Humans make non-ideal inferences about world motion

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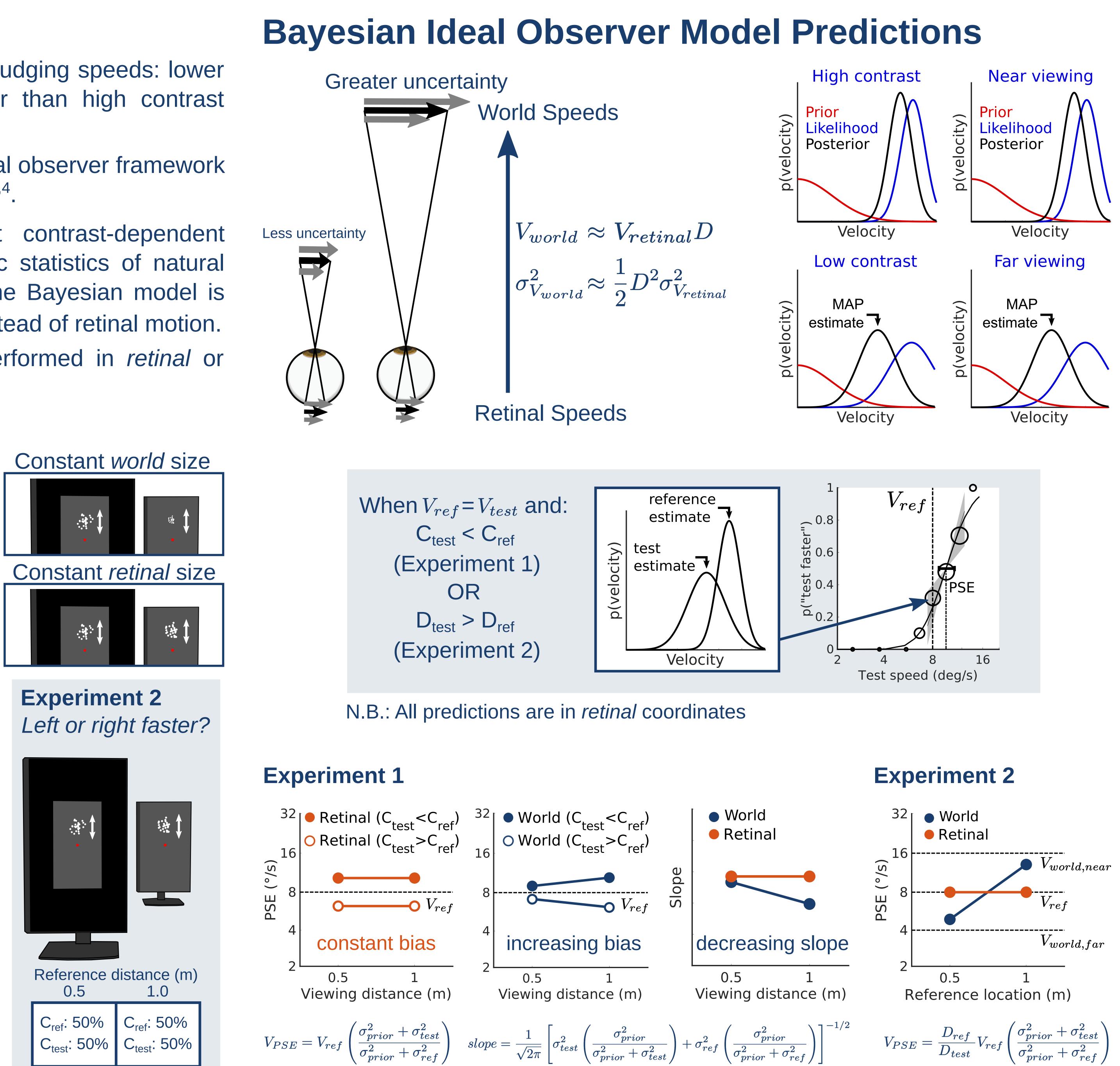Berkeley | Herbert Wertheim School of Optometry & Vision Science

Introduction

Humans are systematically biased when judging speeds: lower contrast objects appear to move slower than high contrast ones[1,2,3].
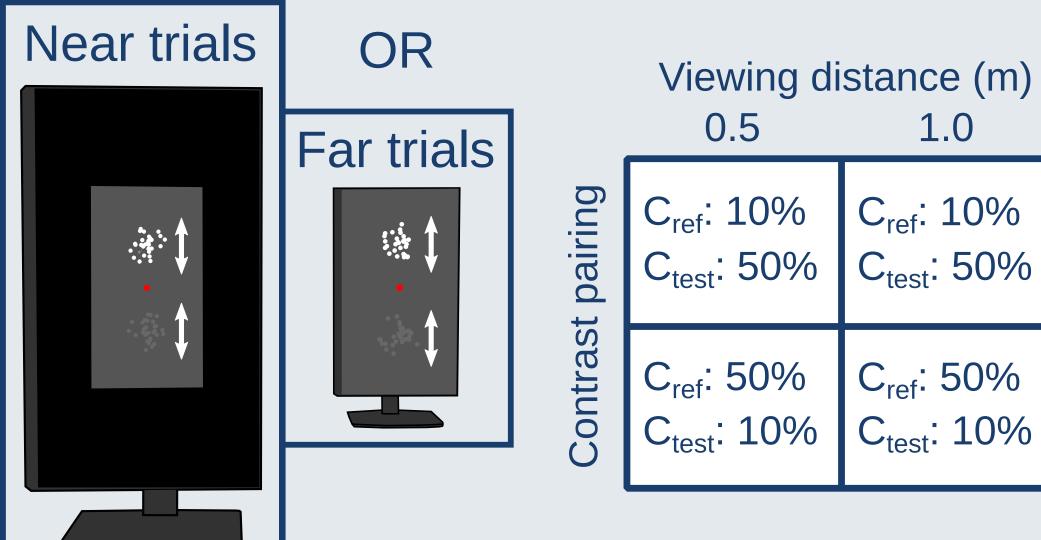
This is explained well with a Bayesian ideal observer framework where observers use a slow speed prior[2,3,4].
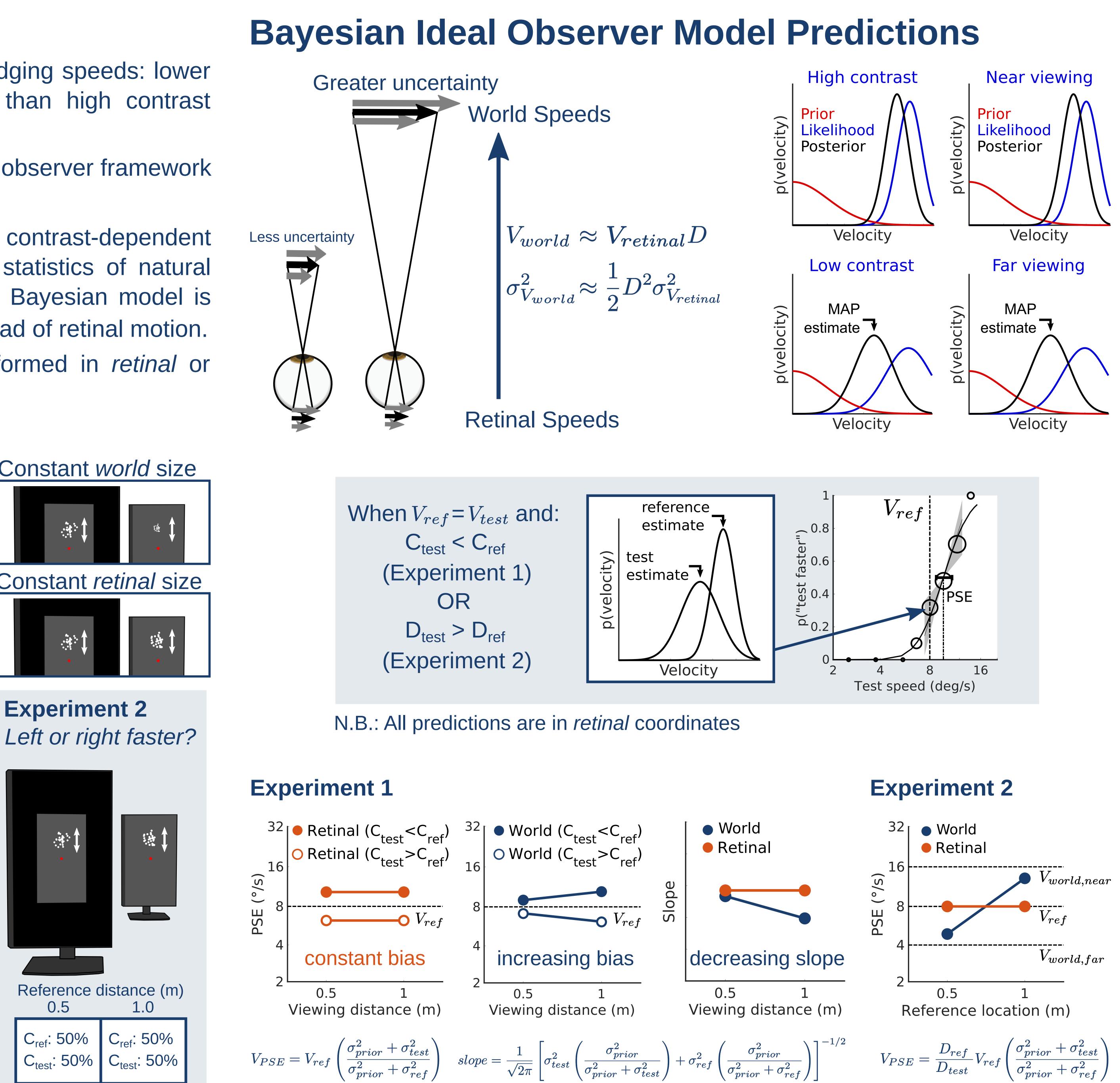
Recent work, however, suggests that contrast-dependent biases are better explained by the static statistics of natural retinal images[5]. A unique prediction of the Bayesian model is that motion biases should reflect world instead of retinal motion.

KEY QUESTION: Is speed inference performed in *retinal* or *world* coordinates?

Methods

Display Setup

Constant *world* size

Constant *retinal* size

Experiment 2
Left or right faster?
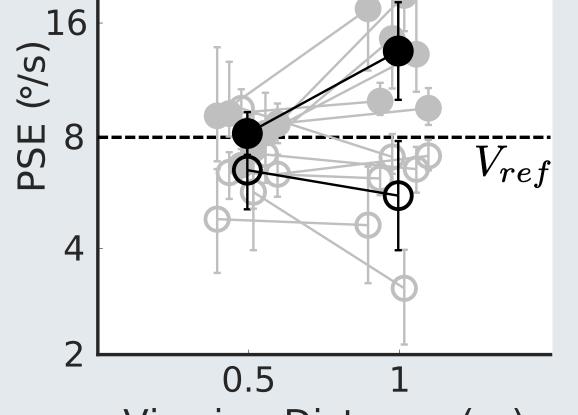
Experiment 1
Top or bottom faster?

Near trials   OR   Far trials

Contrast pairing

Viewing distance (m)	0.5	1.0
	C_{ref}: 10% C_{test}: 50%	C_{ref}: 10% C_{test}: 50%
	C_{ref}: 50% C_{test}: 10%	C_{ref}: 50% C_{test}: 10%

Reference distance (m)

	0.5	1.0
	C_{ref}: 50% C_{test}: 50%	C_{ref}: 50% C_{test}: 50%

Bayesian Ideal Observer Model Predictions

Greater uncertainty

World Speeds

Less uncertainty

Retinal Speeds

$V_{world} \approx V_{retinal} D$

$\sigma^2_{V_{world}} \approx \frac{1}{2} D^2 \sigma^2_{V_{retinal}}$

High contrast — Prior / Likelihood / Posterior

Near viewing — Prior / Likelihood / Posterior

Low contrast — MAP estimate

Far viewing — MAP estimate

When $V_{ref} = V_{test}$ and:
$C_{test} < C_{ref}$
(Experiment 1)
OR
$D_{test} > D_{ref}$
(Experiment 2)

reference estimate / test estimate

V_{ref} / PSE

N.B.: All predictions are in *retinal* coordinates

Experiment 1

● Retinal ($C_{test} < C_{ref}$)
○ Retinal ($C_{test} > C_{ref}$)

constant bias

● World ($C_{test} < C_{ref}$)
○ World ($C_{test} > C_{ref}$)

increasing bias

● World
● Retinal

decreasing slope

Experiment 2

● World
● Retinal

$V_{world,near}$
V_{ref}
$V_{world,far}$

$V_{PSE} = V_{ref}\left(\frac{\sigma^2_{prior} + \sigma^2_{test}}{\sigma^2_{prior} + \sigma^2_{ref}}\right)$

$slope = \frac{1}{\sqrt{2\pi}}\left[\sigma^2_{test}\left(\frac{\sigma^2_{prior}}{\sigma^2_{prior} + \sigma^2_{test}}\right) + \sigma^2_{ref}\left(\frac{\sigma^2_{prior}}{\sigma^2_{prior} + \sigma^2_{ref}}\right)\right]^{-1/2}$

$V_{PSE} = \frac{D_{ref}}{D_{test}} V_{ref}\left(\frac{\sigma^2_{prior} + \sigma^2_{test}}{\sigma^2_{prior} + \sigma^2_{ref}}\right)$

Results

Constant *world* size

● $C_{test} < C_{ref}$ (p = 0.018) ✱
○ $C_{test} > C_{ref}$ (p = 0.19)
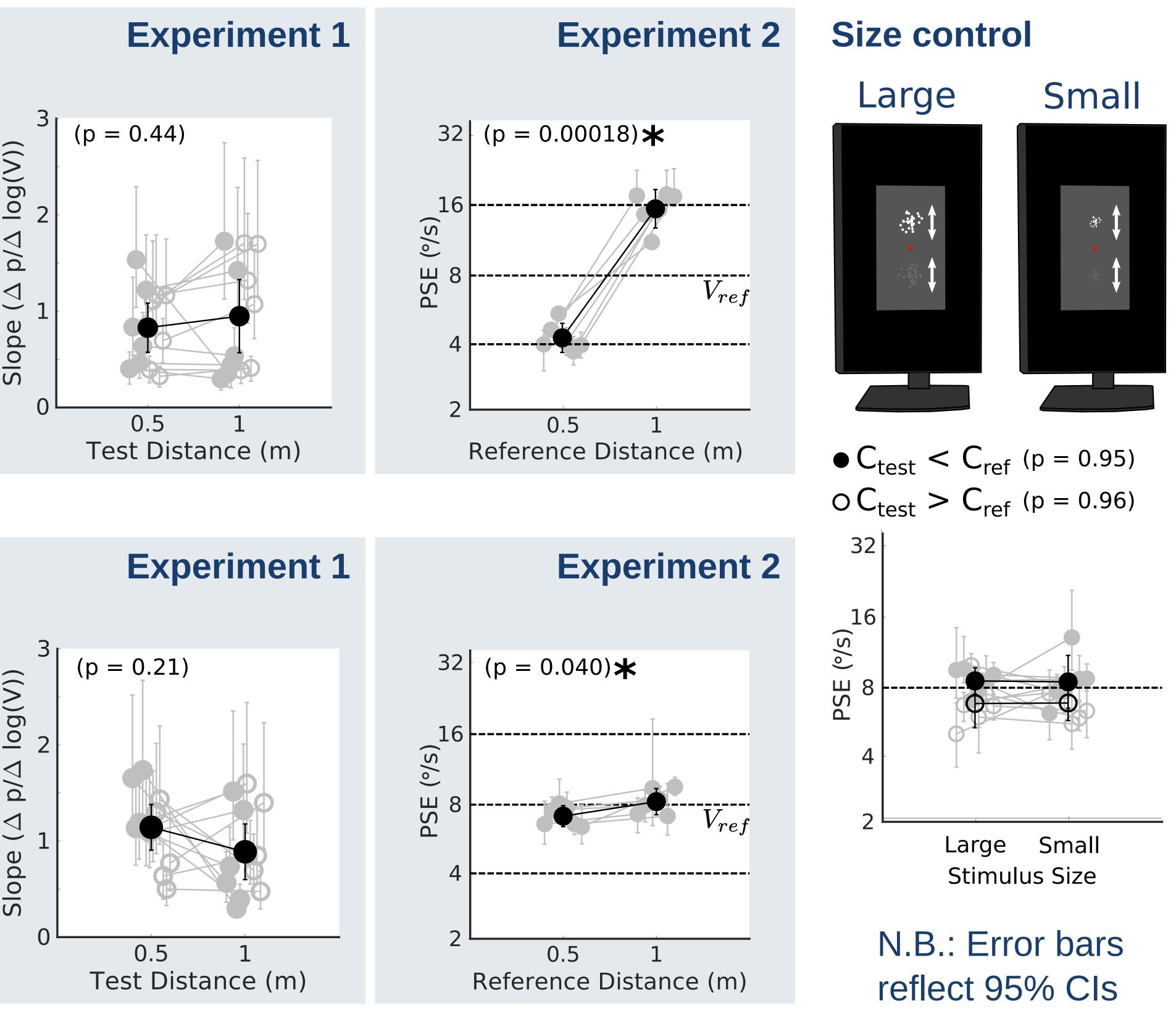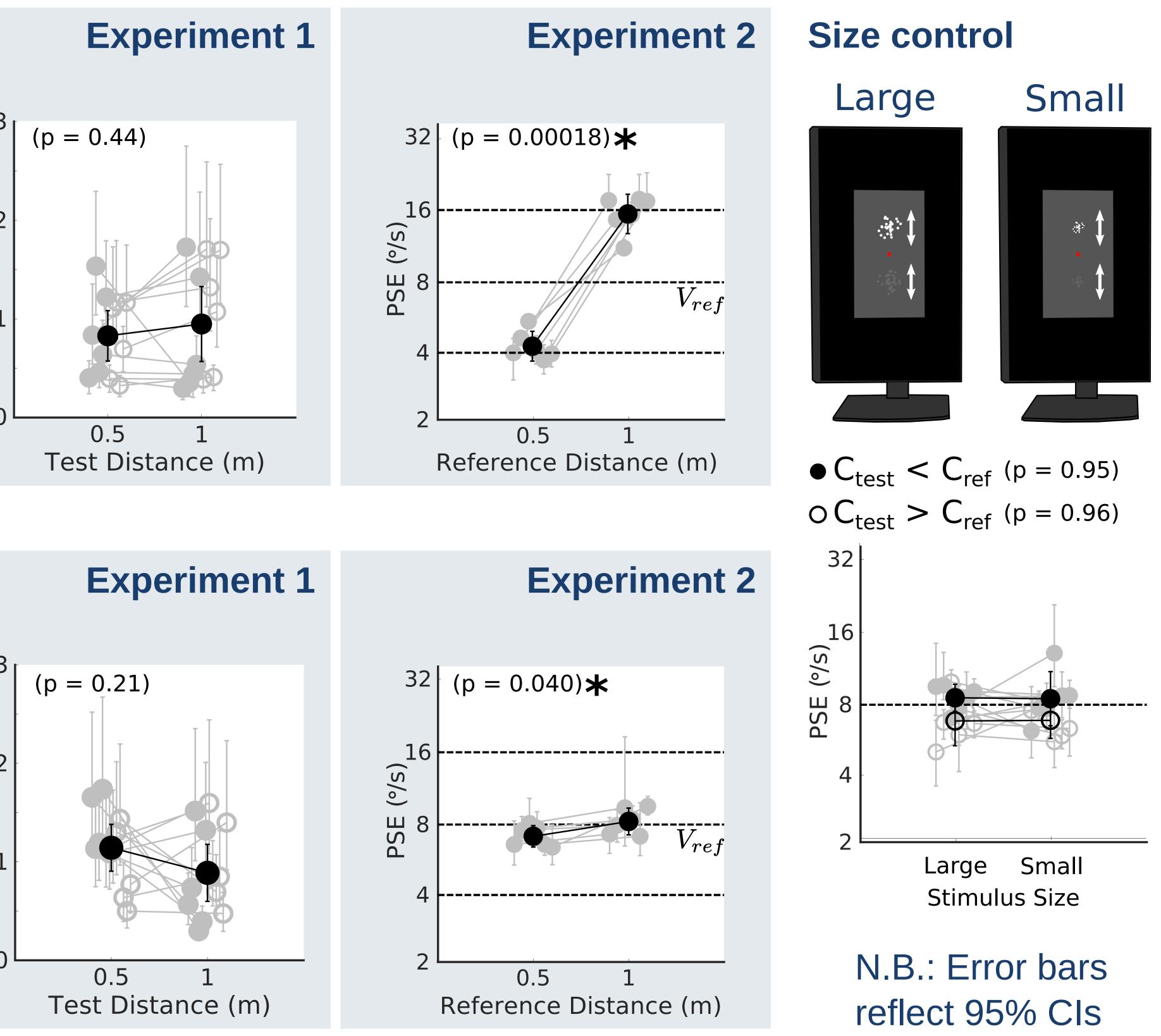
Experiment 1 (p = 0.44)

Experiment 2 (p = 0.00018) ✱

Constant *retinal* size

● $C_{test} < C_{ref}$ (p = 0.24)
○ $C_{test} > C_{ref}$ (p = 0.48)

Experiment 1 (p = 0.21)

Experiment 2 (p = 0.040) ✱

Size control

Large   Small

● $C_{test} < C_{ref}$ (p = 0.95)
○ $C_{test} > C_{ref}$ (p = 0.96)

N.B.: Error bars reflect 95% CIs

Conclusions

We find better support for the world model, but the responses do not perfectly match predictions.

Unless relative perspective cues are present, human observers do not demonstrate distance-dependent increases in speed uncertainty as expected under ideal observer models.

Decreased stimulus size alone cannot account for differences in speed biases between distances.

References

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