The effect of an illumination direction cue based on cast shadows on lightness perception in three dimensional scenes

Huseyin Boyaci and Laurence T. Maloney

Department of Psychology
Center for Neural Science
New York University

boyaci@cns.nyu.edu
http://www.cns.nyu.edu/~boyaci

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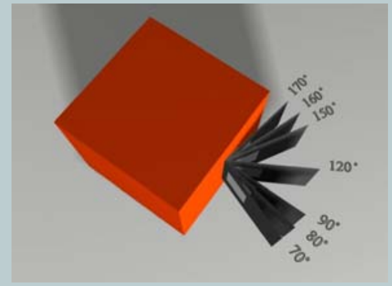
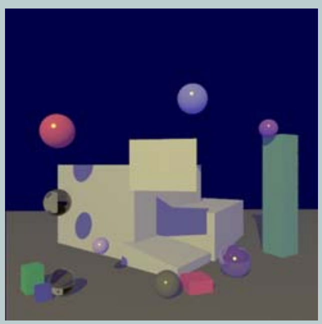
Inter-reflection



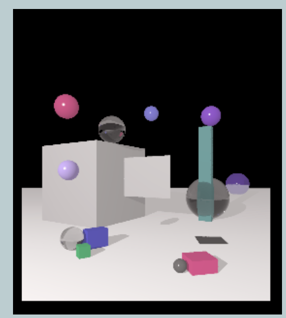
Doerschner, K., Boyaci, H. & Maloney, L. T. (2004), Human observers compensate for secondary illumination originating in nearby chromatic surfaces, *Journal of Vision*, **4**, 92-105.

Orientation and Color

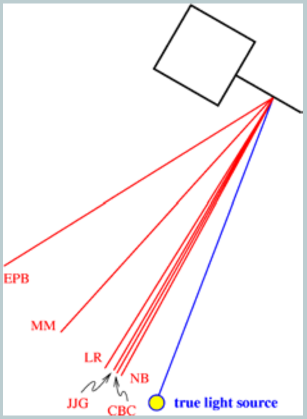


Boyaci, H., Doerschner, K. & Maloney, L. T. (2004), Perceived surface color in binocularly-viewed scenes with two light sources differing in chromaticity. *Journal of Vision*, in press.

Orientation and lightness



Boyaci, H., Maloney, L. T. & Hersh, S. (2003), The effect of perceived surface orientation on perceived surface albedo in three-dimensional scenes, *Journal of Vision*, **3**, 541-553.

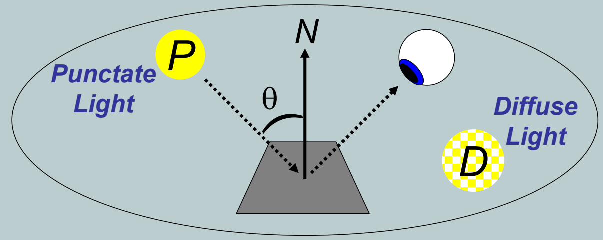


Observers are sensitive to:

- direction to the punctate light source,
- punctate-total ratio

Equivalent illuminant model: Brainard, D.H. (1998). Color constancy in the nearly natural image. 2. Achromatic loci. Journal of the Optical Society of America A, **15**, 307-325.

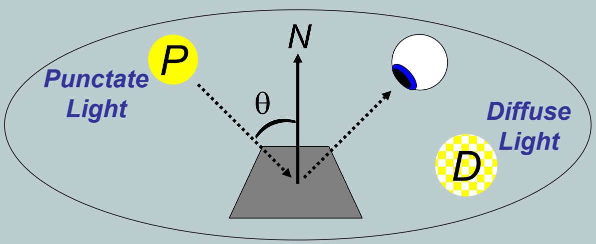
Lambertian Model



$$Lum = \left[E_P \cos\theta + E_D\right] \times \alpha$$

luminance (Lum); *albedo* (α)

Lambertian Model



$$Lum = (E_P + E_D) \times \left[\pi \cos\theta + 1 - \pi\right] \times \alpha$$

$$\pi = \frac{E_P}{E_P + E_D}$$

Punctate-total ratio

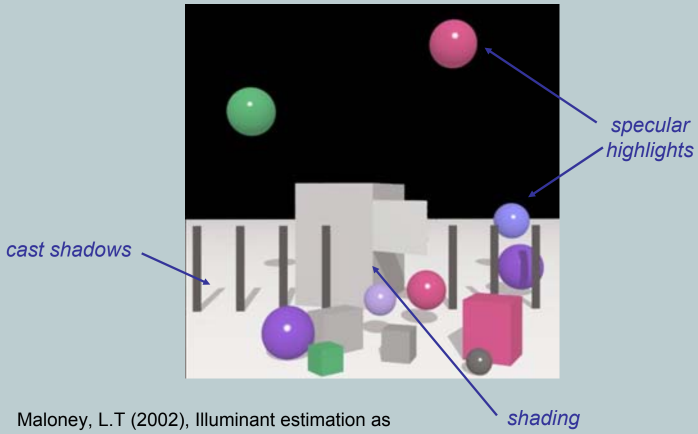
This is going to be the story of

π

punctate-total ratio

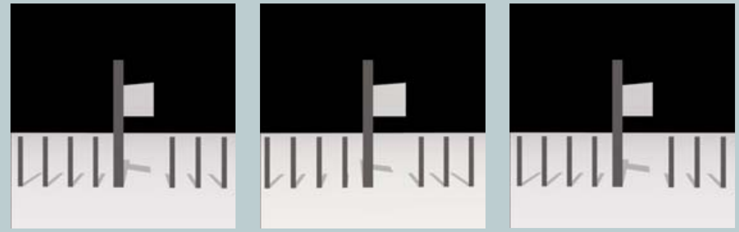
$$\pi = \frac{E_P}{E_P + E_D}$$

Cues to the illuminant



Maloney, L.T (2002), Illuminant estimation as cue combination, JOV **2**, 493-504

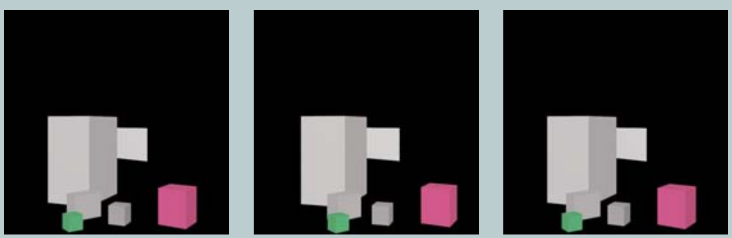
Only cast shadows



Right Left Right

Crossed Uncrossed

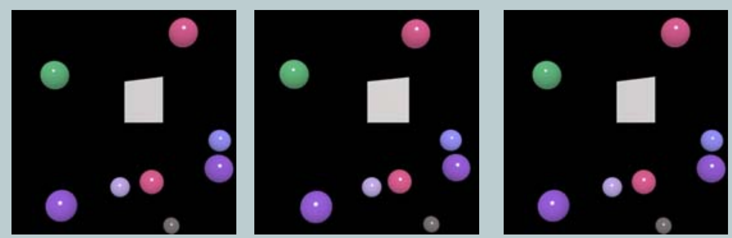
Only shading



Right Left Right

Crossed Uncrossed

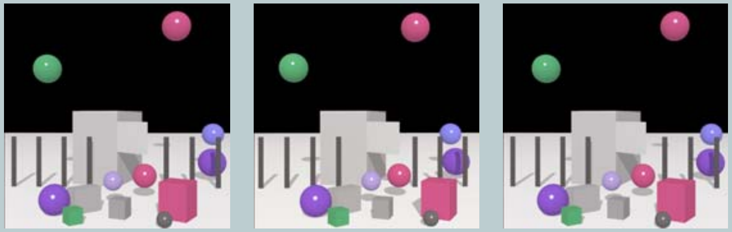
Only specular highlights



Right Left Right

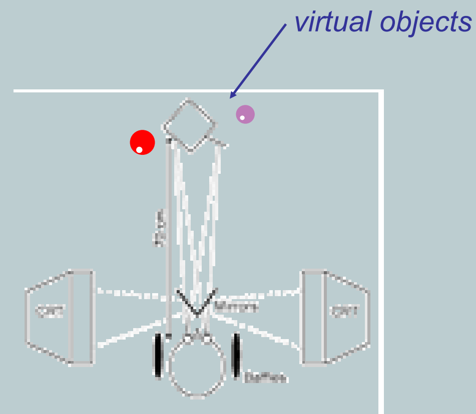
Crossed Uncrossed

All three cues



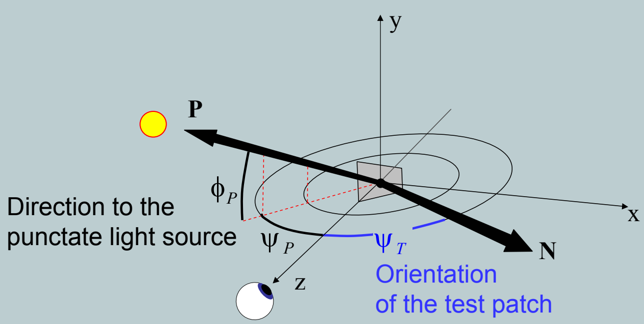
Right Left Right

Crossed Uncrossed

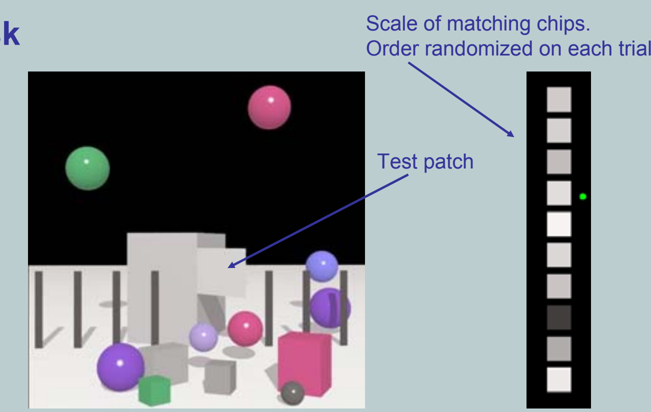


Wheatstone Stereoscope

Coordinates: Azimuth and elevation

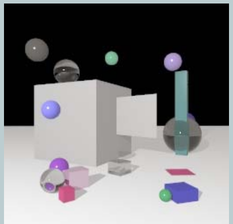


Task

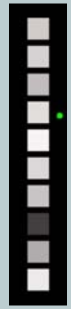


“Choose the matching chip which looks like cut out of the same piece of grey paper as the test patch”

Dependent variable

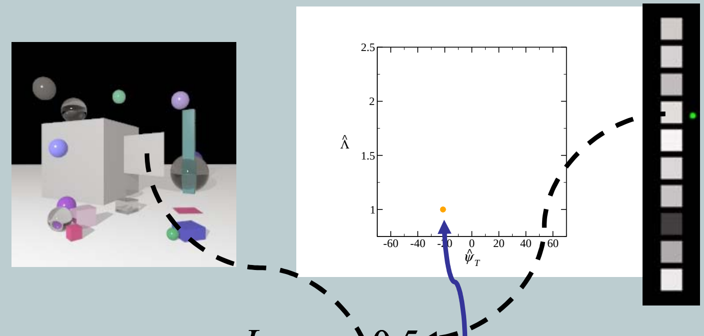


What would the lightness constant observer do?



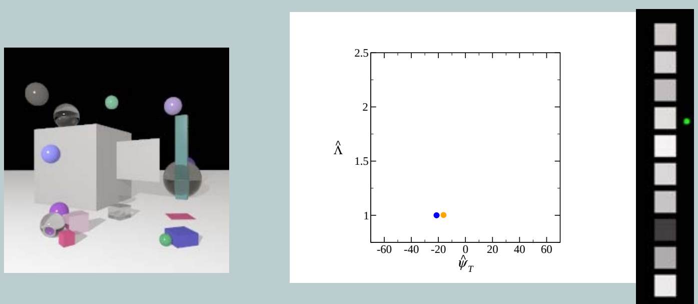
$$\hat{\Lambda} = \frac{Lum_S}{Lum_T}$$

What would the lightness constant observer do?



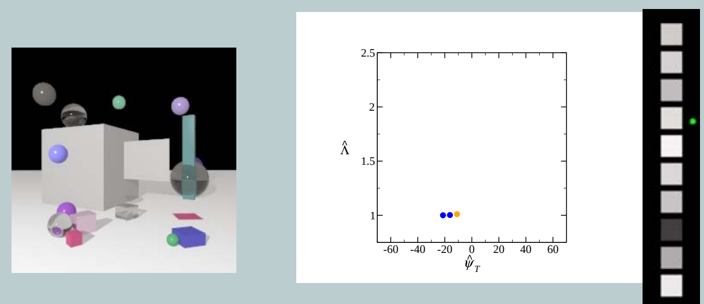
$$\hat{\Lambda} = \frac{Lum_S}{Lum_T} = \frac{0.5}{0.5} = 1$$

What would the lightness constant observer do?



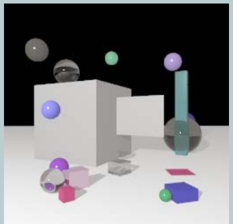
$$\hat{\Lambda} = \frac{Lum_S}{Lum_T} = 1.003$$

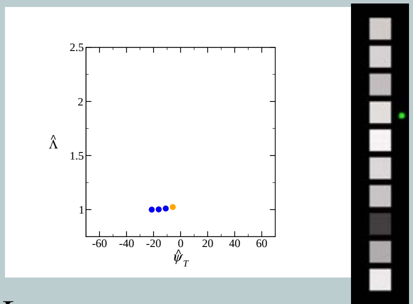
What would the lightness constant observer do?



$$\hat{\Lambda} = \frac{Lum_S}{Lum_T} = 1.010$$

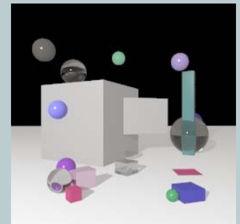
What would the lightness constant observer do?

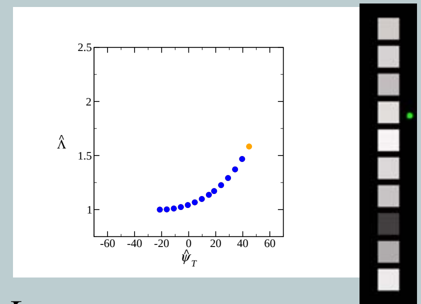




$$\hat{\Lambda} = \frac{Lum_S}{Lum_T} = 1.023$$

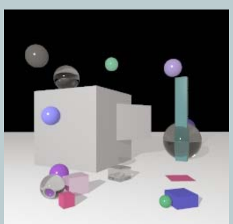
What would the lightness constant observer do?

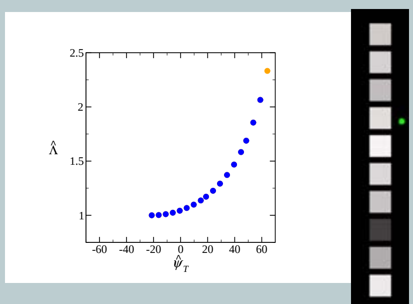




$$\hat{\Lambda} = \frac{Lum_S}{Lum_T} = 1.584$$

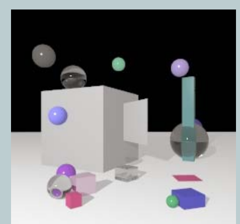
What would the lightness constant observer do?

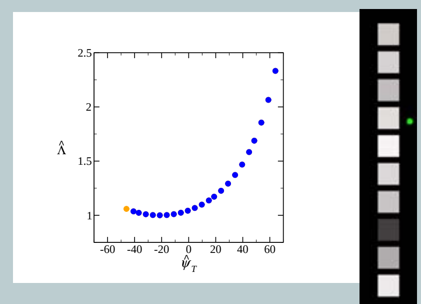




$$\hat{\Lambda} = \frac{Lum_S}{Lum_T} = 2.333$$

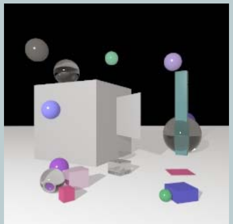
What would the lightness constant observer do?

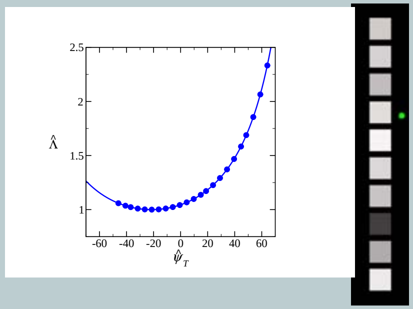




$$\hat{\Lambda} = \frac{Lum_S}{Lum_T} = 1.059$$

What would the lightness constant observer do?

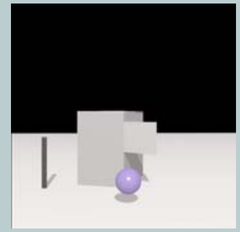


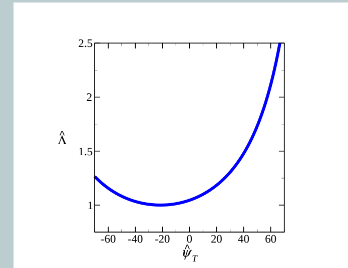


$$\hat{\Lambda} = \frac{Lum_S}{Lum_T} = m\frac{1}{\pi\cos(\psi_T - \psi_P)\cos\varphi_P + 1 - \pi}$$

Effect of π (punctate-total ratio)

Actual



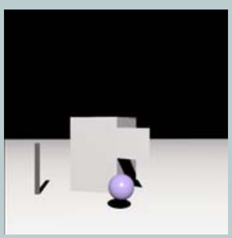


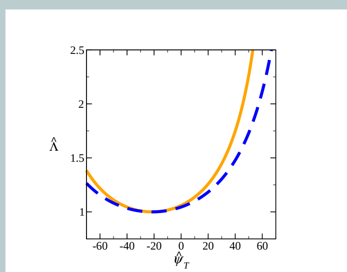
$$\pi = 0.67$$

Curvature $\left.\frac{\partial^2\hat{\Lambda}}{\partial\psi_T^2}\right|_{\psi_T=\psi_P} \propto \pi$

Effect of π (punctate-total ratio)

Larger



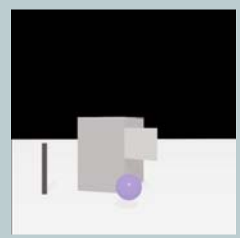


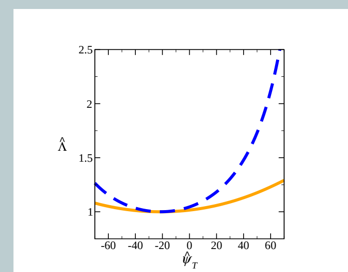
$$\pi = 1$$

Curvature $\left.\frac{\partial^2\hat{\Lambda}}{\partial\psi_T^2}\right|_{\psi_T=\psi_P} \propto \pi$

Effect of π (punctate-total ratio)

Smaller





$$\pi = 0.18$$

Curvature $\left.\frac{\partial^2\hat{\Lambda}}{\partial\psi_T^2}\right|_{\psi_T=\psi_P} \propto \pi$

Procedure

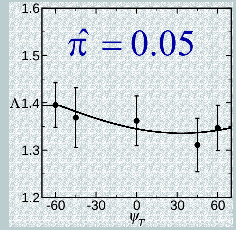
- 4 Cue conditions:
  - Only cast shadows
  - Only shading
  - Only specular highlights
  - All 3 cues

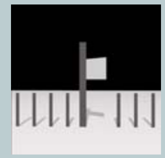
    In separate sessions
- 5 Orientations: $\psi_T = \{-60, -45, 0, 45, 60\}$
- 4 Luminances
- 10 repetitions of each conditions:

  10x5x4x4=800 trials per observer
- 5 Observers (one author HB)

Results: Observer KN

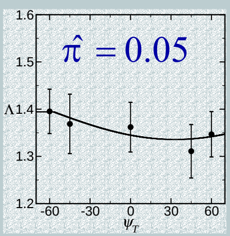
Only cast shadows



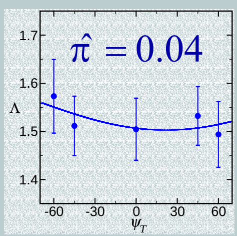


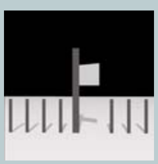
Results: Observer KN

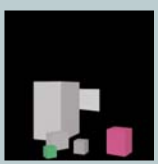
Only cast shadows



Only shading

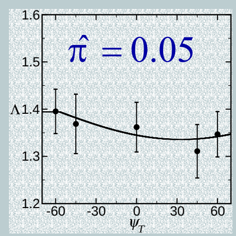




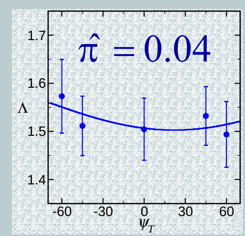


Results: Observer KN

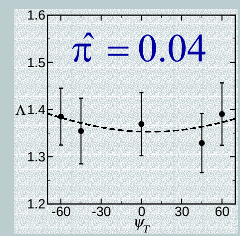
Only cast shadows

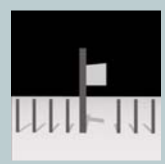


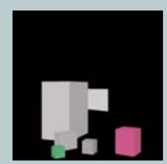
Only shading

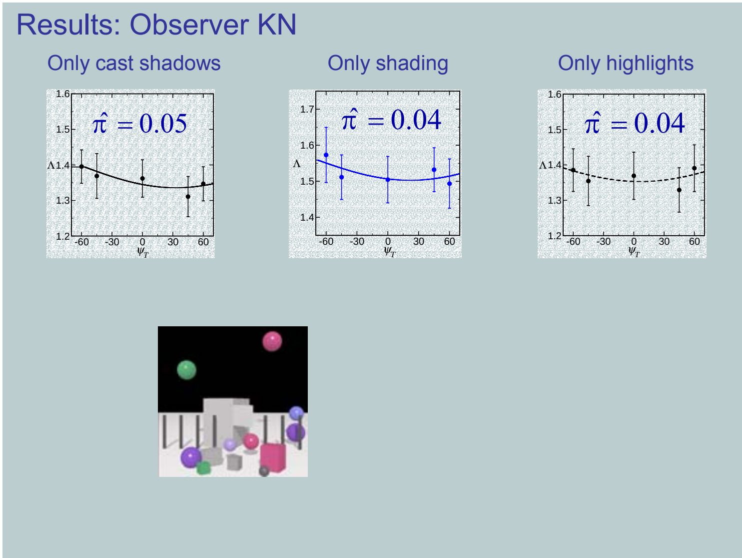


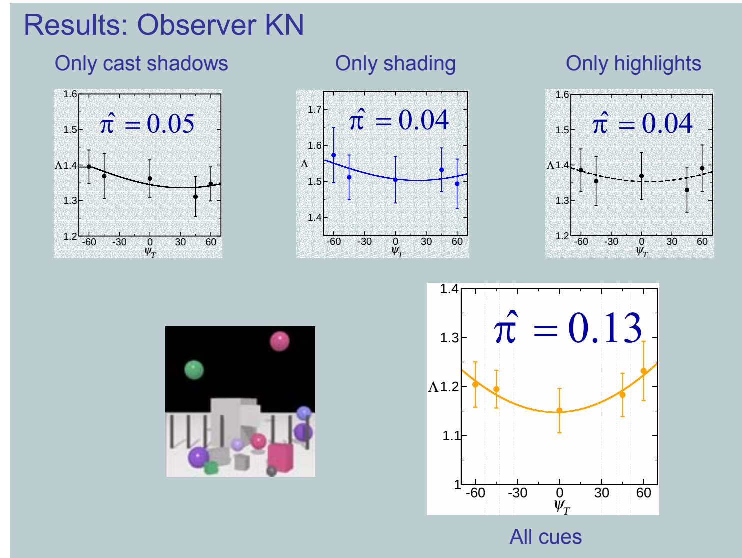
Only highlights

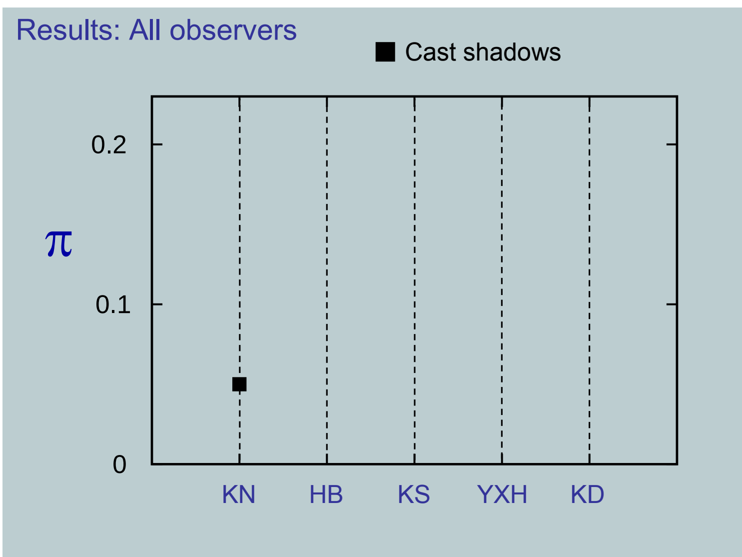


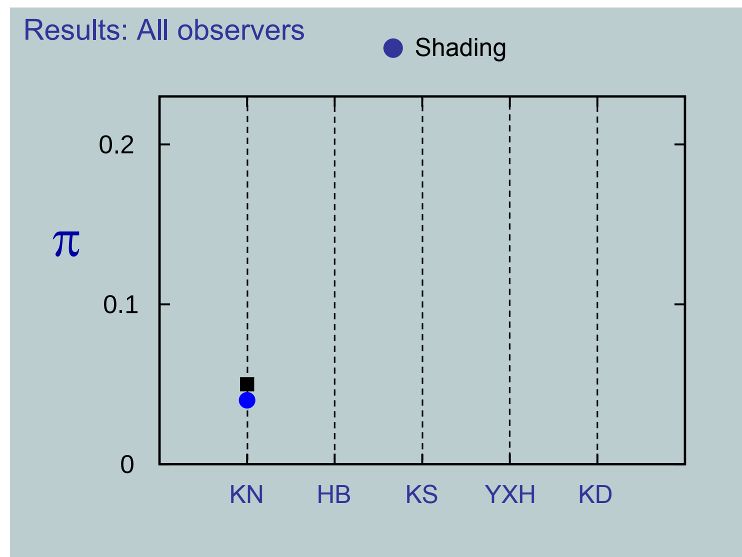


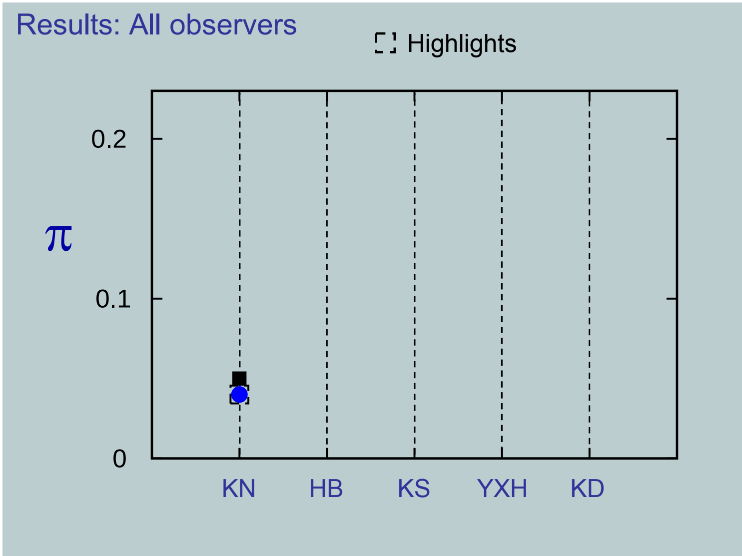


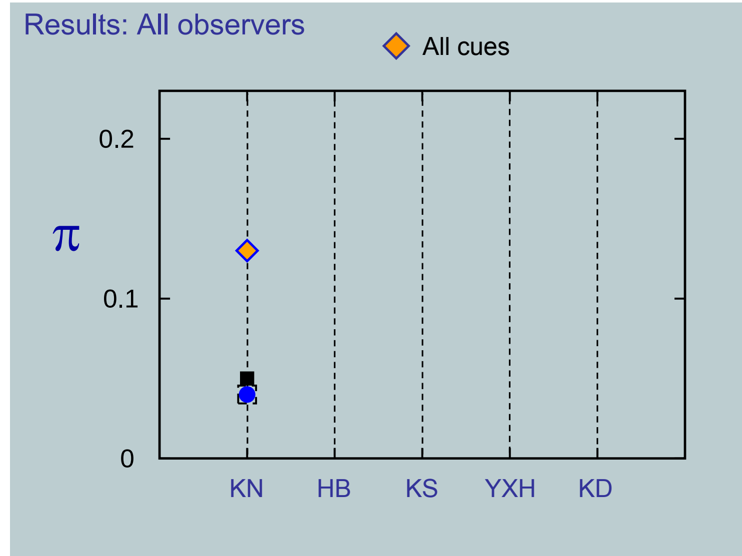

Results: Observer KN
Only cast shadows
Only shading
Only highlights
$\hat{\pi} = 0.05$
$\hat{\pi} = 0.04$
$\hat{\pi} = 0.04$

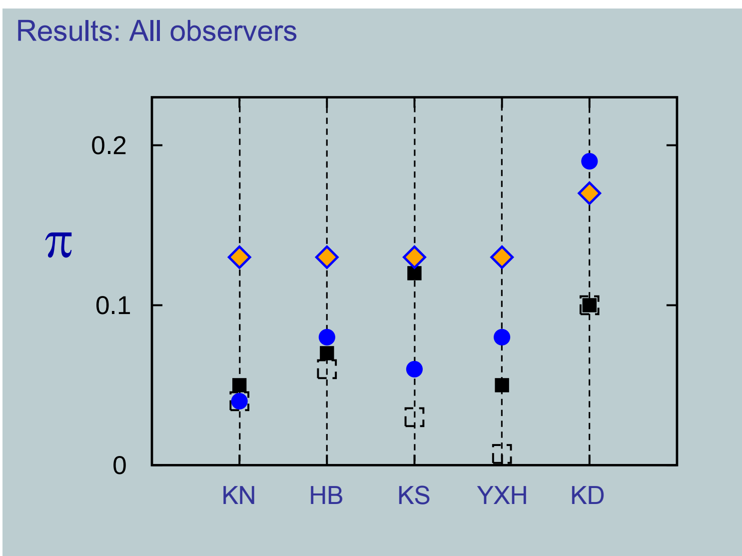

Results: Observer KN
Only cast shadows
Only shading
Only highlights
$\hat{\pi} = 0.05$
$\hat{\pi} = 0.04$
$\hat{\pi} = 0.04$
$\hat{\pi} = 0.13$
All cues

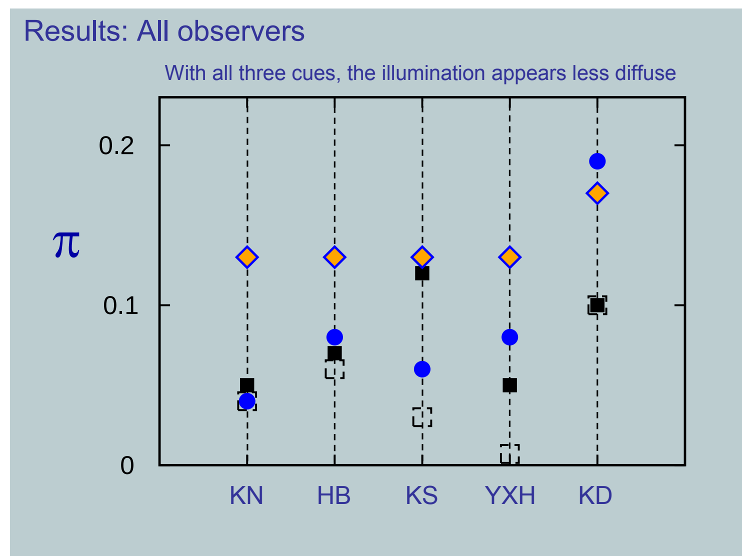

Results: All observers
Cast shadows
π
0.2
0.1
0
KN
HB
KS
YXH
KD


Results: All observers
Shading
π
0.2
0.1
0
KN
HB
KS
YXH
KD


Results: All observers
Highlights
0.2
π
0.1
0
KN
HB
KS
YXH
KD


Results: All observers
All cues
0.2
π
0.1
0
KN
HB
KS
YXH
KD


Results: All observers
0.2
π
0.1
0
KN
HB
KS
YXH
KD


Results: All observers
With all three cues, the illumination appears less diffuse
0.2
π
0.1
0
KN
HB
KS
YXH
KD

Model 0: Optimal Cue Combination

Given independent unbiased Gaussian estimates from multiples cues,

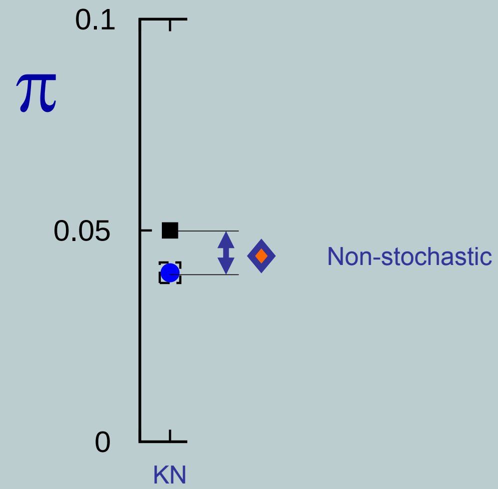
$$\hat{\pi}_i \sim \Phi\left(\pi, \sigma_i^2\right), \quad i = 1,2,\cdots,N$$

the minimum variance unbiased estimate of π is the weighted convex combination

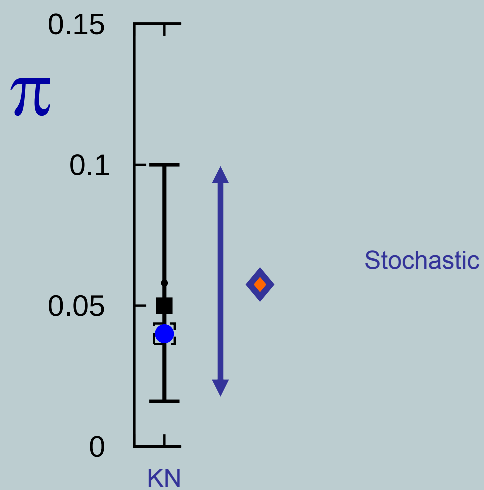
$$\hat{\pi} = \sum_{j=1}^{N} w_j \hat{\pi}_j \qquad w_j = \sigma_j^{-2} \Big/ \sum_{i=1}^{N} \sigma_i^{-2}$$

Oruc, I, et.al, (2003) Weighted linear cue combination with possibly correlated error, Vision Research **43**, 2451-2468

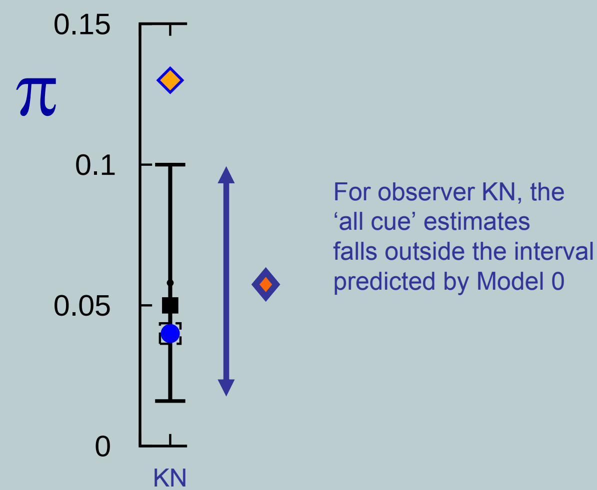
What would model 0 predict?



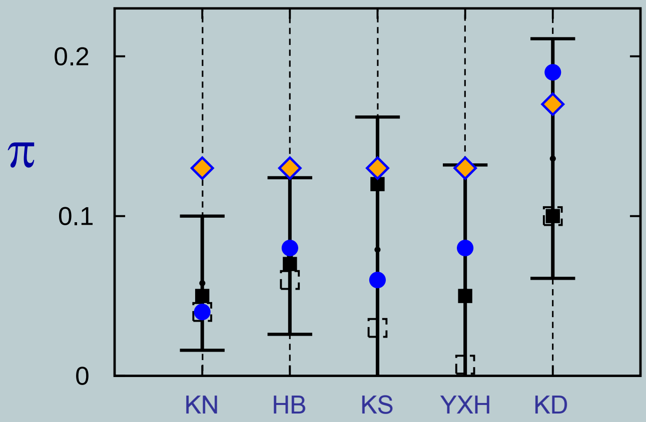
What would model 0 predict?



What would model 0 predict?



Results: All observers



We cannot explain these results by Model 0

We cannot explain these results by Model 0

Similar findings (for surface color estimation) were reported before

Kraft, J., Maloney S.I., and Brainard, D.H. (2002)
Perception, **31**, 247-263.

Bayesian Approach

Suppose that there is a *prior* towards a more diffuse illumination.

A prior is effectively an additional cue that always signals a fixed value.

$$\hat{\pi}_p \sim \Phi(\pi_0, \sigma_p^2)$$

$$\pi_0 \sim 0$$

Model 1: Optimal Cue Combination with a prior

$$\hat{\pi}_p \sim \Phi(\pi_0, \sigma_p^2)$$

$$\hat{\pi}_i \sim \Phi(\pi, \sigma_i^2)$$

$$E(\hat{\pi}_{i,p}) = w_i E(\hat{\pi}_i) + w_p E(\hat{\pi}_p)$$

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Contraction toward 0

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$$w_i = \frac{E(\hat{\pi}_{i,p}) - \pi_0}{\pi - \pi_0}$$

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Single Cues

$$E(\hat{\pi}_{i,p}) = w_i \pi + (1 - w_i)\pi_0 \quad i = 1,2,3$$

Three Cues

$$E(\hat{\pi}_{all}) = W\pi + (1 - W)\pi_0$$

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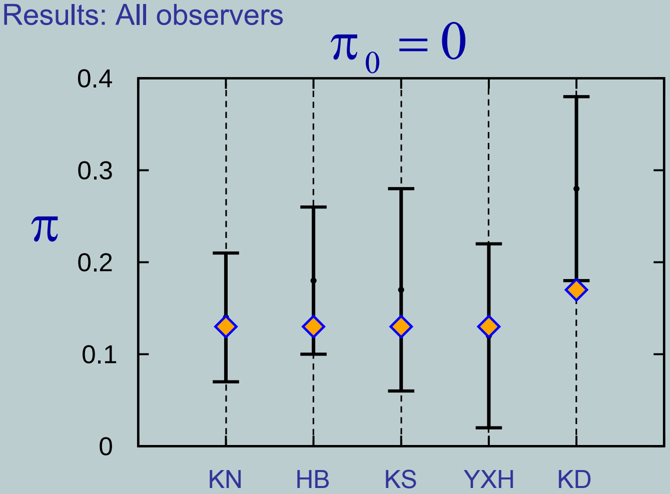
$$W = \frac{w_1 + w_2 + w_3}{[w_1 + w_2 + w_3 + 1]}$$

Results: All observers



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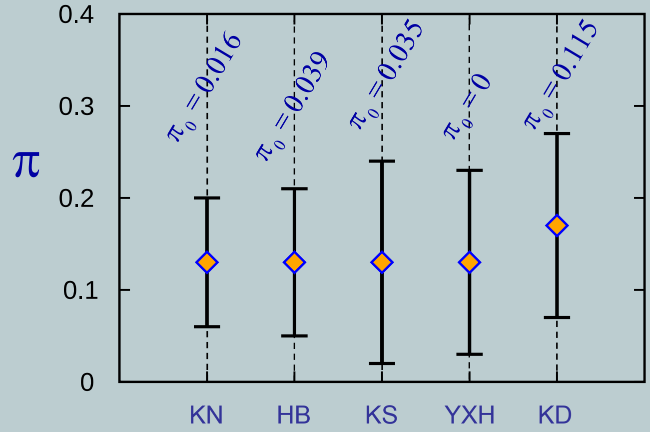

Conclusions

- All three illuminant cues seem to be used
- Single and multiple cue estimates of the punctate-total ratio π are *biased.*
- The weighted convex cue combination rule is not consistent with these results.
- The data is consistent with a model that assumes a prior towards more diffuse illumination ($\pi \sim 0$)