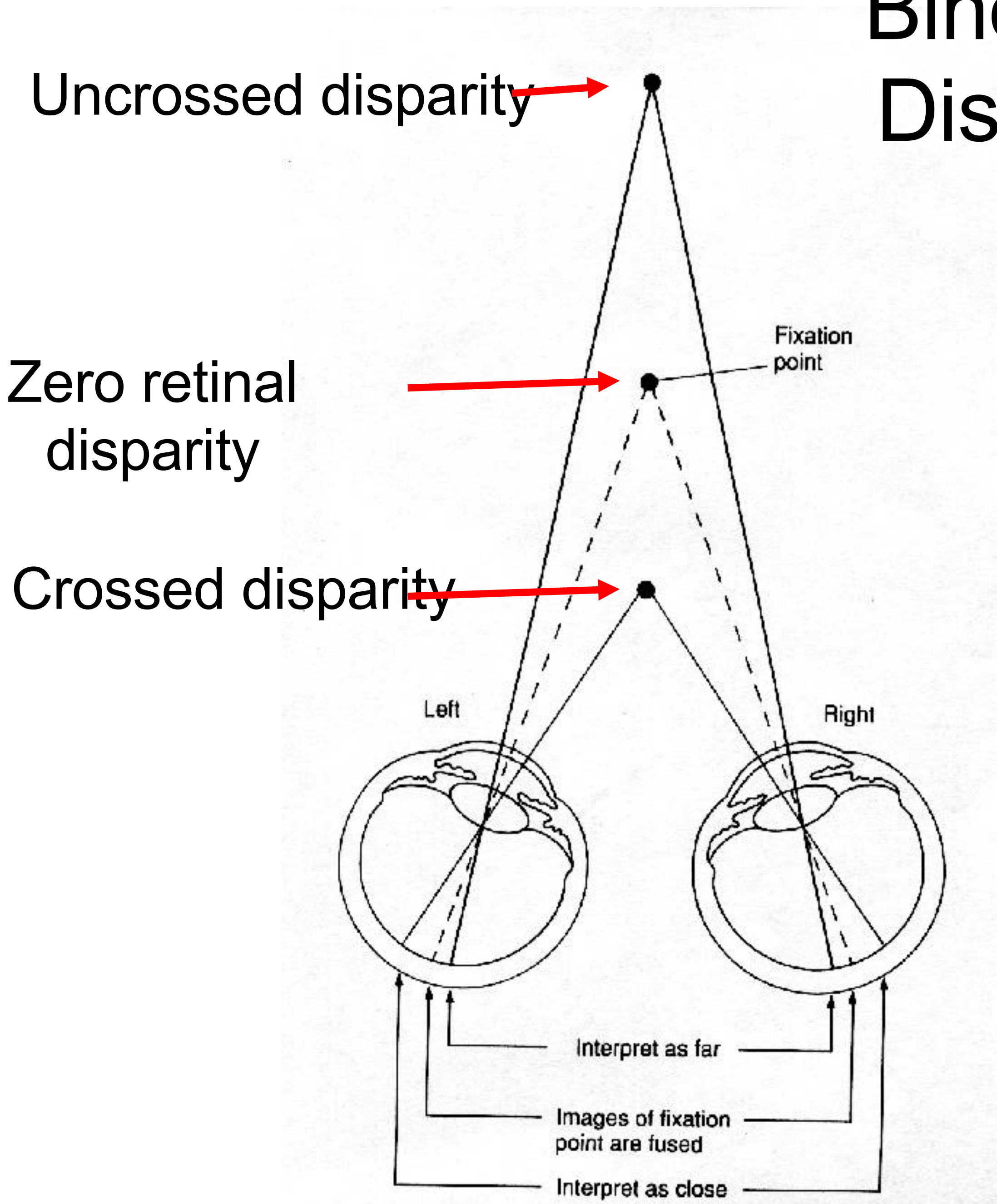
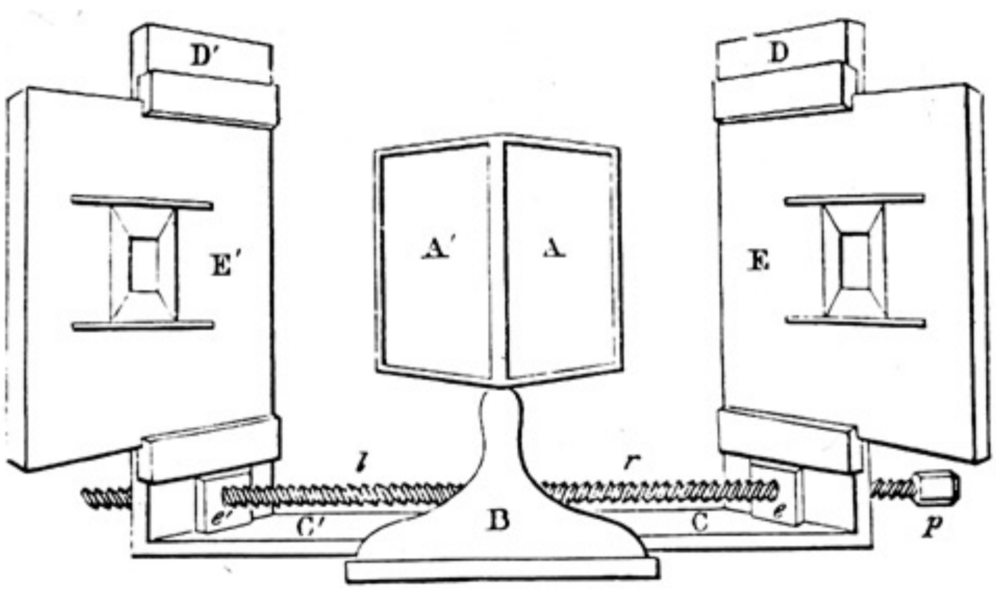


Binocular Disparity

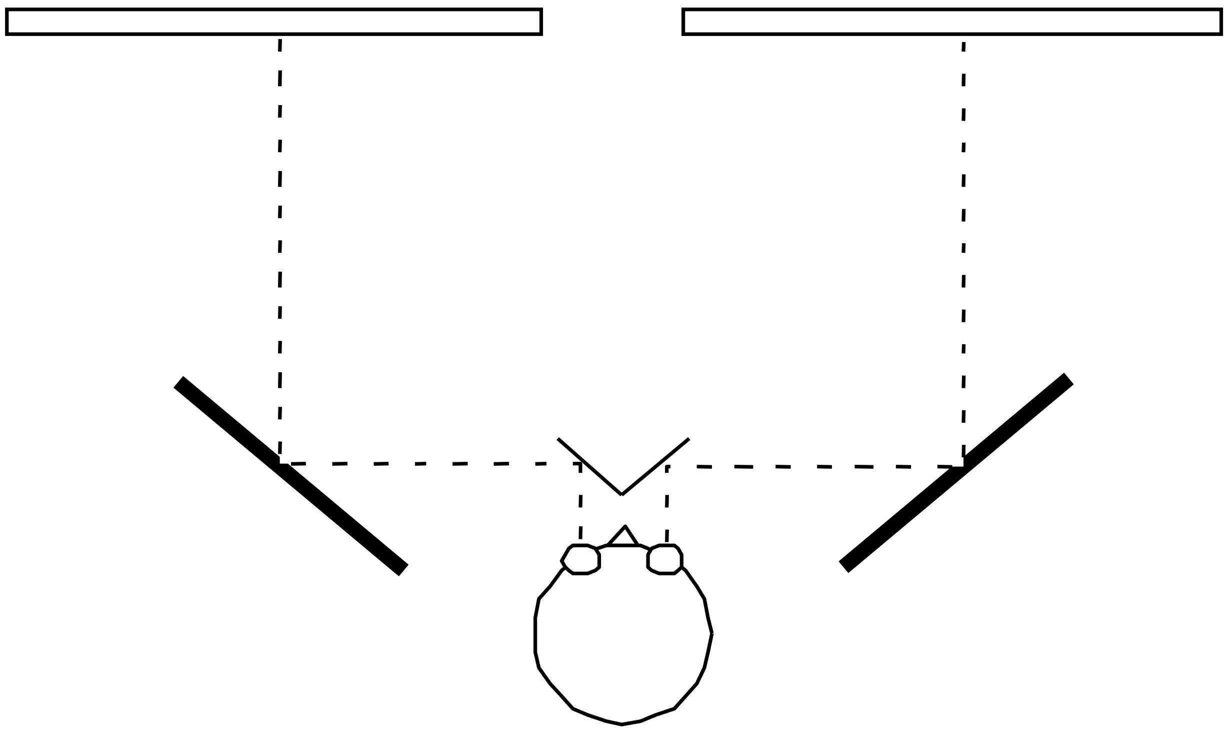


Wheatstone stereoscope (c. 1838)



Sir Charles Wheatstone

Dual mirror stereoscope



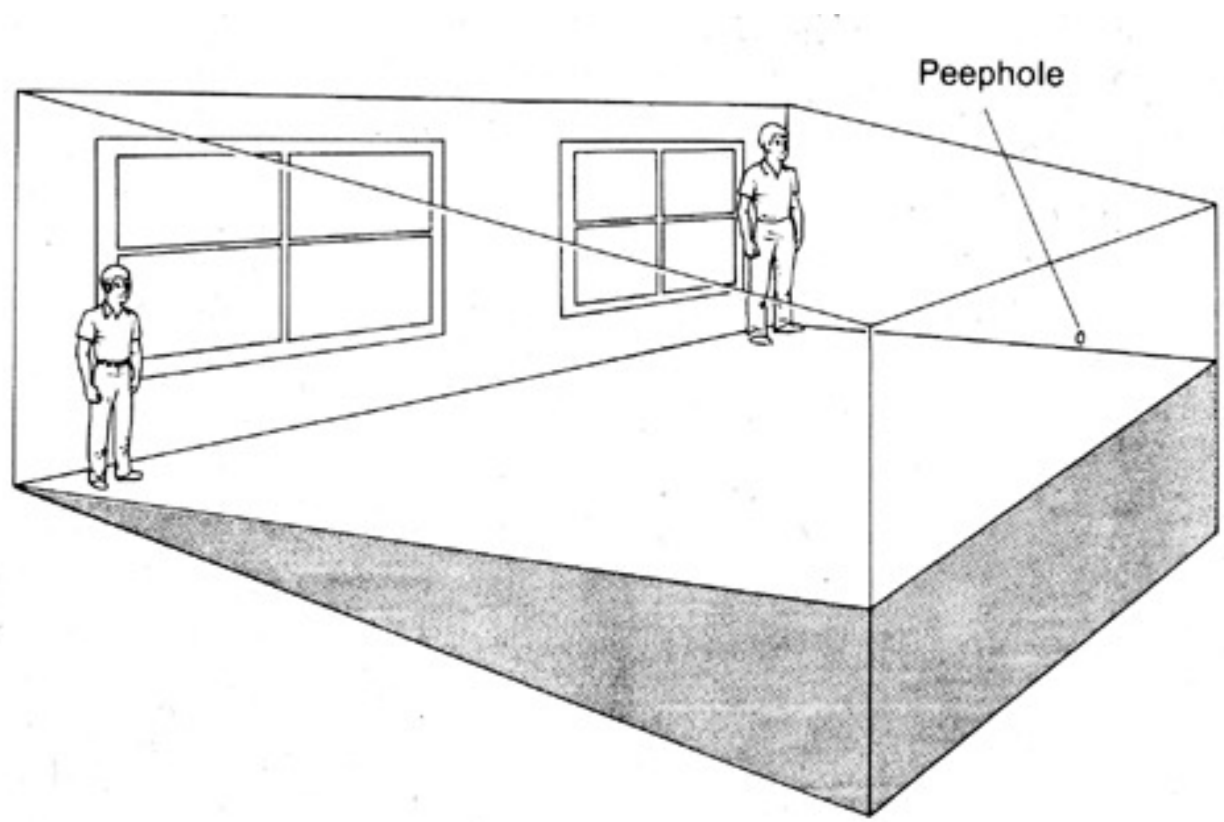
Cues in Conflict

When we have multiple cues to depth or shape the cues may conflict

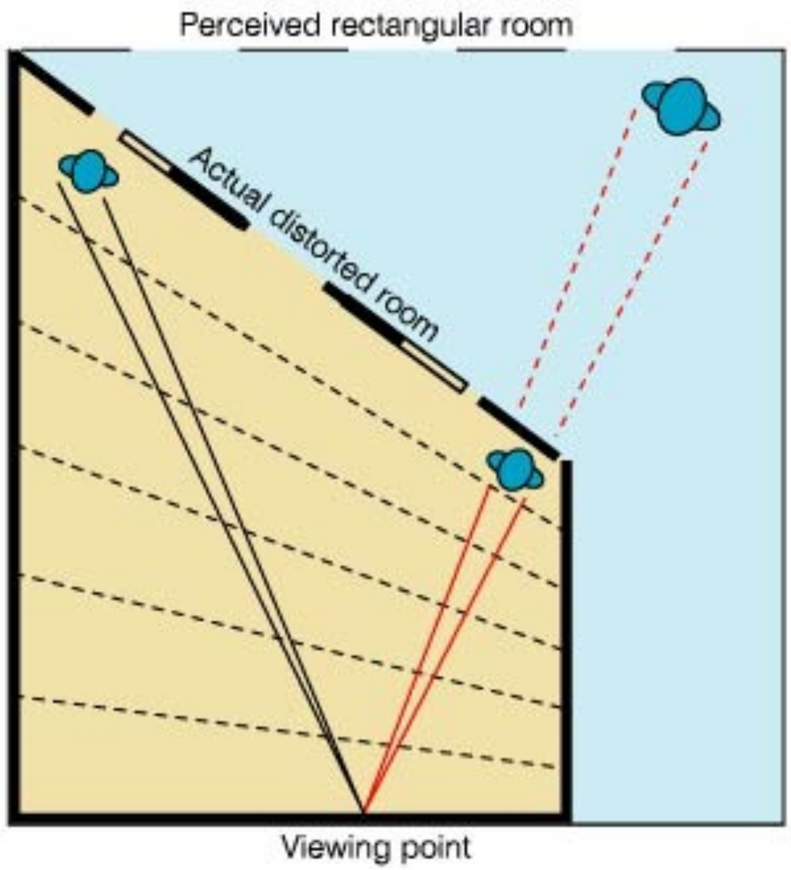
When two cues disagree (a lot) what do we do?

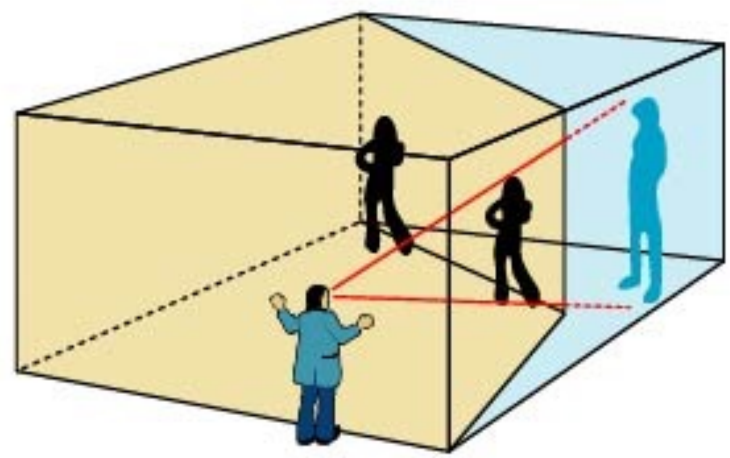
Ames Room

Ames Room: Real Layout



Ames room


Perceived rectangular room
Actual distorted room
Viewing point



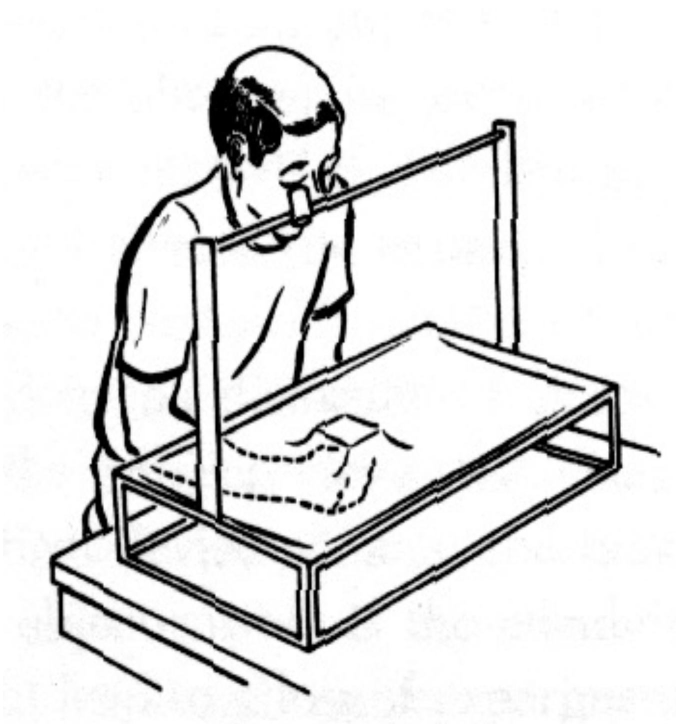
Cue Integration

When we have multiple cues to the same thing:

- What should we do?
- Can we do better than we could with any single cue?

Rock & Victor (1964)

View object through distorting lens while exploring object haptically

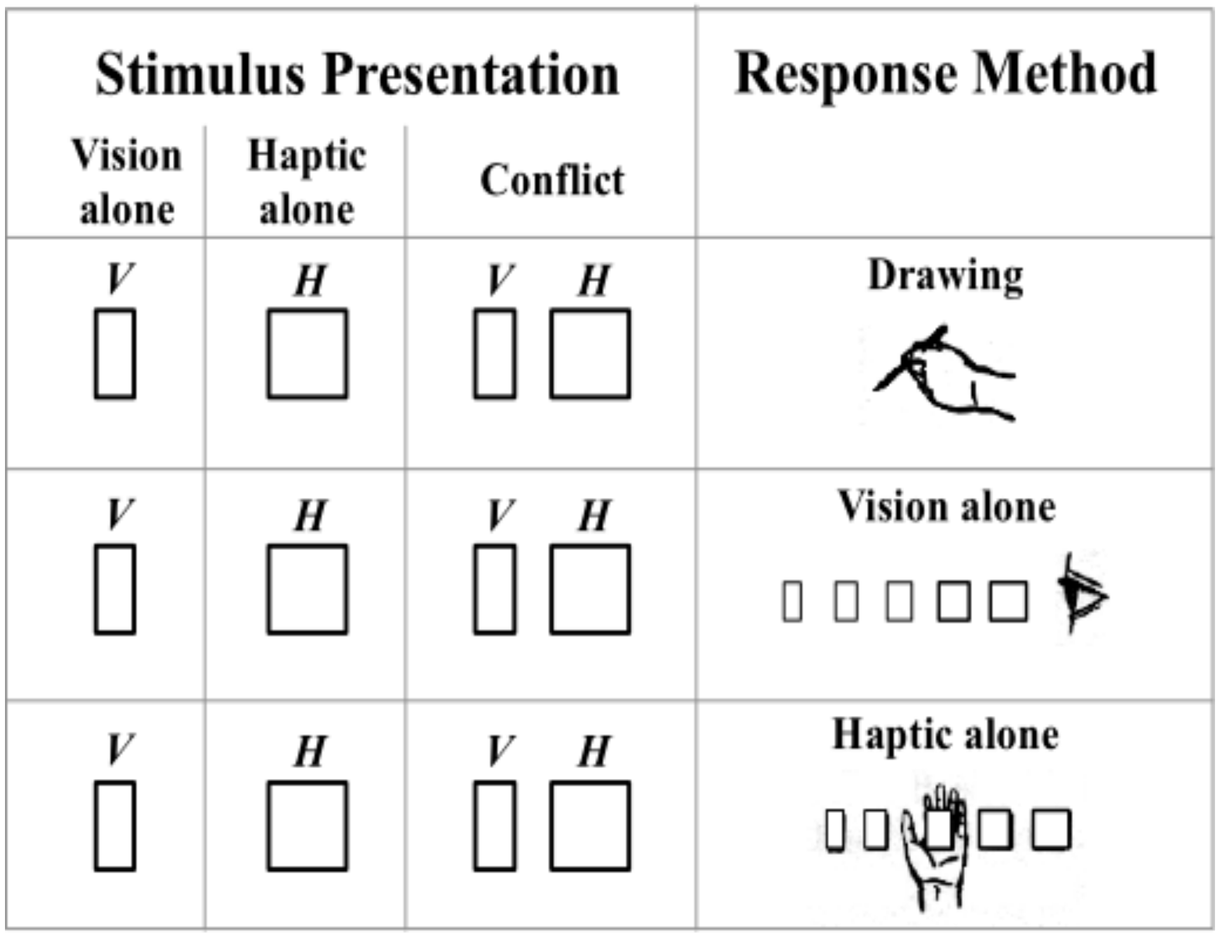


Irv Rock

Visually and haptically specified shapes differed.

What shape is perceived?

Rock & Victor (1964) Experimental Design



Rock & Victor (1964) Results

Stimulus Presentation			Response Method
Vision alone	Haptic alone	Conflict	
V 1.90	*H* 0.98	*V* *H* 1.85	Drawing 
V 13.4	*H* 23.1	*V* *H* 14.1 mm	Vision alone 
V 14.1	*H* 20.5	*V* *H* 14.5 mm	Haptic alone 

Rock & Victor (1964)
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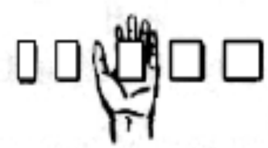
V 14.1	*H* 20.5	*V* *H* 14.5 mm	Haptic alone 

Vision seems to dominate haptic.

Visual Capture

(How) should we combine cues?

S_H haptic size estimate

S_V visual size estimate

random variables

Modeling Cue Combination

Modeling Cue Integration

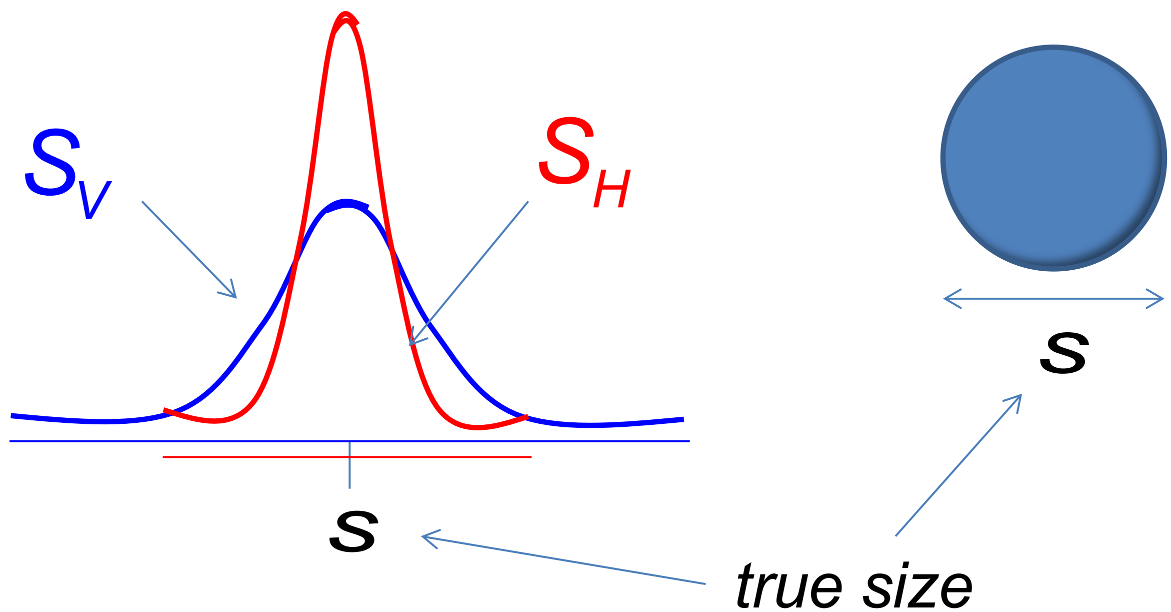
**Different people use different terminology.*

true size

ASSUMPTION

$$S_H \sim Gaussian\left(s, \sigma_H\right)$$

$$S_V \sim Gaussian\left(s, \sigma_V\right)$$

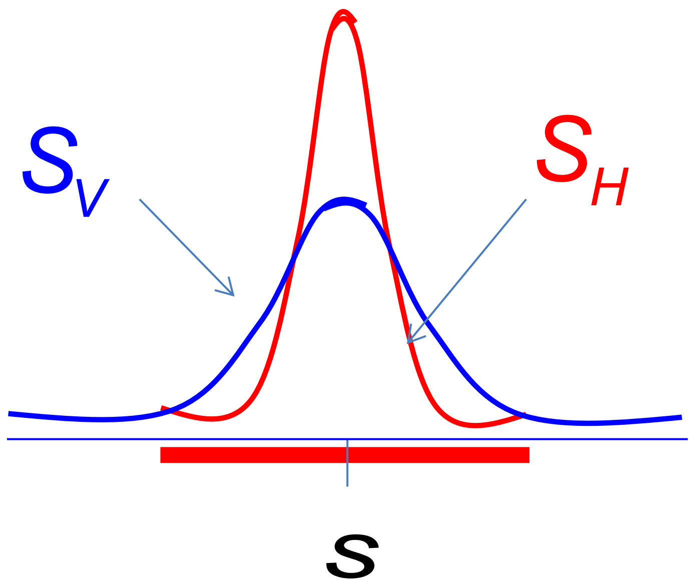


Thought Example

haptic cue is
less variable

$$S_H \sim Gaussian(10\,cm, 1cm)$$

$$S_V \sim Gaussian(10\,cm, 2\,cm)$$



$10 if you are within
1 cm of *s*

Which cue?
Chances of winning?

Some Possible Rules

1. Fixed hierarchy rule

   Vision > Auditory > Haptic > …. hypothetical order

   Use first available cue in order above.

2. Best single cue

   Use cue with lowest variance.

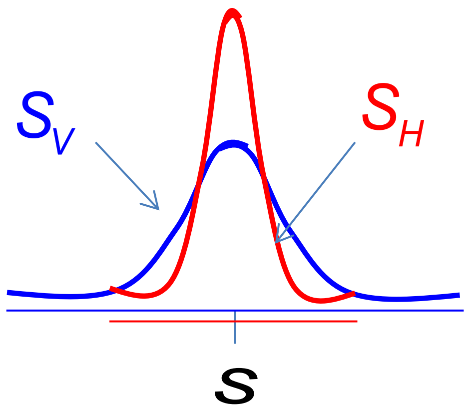
   Discard others.

   How does the visual system get an estimate of variance?

3. Weighted average of the cues …

   How choose weights?

Can we do better by combining cues?

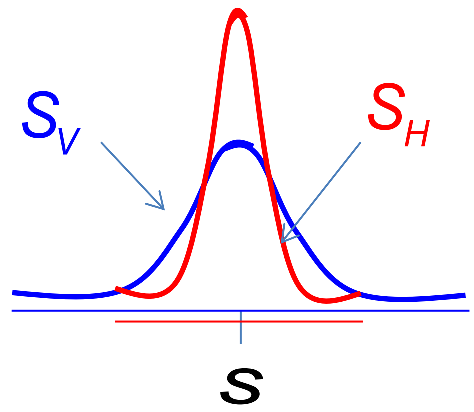


$$S = wS_H + (1 - w)S_V$$

$$0 \leq w \leq 1$$

"weighted linear combination"

All Three Rules are weighted liner combinations



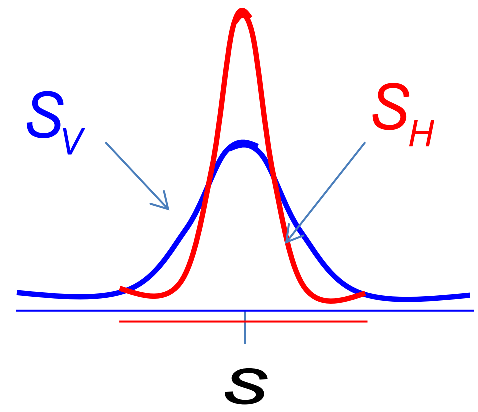
$$S = wS_H + (1-w)S_V$$

1. Fixed hierarchy rule   w = 0 (Vision)

2. Best single cue   w = 1 (Haptic)

3. Combine the cues somehow … w = ?

Can we do better by combining cues?



$$S \quad = wS_H + (1-w)S_V$$

$$0 \;\le\; w \le\; 1$$

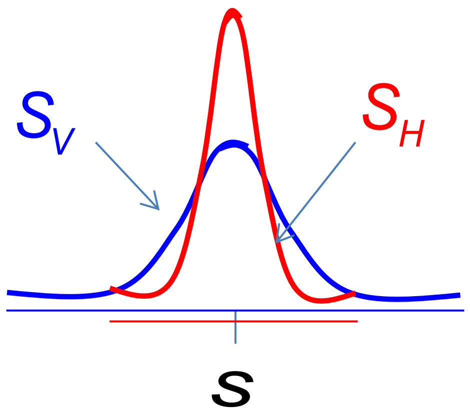
What is the "best" value of *w*?

We have to decide what our goal is

We combine two cue S_H and S_V to get a new cue S.

Goal: We want S to be *unbiased* and to have *minimum variance*.

ASSUMPTION: UMVUE



$$E[S] = wE[S_H] + (1-w)E[S_V]$$
$$= ws + (1-w)s = s$$

unbiased

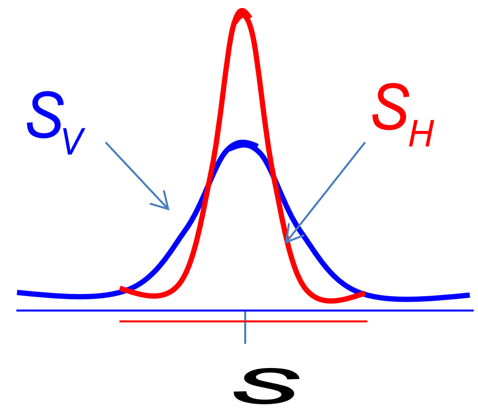
Review on variance σ^2

$$Var[sX] = s^2 Var[X]$$

$$Var[X+Y] = Var[X] + Var[Y]$$

X, Y *independent* variables

ASSUMPTION: S_H and S_V independent
See Oruc, Maloney & Landy (2003)

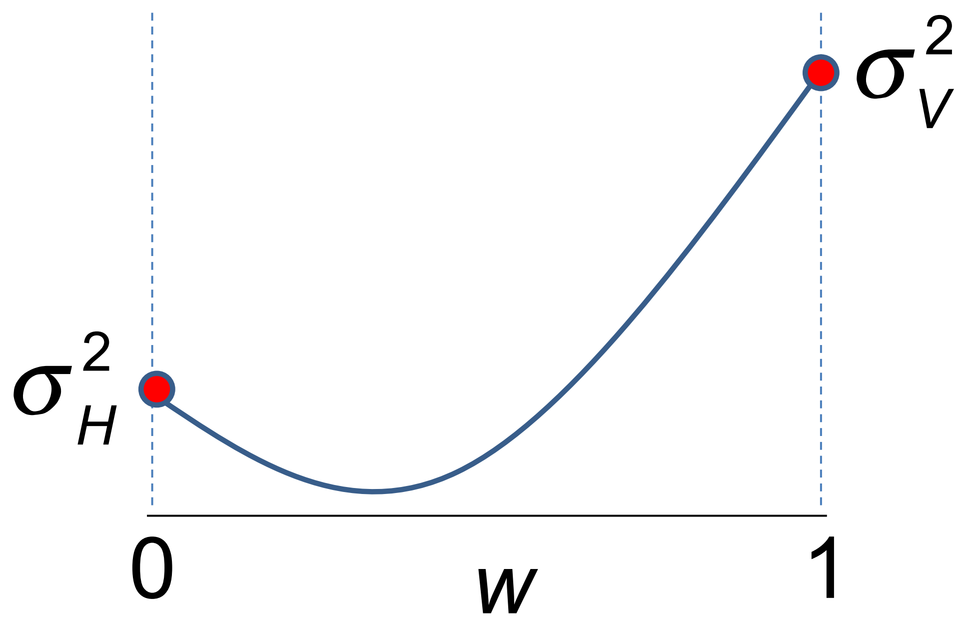


$$Var[S] = w^2 Var[S_H] + (1-w)^2 Var[S_V]$$
$$= w^2\sigma_V^2 + (1-w)^2\sigma_H^2$$

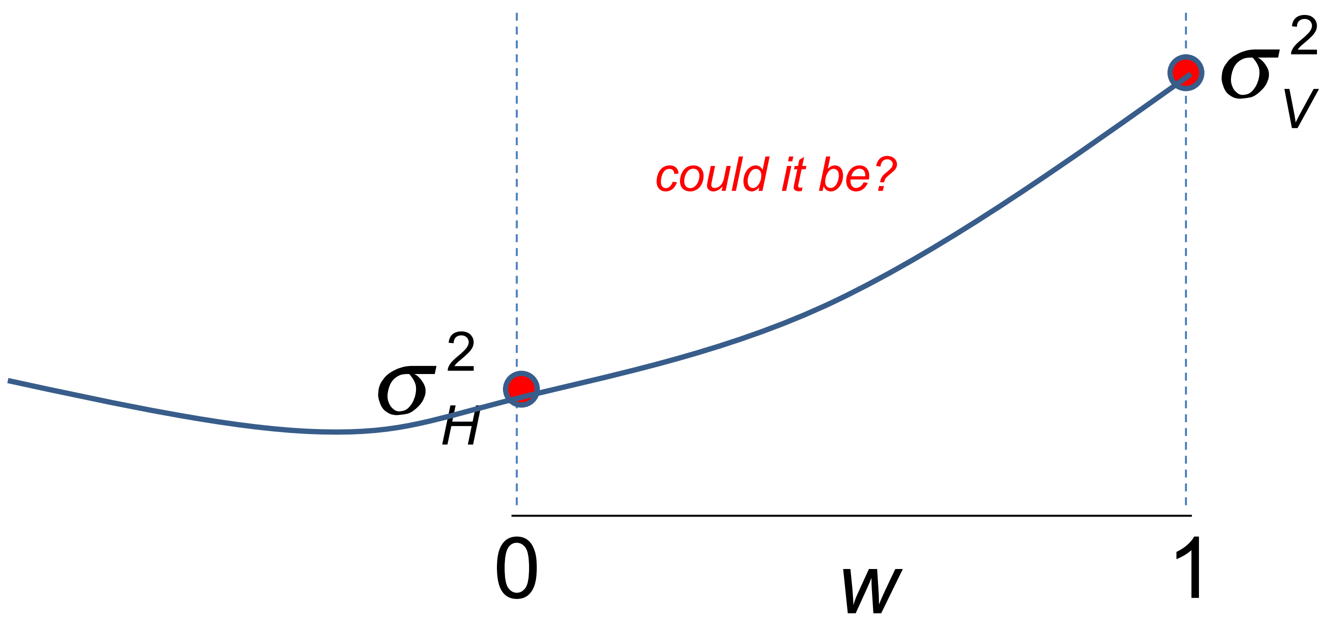
a parabola in *w*

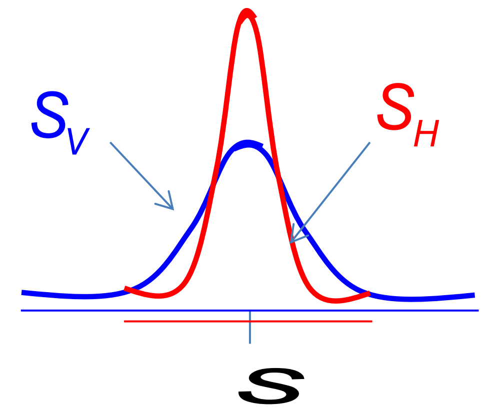
up-facing or down?

$$Var[S] = w^2\sigma_H^2 + (1-w)^2\sigma_V^2$$



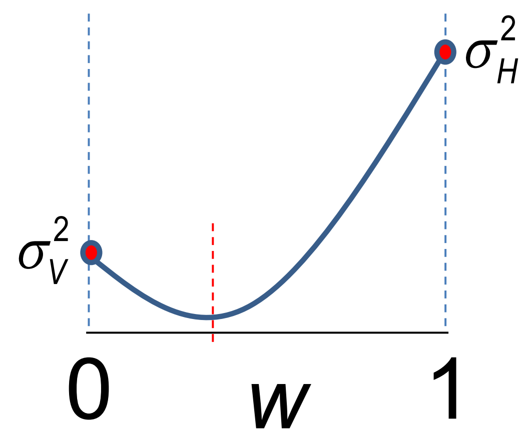
$$Var\left[S\right] = w^2\sigma_H^2 + (1-w)^2\sigma_V^2$$



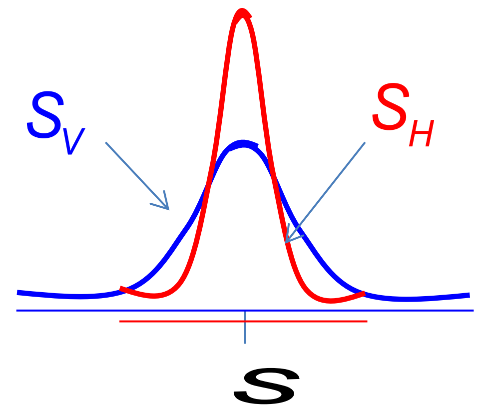


$$\frac{\partial Var[S]}{\partial w} = 2w\sigma_H^2 - 2(1-w)\sigma_V^2 \quad =!\,0$$

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

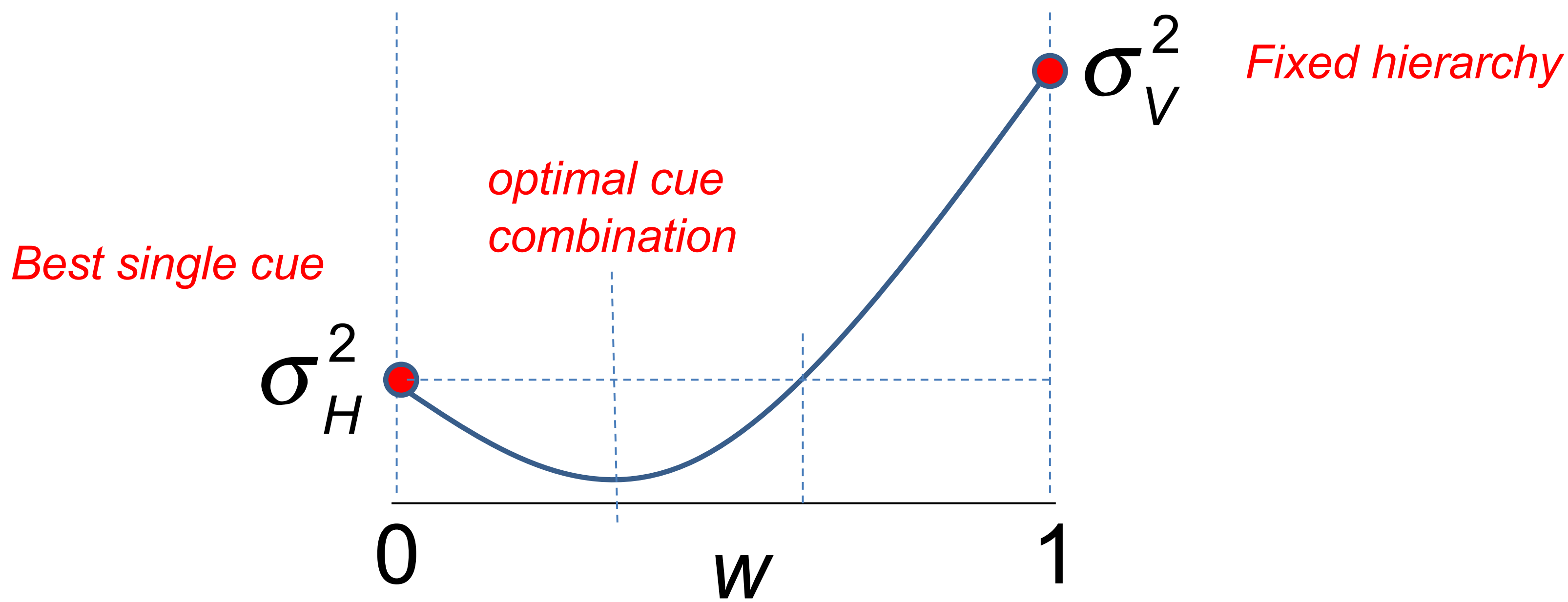


minimum or maximum?



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

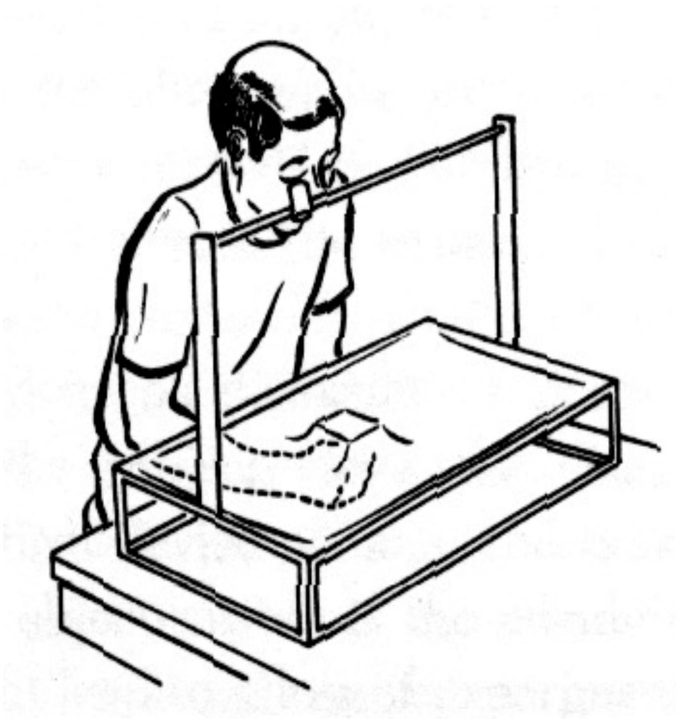
$$Var\left[S\right] = w^2\sigma_H^2 + (1-w)^2\sigma_V^2$$



It is always better to use all available cues – wisely.

Rock & Victor (1964)

View object through distorting lens while exploring object haptically



Irv Rock

Why visual capture?

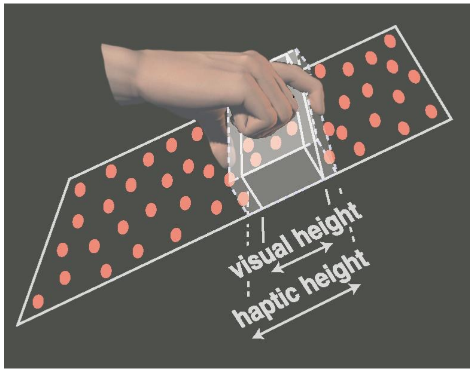
Visually and haptically specified shapes differed.

What shape is perceived?

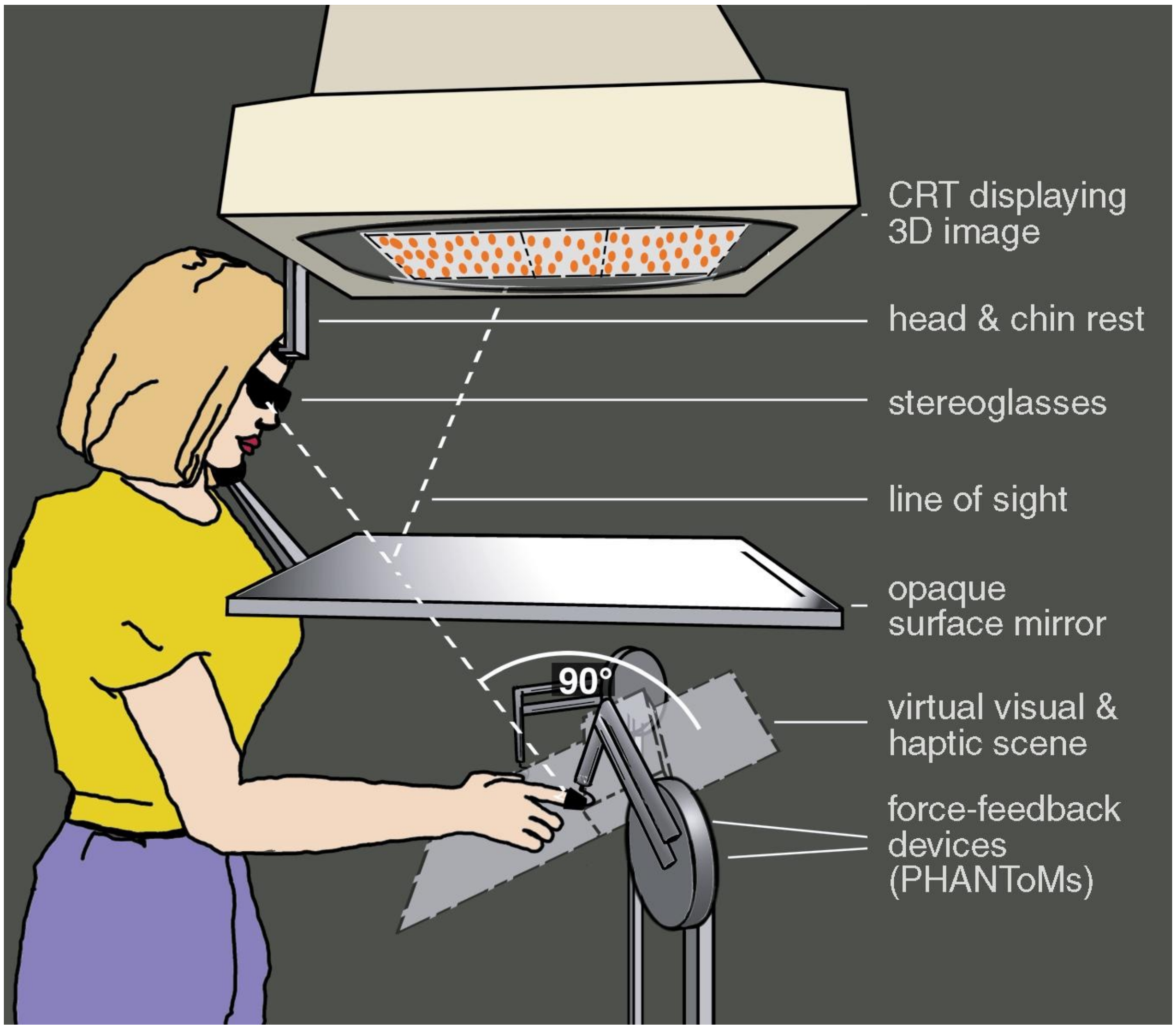
Humans integrate visual and haptic information in a statistically optimal fashion

Marc O. Ernst* & Martin S. Banks

Vision Science Program/School of Optometry, University of California, Berkeley 94720-2020, USA



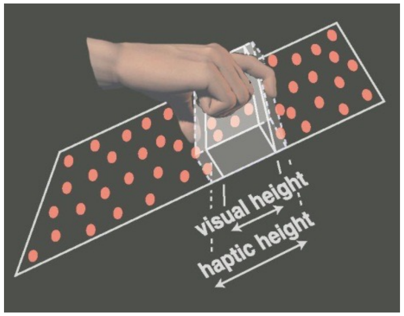
Visual/Haptic Setup

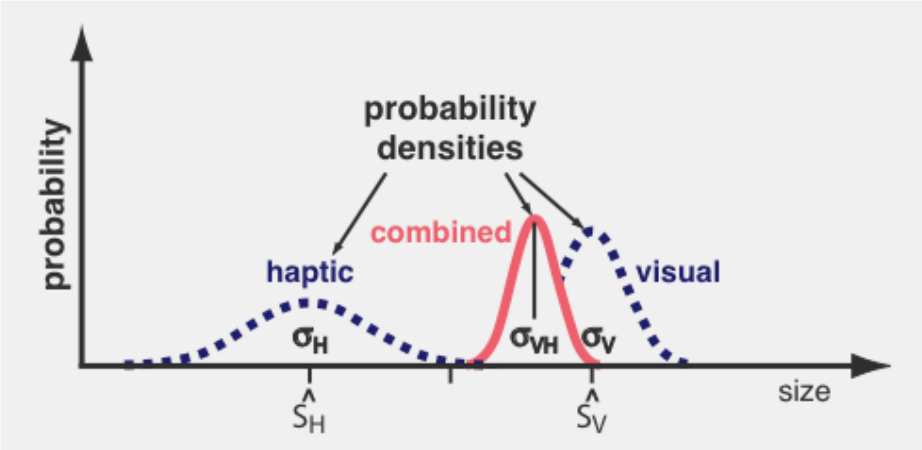


Visual Capture ?

Why should vision be the "gold standard" all other modalities are compared to?

NOT MINIMUM VARIANCE





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

Weights

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

Variance

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

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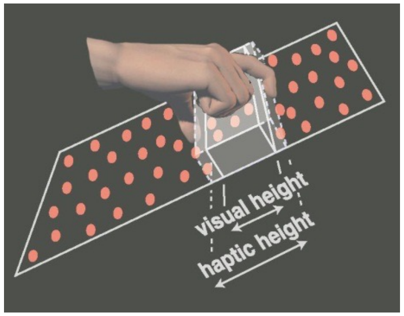

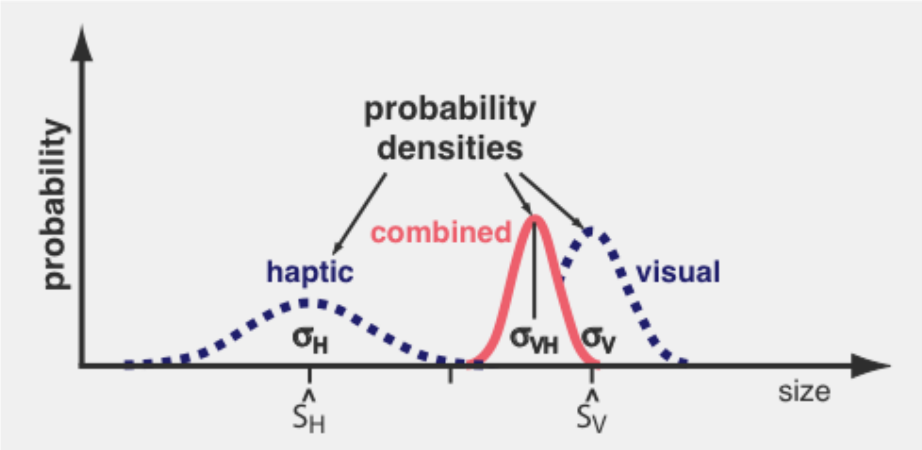

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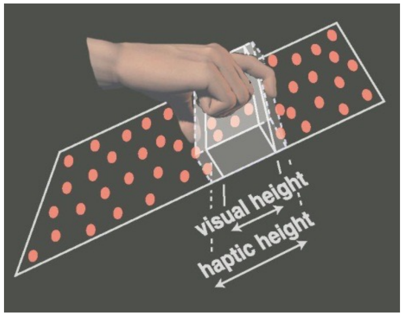

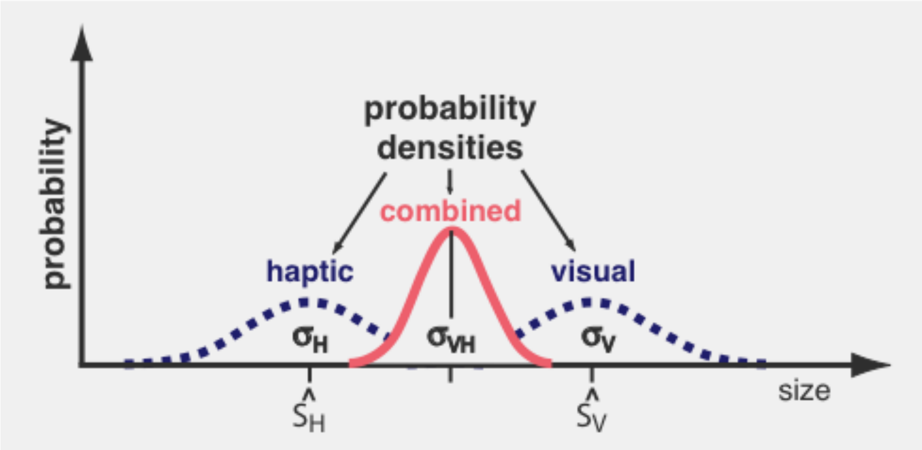

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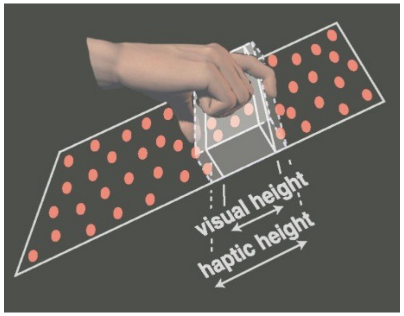

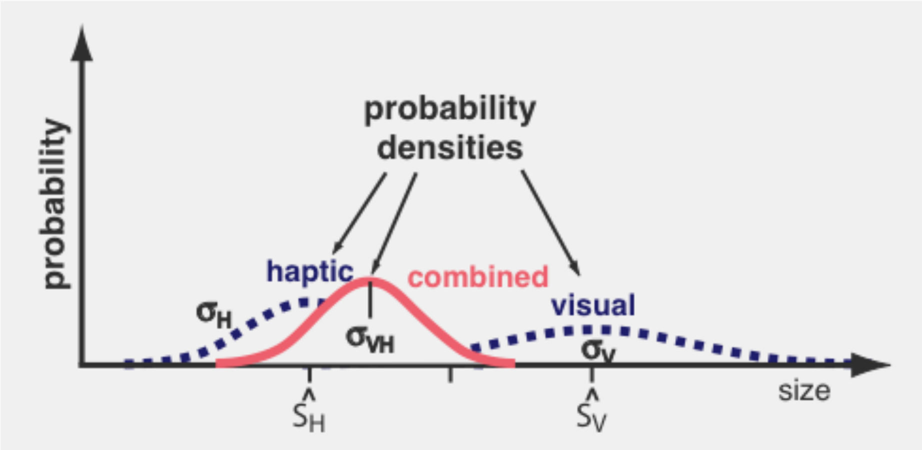

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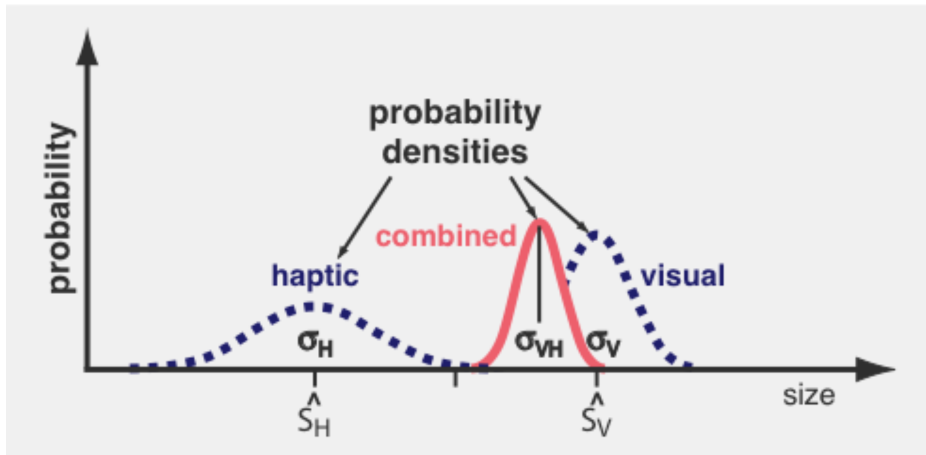
<u>Variance</u>

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

Experimental Outline



1) manipulate & determine within-modality variances

• discrimination thresholds (2-IFC, constant stimuli)

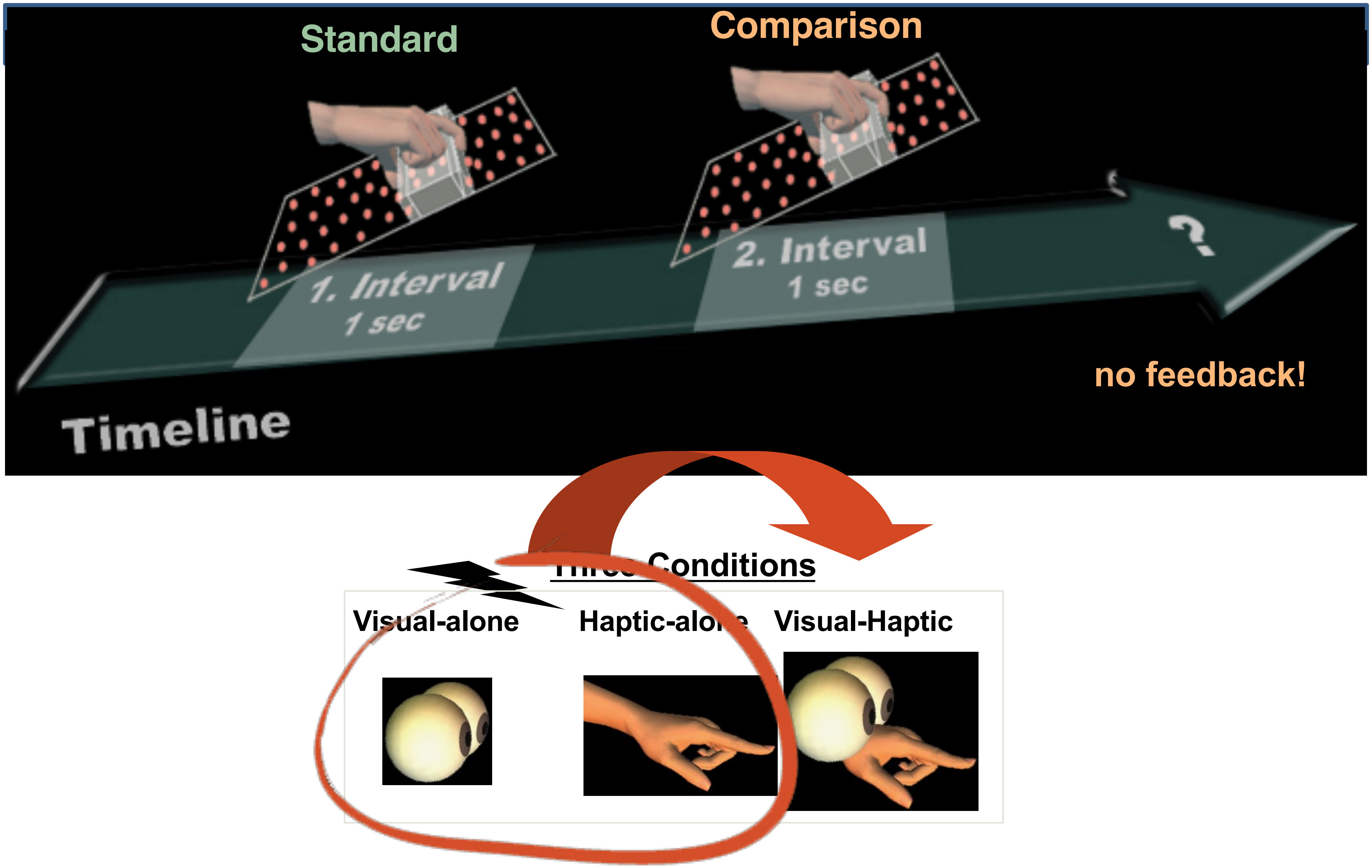
2) make predictions for combined performance

• using MLE model to predict weights & combined variance.

3) measure combined performance & compare to prediction

• similar to within-modality 2-IFC discrimination task (get PSE and thresholds)

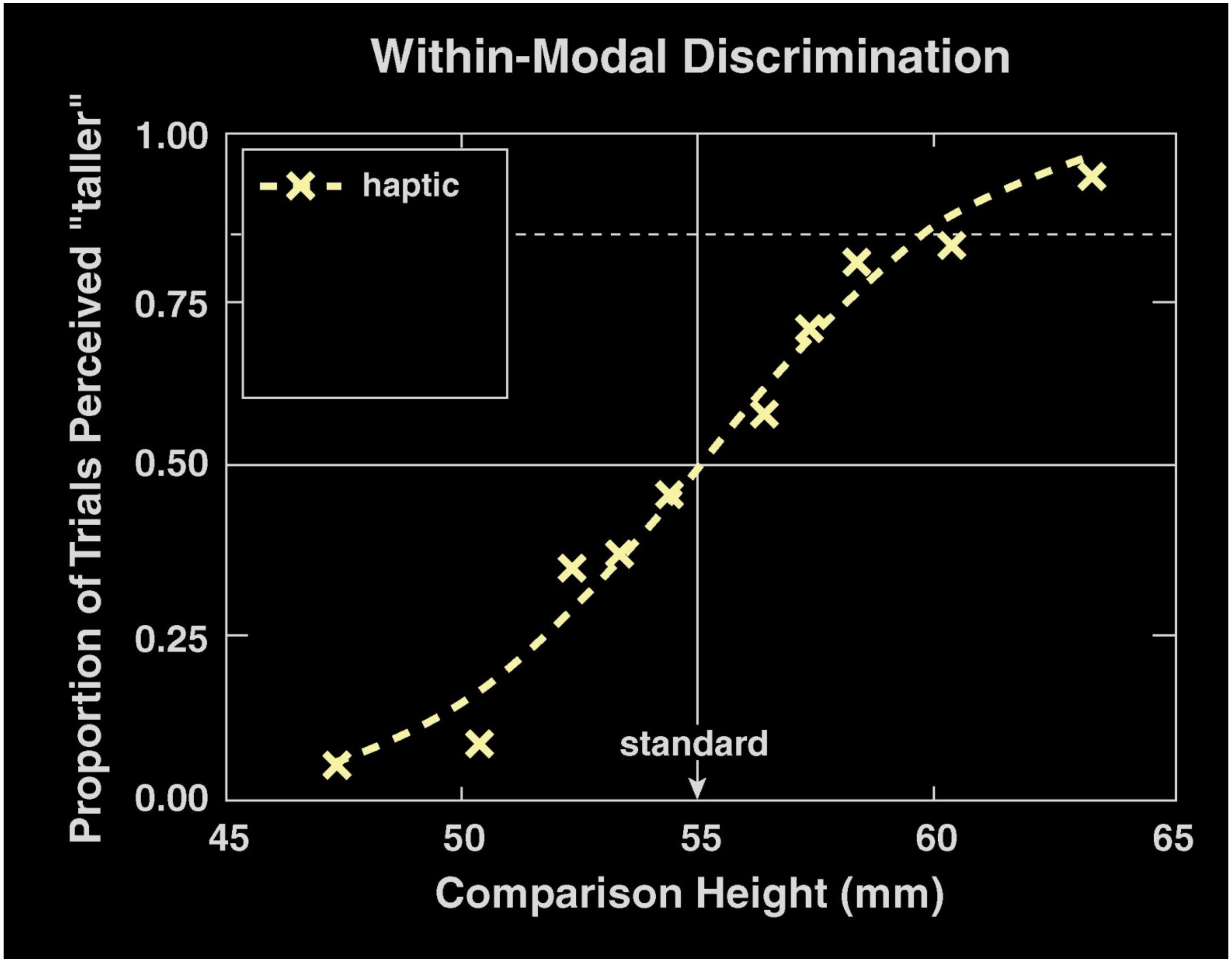
2-IFC Task


Standard
Comparison
1. Interval
1 sec
2. Interval
1 sec
?
no feedback!
Timeline
Conditions
Visual-alone
Visual-Haptic

STOP: How do we estimate the variance (or SD) of a cue?

$$X \sim Gaussian(s, \sigma)$$

Determining Within-Modality Variance



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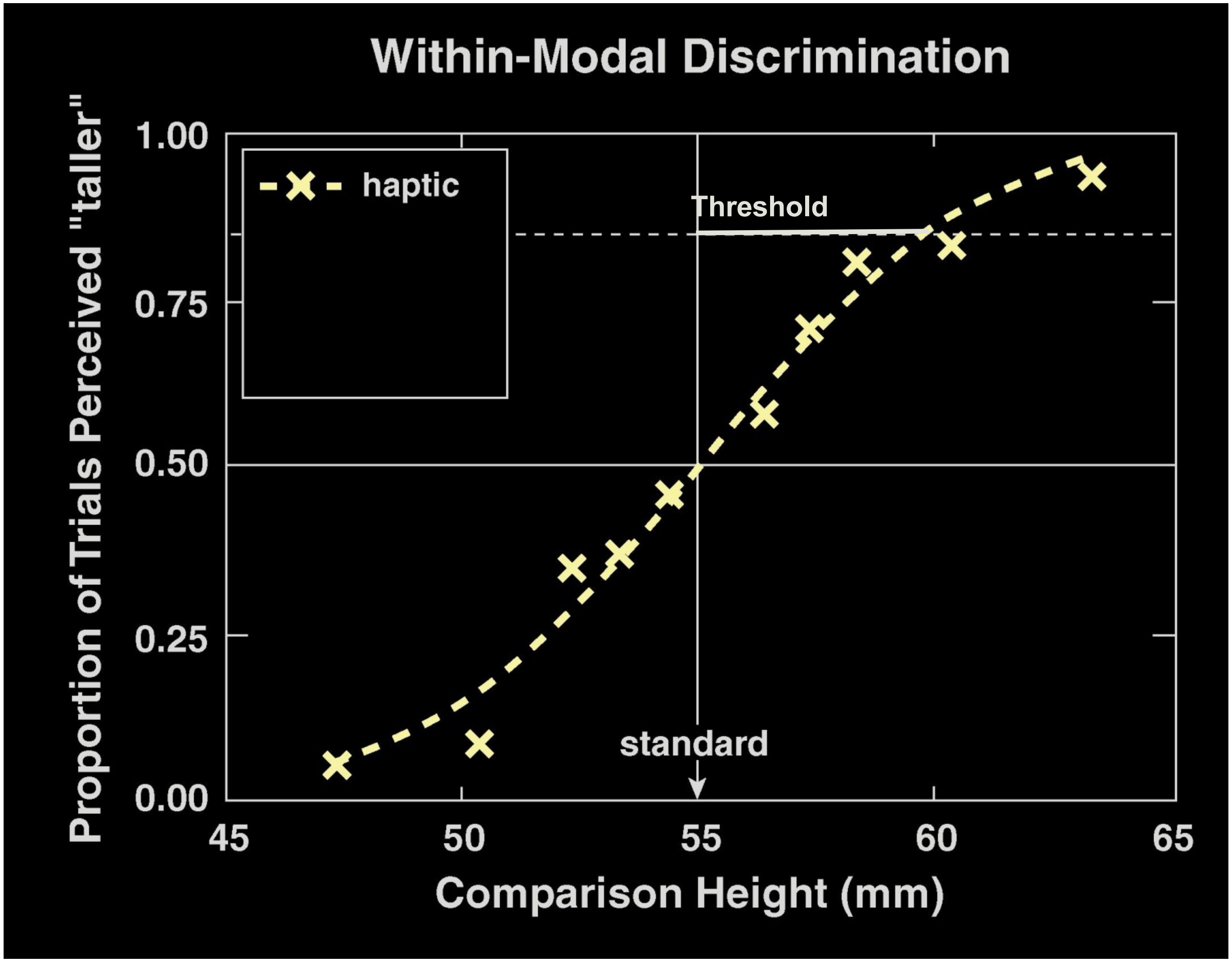

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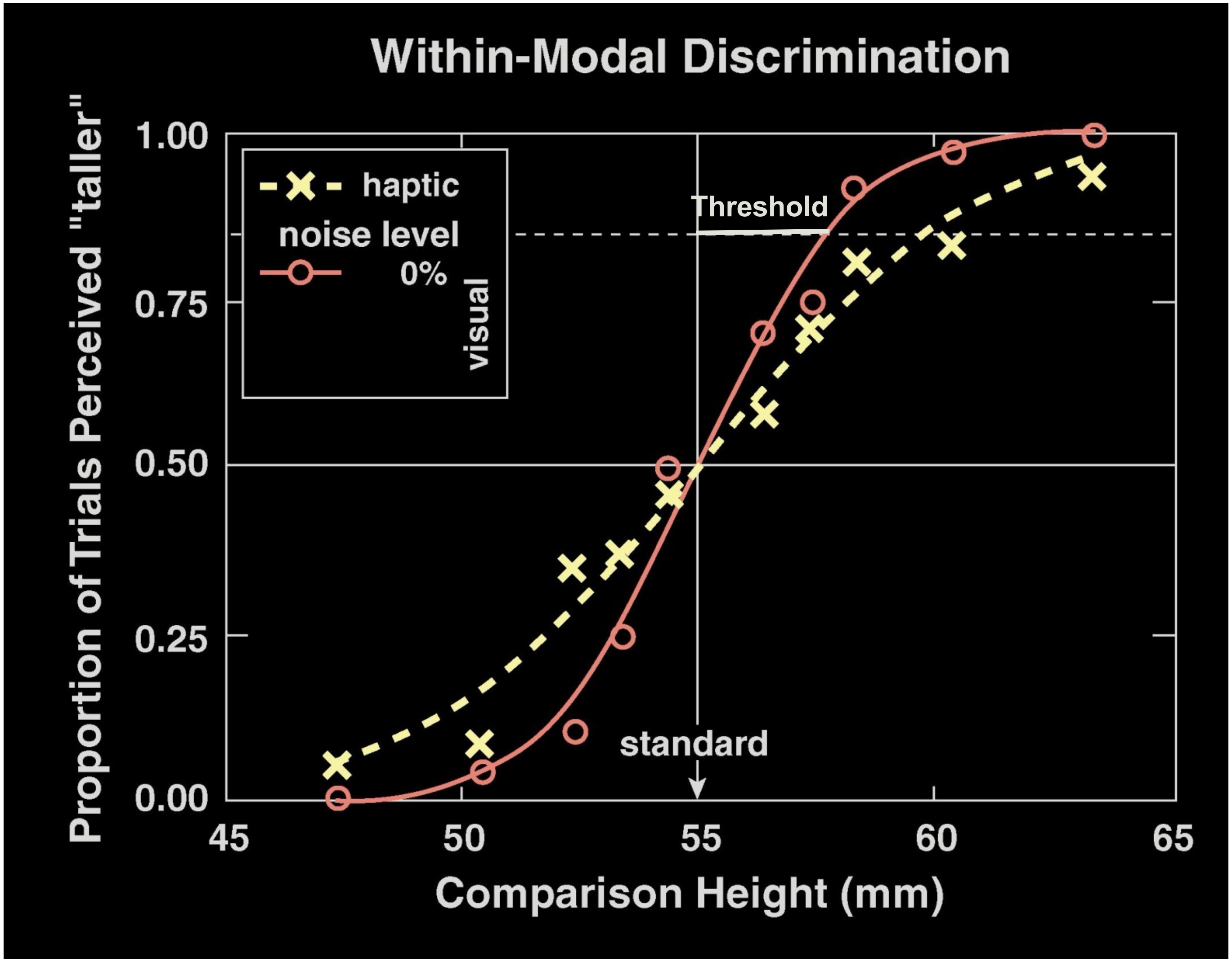

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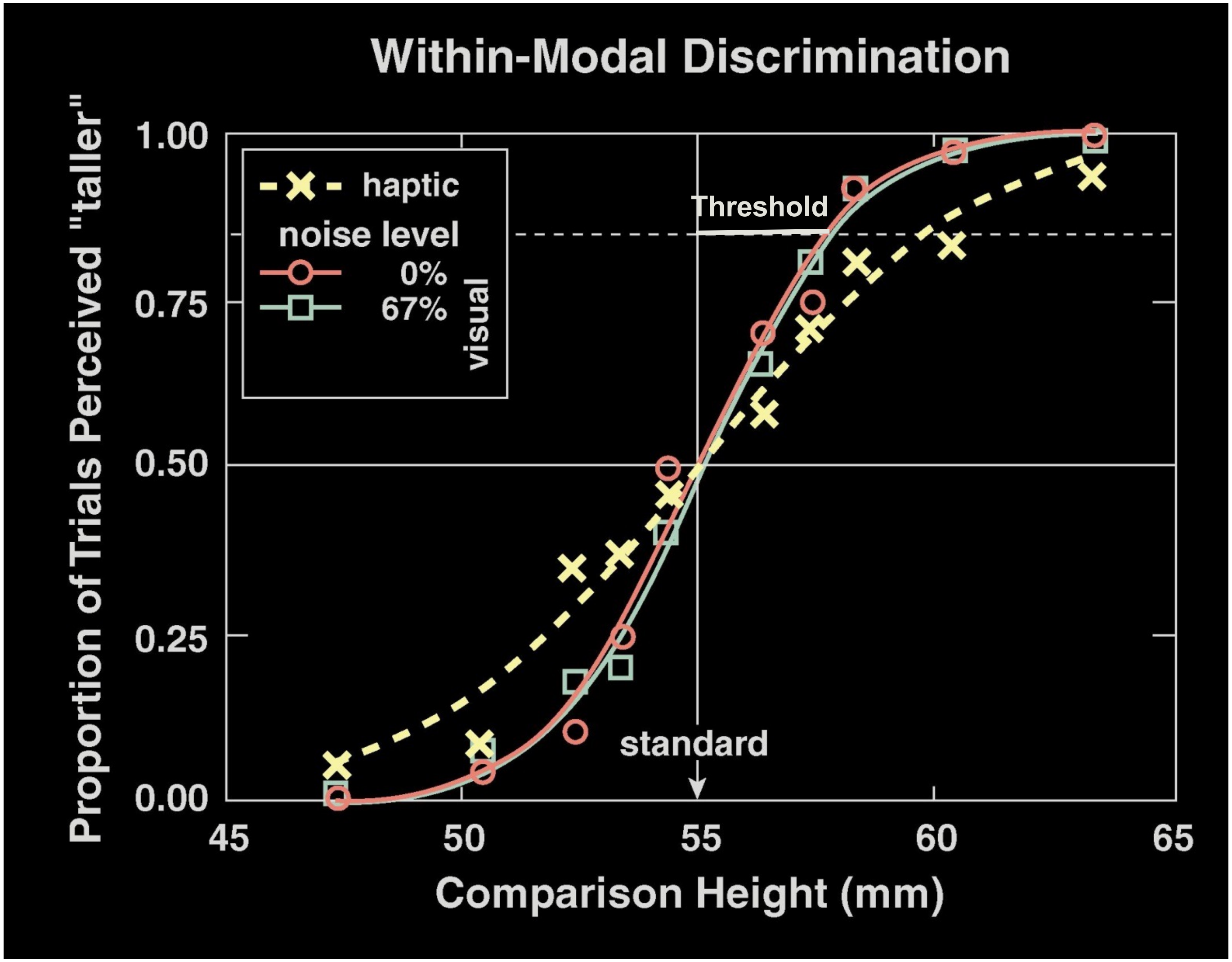

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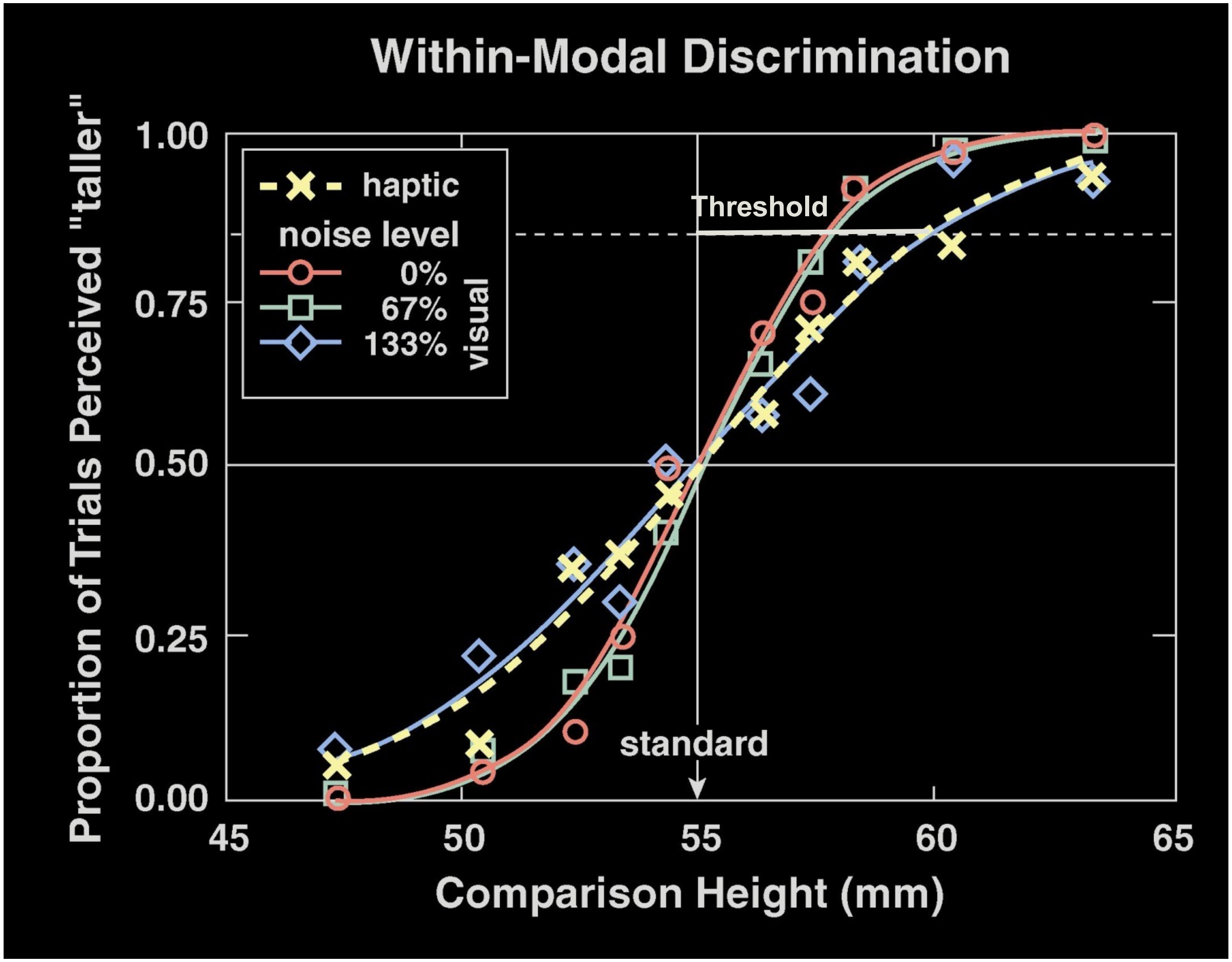

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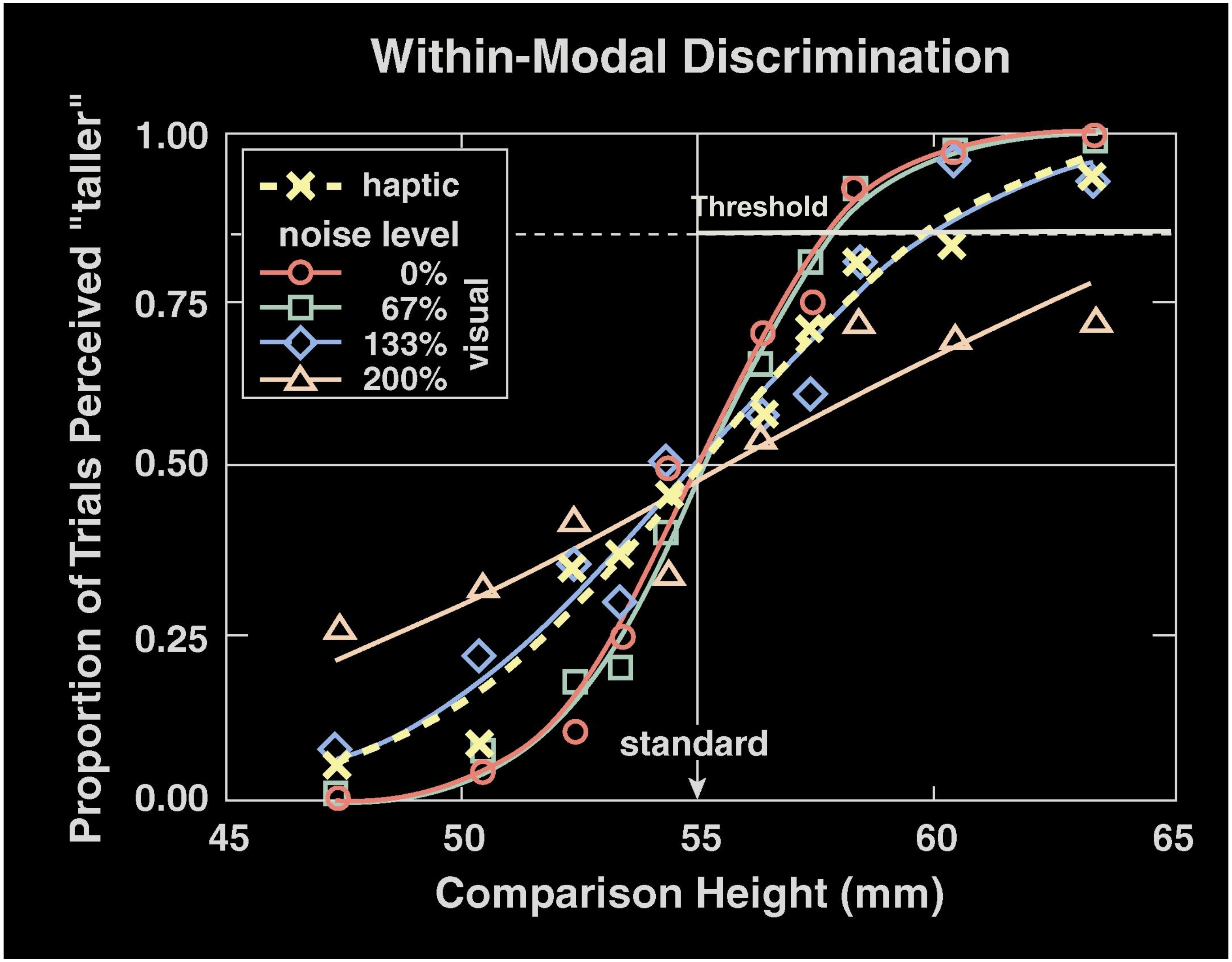


From Variance to Threshold

Predicted weights for combined performance from within-modal data

estimators weights

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

$$JND_i = \sqrt{2} \cdot \sigma_i$$

estimators weights

$$w_V = \frac{JND_H^2}{JND_V^2 + JND_H^2}$$

Predicted combined threshold from within-modal data

visual-haptic variance

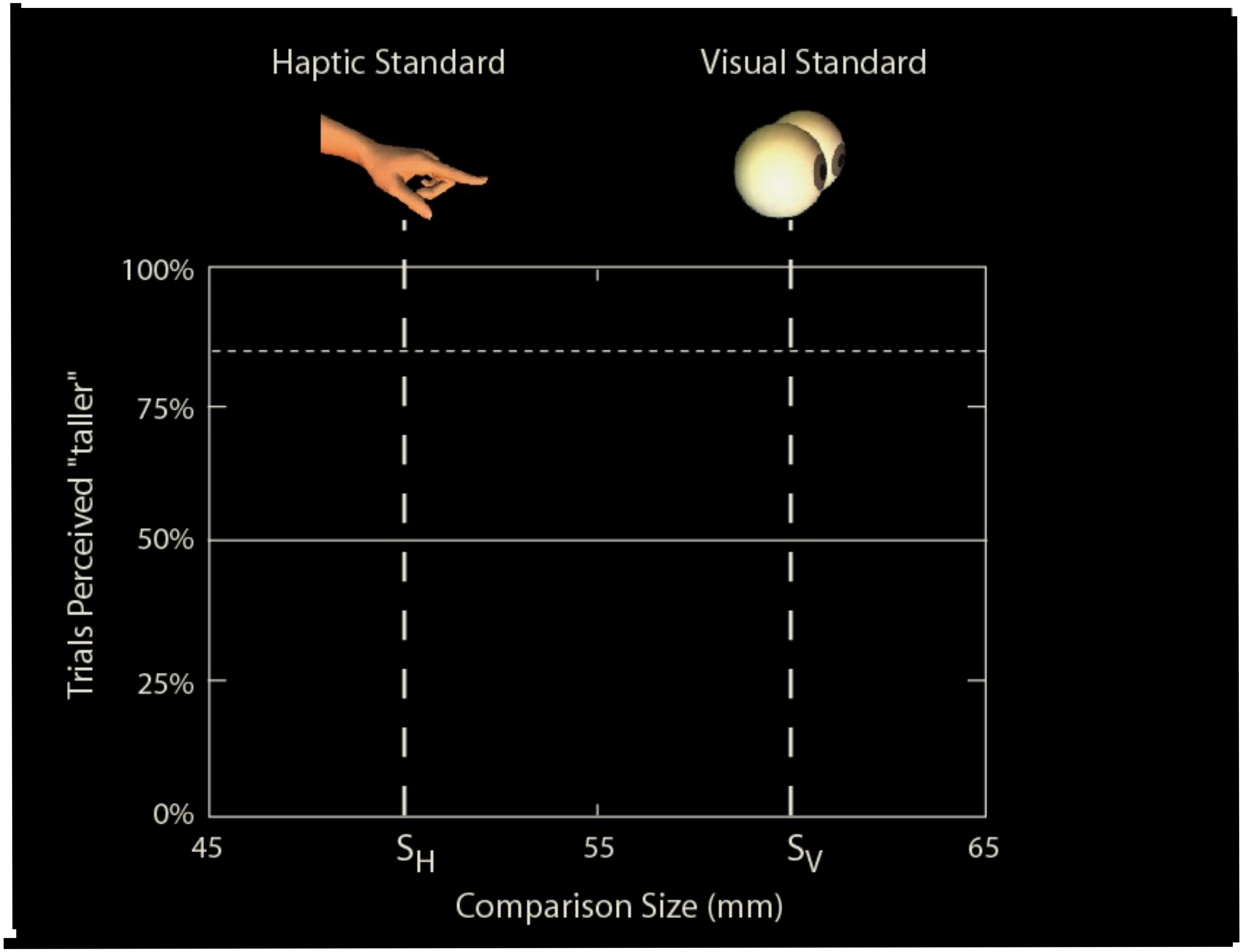
$$\frac{1}{\sigma_{VH}^2} = \frac{1}{\sigma_V^2} + \frac{1}{\sigma_H^2}$$

$$JND_i = \sqrt{2} \cdot \sigma_i$$

visual-haptic threshold

$$\frac{1}{JND_{VH}^2} = \frac{1}{JND_V^2} + \frac{1}{JND_H^2}$$

Visual-Haptic Discrimination



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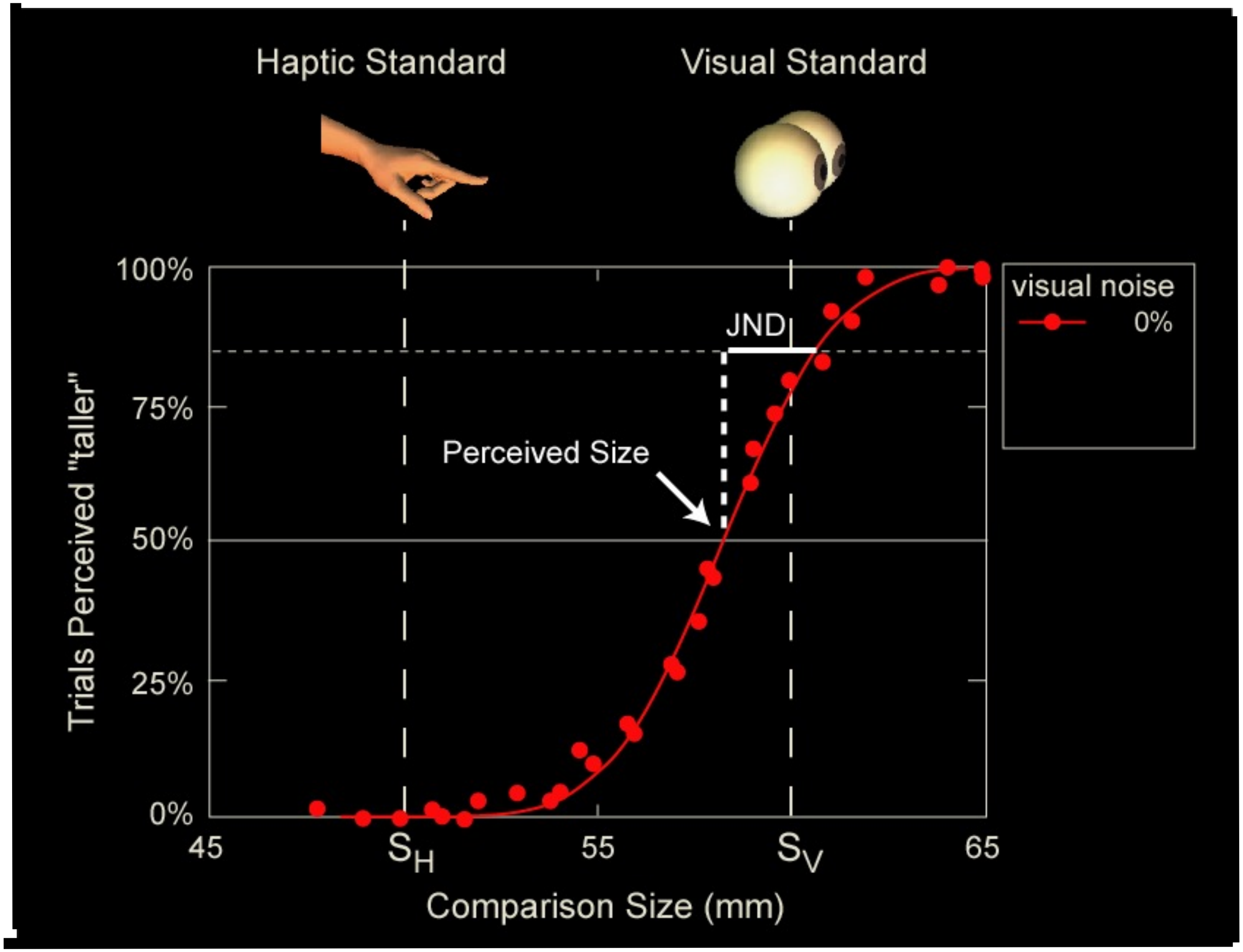

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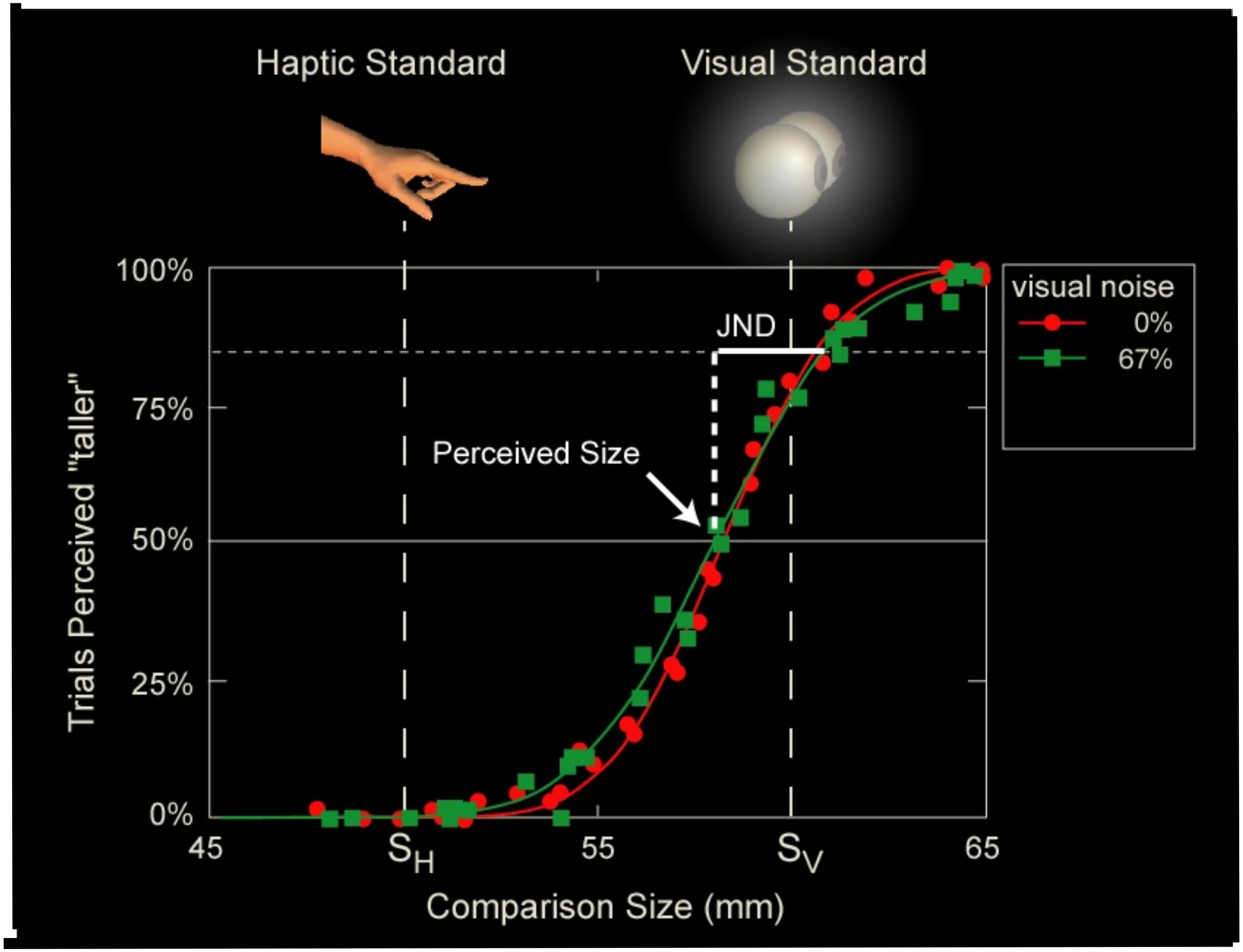
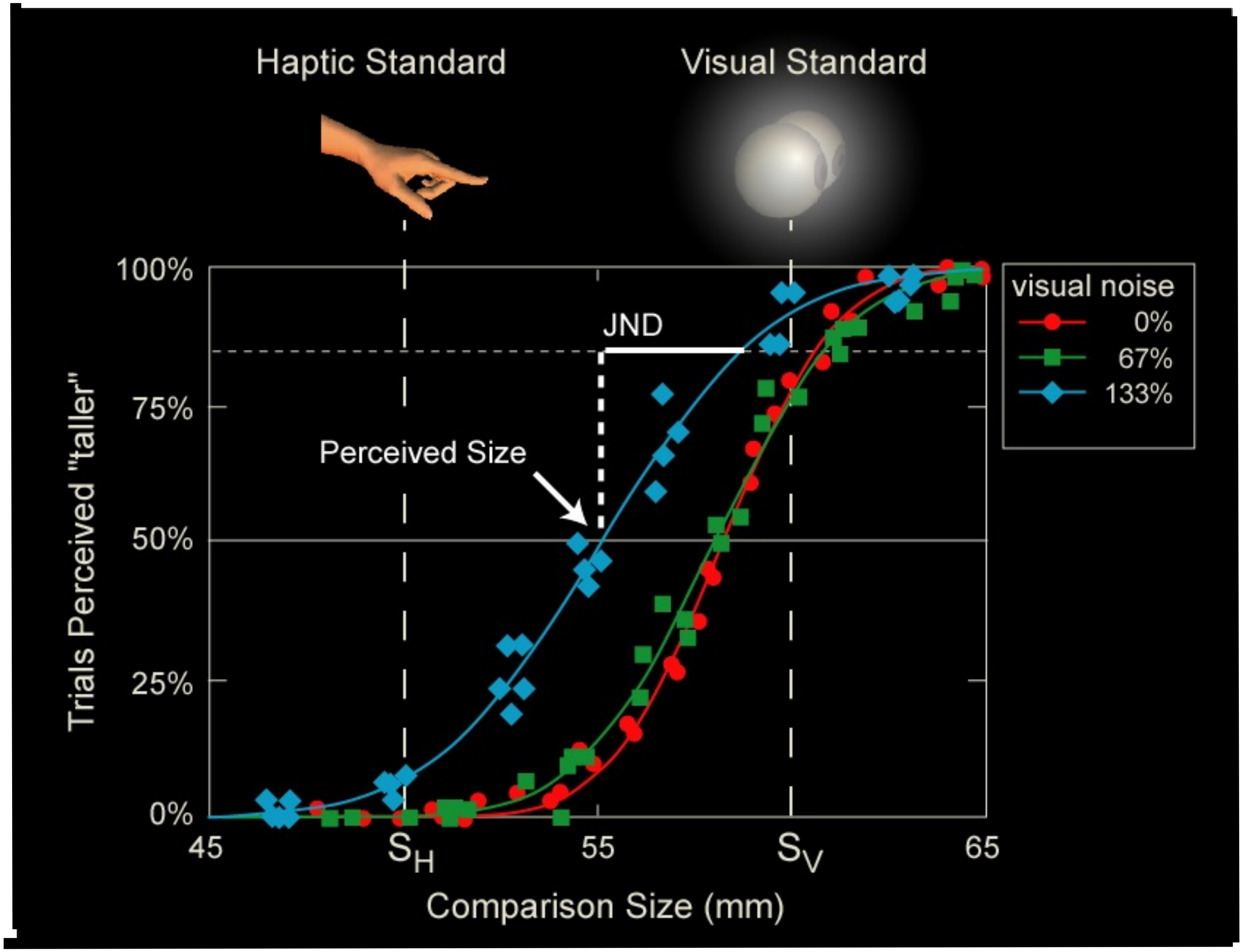
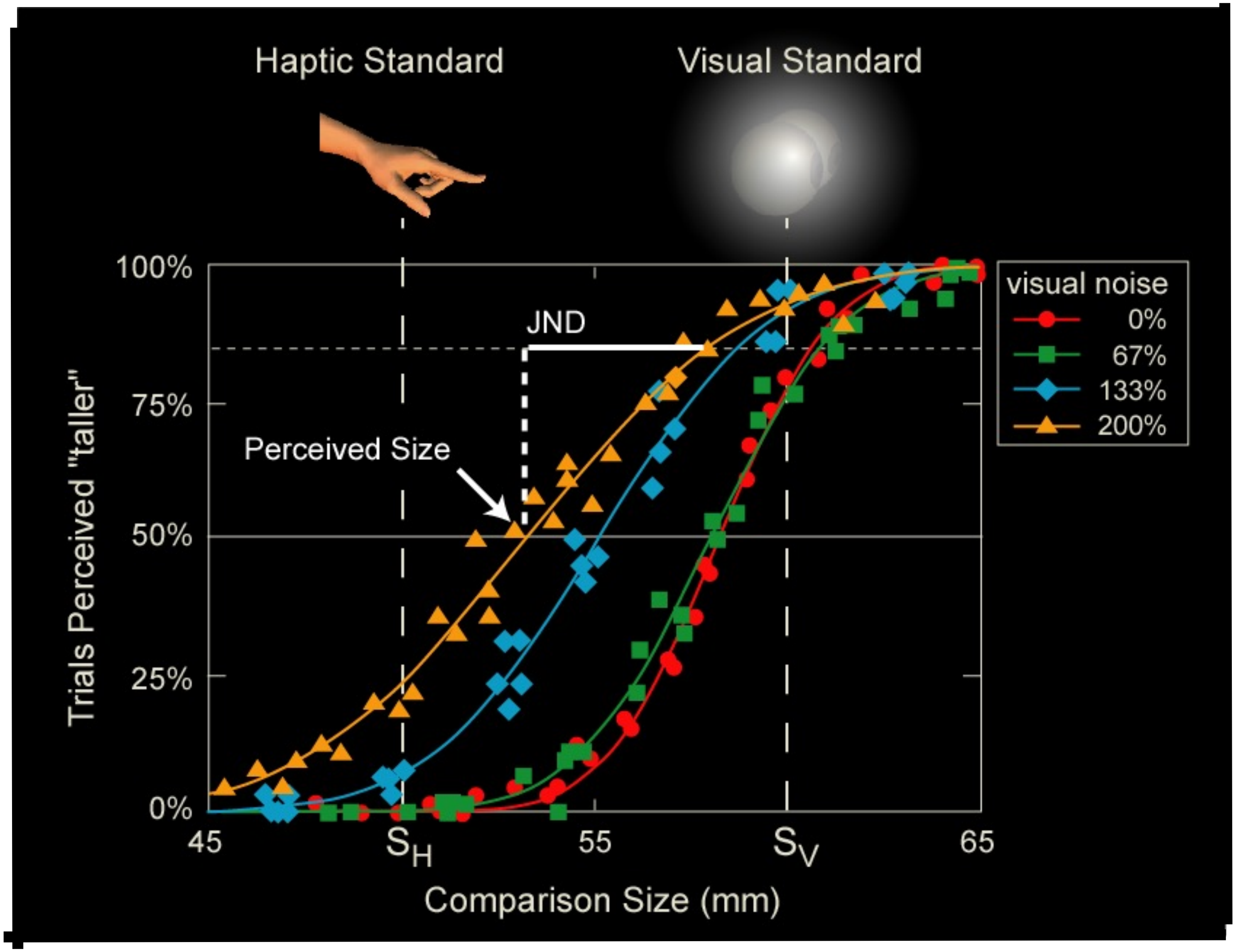


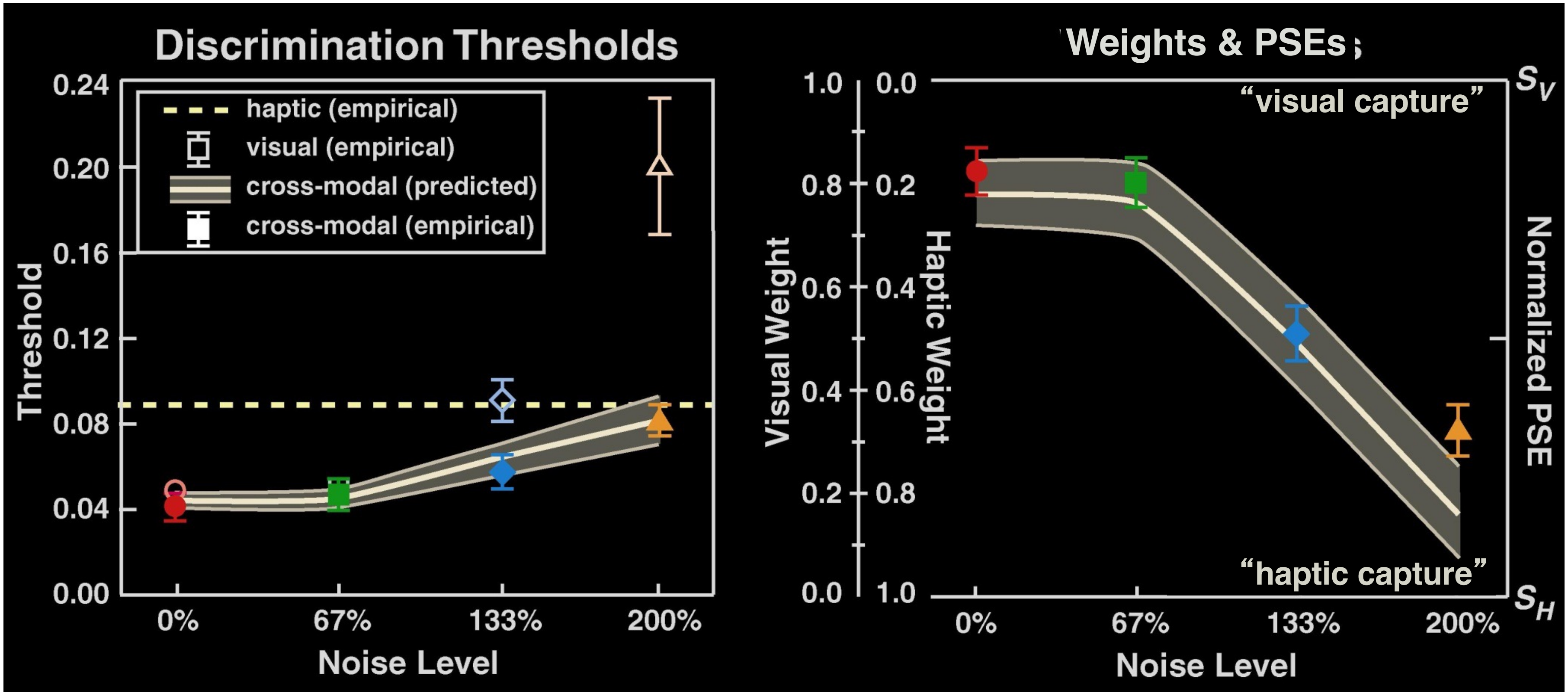
Visual-Haptic Discrimination



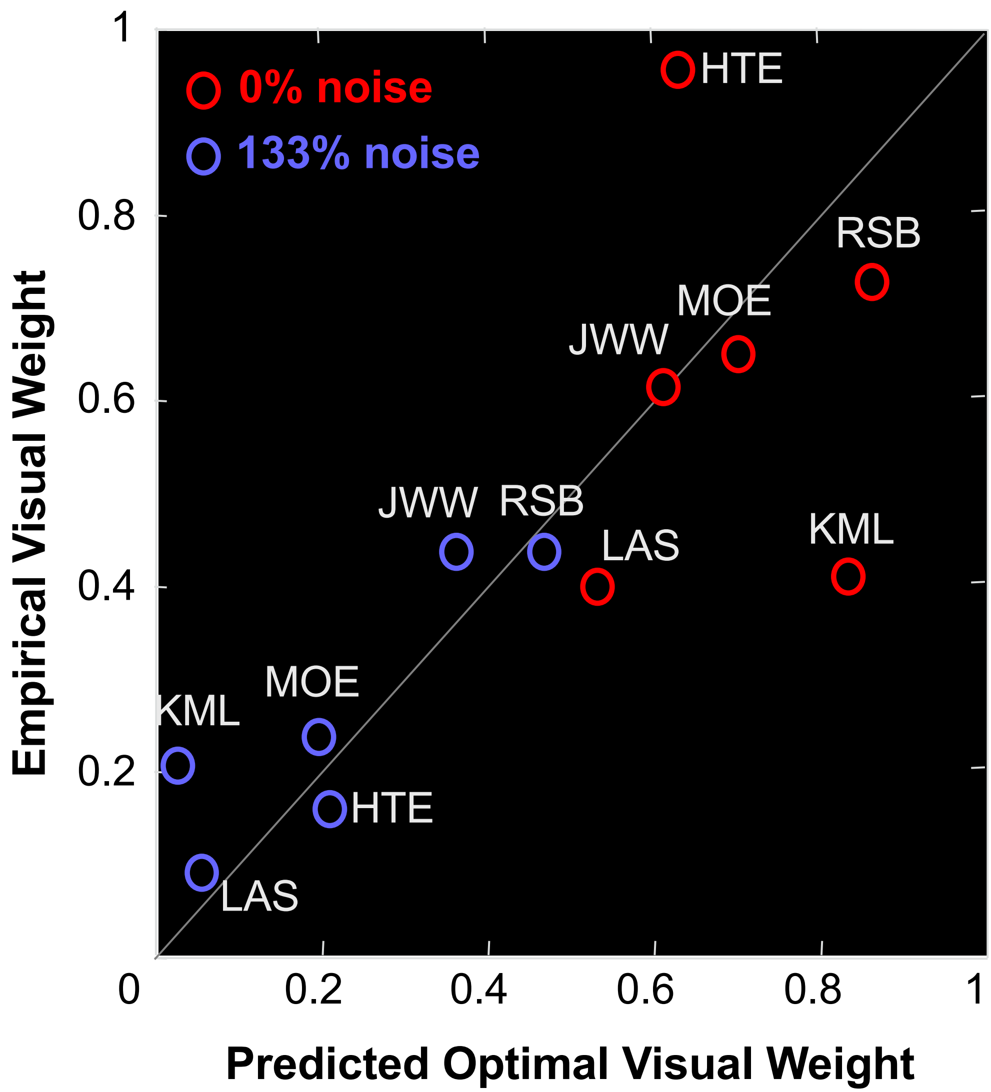
Visual-Haptic Discrimination



Empirical Thresholds and Weights



Individual Differences



Conclusions

Humans integrate visual and haptic information in a statistically optimal fashion

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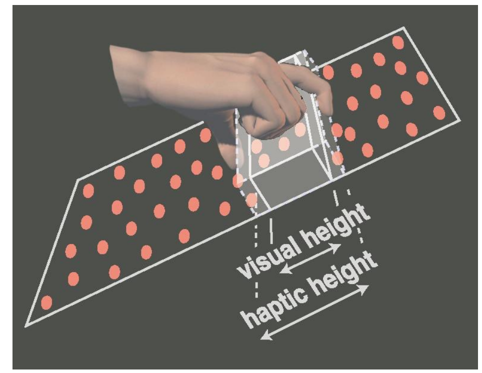

- Combination reduces variance. below that of either cue.
- Linear weighting scheme for visual-haptic perception.
- Explains behavior like apparent “visual capture” or visual dominance.

ASSUMPTIONS

- Cues are

  Gaussian
  Independent

What if they are not?

Oruç, I, Maloney, L. T., & Landy, M. S. (2003), Weighted linear cue combination with possibly correlated error, *Vision Research,* 43, 2451-2468.

- Goal: UMVUE

What if we have other goals?
next lecture