

Constraining computational models of brightness perception: what's the right psychophysical data?

MODVIS 2022

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* : equal contribution

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Technische Universität Berlin

Outline

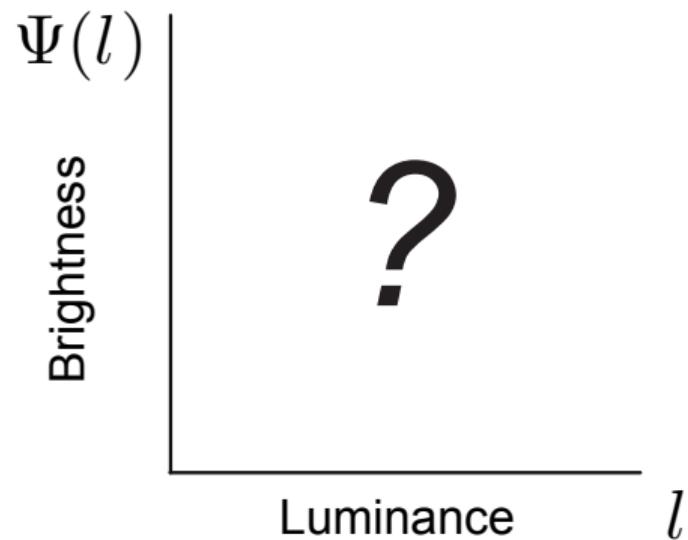
General question of Psychophysics:

Mapping between physical and perceptual dimensions (Fechner, 1860)

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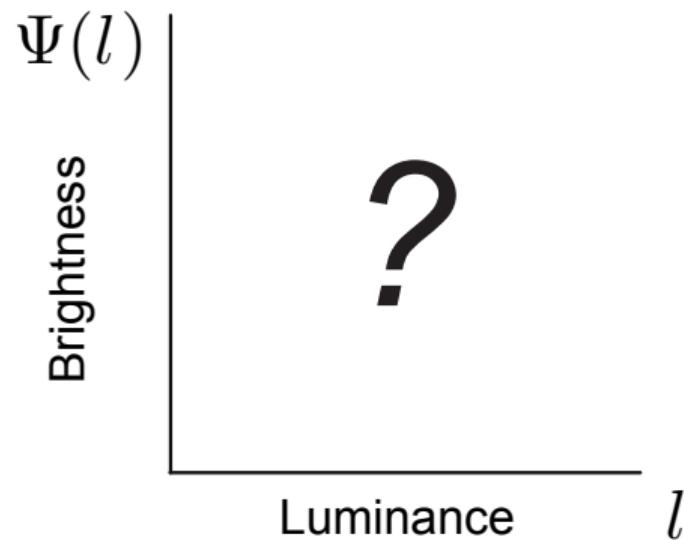
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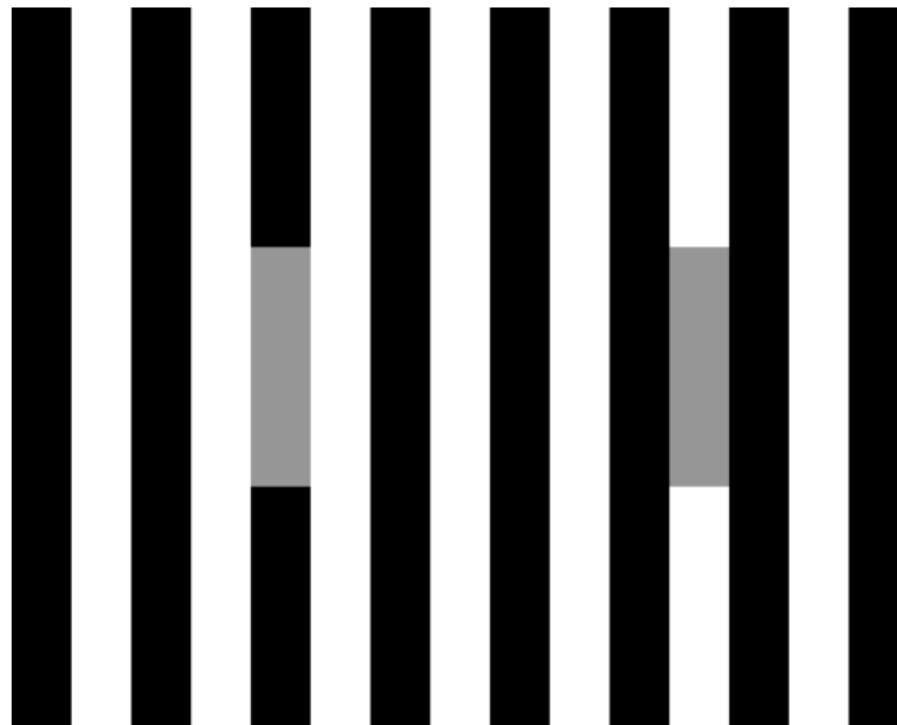
Open questions:

- ▶ how do we measure transfer functions psychophysically?
- ▶ do current models account for these transfer functions?

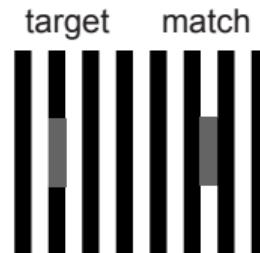


Brightness depends on luminance and surround context

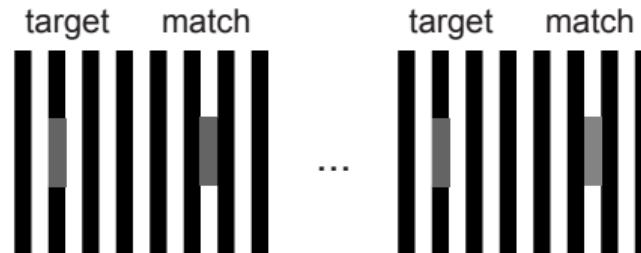
White's stimulus



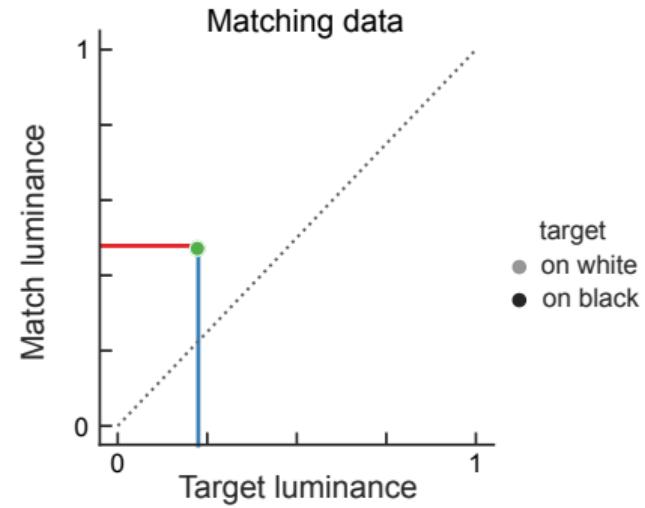
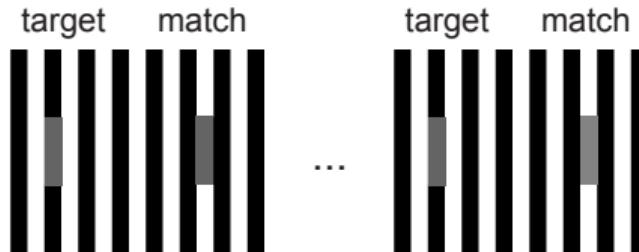
Matching's logic and assumptions



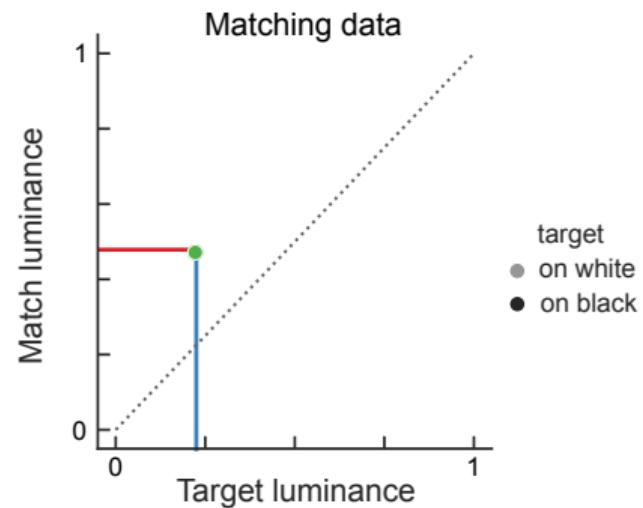
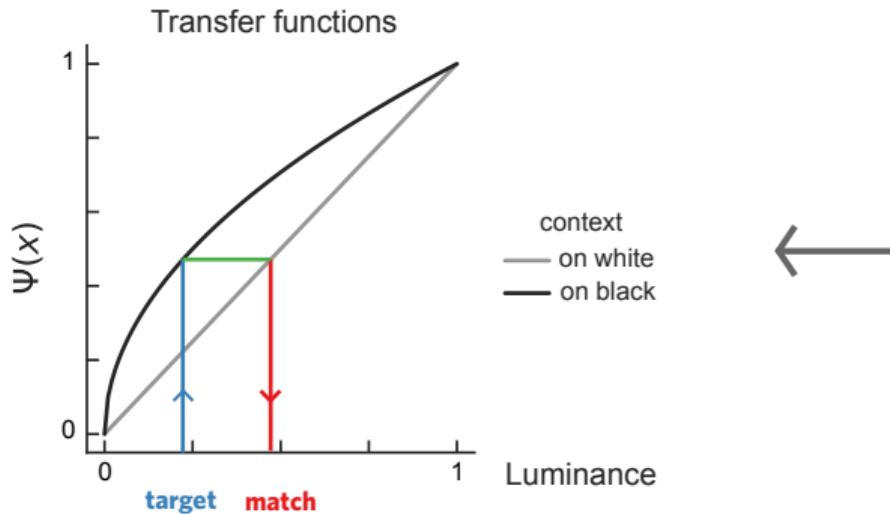
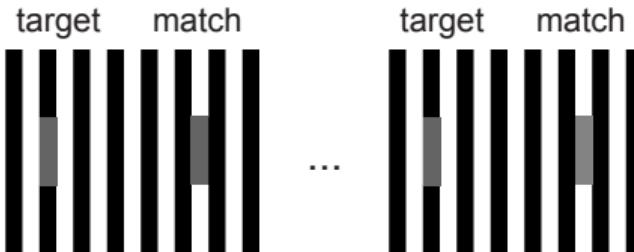
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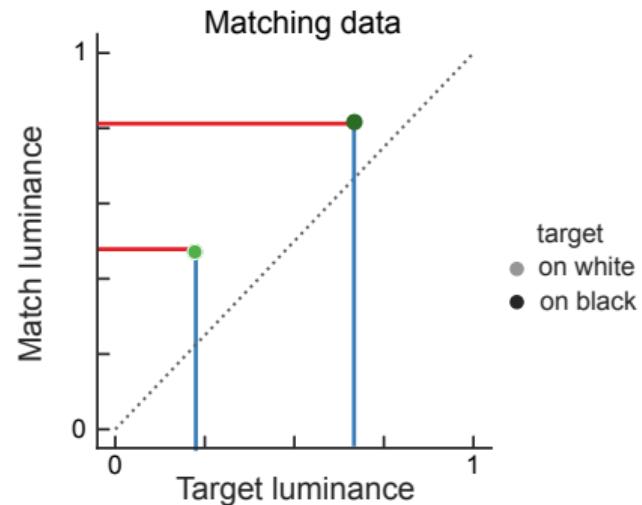
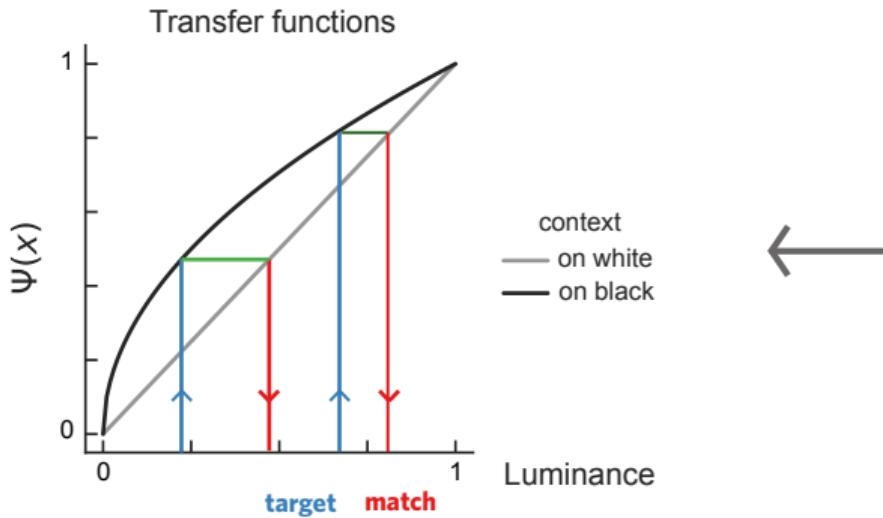
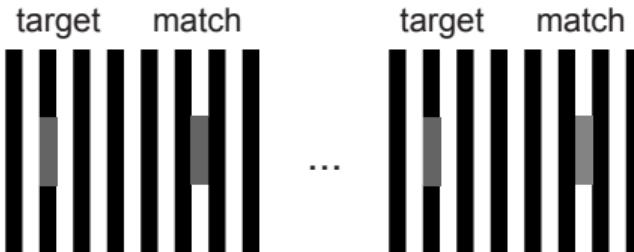
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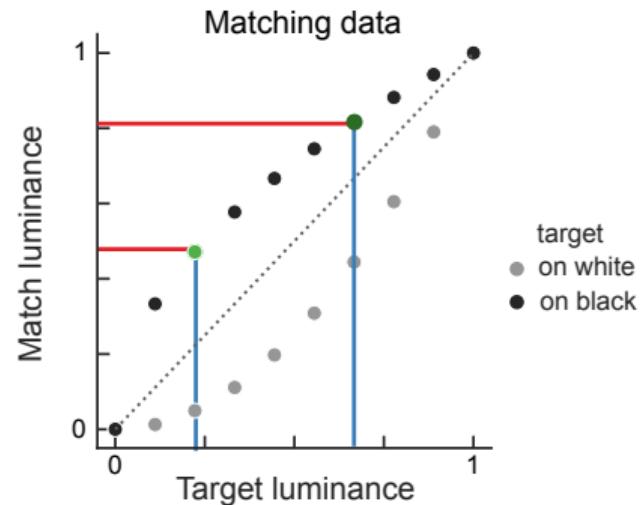
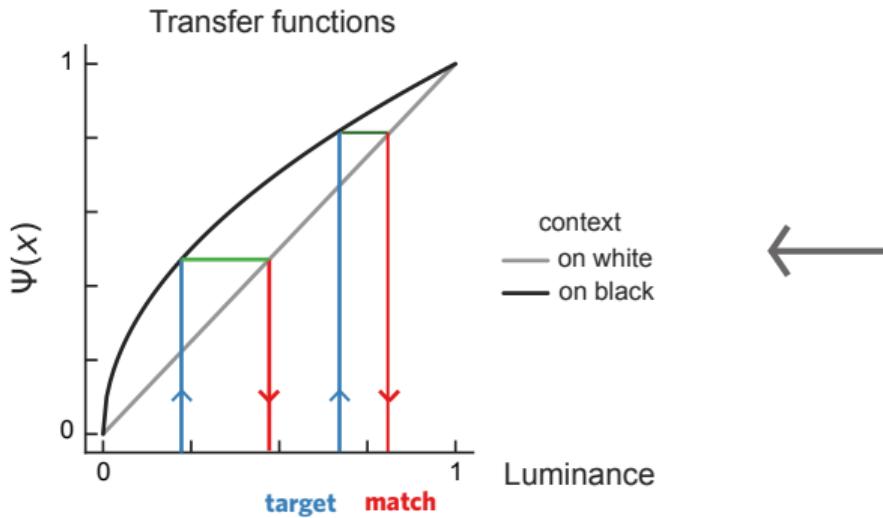
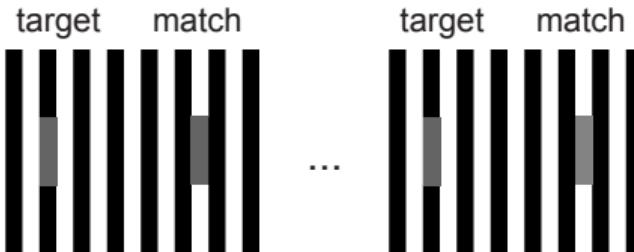
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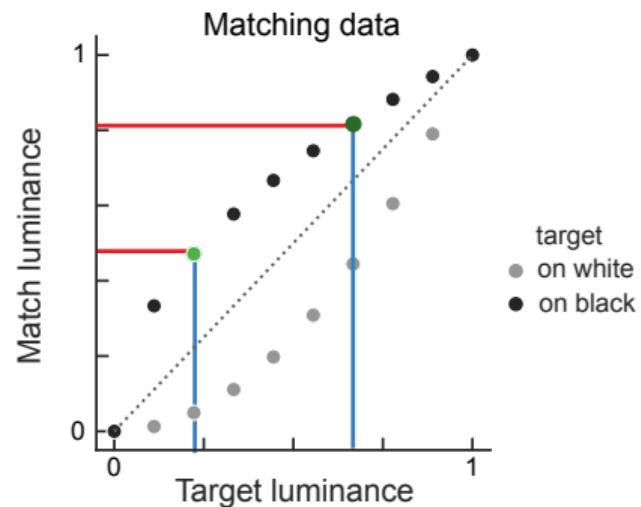
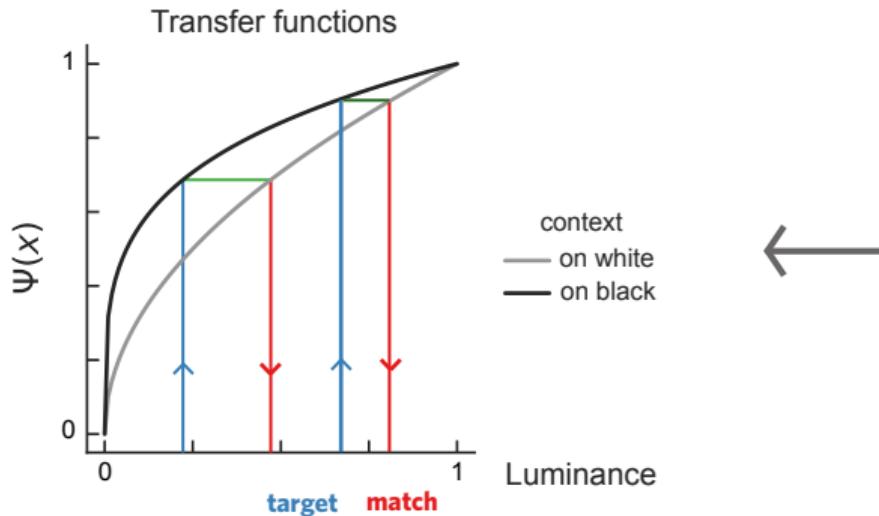
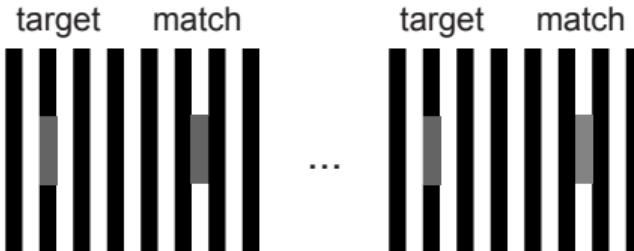
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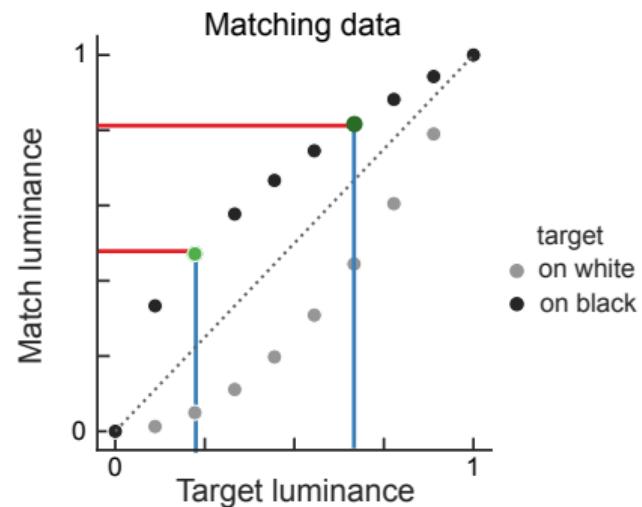
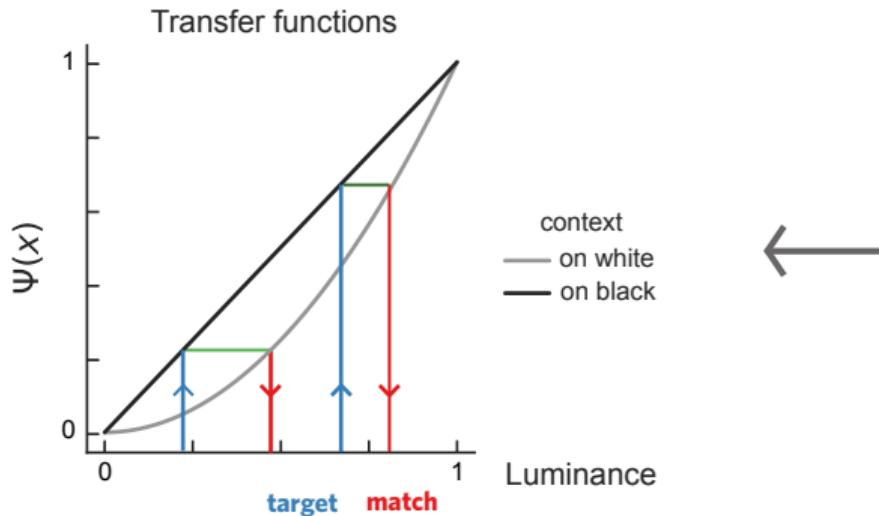
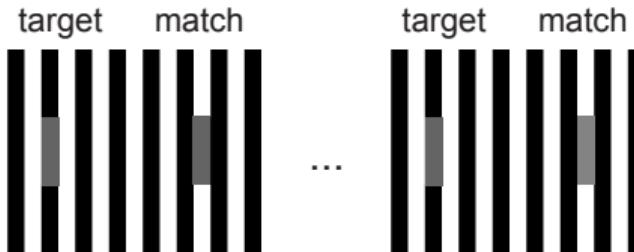
Matching's logic and assumptions



Matching's logic and assumptions



Matching's logic and assumptions



Alternative: scaling methods

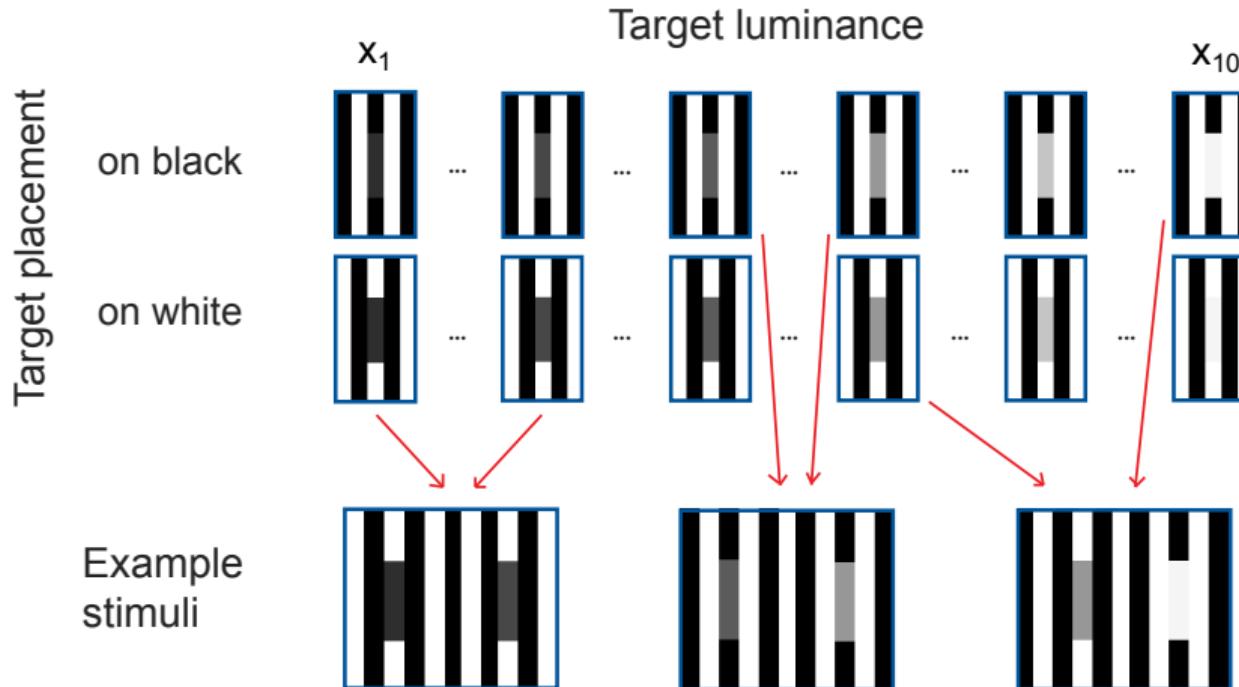
Maximum Likelihood Conjoint Measurement (MLCM)

Ho, Landy & Maloney (2008)

Knoblauch & Maloney (2012)

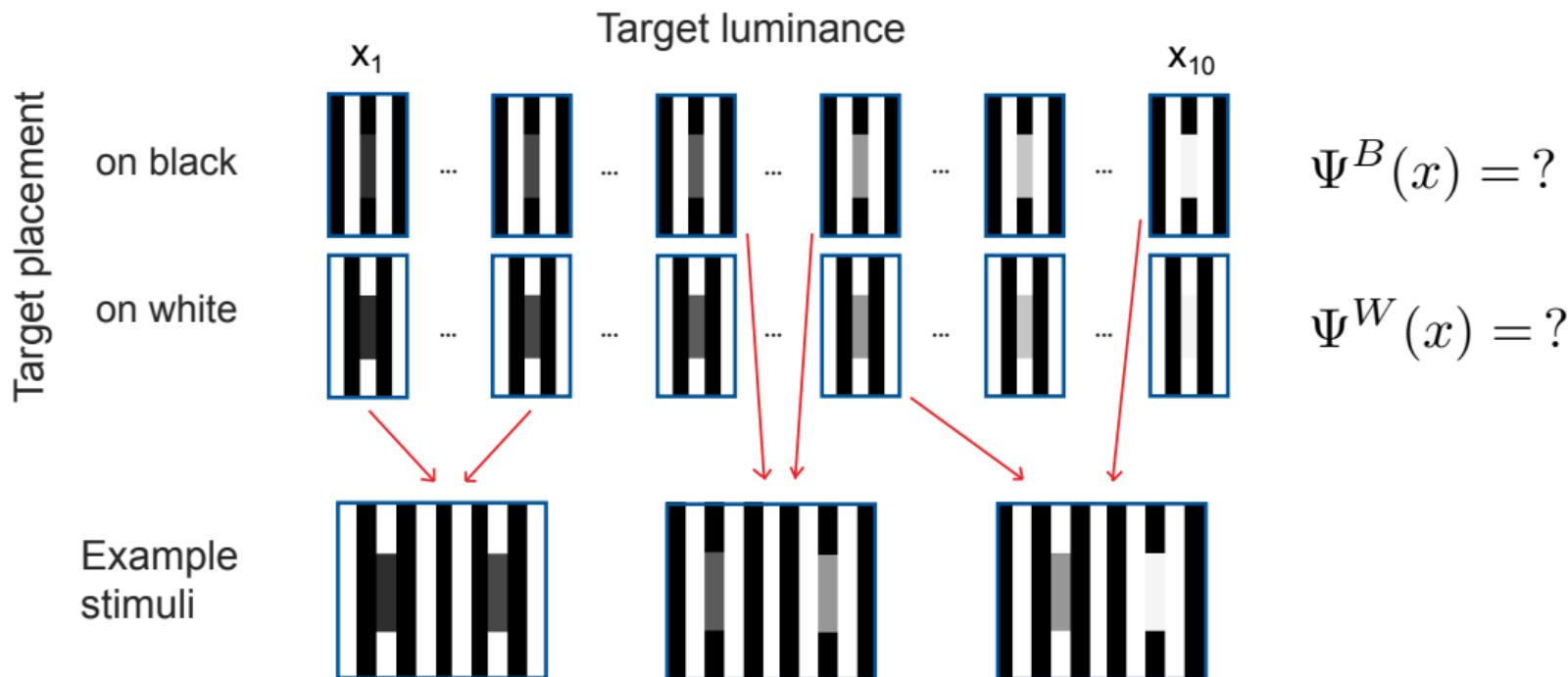
Aguilar & Maertens (2020, 2022)

MLCM experiment for White's stimulus



Task: which one is brighter? left or right

MLCM experiment for White's stimulus



Task: which one is brighter? left or right

Scales estimation

Raw judgments

trial	R
1	
2	0
3	
	⋮

Decision model

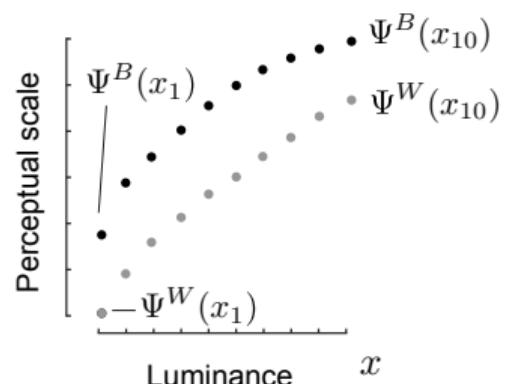
$$\Delta = \Psi^{\{W,B\}_R}(x_R) - \Psi^{\{W,B\}_L}(x_L) + \epsilon$$

$$\epsilon \sim N(0, \sigma^2)$$

$$\Delta > 0 \rightarrow R = 1$$

$$\Delta < 0 \rightarrow R = 0$$

Output: scales



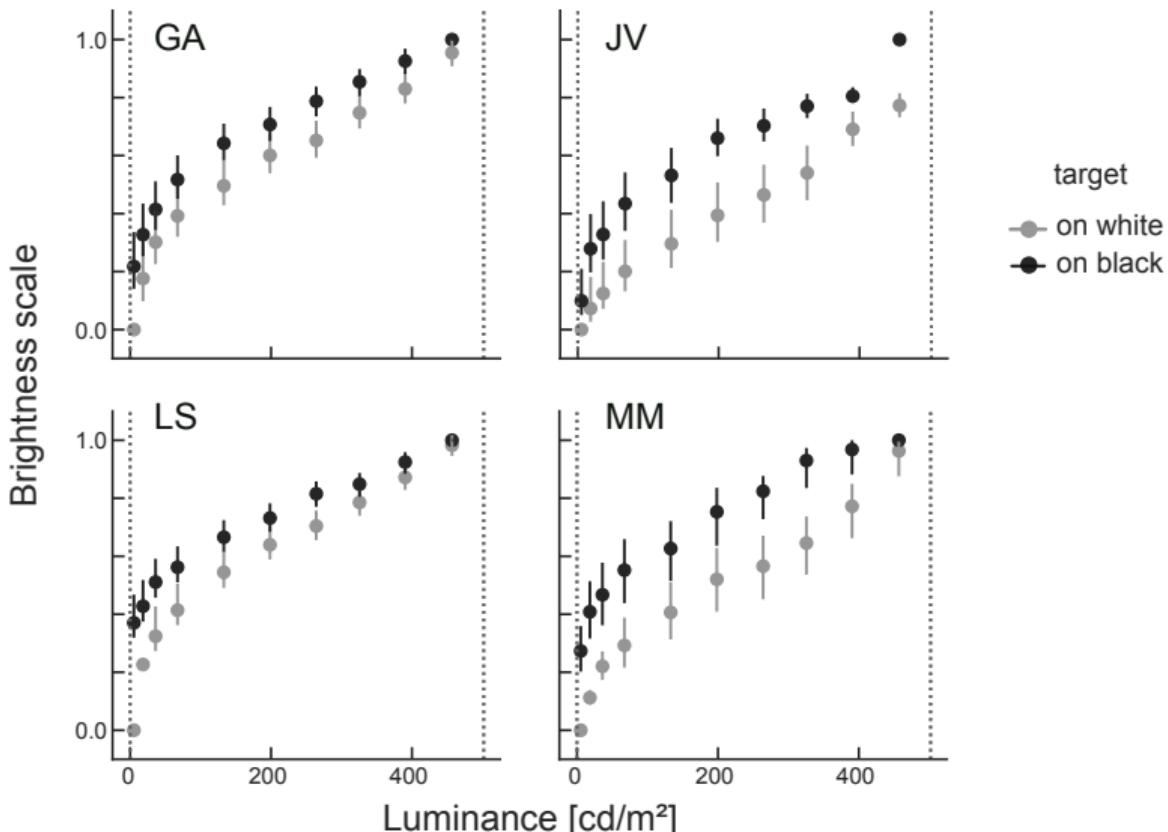
$$\Delta_1 = \Psi^W(x_6) - \Psi^W(x_4) + \epsilon$$

$$\Delta_2 = \Psi^B(x_3) - \Psi^B(x_6) + \epsilon$$

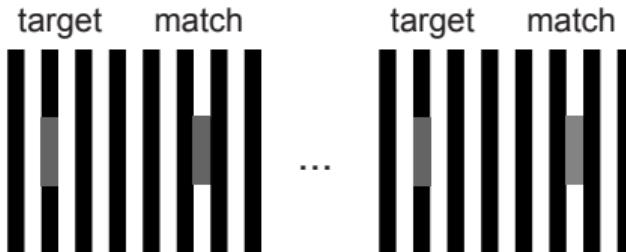
$$\Delta_3 = \Psi^B(x_8) - \Psi^W(x_4) + \epsilon$$

⋮

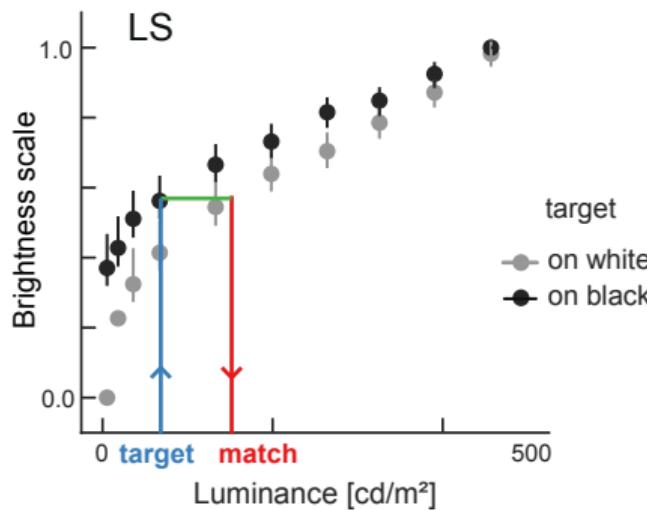
Results: brightness scales are non-linear



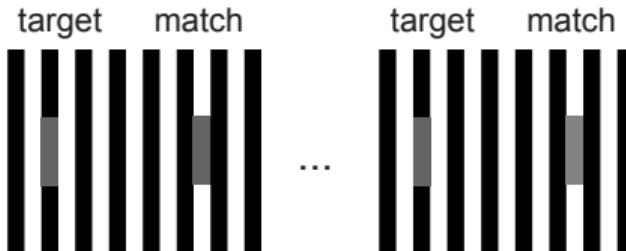
Brightness scales can predict matches



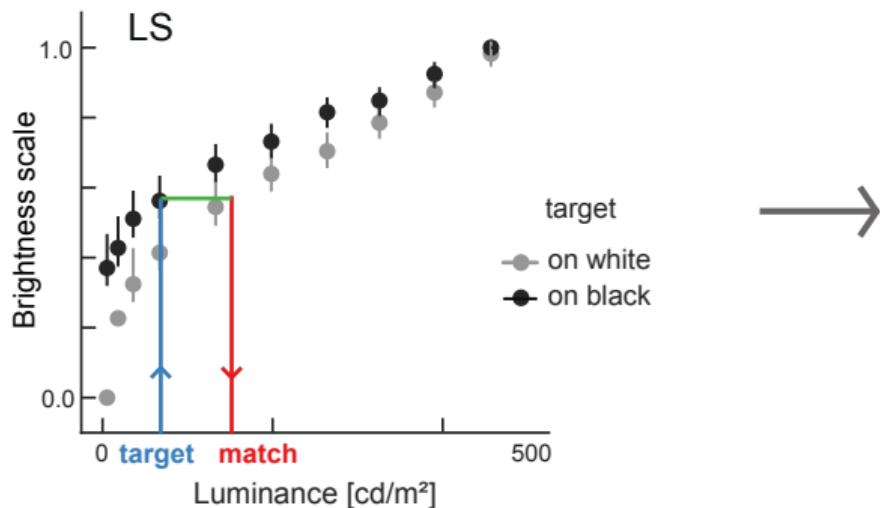
Brightness scale \sim Transfer function



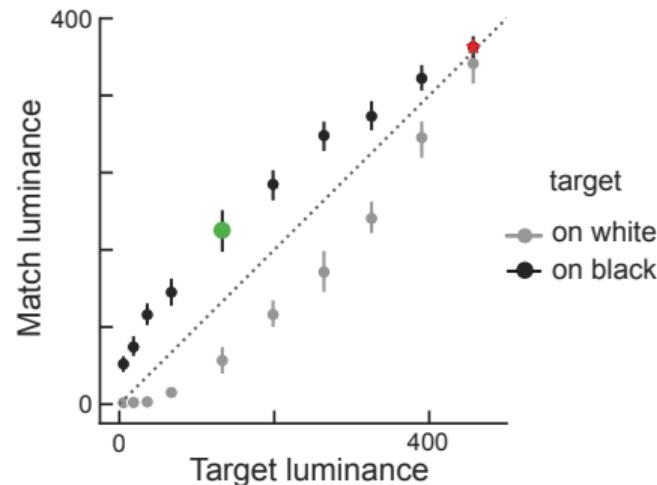
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Brightness scale \sim Transfer function

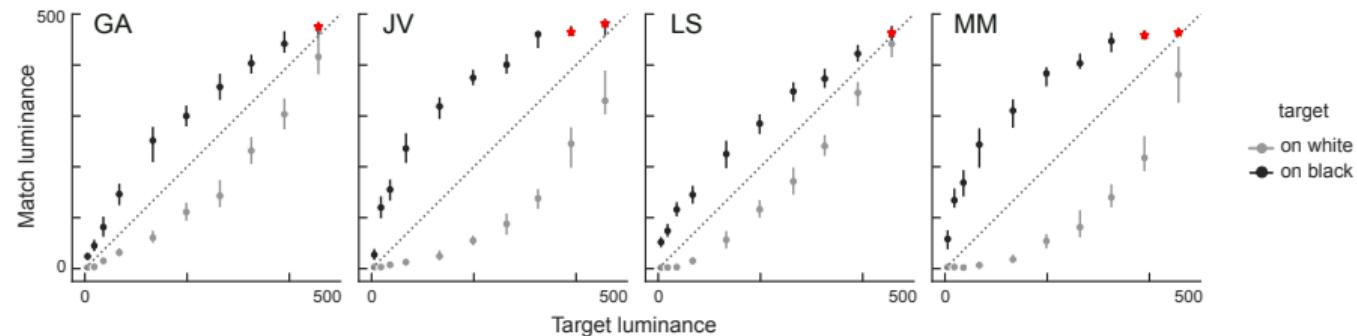


Predicted matching data

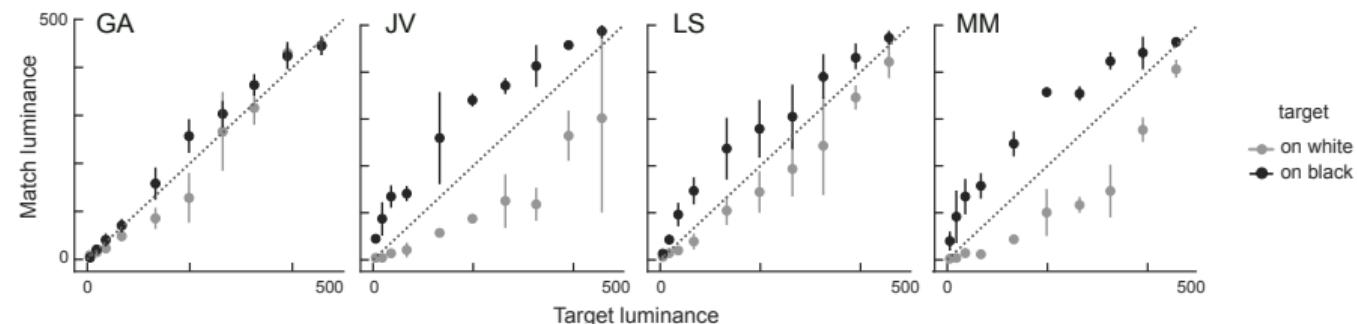


Predicted and actual matches

Predicted matches



Actual matches



Interim summary

General question of Psychophysics:

Mapping between physical and perceptual dimensions (Fechner, 1860)

Open questions:

- ▶ how do we measure transfer functions psychophysically?

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perceptual scales are more informative than matches

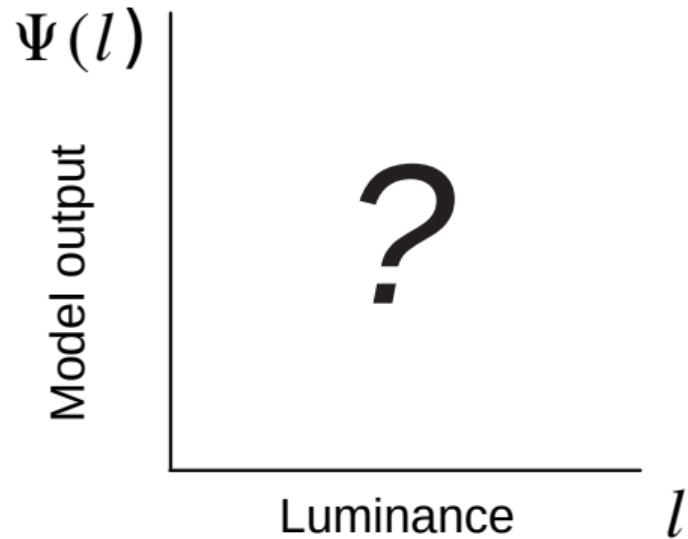
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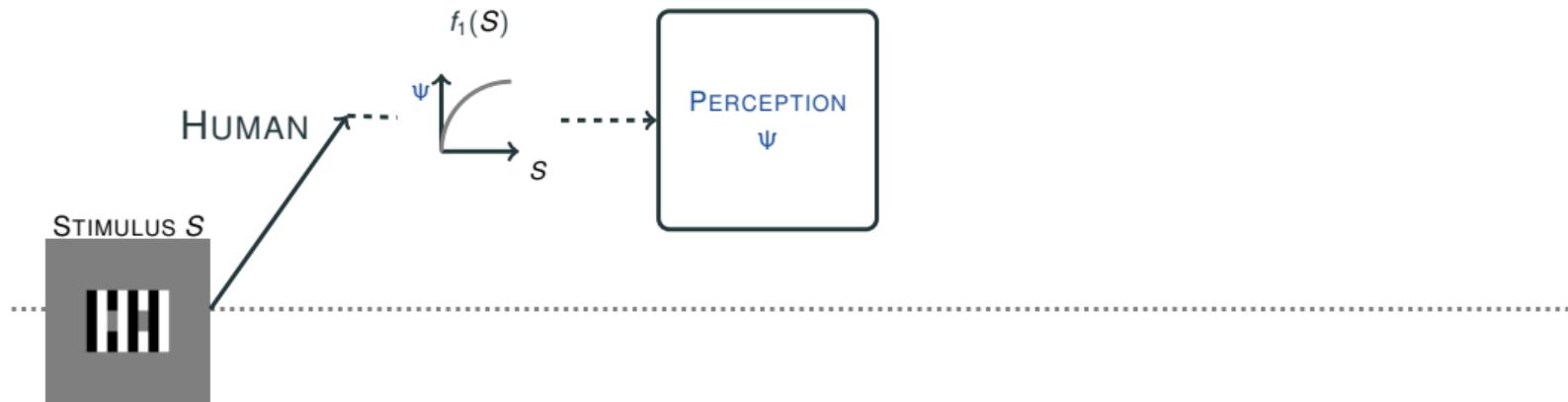


Cannot directly compare model and perception

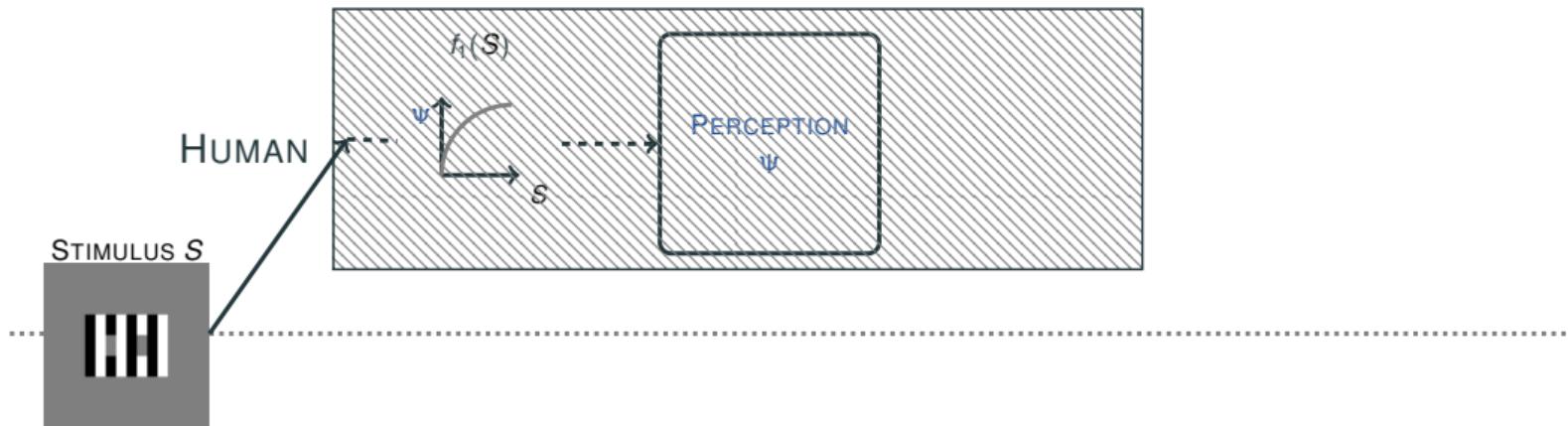
STIMULUS S



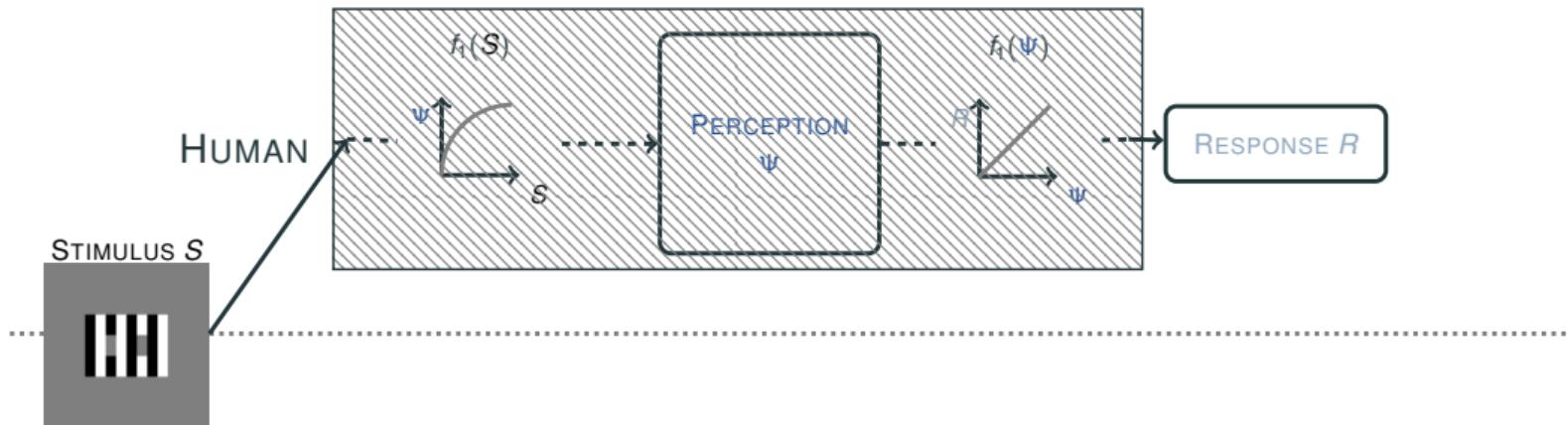
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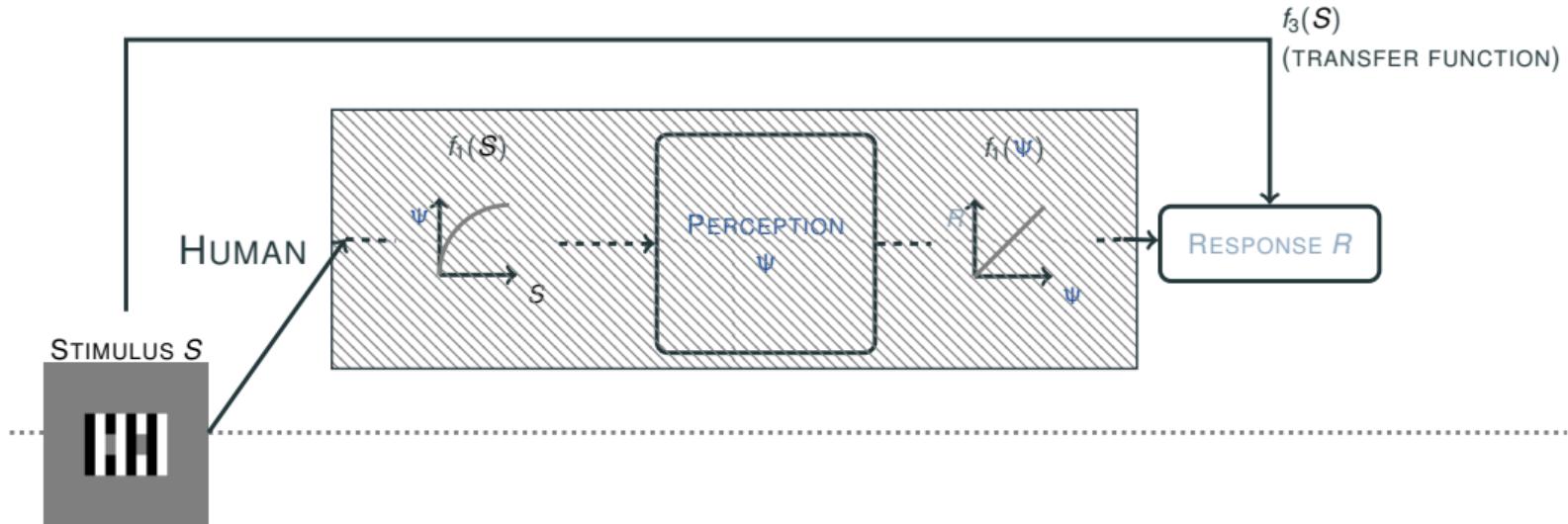
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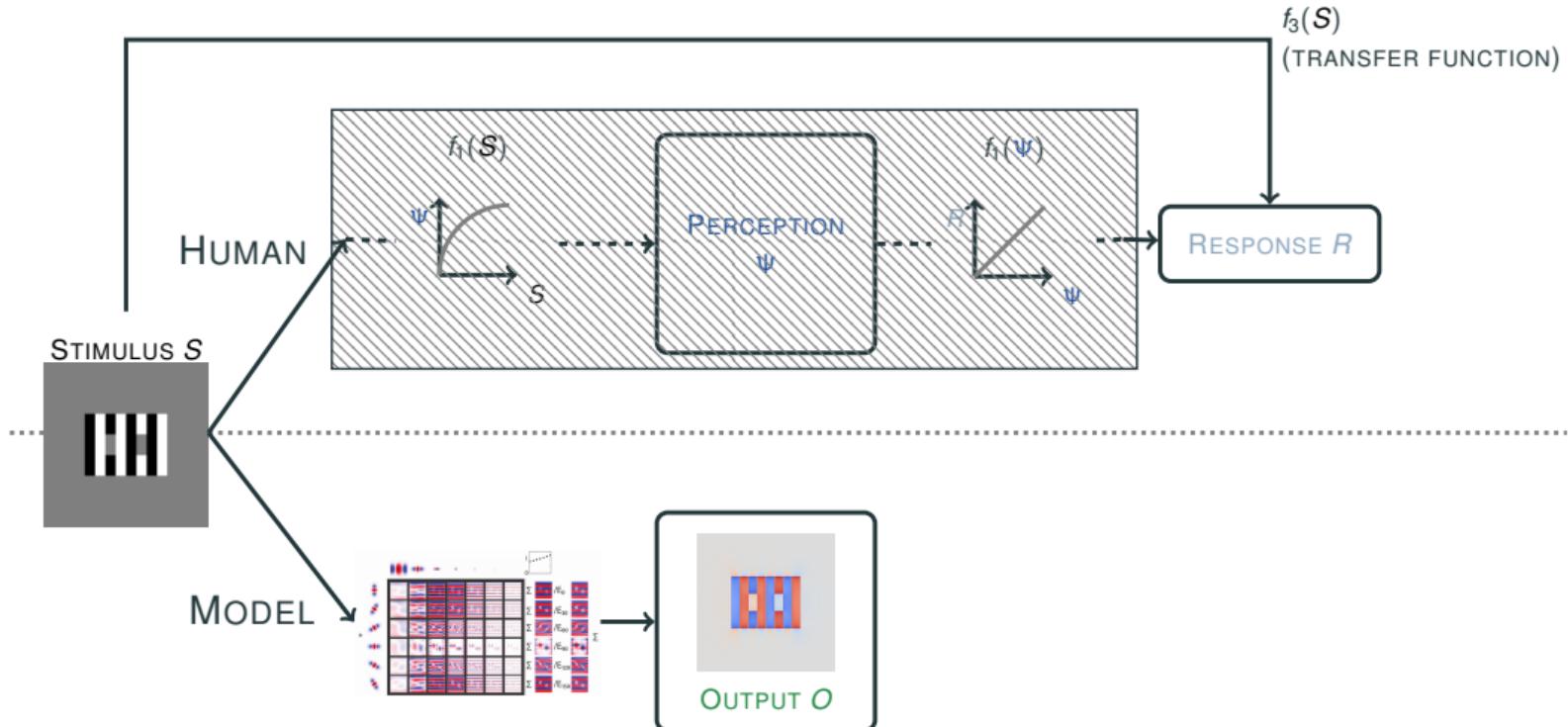
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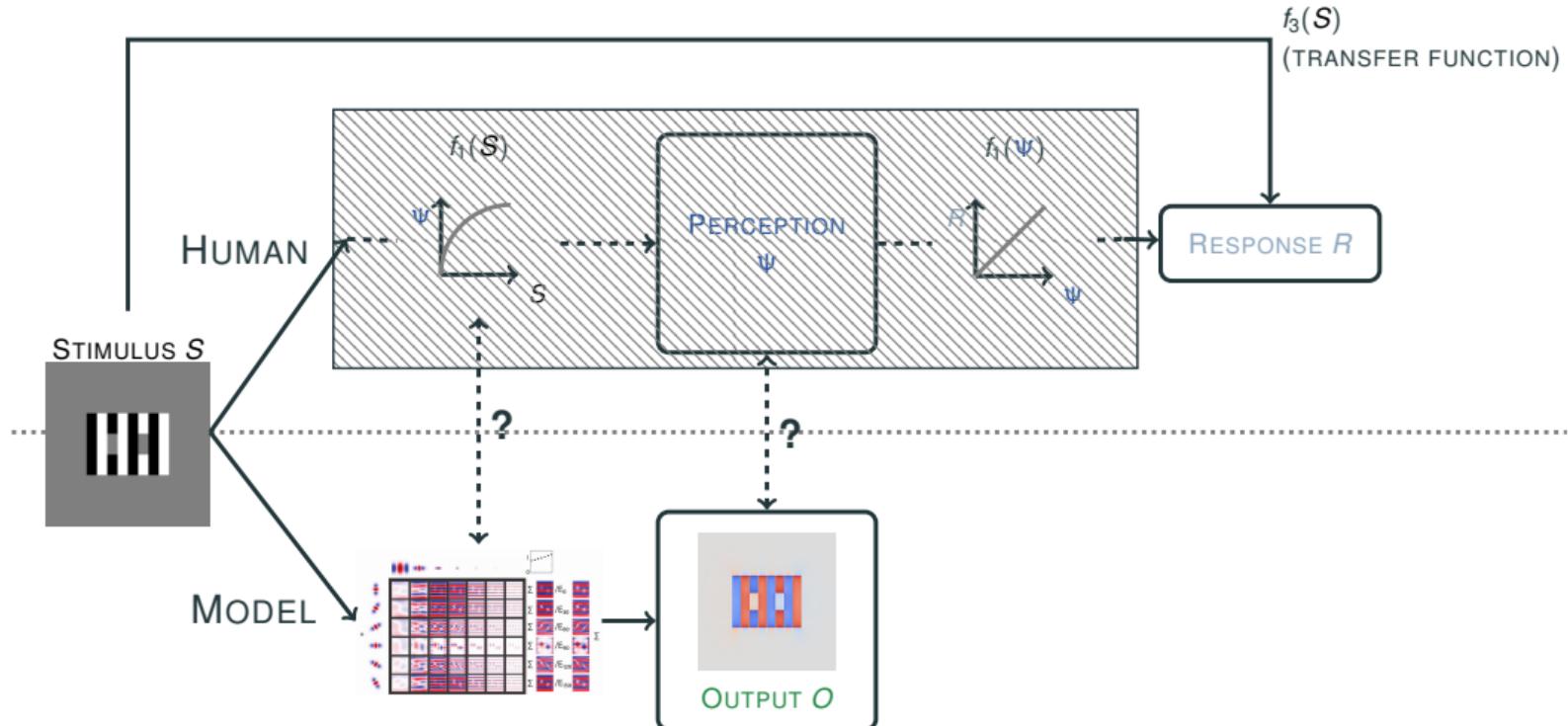
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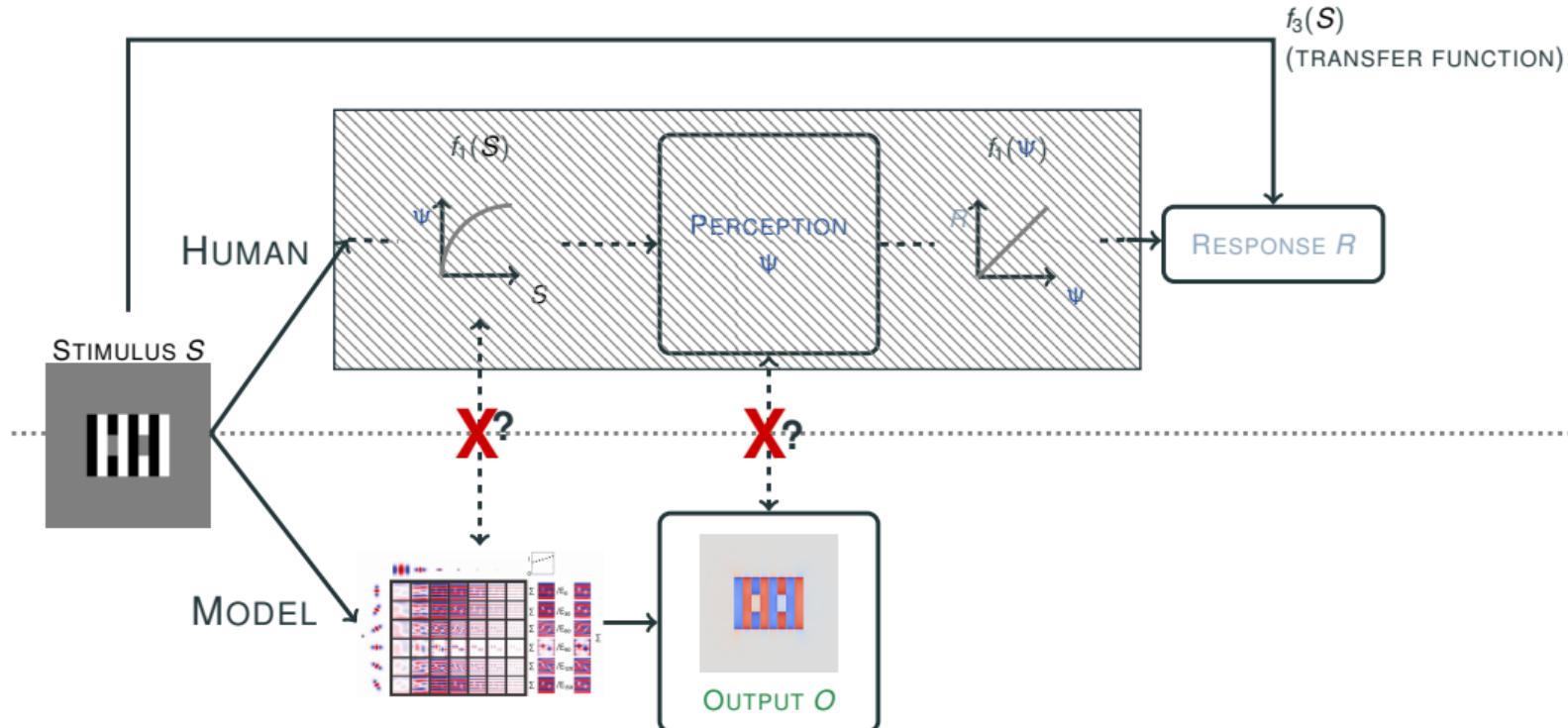
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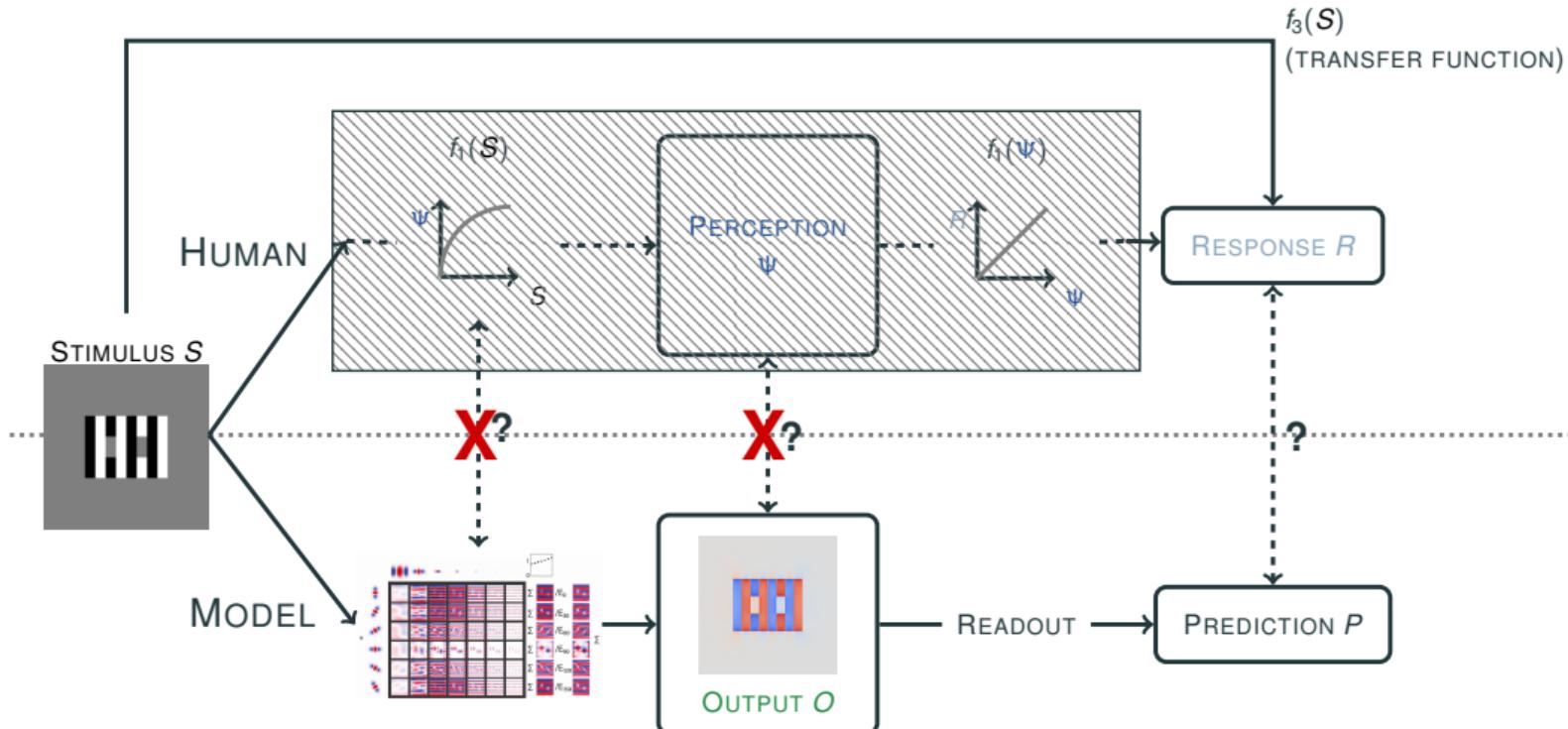
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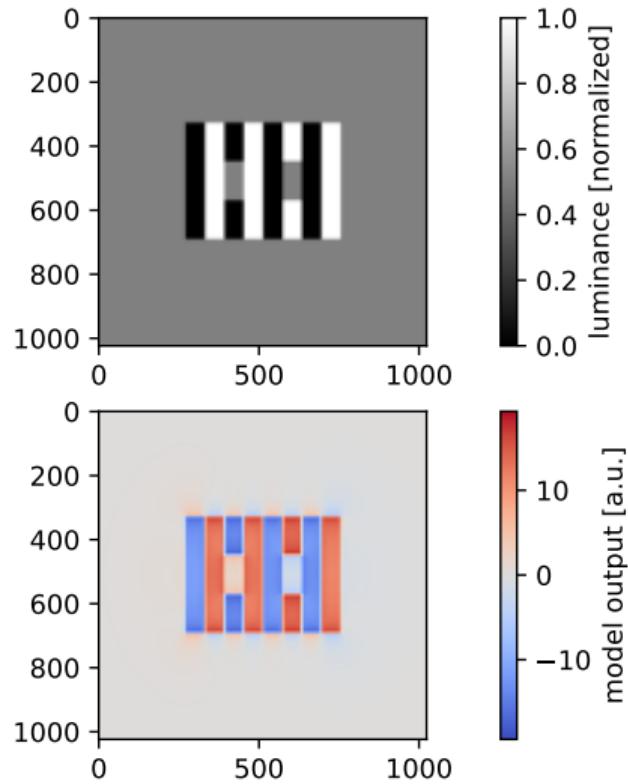
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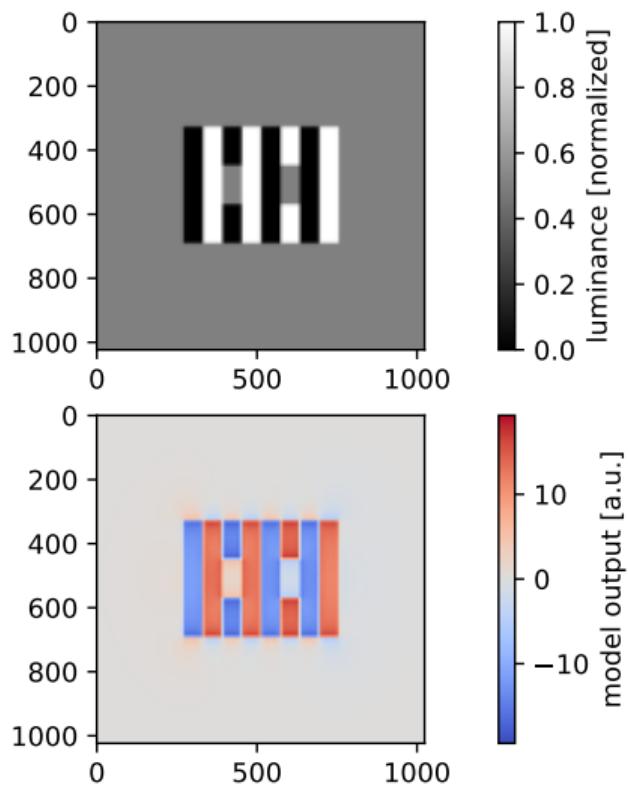
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How to compare model READOUT and psychophysical response?



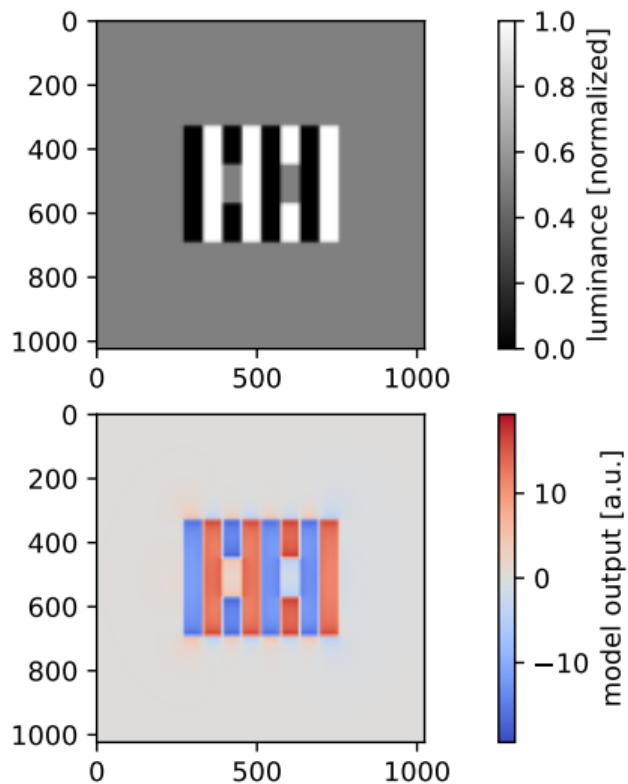
How to compare model READOUT and psychophysical response?



► Average over pixels in target regions:

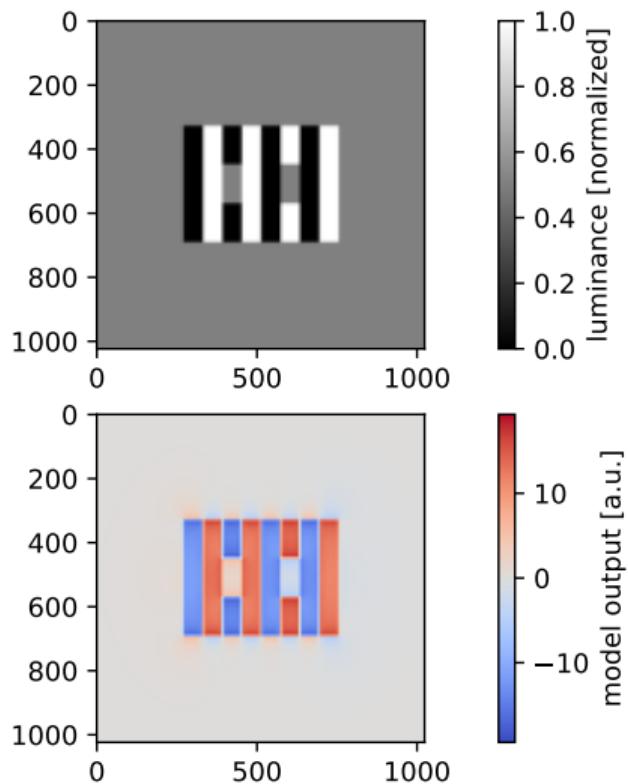
$$O_b = \text{mean}(O_b), O_b = \text{mean}(O_b)$$

How to compare model READOUT and psychophysical response?



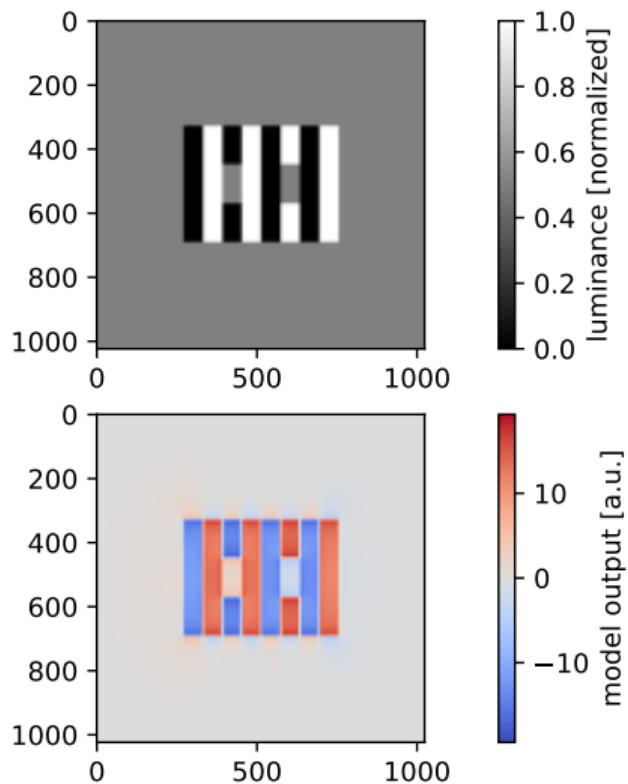
- ▶ Average over pixels in target regions:
 $O_b = \text{mean}(O_b), O_w = \text{mean}(O_w)$
- ▶ Qualitative pred.: direction of effect
 $(O_b > O_w)$

How to compare model READOUT and psychophysical response?



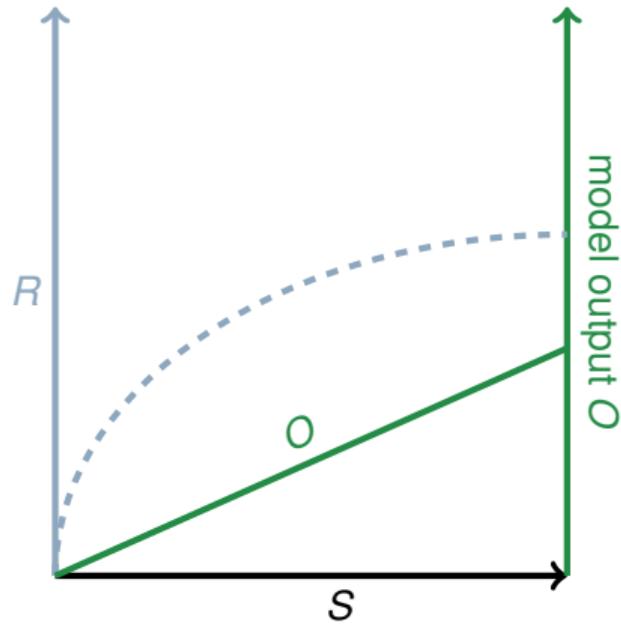
- ▶ Average over pixels in target regions:
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 $(O_b > O_w)$
- ▶ Detection/discrimination thresholds (with noise)

How to compare model READOUT and psychophysical response?



- ▶ Average over pixels in target regions:
 $O_b = \text{mean}(O_b), O_w = \text{mean}(O_w)$
- ▶ Qualitative pred.: direction of effect
 $(O_b > O_w)$
- ▶ Detection/discrimination thresholds (with noise)
- ▶ Quantitative (appearance) pred.: difference?
 $(O_b - O_w)$

Single point on transfer function can always be fit perfectly

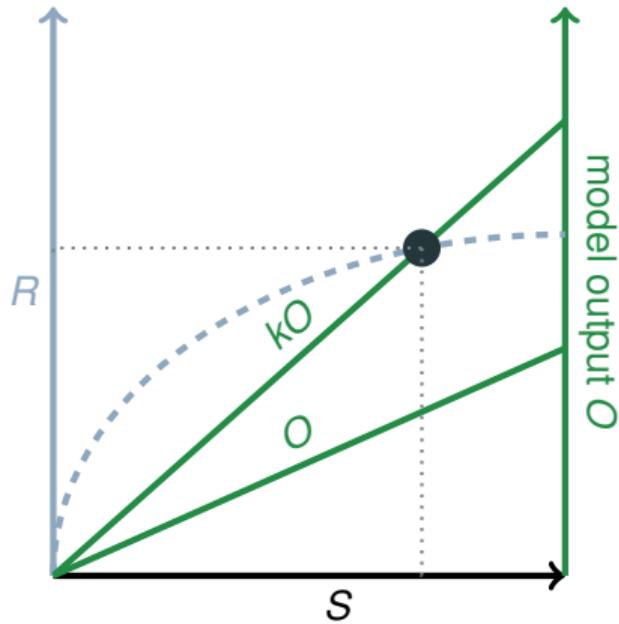


► Quantitative pred.: difference?

$$(O_b - O_w)$$

► model output is in arbitrary units

Single point on transfer function can always be fit perfectly



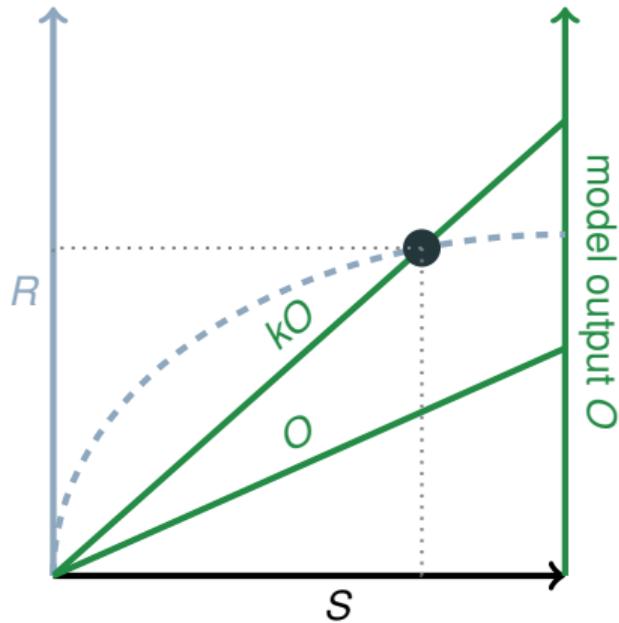
► Quantitative pred.: difference?

$$(O_b - O_w)$$

- model output is in arbitrary units
- scale to R psychophysical units:

$$R = k(O_b - O_w)$$

Single point on transfer function can always be fit perfectly



- Quantitative pred.: difference?

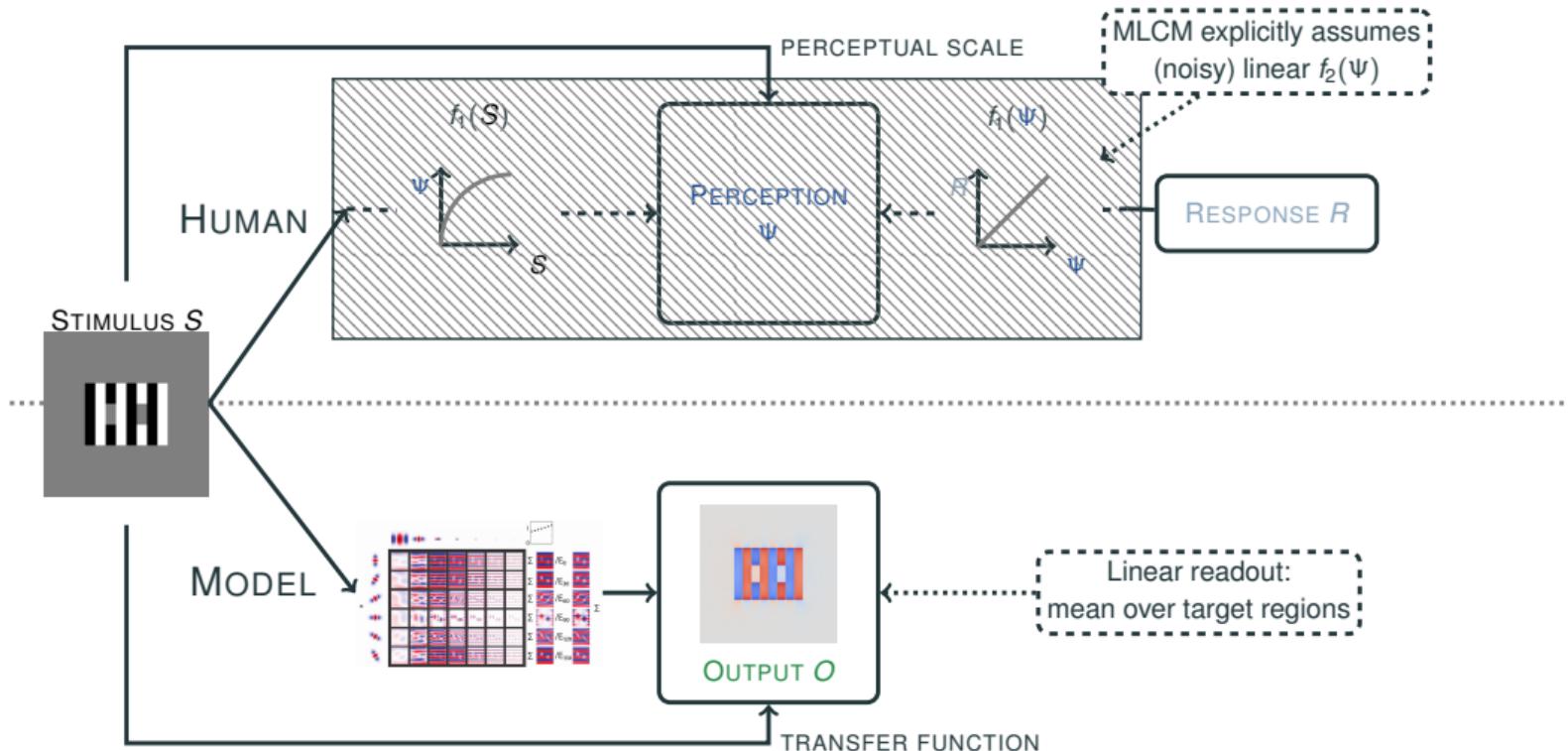
$$(O_b - O_w)$$

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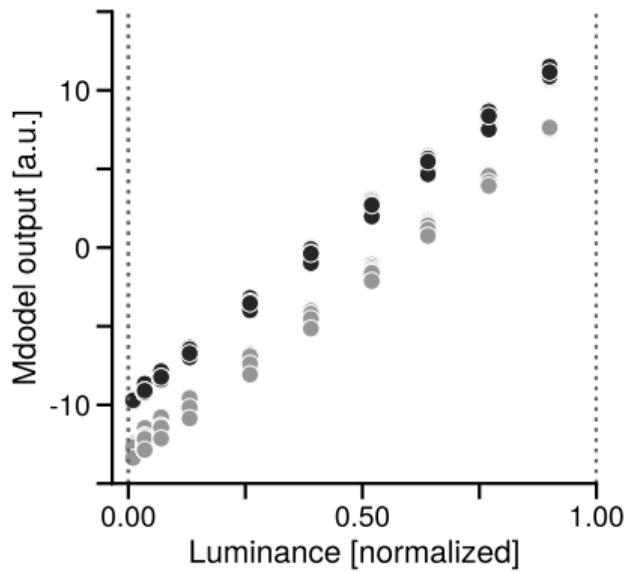
$$R = k(O_b - O_w)$$

- can always perfectly fit single point on transfer functions
- as in psychophysics: not enough info to constrain shape
- **need to look at whole transfer function instead**

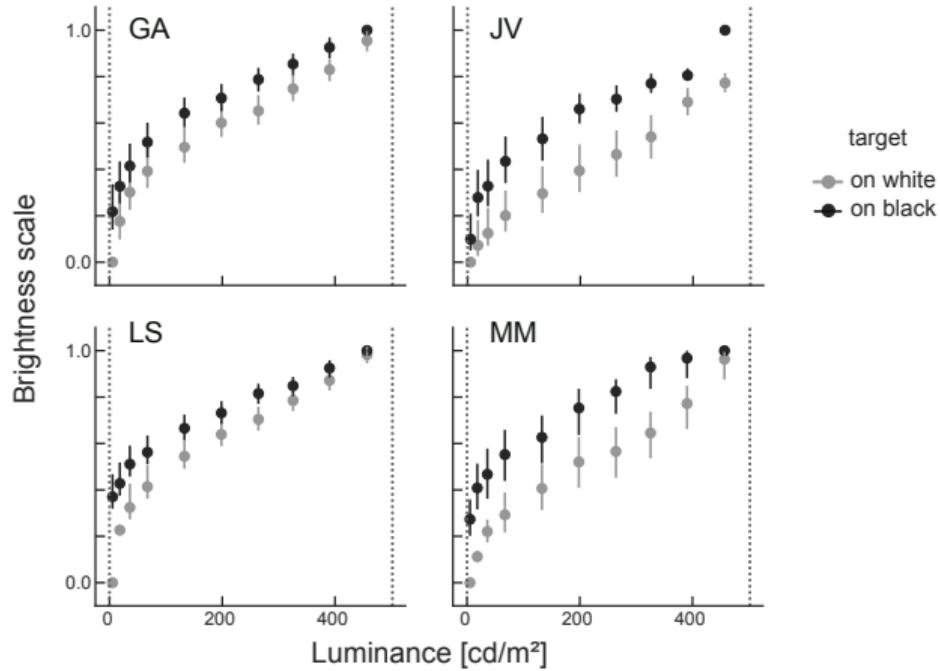
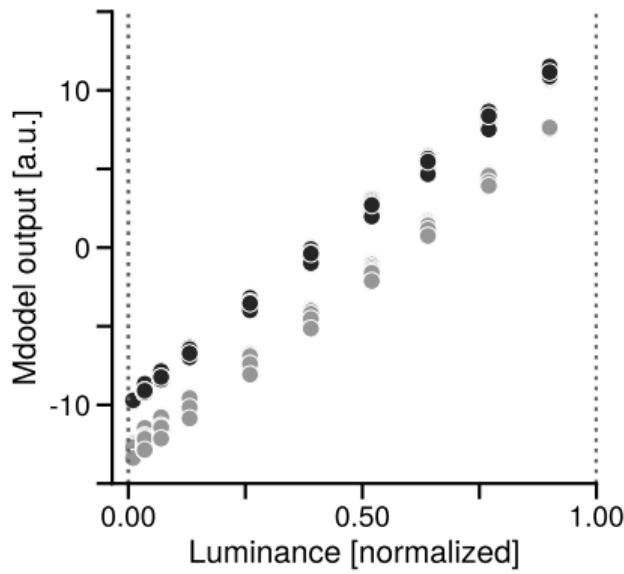
Compare perceptual scale



Model transfer functions are linear



Model transfer functions are linear



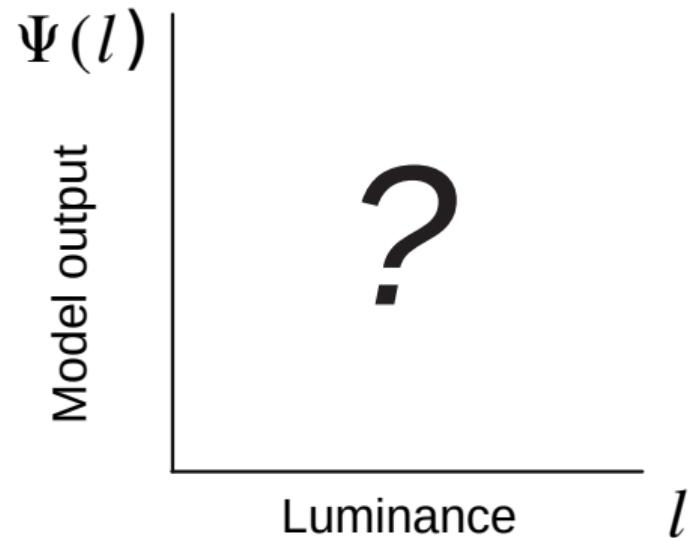
Summary

General question of Psychophysics:

Mapping between physical and perceptual dimensions (Fechner, 1860)

Main message:

- ▶ perceptual scales **constrain** human brightness transfer functions more than matching
 - ▶ Distinct nonlinearities for targets in White's effect
- ▶ current image-computable models **should, but fail to**, predict these scales
 - ▶ Linear transfer functions, with fixed offset



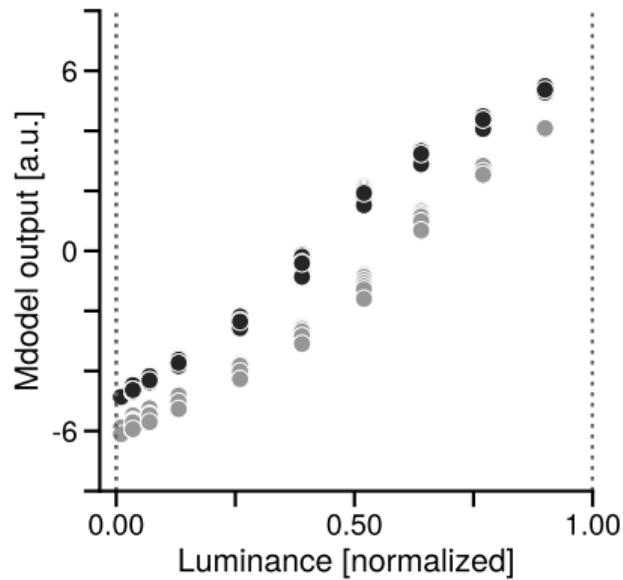
Epilogue: Can we improve the models?

Can we improve the models?

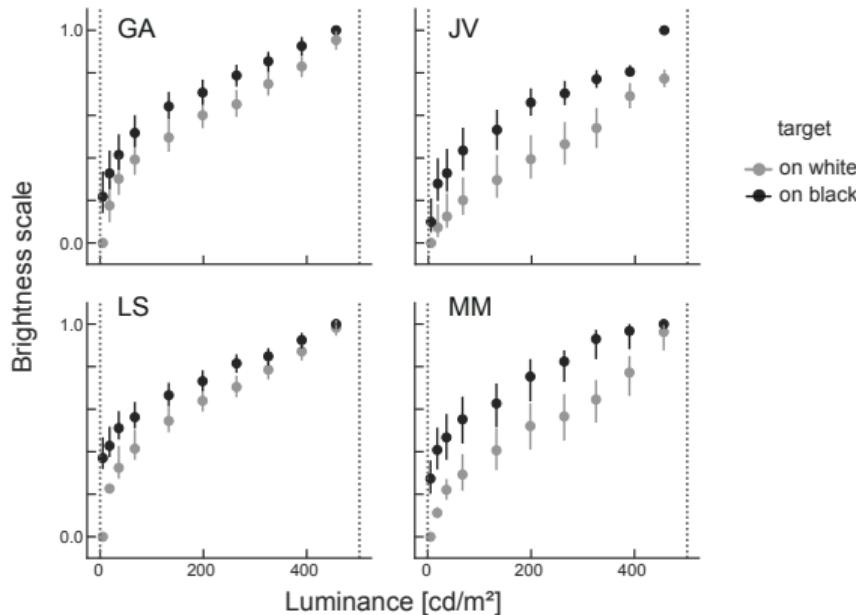
Need to add some (additional) nonlinearity

1. Nonlinear READOUT?

Nonlinear model READOUT does not fix transfer functions



$$O^{0.7}$$

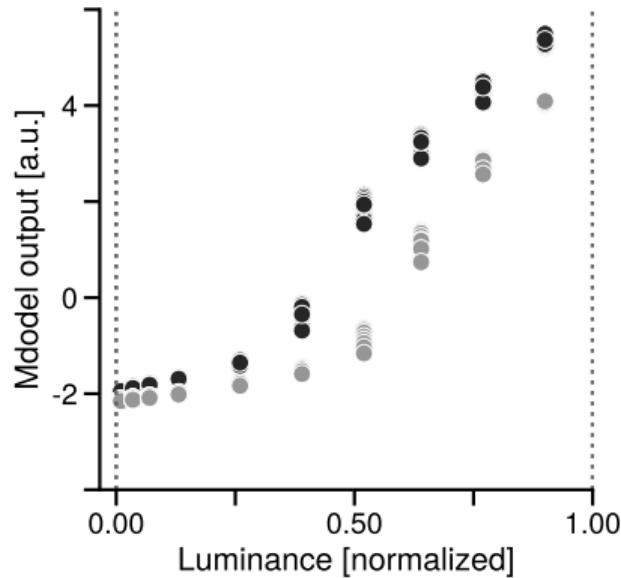


Can we improve the models?

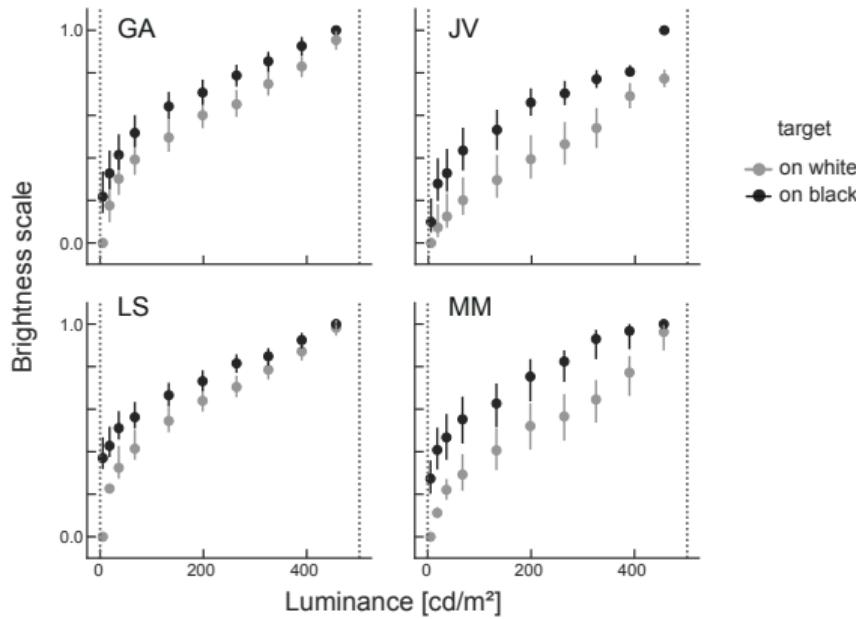
Need to add some (additional) nonlinearity

1. Nonlinear READOUT – does not work.
2. Model output can be negative, separate readout nonlinearity for +/-?

Nonlinear READOUT separately for +/- also does not fix



$$\begin{cases} O^{0.7} & \text{for } O > 0 \\ O^{0.3} & \text{for } O < 0 \end{cases}$$



Can we improve the models?

Need to add some (additional) nonlinearity

1. Nonlinear READOUT – does not work.
2. Model output can be negative, separate nonlinear READOUT for +/- – does not work.
3. Separate nonlinearity for +/- ("ON"/"OFF") earlier in model – ?

Thank you for your attention!