@meganakpeters
meganakpeters.org

Introspective psychophysics and the quantitative study of subjective experience

Megan Peters, PhD

Associate Professor, Cognitive Sciences & Logic & Philosophy of Science, University of California Irvine
Fellow, CIFAR Program in Brain, Mind, & Consciousness
Fellow, Research Corporation for Science Advancement - Scialog: Molecular Basis of Cognition
President , Co-Founder, & Chair of the Board, Neuromatch

@meganakpeters
meganakpeters.org

psychophysics: the next generation

psychophysics: the next generation of the scientific study of subjective experience

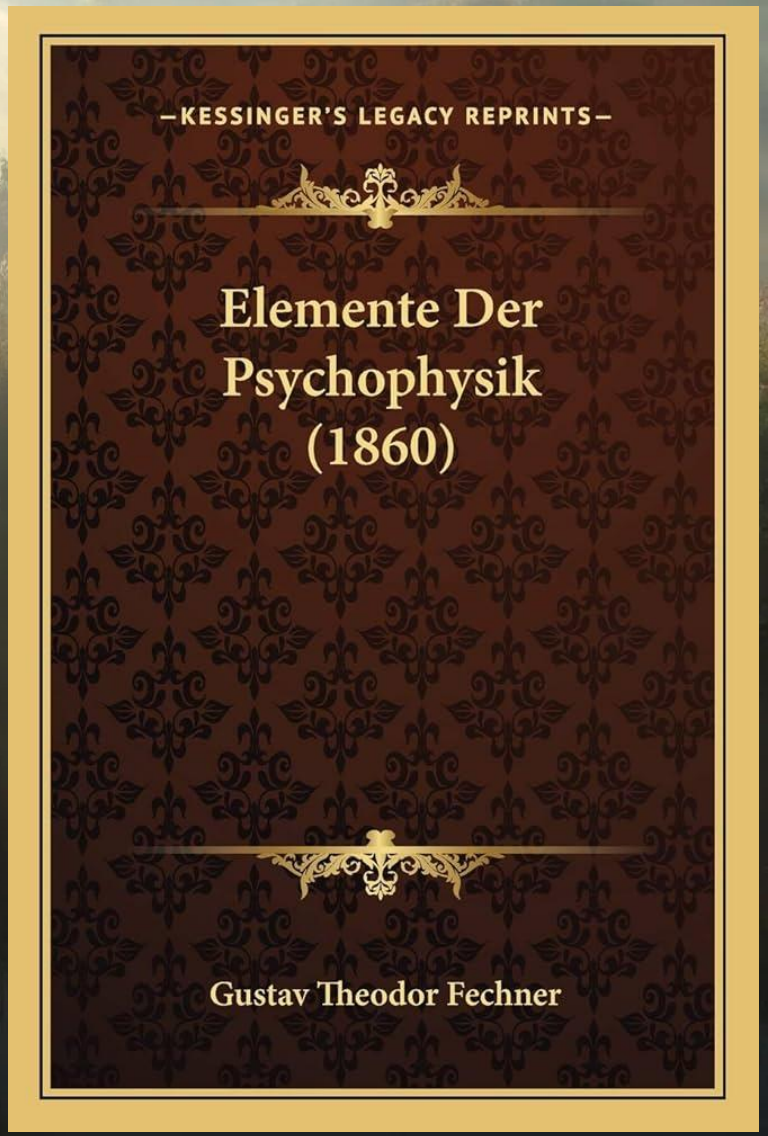
Megan Peters, PhD

Associate Professor, Cognitive Sciences & Logic & Philosophy of Science, University of California Irvine
Fellow, CIFAR Program in Brain, Mind, & Consciousness
Fellow, Research Corporation for Science Advancement - Scialog: Molecular Basis of Cognition
President , Co-Founder, & Chair of the Board, Neuromatch

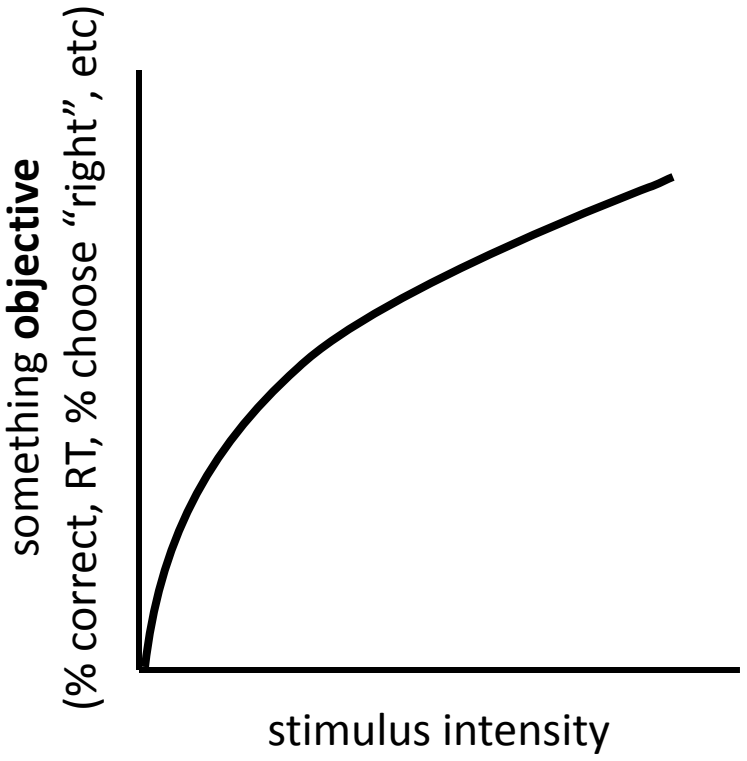
let us boldly go where no psychophysicist has gone before

our journey begins in Germany, 1860

the birth of psychophysics

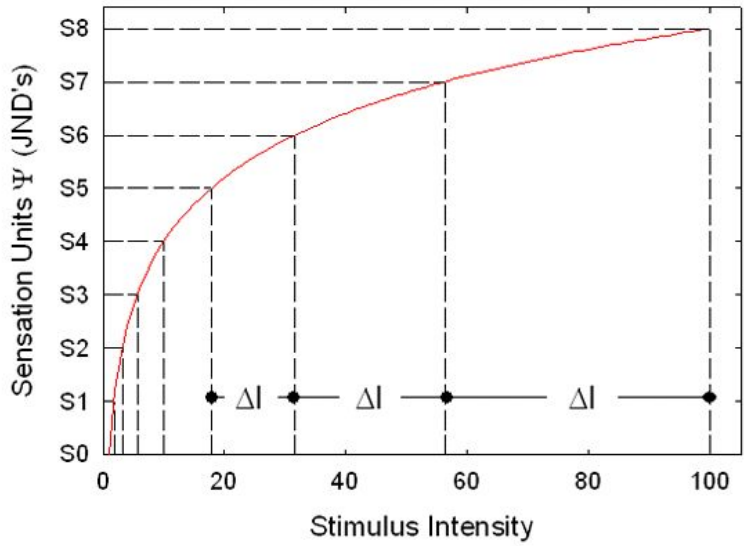


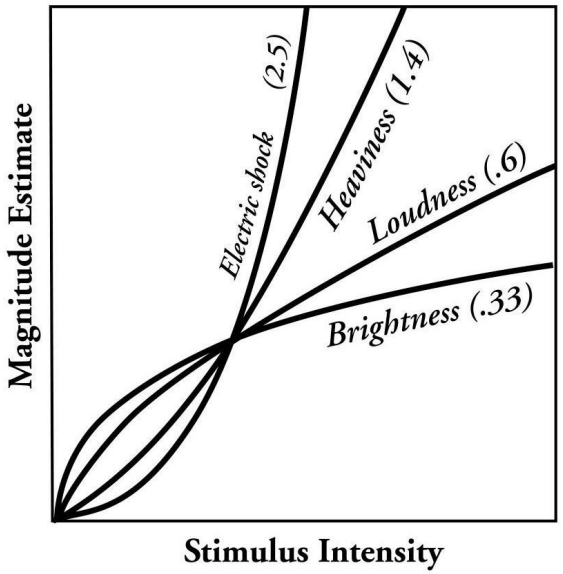
stimulus vs [objective]



stimulus vs [subjective]

Fechner's Law: $\Psi = k \log I$





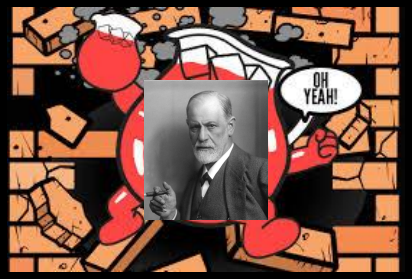
ON SMALL DIFFERENCES OF SENSATION.

READ OCTOBER 17, 1884.

By C. S. PEIRCE and J. JASTROW.

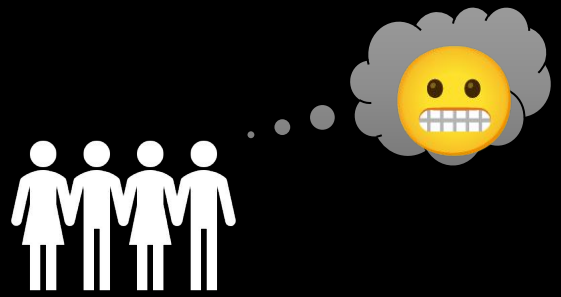
threshold

The quantity which we have called the degree of confidence was probably the secondary sensation of a difference between the primary sensations compared. The evidence of our experiments seems clearly to be that this sensation has no *Schwelle*, and vanishes only when the difference to which it refers vanishes. At the same time we found the subject often overlooked this element of his field of sensation, although his attention was directed with a certain strength toward it, so that he marked his confidence as *zero*. This happened in cases where the judgments were so much affected by the difference of pressures as to be correct three times out of five. The general fact has highly important practical bearings, since it gives new reason for believing that we gather what is passing in one another's minds in large measure from sensations so faint that we are not fairly aware of having them, and can give no account of how we reach our conclusions about such matters. The



Sigmund Freud

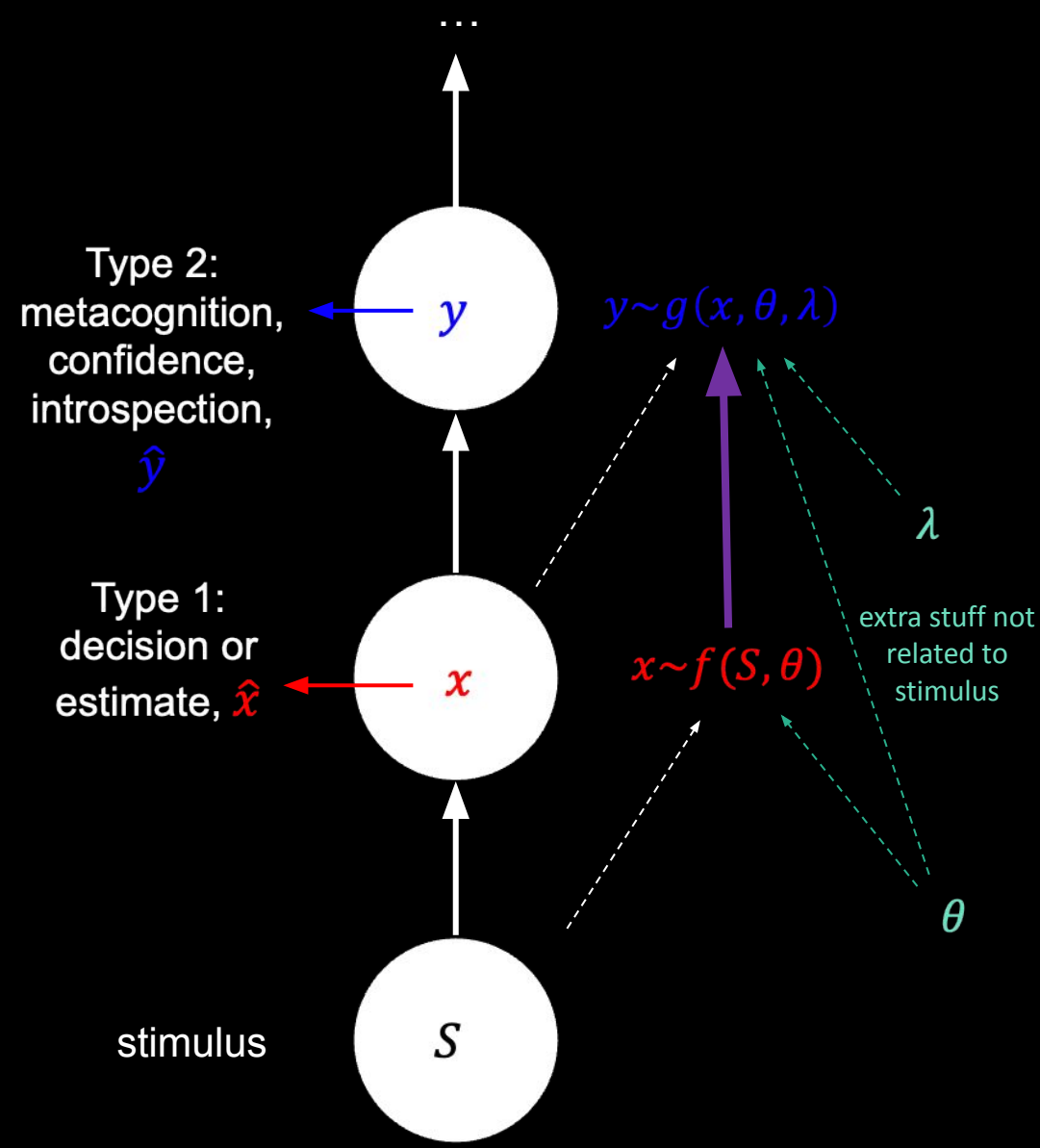
introspection is great! **totally valid** for **dream analysis** and revealing your **darkest subconscious thoughts about your parents**…



everybody else

type 2 psychophysics

type 1 psychophysics



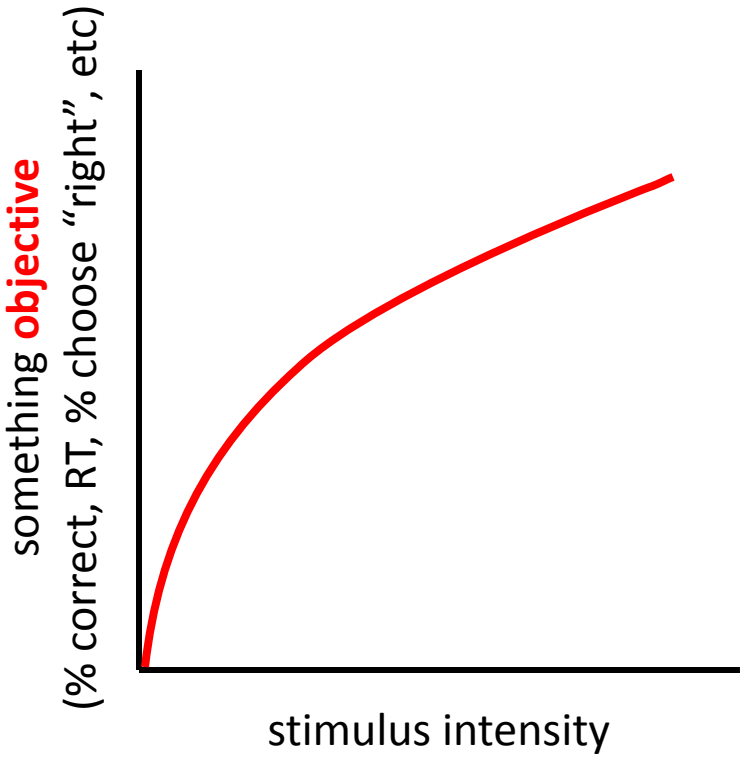
(and yes, introspection is noisy/ unreliable, "not objectively verifiable"*, which also doesn't help…)

(Peters, 2022, *Neuro & Biobeh Rev*; Peters, in press, *Cerebral Cortex*)

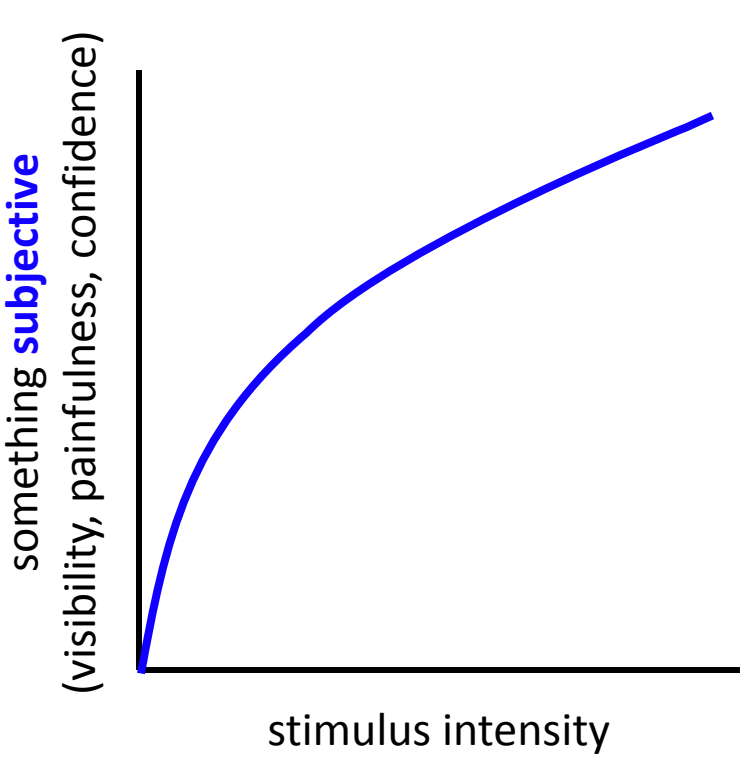
* stay tuned…?

type 1

stimulus vs [objective]

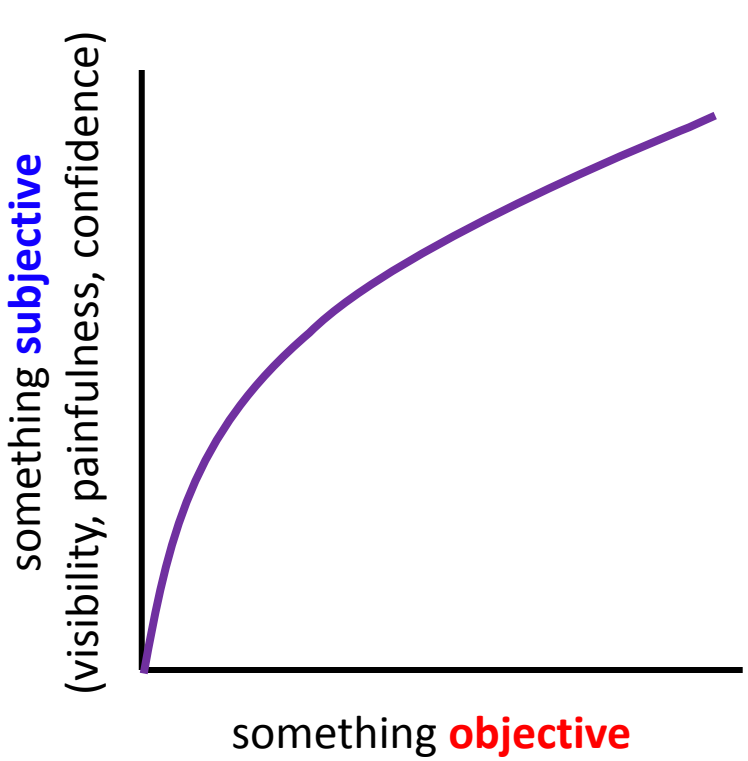


stimulus vs [subjective]



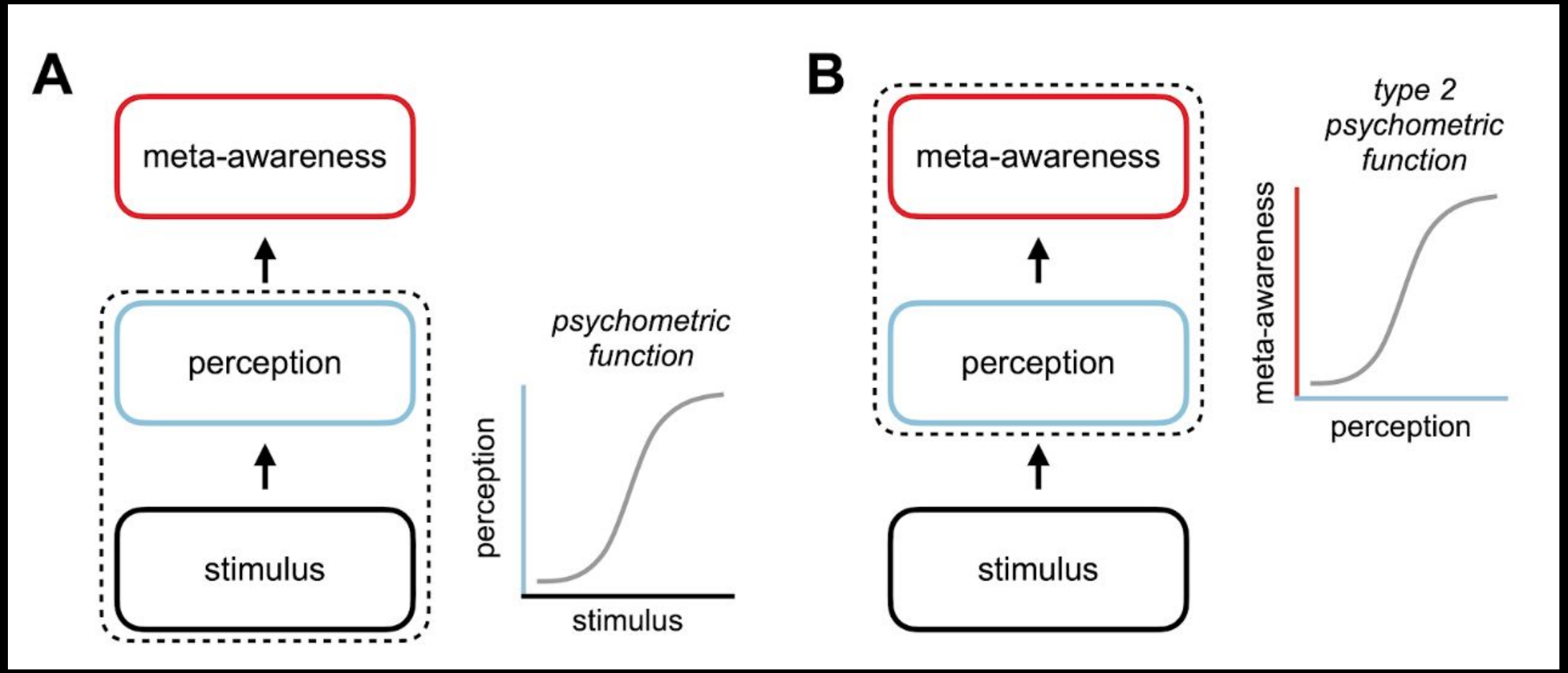
type 2

objective vs subjective



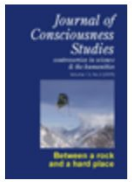
the ~~metaperceptual function~~

relative psychometric function (RPF)



(Maniscalco*, Graham Castaneda*, Odegaard, Morales, Rajananda, Denison, & Peters, 2020 *psyArxiv,* & just updated)

the ~~metaperceptual function~~
relative psychometric function (RPF)



What Forms Could Introspective Systems Take? A Research Programme

Authors: Kammerer, François [1] ; Frankish, Keith [2] ;
Source: Journal of Consciousness Studies, Volume 30, Numbers 9-10, September 2023, pp. 13-48(36)
Publisher: Imprint Academic
DOI: https://doi.org/10.53765/2

Forthcoming in the *British Journal for the Philosophy of Science*

Introspection Is Signal Detection

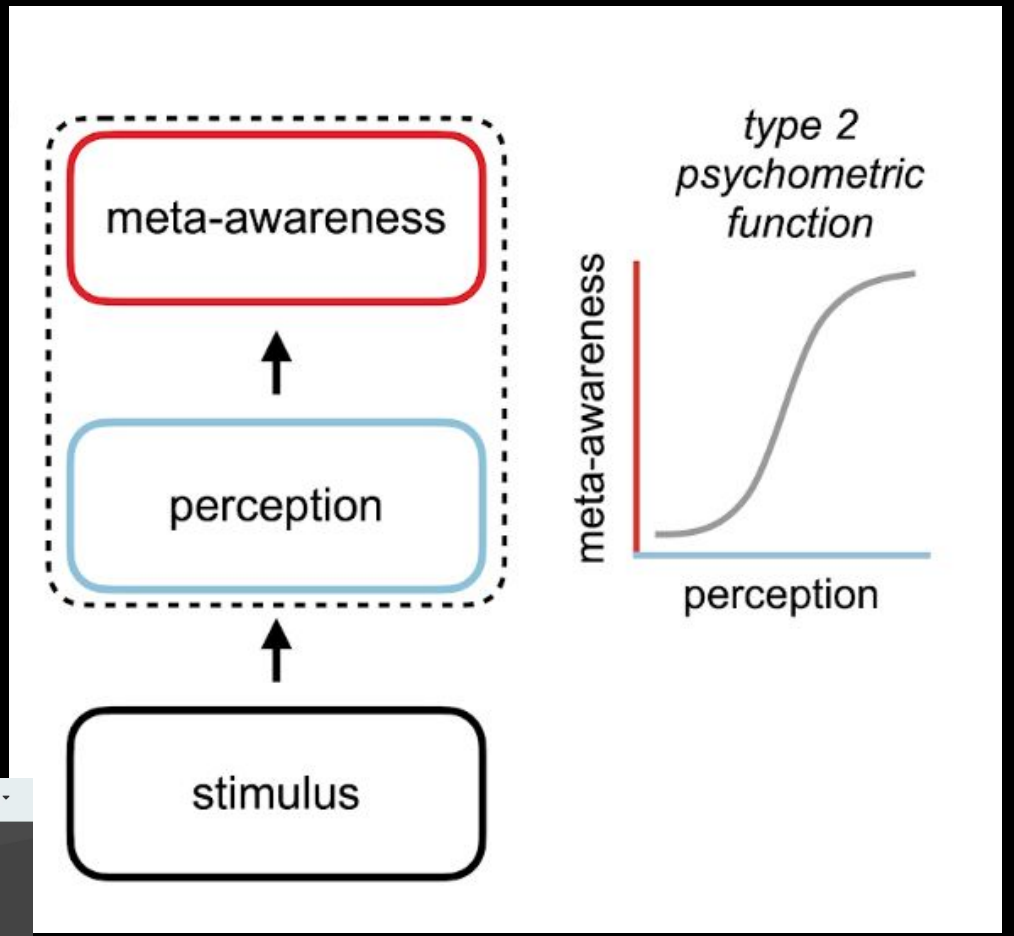
Jorge Morales

Consciousness, Metacognition, & Perceptual Reality Monitoring

Hakwan Lau[1,2,3,4]
hakwan@gmail.com

PsyArXiv Preprints My Preprints Add a preprint Donate Megan A. K. Peters

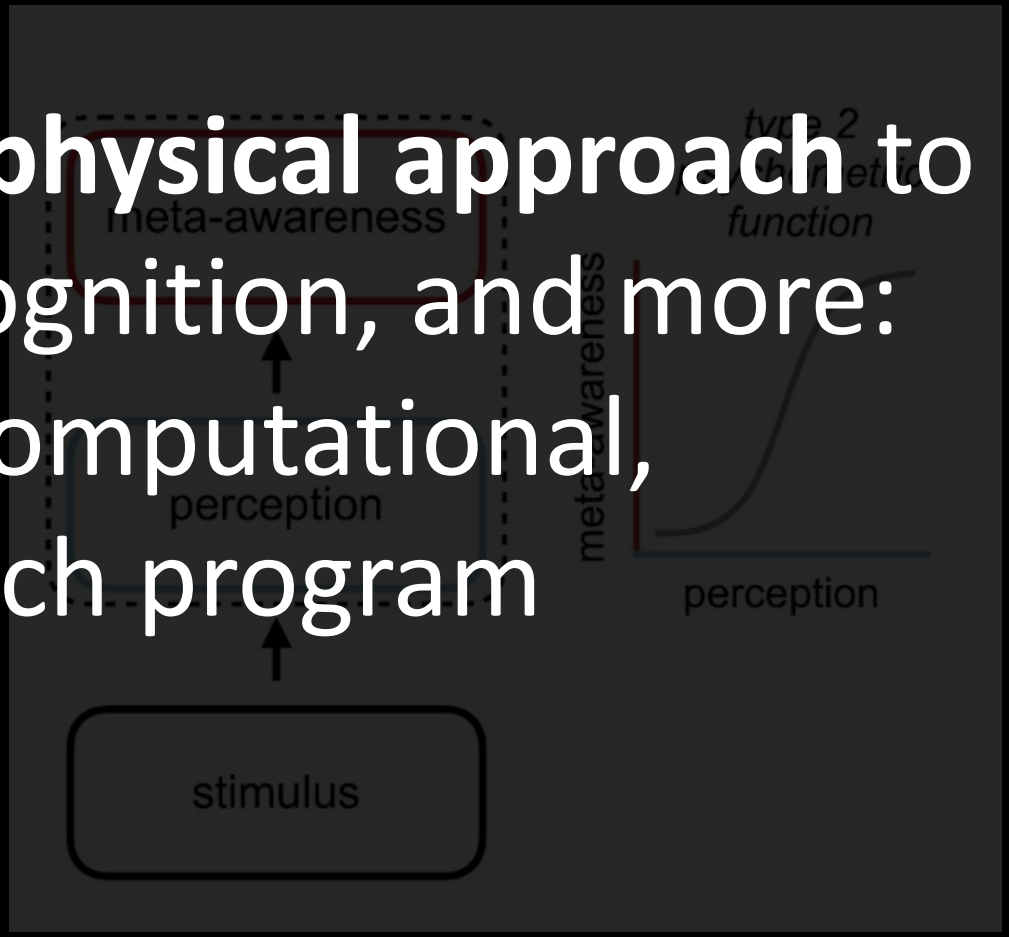
Introspective psychophysics for the study of subjective experience



(Maniscalco*, Graham Castaneda*, Odegaard, Morales, Rajananda, Denison, & Peters, 2020 *psyArxiv,* & just updated)

the ~~metaperceptual function~~
relative psychometric function (RPF)

let's define the **psychophysical approach** to introspection, metacognition, and more:
a quantitative, computational, precise research program



(Maniscalco*, Graham Castaneda*, Odegaard, Morales, Rajananda, Denison, & Peters, 2020 *psyArxiv,* & just updated)

some relevant recent history & examples

blindsight: performance w/o confidence

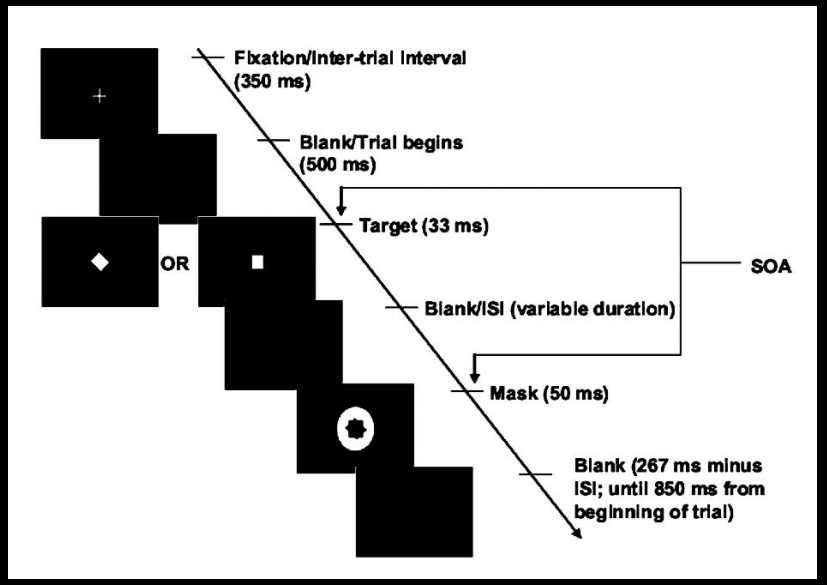
an extreme case of manipulating the typical covariation between performance and confidence/awareness

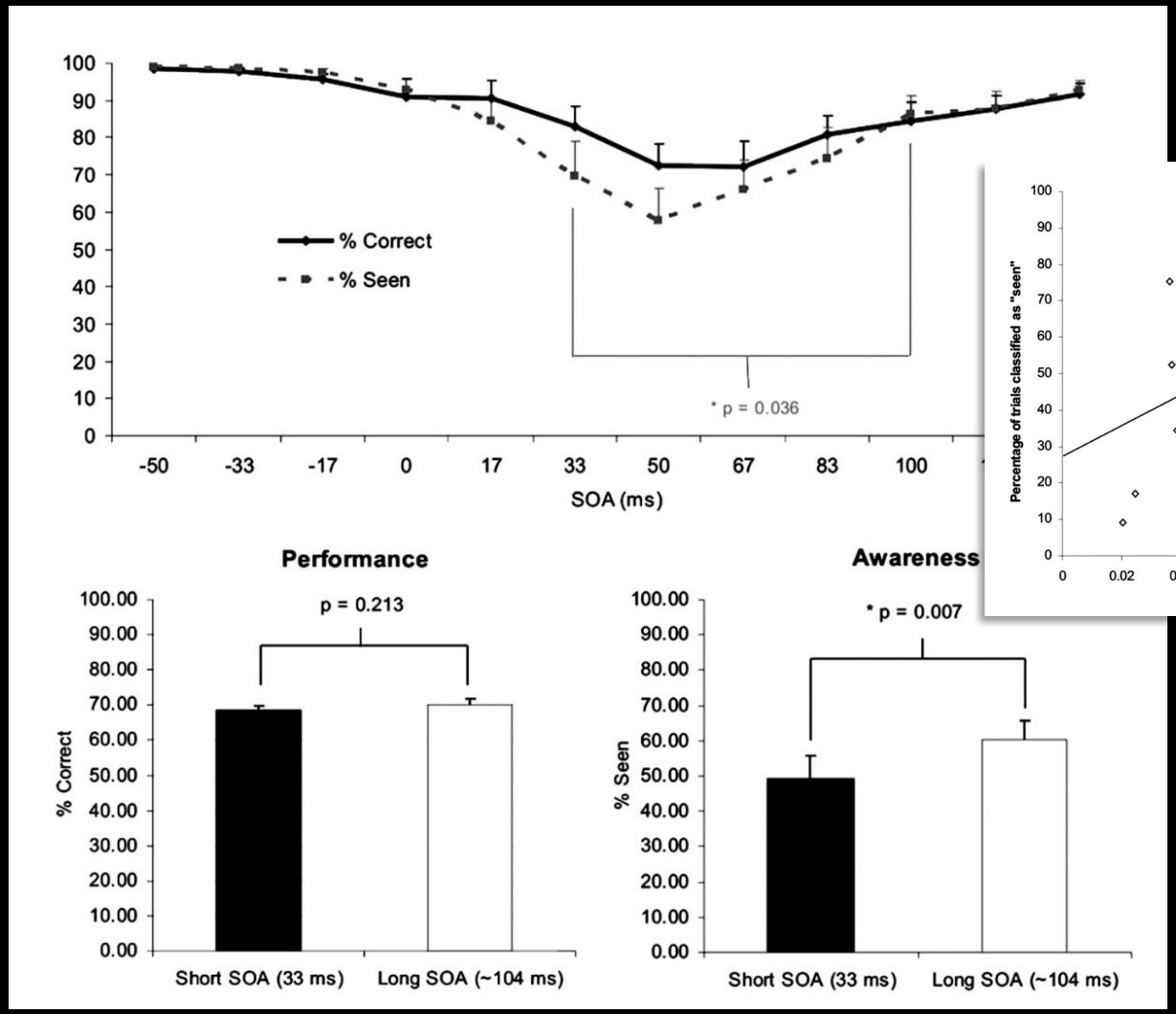
(deGelder et al., 2008, Curr Bio)

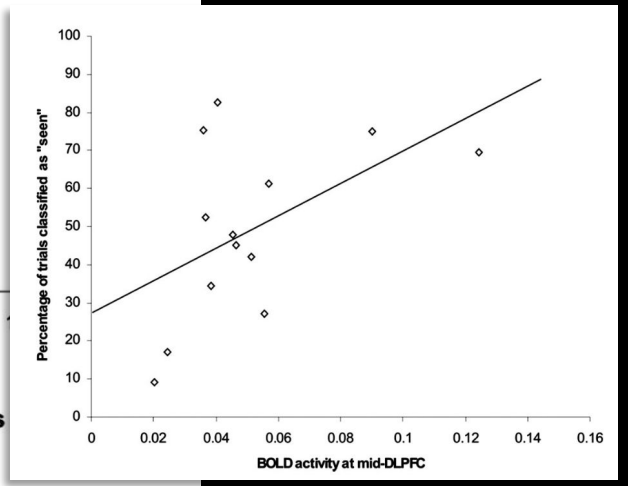
“relative blindsight” in neurotypical observers

Relative blindsight in normal observers and the neural correlate of visual consciousness

Hakwan C. Lau* and Richard E. Passingham



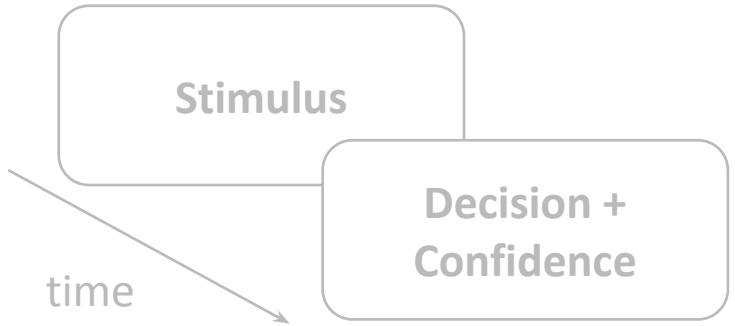


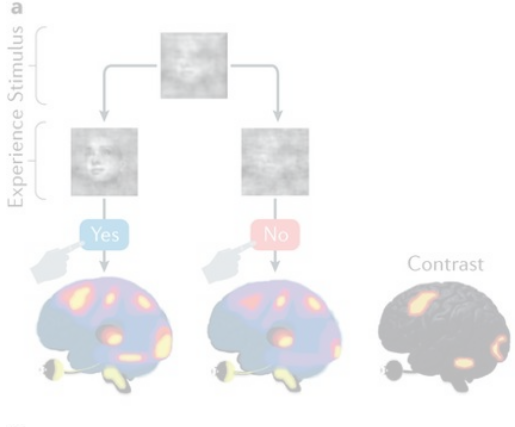


fast forward 8 years

blindsight in neurotypical individuals?

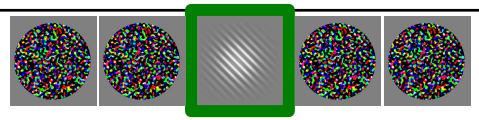
an extreme case of manipulating the typical covariation between performance and confidence/awareness



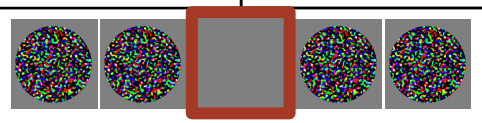


mandatory:
$d'_{"yes"} = d'_{"no"}$

$d'_{"no"} > 0$ □ $d'_{\text{present \& 50-50 betting}} > 0$



Target present



Target absent

up to 13 contrast levels per subject

bias-free 2-interval forced choice

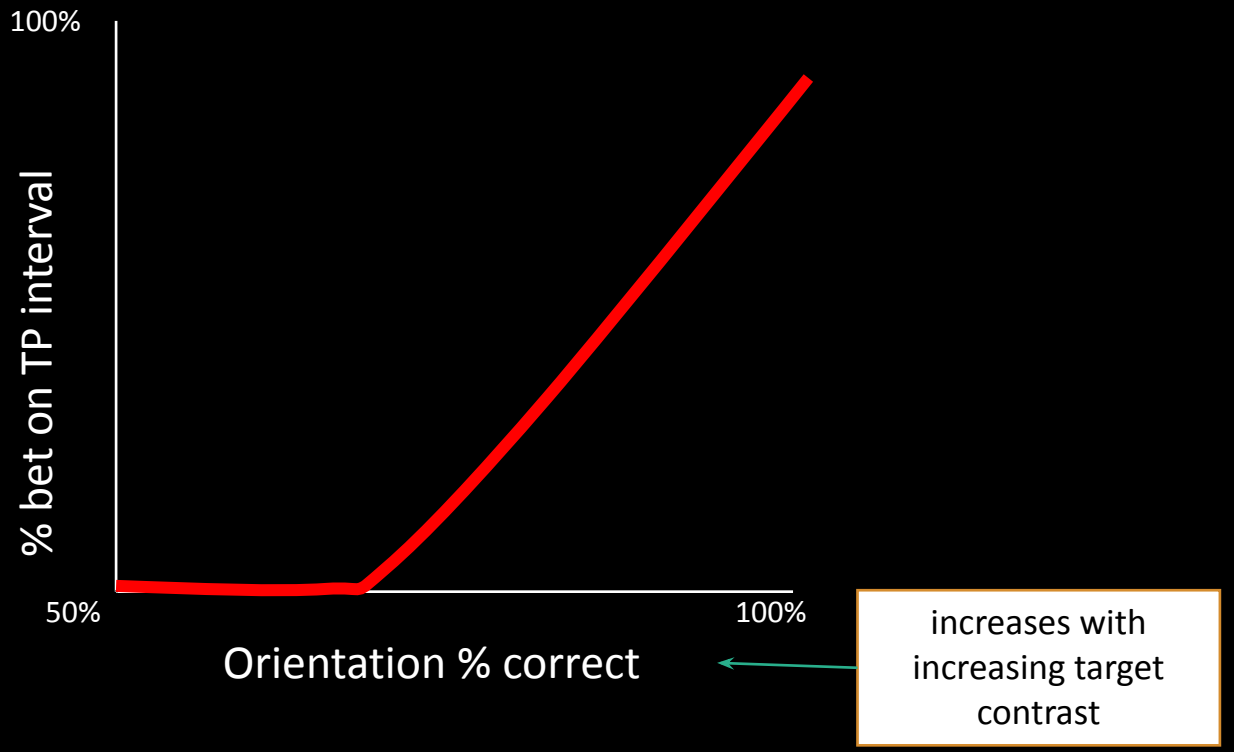
time

Which decision will you "bet" on?

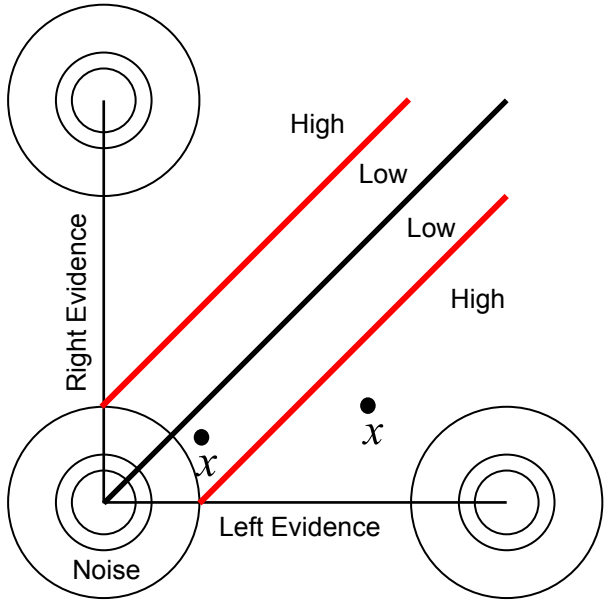
(Peters & Lau, 2015, *eLife*)

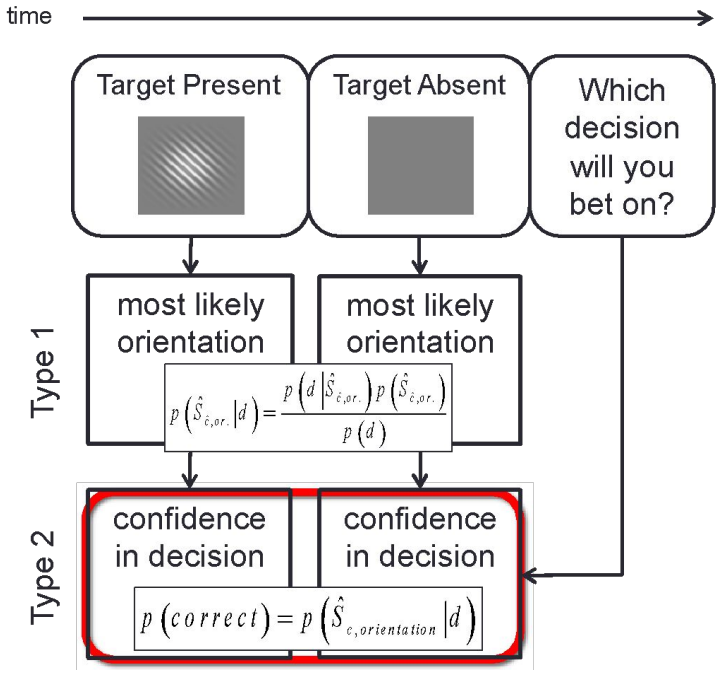
expectations of "blindsight"-like behavior in normal observers

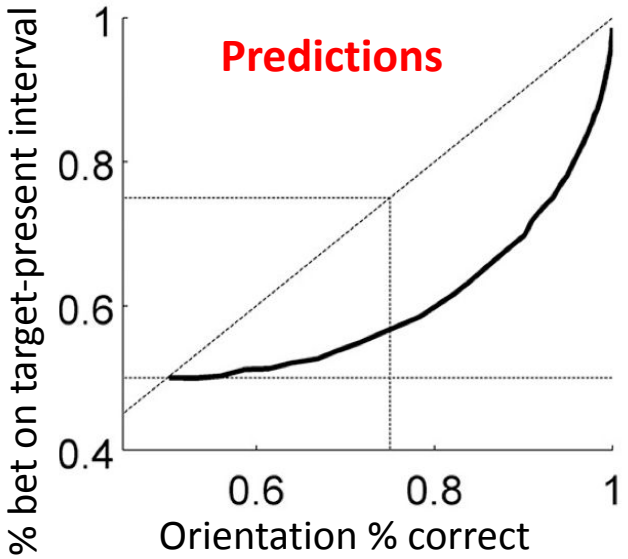
$d'_{\text{target present, 50-50 betting}} > 0$



(Peters & Lau, 2015, *eLife*)



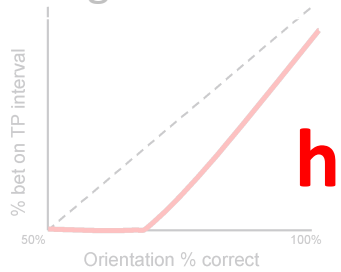




(Peters & Lau, 2015, *eLife*)

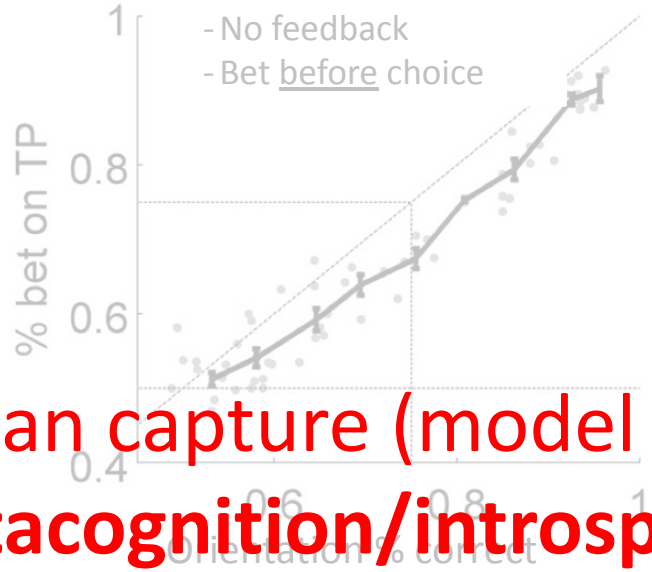
ideal observer

"blindsight" observer



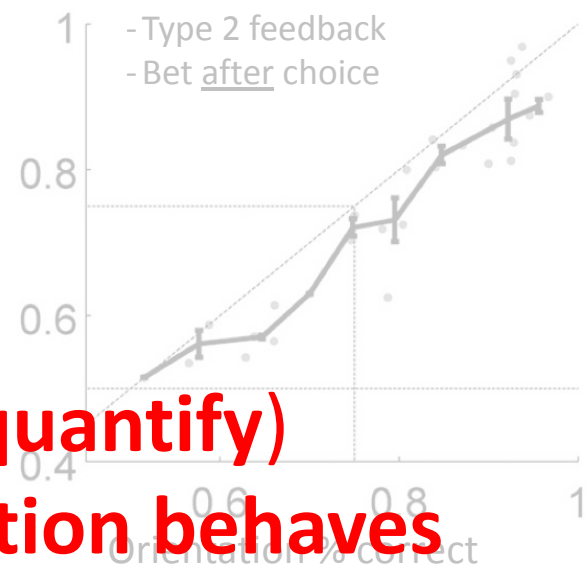
Experiment 1

- No feedback
- Bet before choice



Experiment 2

- Type 2 feedback
- Bet after choice



we can capture (model + **quantify**)

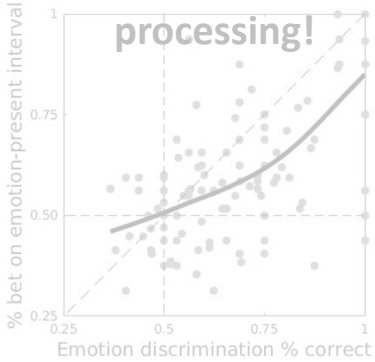
how metacognition/introspection behaves

*(and maybe how it "ought to" behave)

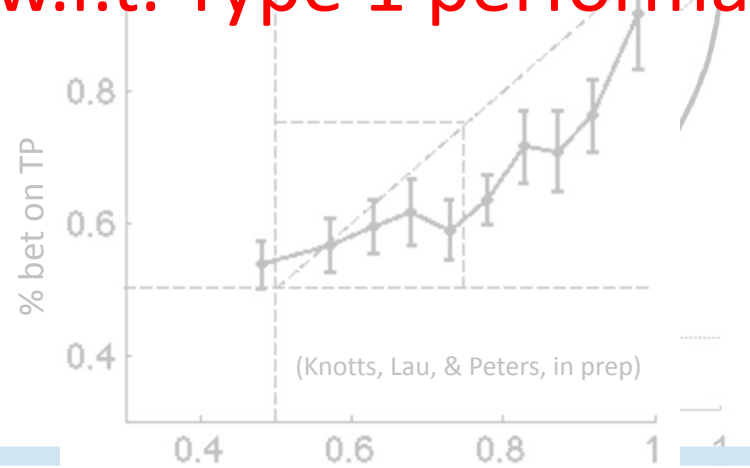
w.r.t. Type 1 performance

related publications: (Peters, Lau, & Ro, 2016, *Neuro Consc*; Peters, Kentridge, Phillips, & Block, 2017, *Neuro Consc*; Peters et al., 2017, *Nat Hum Beh*; Knotts, Lau, & Peters, 2018, *AP&P*; Rajananda, Lau, & Peters, 2020, *NoC*, Amerio, Goerttler, Michel, Peters, & Cleeremans, 2024s, *Open Mind*)

Facial emotion processing!

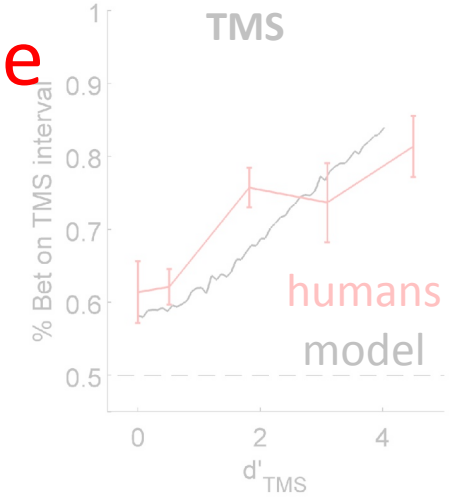


Continuous flash suppression



(Knotts, Lau, & Peters, in prep)

TMS

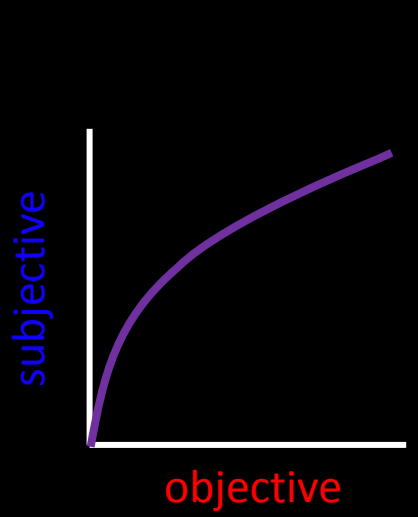


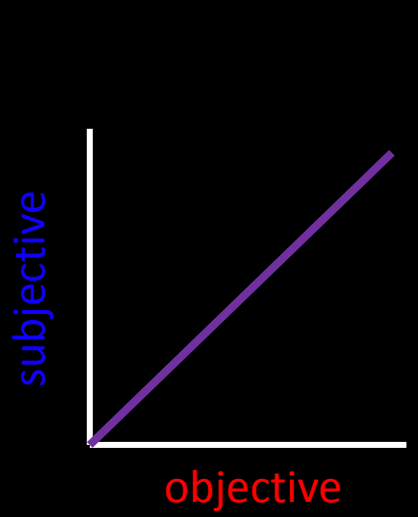
"anti-blindsight"??

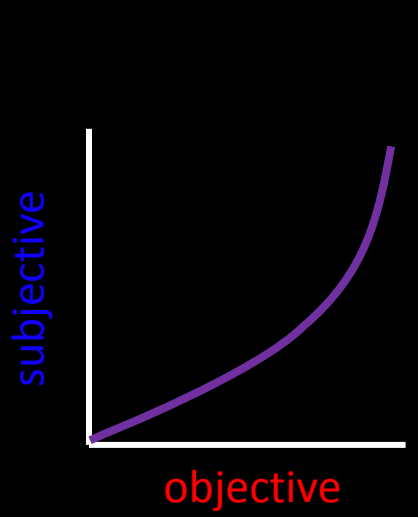
(Peters, Fesi et al., 2017 *Cortex*)

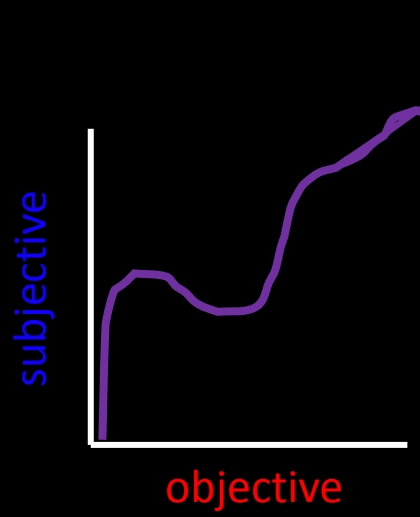
(Peters & Lau, 2015, *eLife*)

what is the form of this objective-subjective relationship?
what affects it?





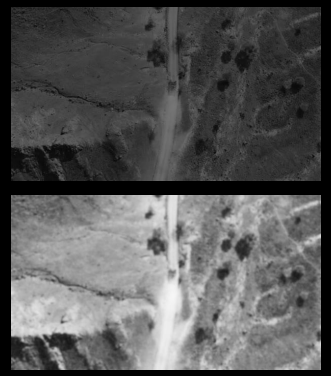




ok wow, we have a lot of work to do.

we can rely on known "*metacognitive illusions*" to get us started

high task performance + low confidence



poor task performance + high confidence

can happen across conditions, or even **trial by trial**

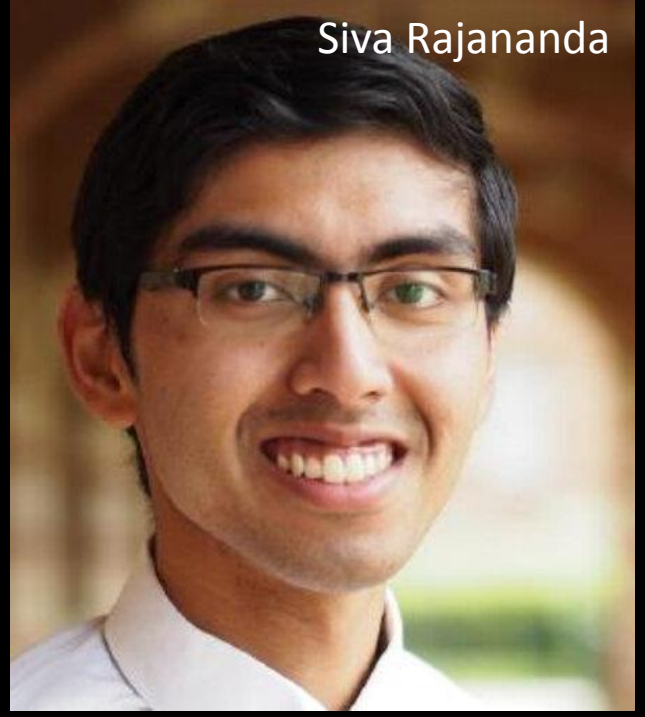
leading to **poor metacognitive sensitivity**: confidence fails to track accuracy

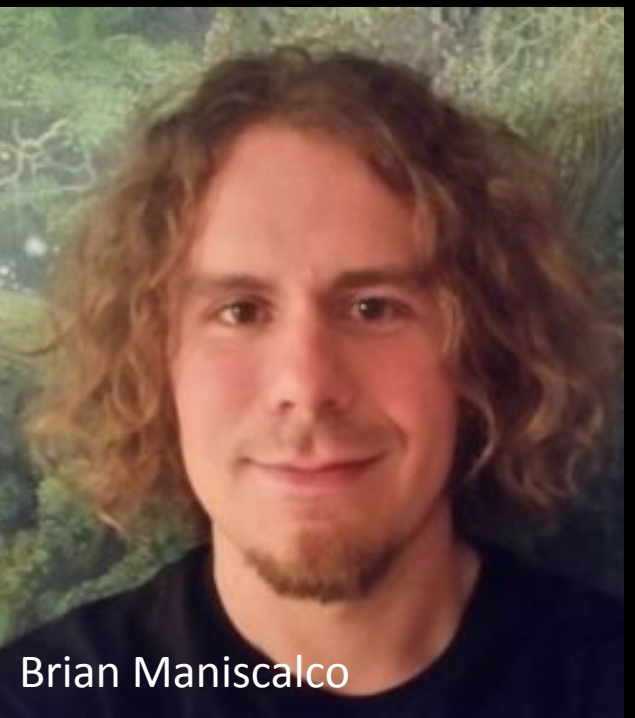
we can use these 'illusions' to create systematic shifts in

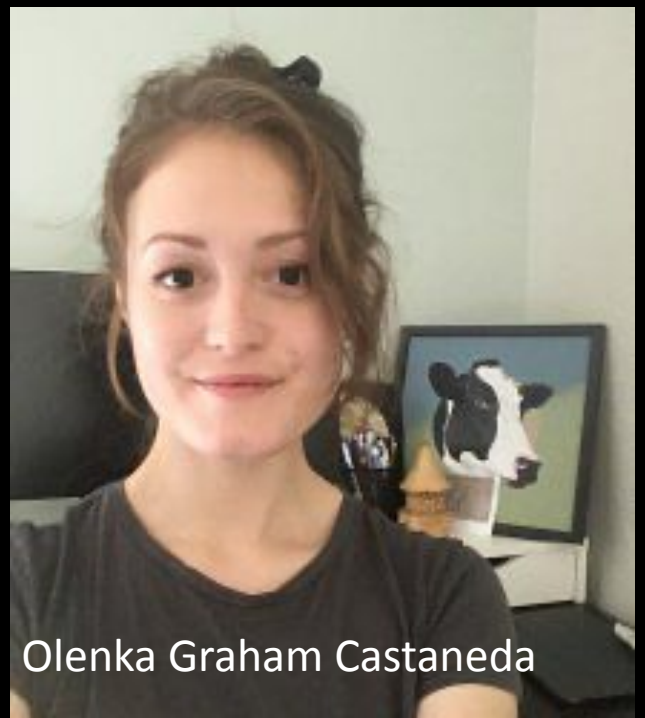
subjective as a function of objective behavior:

subjective-objective relative psychometric function (RPF)

get data	stimulus manipulations
	visual field manipulations
	attentional manipulations
do analytic work	characterizing the relative psychometric function (RPF)
	thinking about how confidence “should” behave





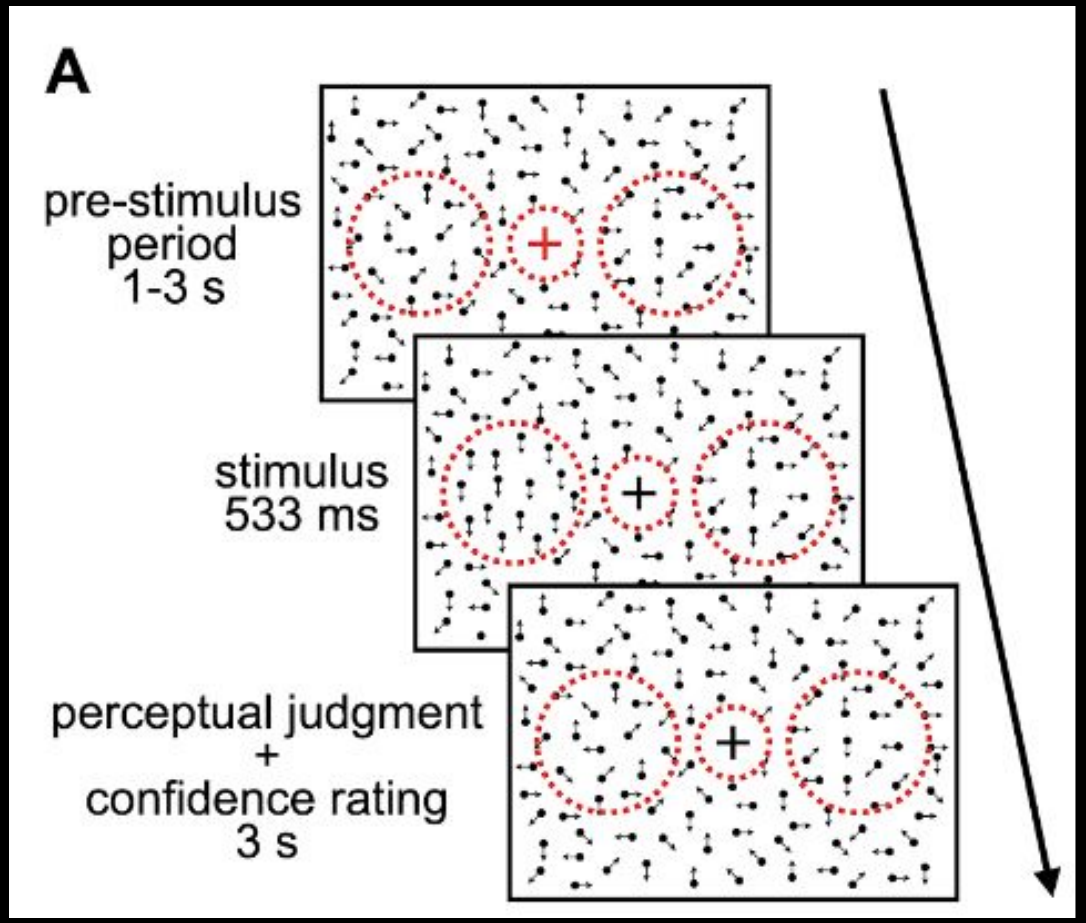


stimulus manipulations

(Maniscalco*, Graham Castaneda*, Odegaard, Morales, Rajananda, Denison, & Peters, 2020 *psyArxiv,* & just updated)

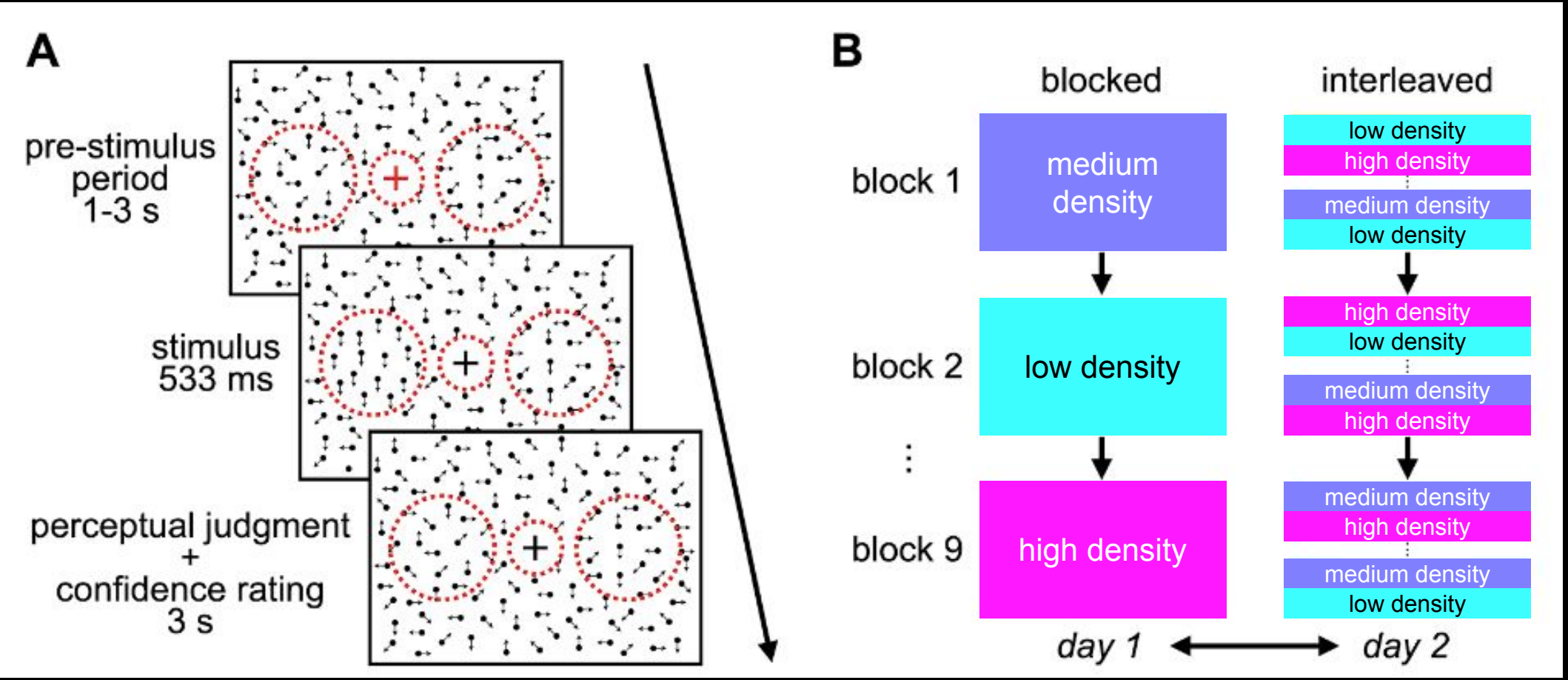
what happens to the subjective-objective RPF if we change how much stimulus is available?

what we did



(Maniscalco*, Graham Castaneda*, Odegaard, Morales, Rajananda, Denison, & Peters, 2020 *psyArxiv,* & just updated)

what we did

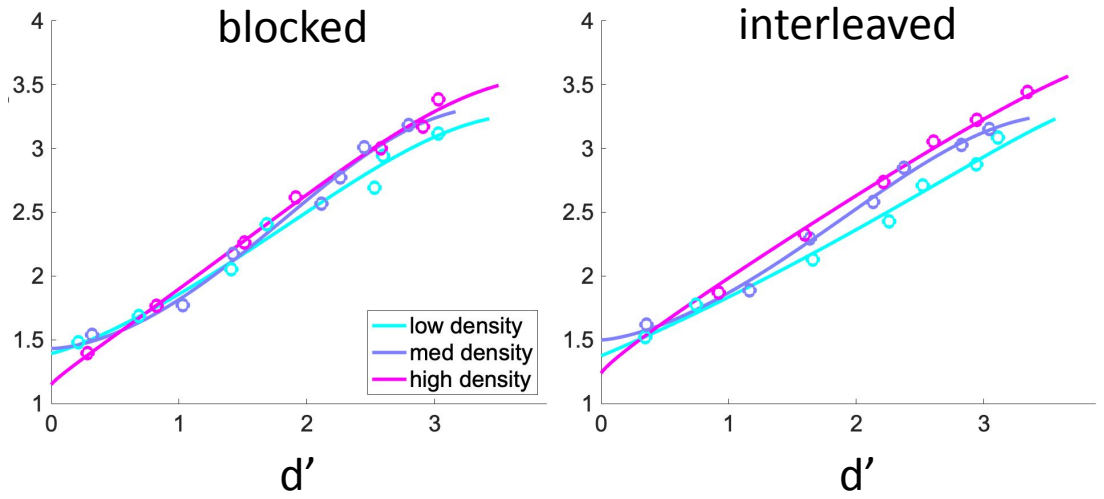


(Maniscalco*, Graham Castaneda*, Odegaard, Morales, Rajananda, Denison, & Peters, 2020 *psyArxiv,* & just updated)

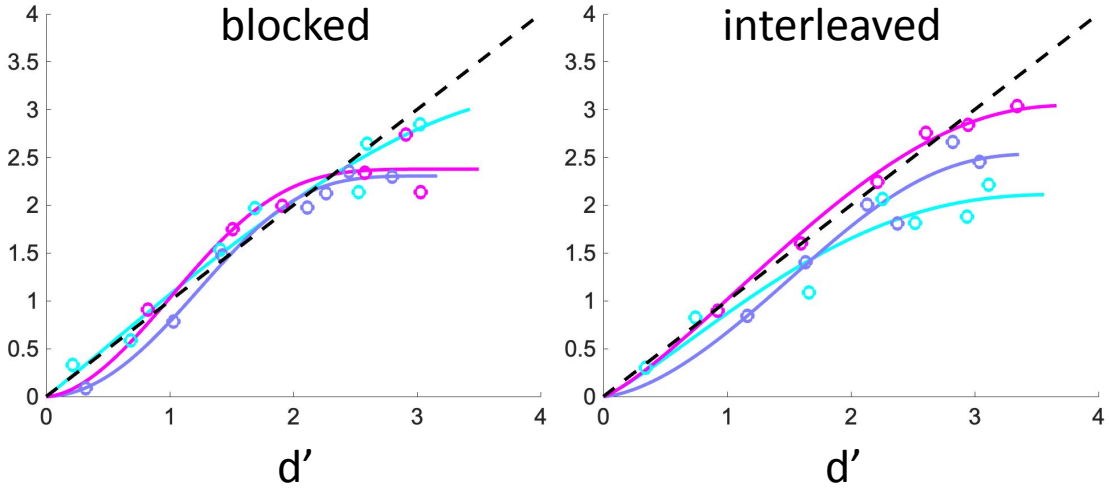
what we found

n = 21

mean confidence



meta-cog nitive sensitivity (meta-d')



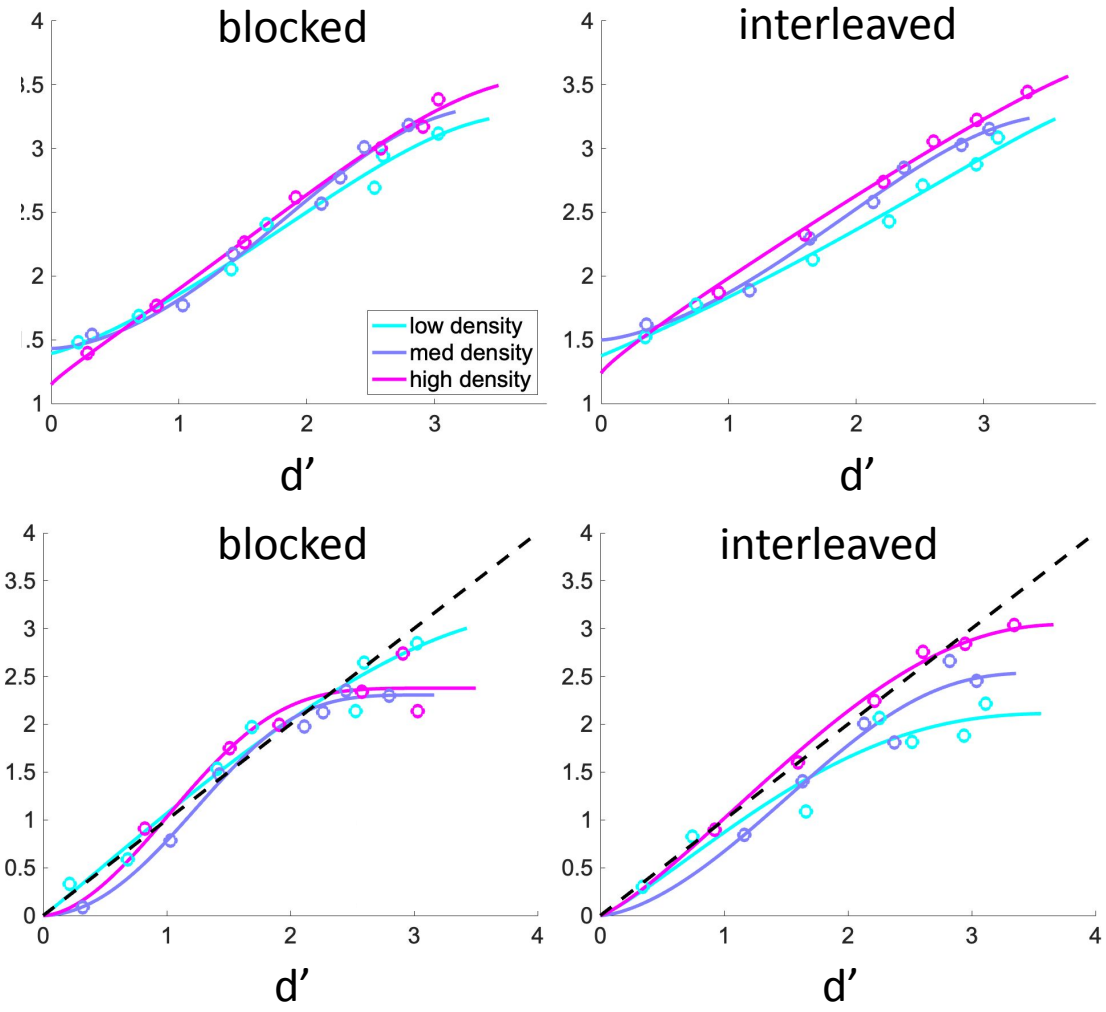
(Maniscalco*, Graham Castaneda*, Odegaard, Morales, Rajananda, Denison, & Peters, 2020 *psyArxiv,* & just updated)

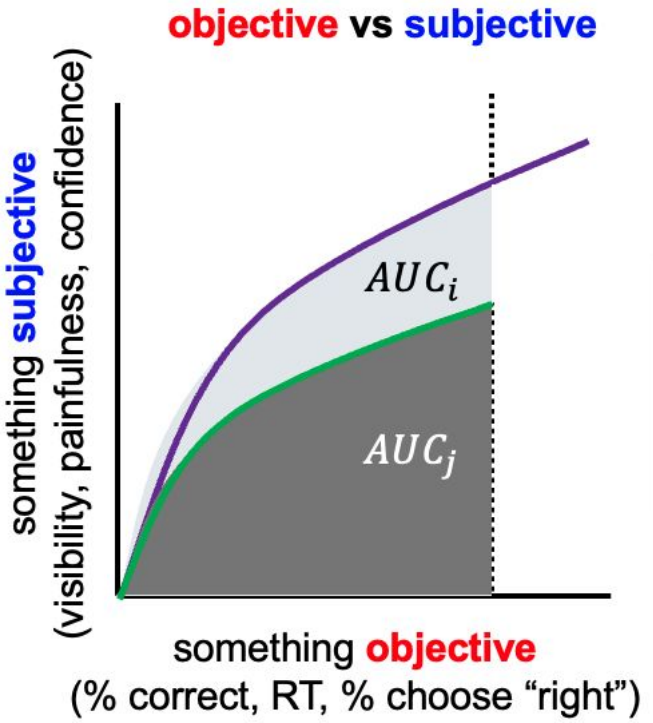
what we found

n = 21

mean confidence

meta-cog nitive sensitivity (meta-d')



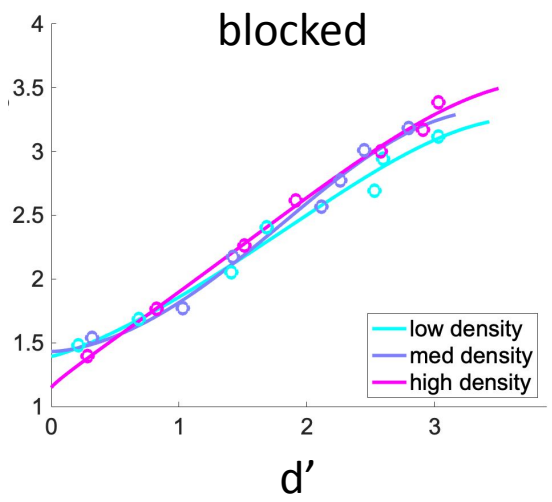


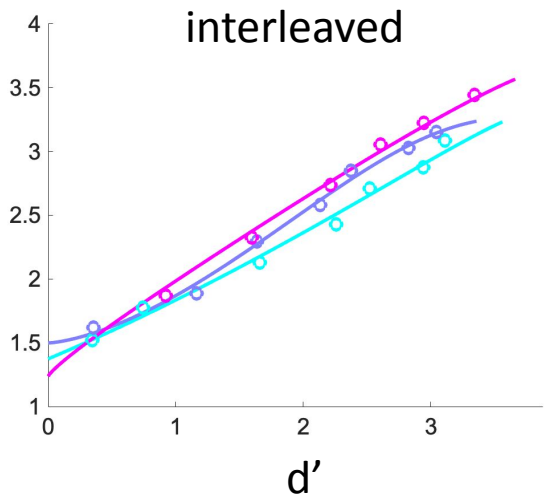
(Maniscalco*, Graham Castaneda*, Odegaard, Morales, Rajananda, Denison, & Peters, 2020 *psyArxiv,* & just updated)

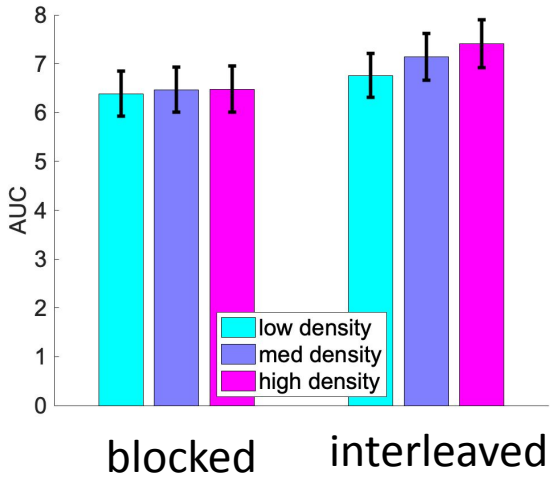
what we found

n = 21

mean confidence

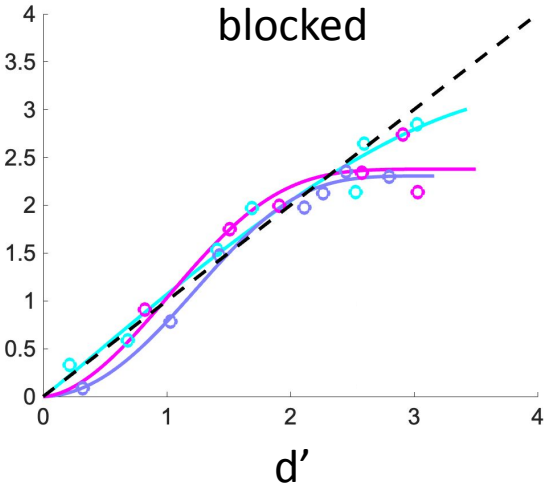


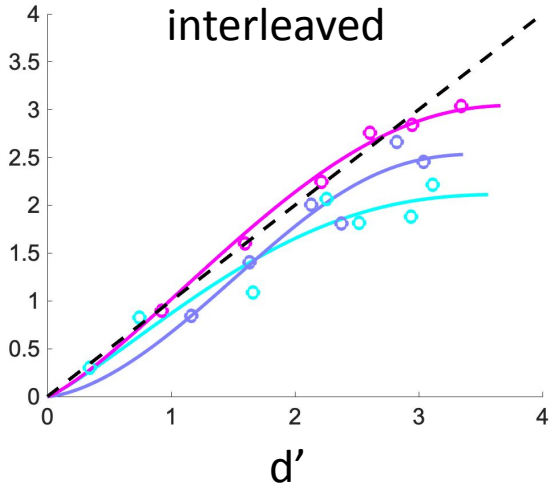


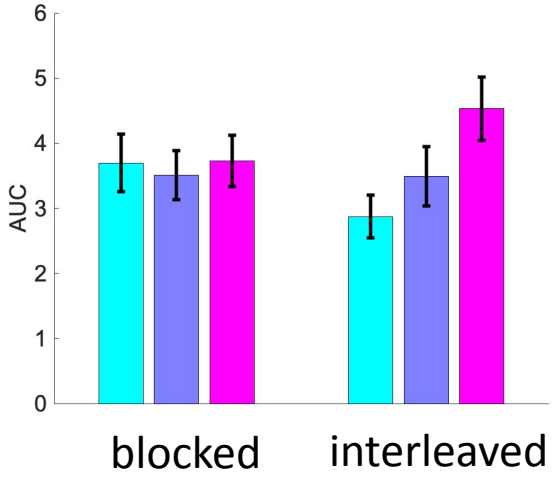


density p = 0.00121,
block x density p = 0.0154

meta-cog nitive sensitivity (meta-d')







density p = 0.00659
block x density p = 0.00754

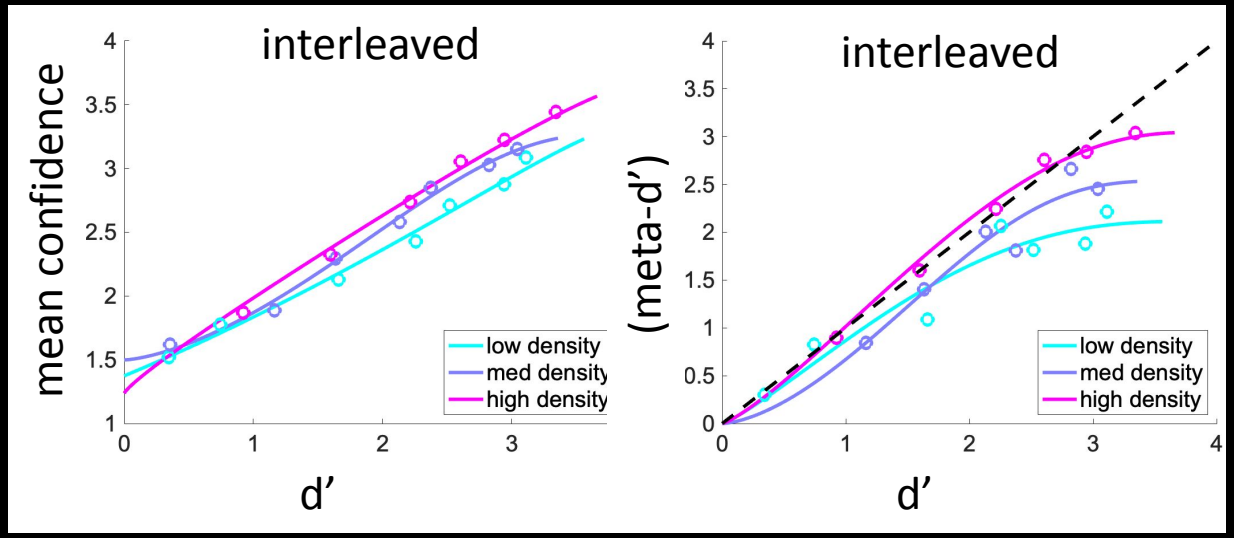
(Maniscalco*, Graham Castaneda*, Odegaard, Morales, Rajananda, Denison, & Peters, 2020 *psyArxiv,* & just updated)

take-homes:

it didn't "have to" be this way! metacognitive sensitivity *should in theory be decoupled from overall confidence*

we might not have seen this without the full RPF

- stimulus manipulations:
  - higher dot density higher confidence as a function of performance
  - higher dot density higher metacognitive sensitivity as a function of performance

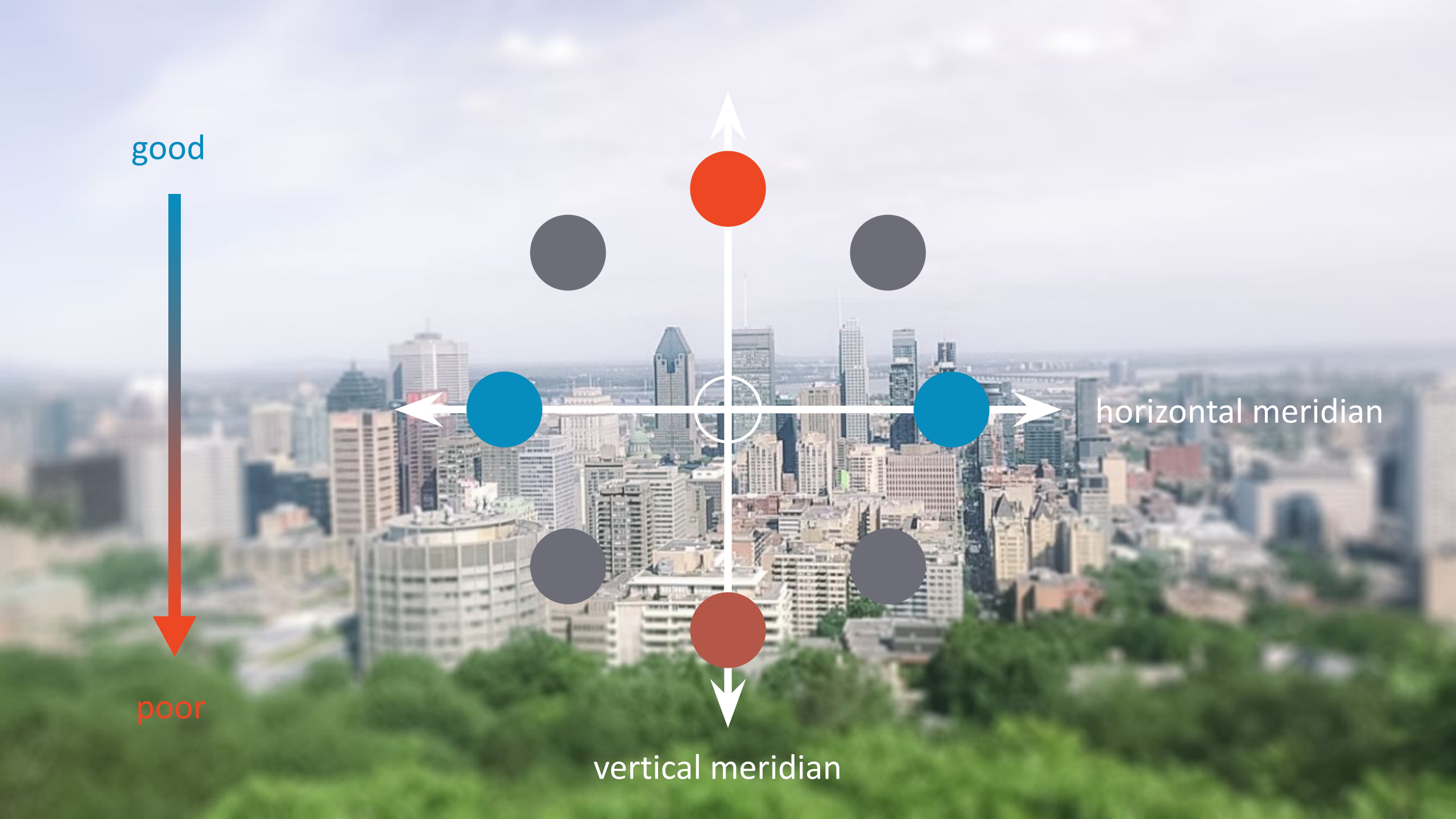


(Maniscalco*, Graham Castaneda*, Odegaard, Morales, Rajananda, Denison, & Peters, 2020 *psyArxiv,* & just updated)

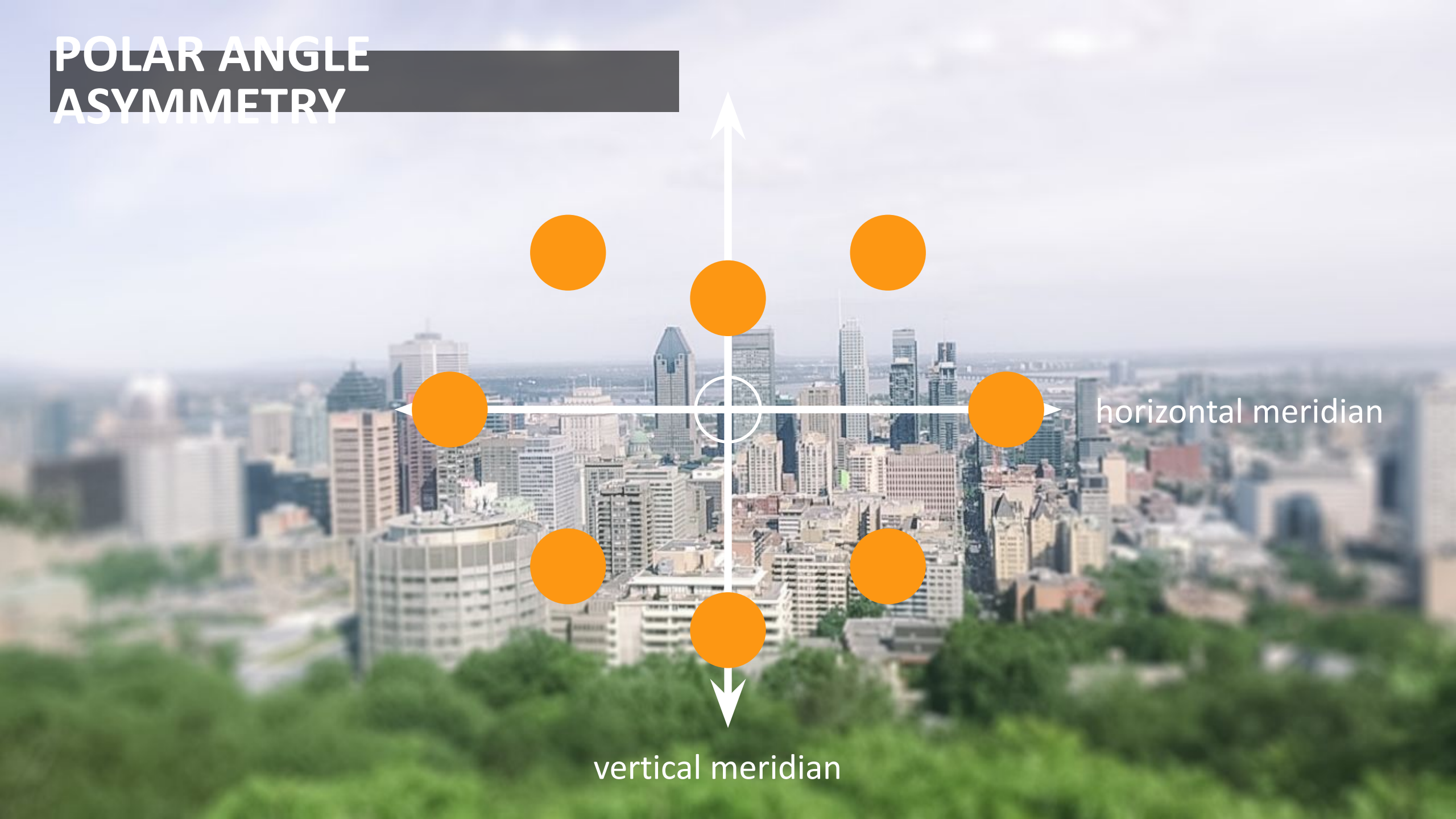
get data	stimulus manipulations
	visual field manipulations
	attentional manipulations
do analytic work	characterizing the relative psychometric function (RPF)
	thinking about how confidence “should” behave

Angela Shen

visual field manipulations

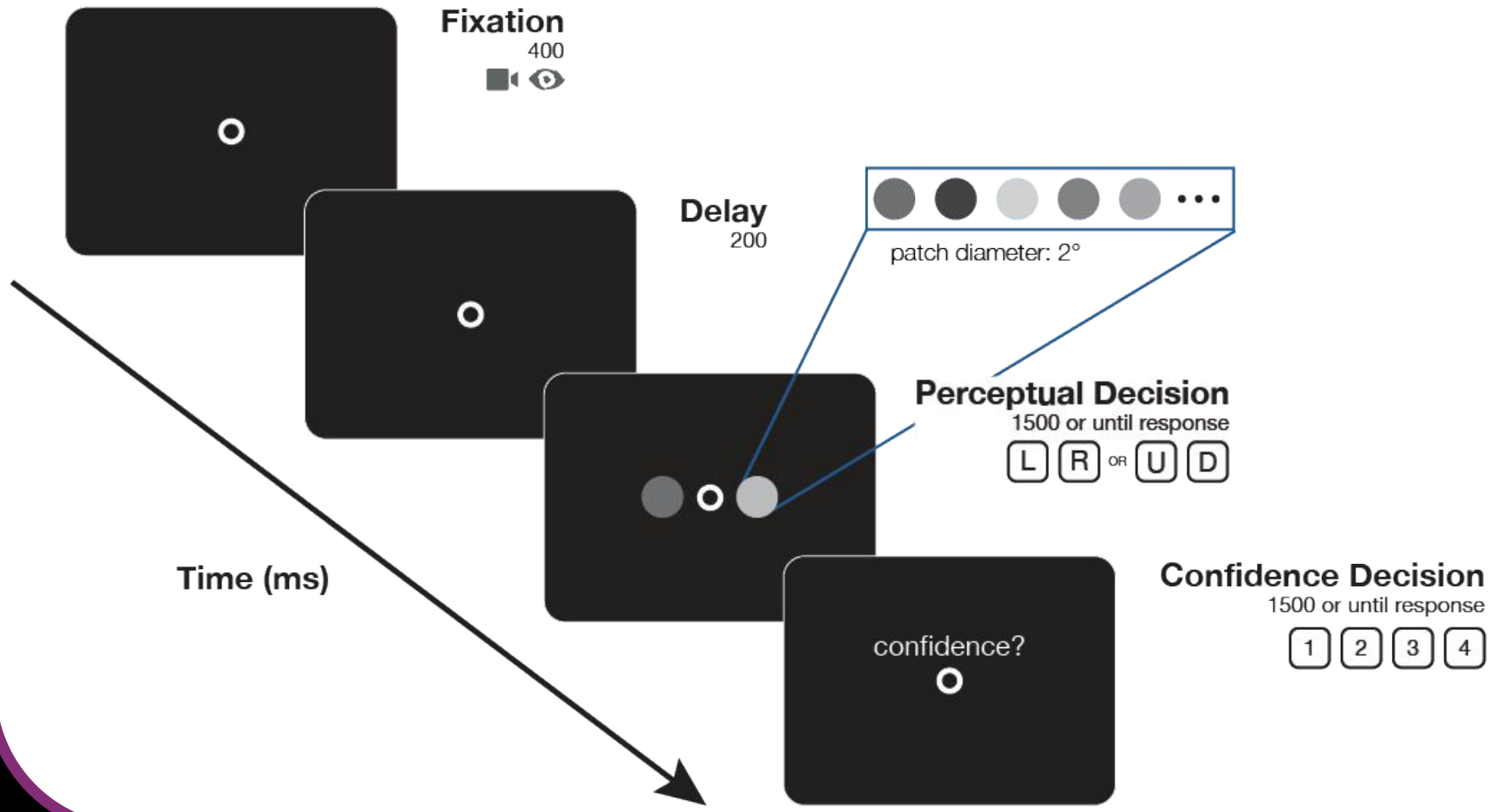

good
poor
horizontal meridian
vertical meridian

POLAR ANGLE ASYMMETRY



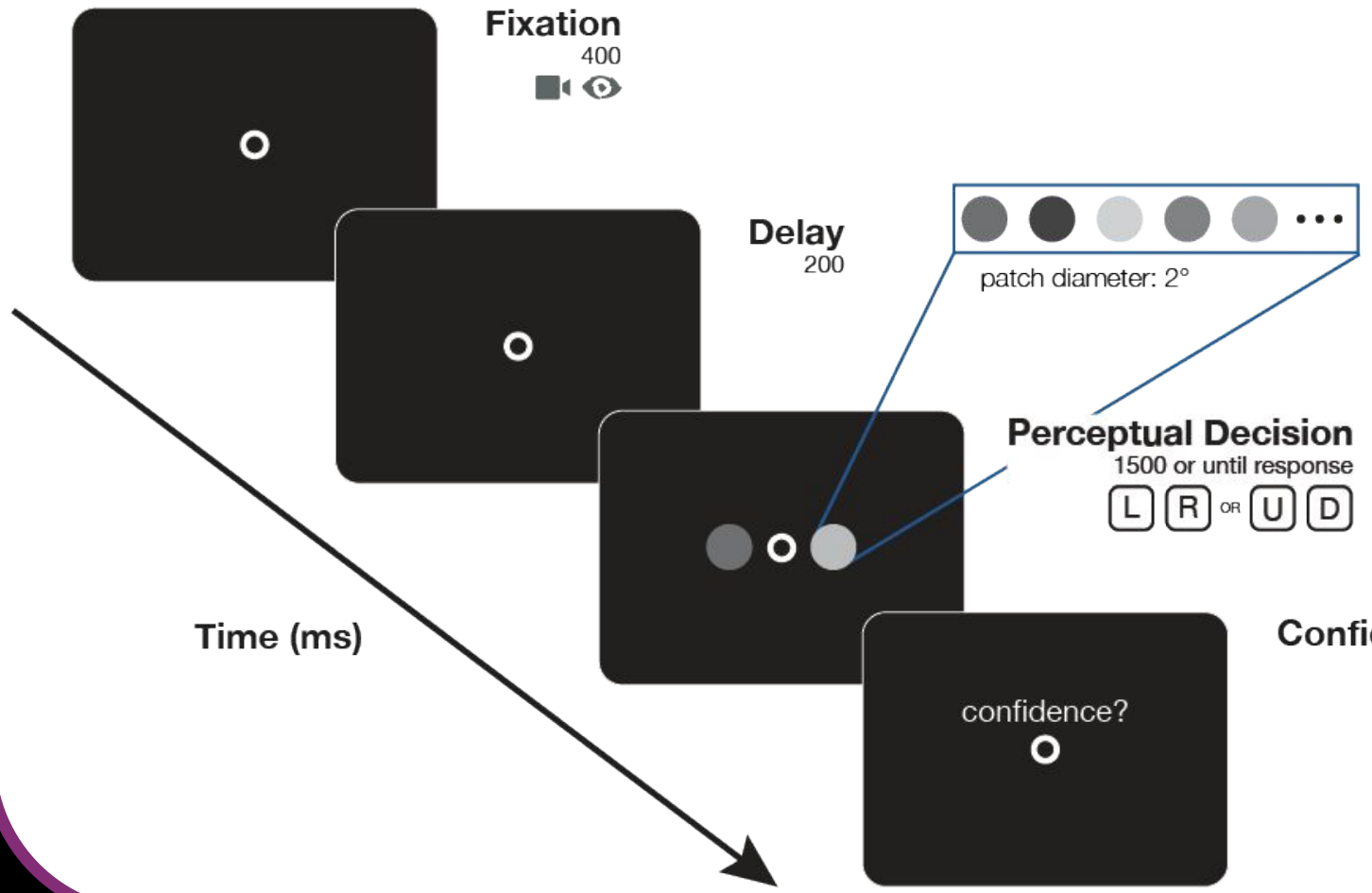
what happens to the subjective-objective RPF around the visual field?

what we did

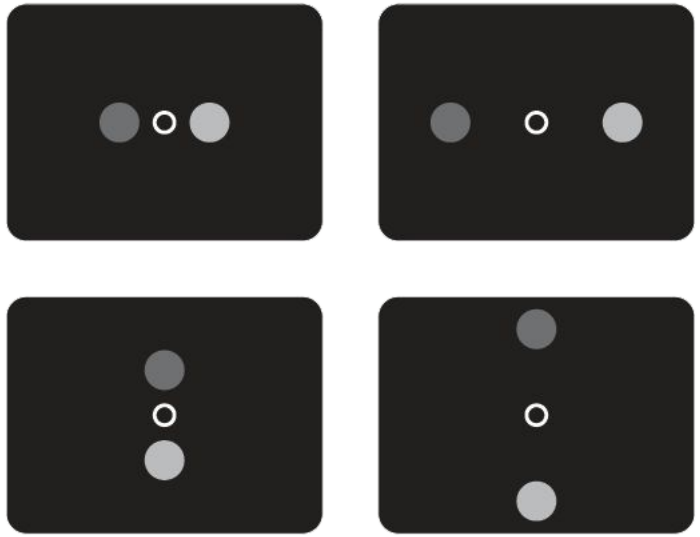


(Shen, Maniscalco, & Peters, in prep)

what we did

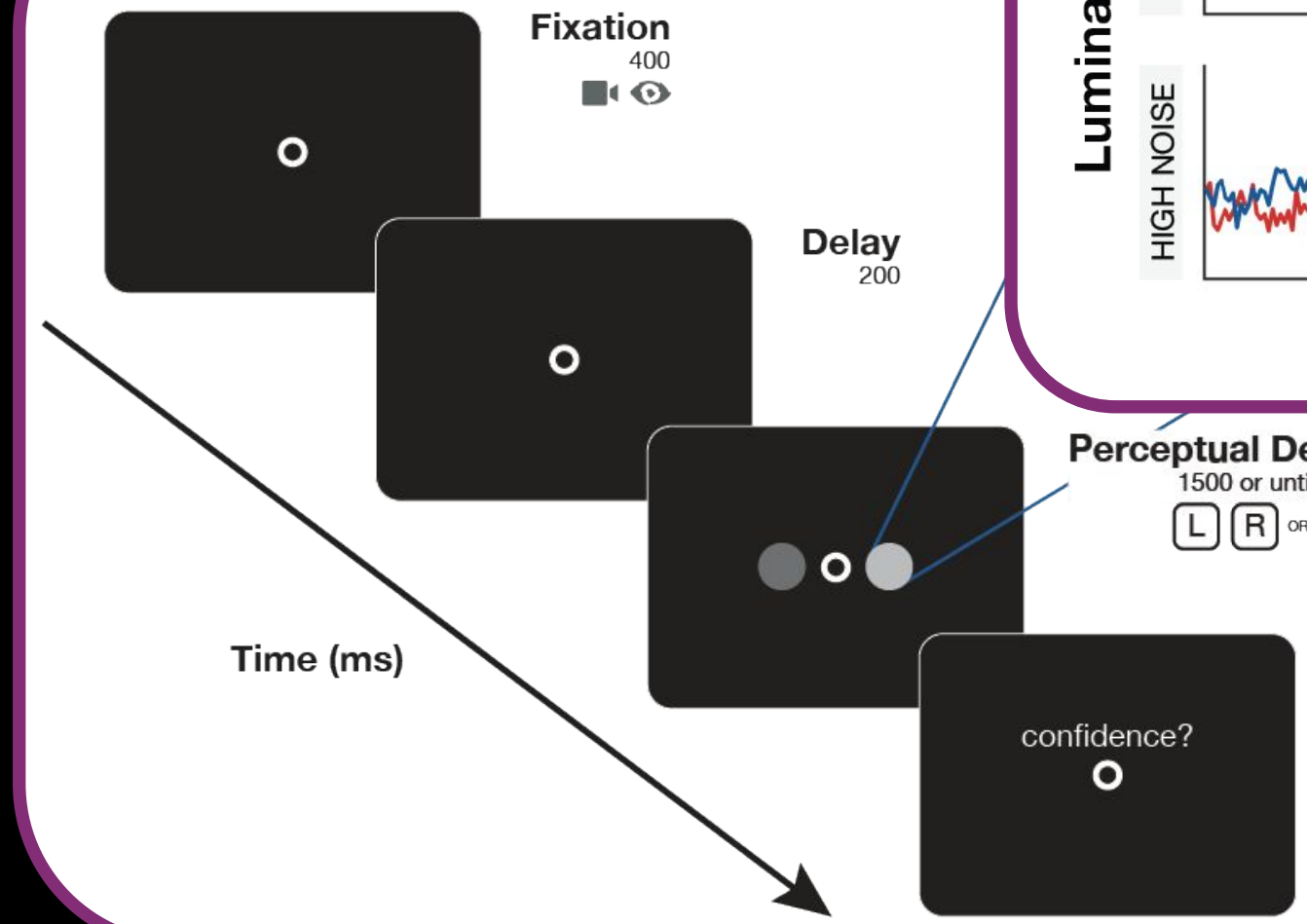


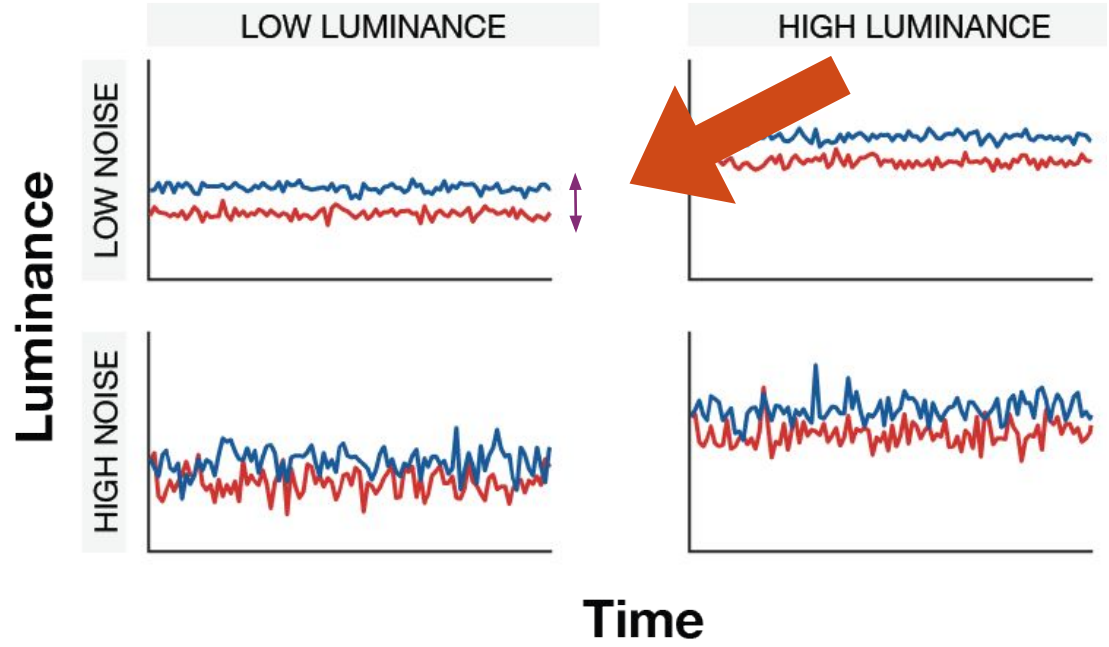
STIMULI LOCATION:
vertical or horizontal axis (blocked)
parafovea (2°) or periphery (8°)



(Shen, Maniscalco, & Peters, in prep)

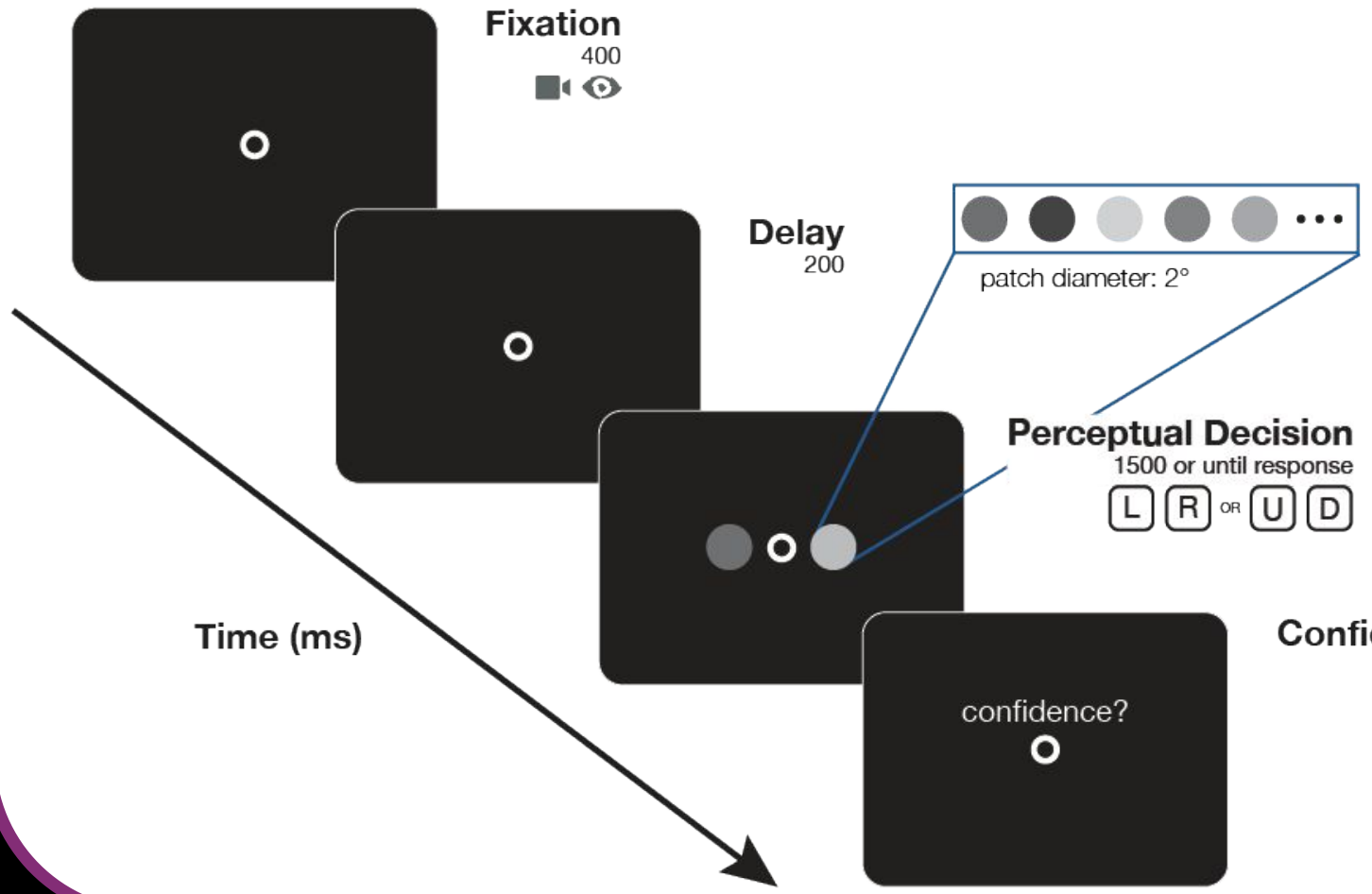
what we did





(Shen, Maniscalco, & Peters, in prep)

what we did



2 location comparison axes
2 eccentricities
2 levels of overall luminance
2 levels of noise
7 levels of relative luminance

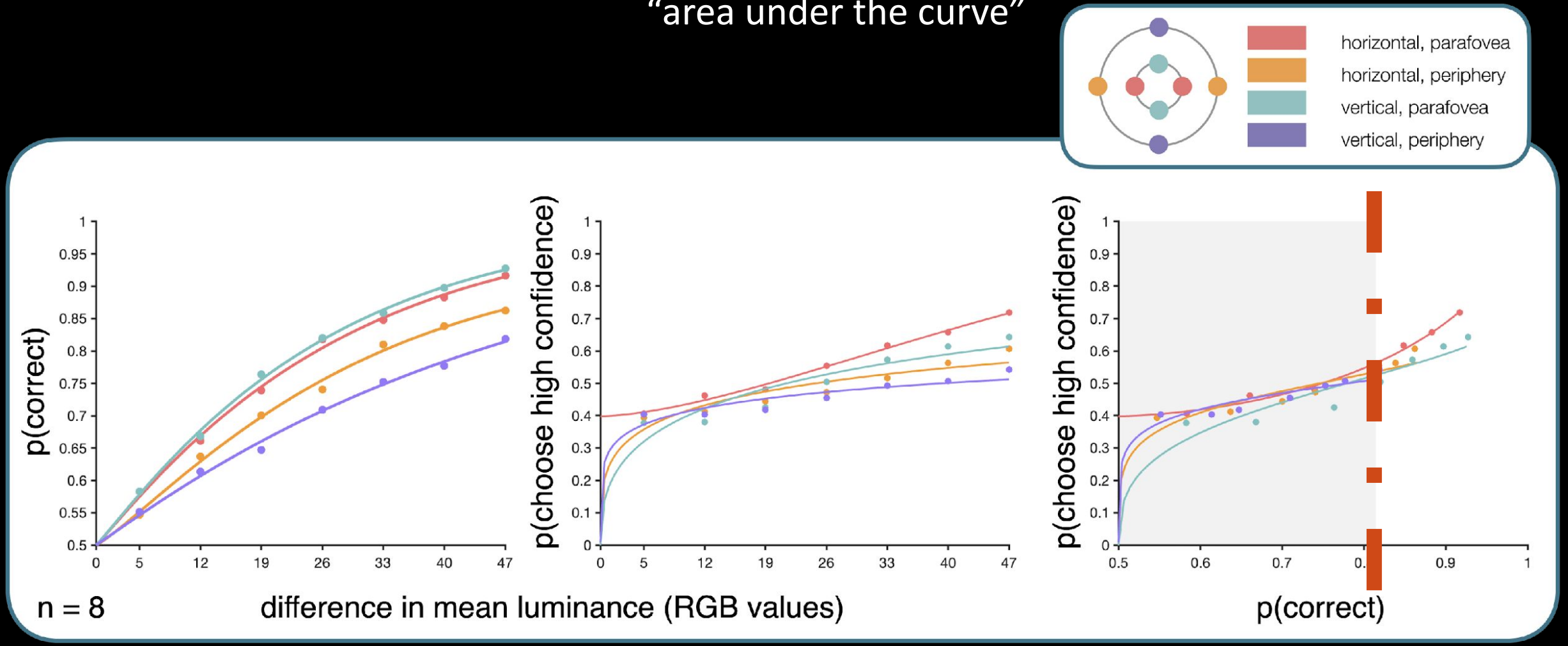
× 64 trials per data point

= 7168 trials per observer

(Shen, Maniscalco, & Peters, in prep)

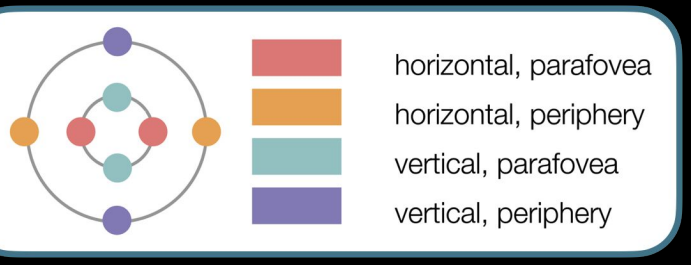
what we found

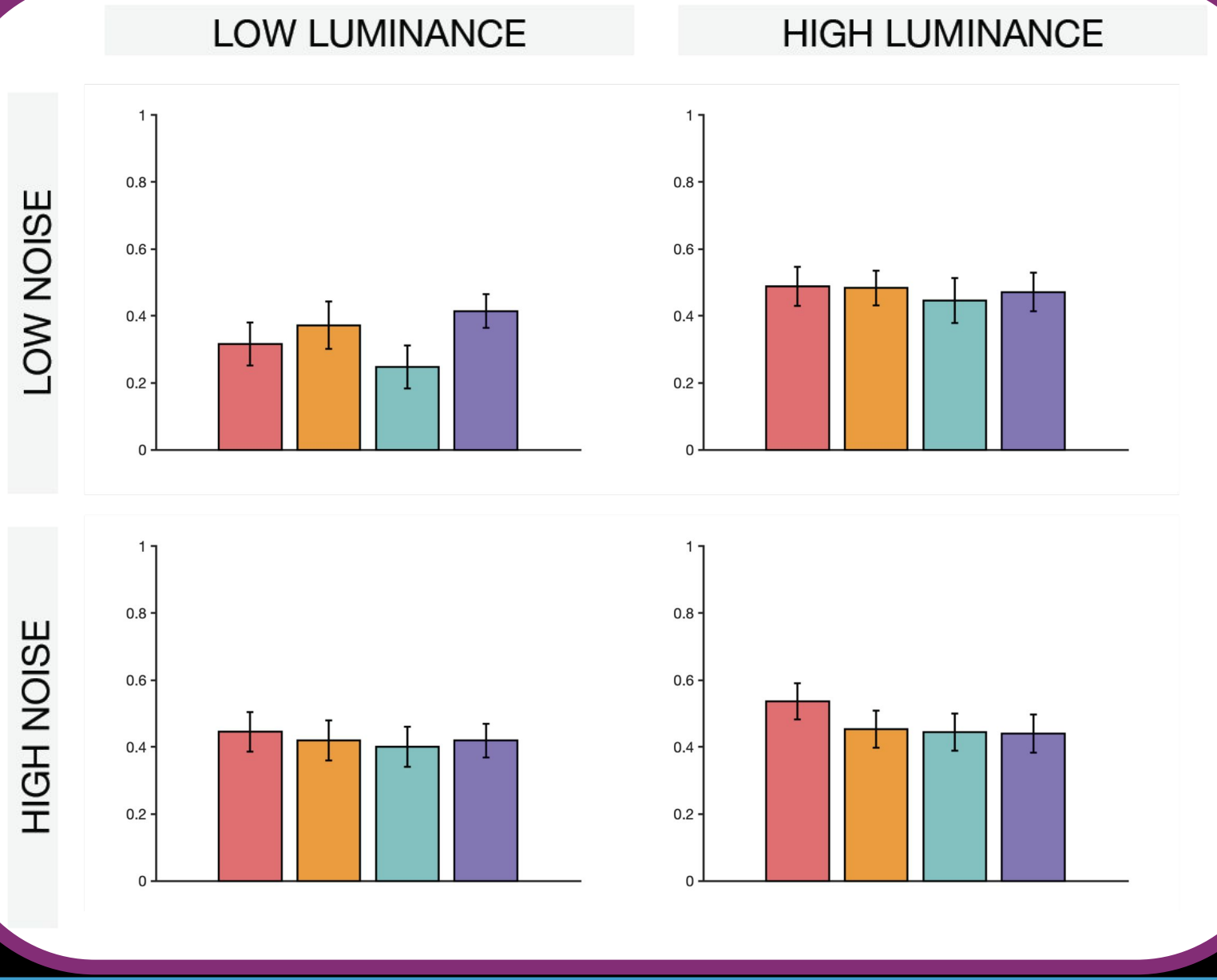
we can summarize the RPF with the "area under the curve"



(Shen, Maniscalco, & Peters, in prep)

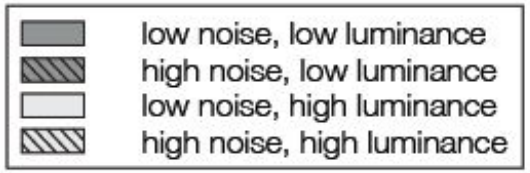
we can summarize the RPF with the “area under the curve”

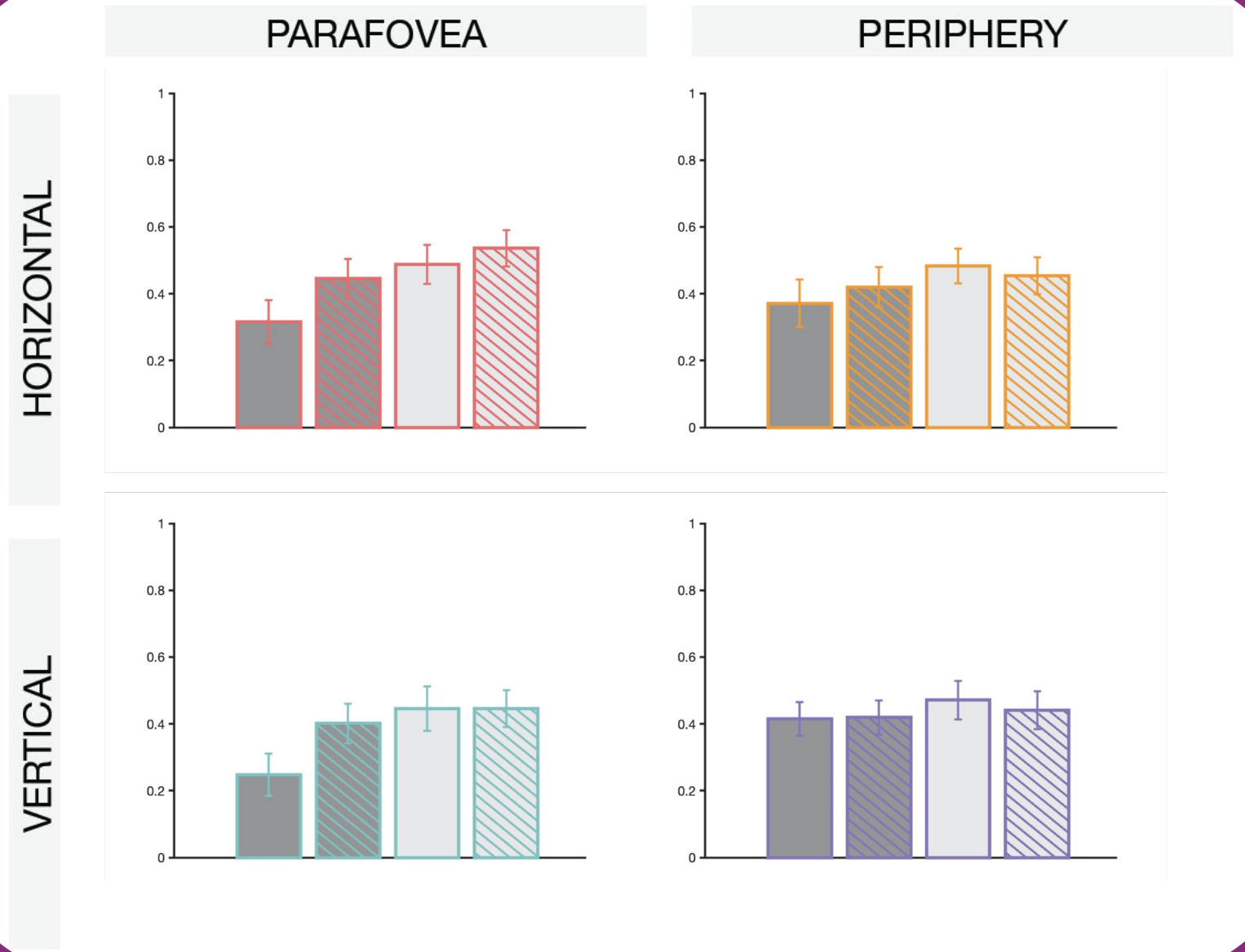




(Shen, Maniscalco, & Peters, in prep)

we can summarize the RPF with the “area under the curve”



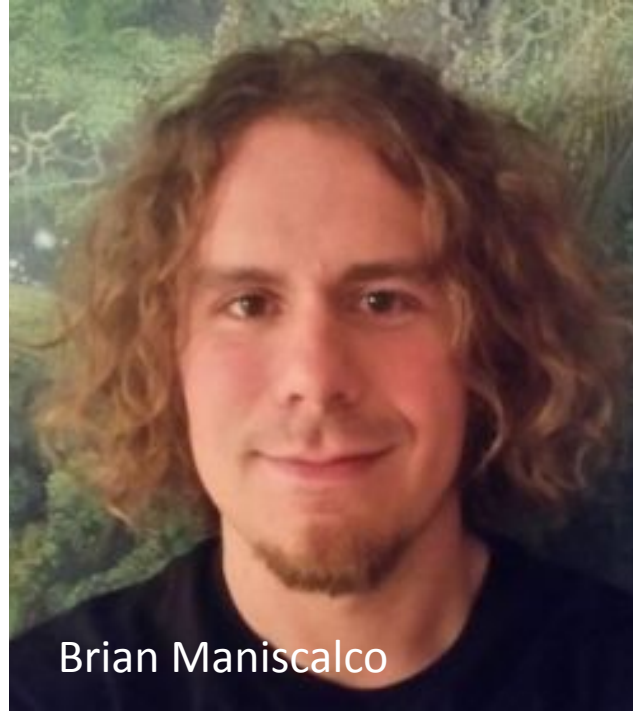


(Shen, Maniscalco, & Peters, in prep)

take-homes:

- stimulus manipulations:
  - higher dot density higher confidence as a function of performance
- visual field manipulations:
  - periphery, and especially upper visual periphery higher confidence as a function of performance under near-threshold noise & luminance

get data	stimulus manipulations
	visual field manipulations
	attentional manipulations
do analytic work	characterizing the relative psychometric function (RPF)
	thinking about how confidence “should” behave

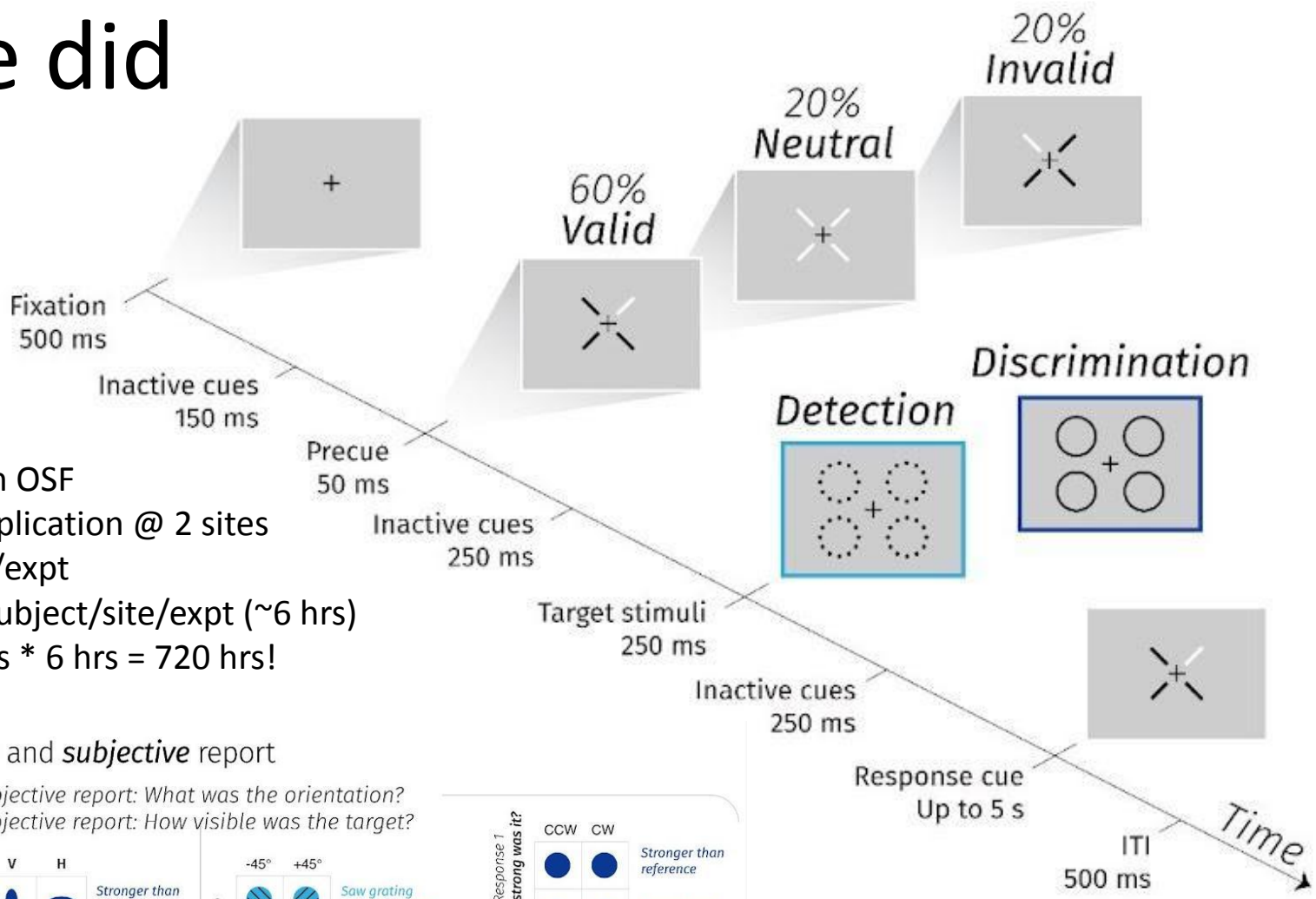


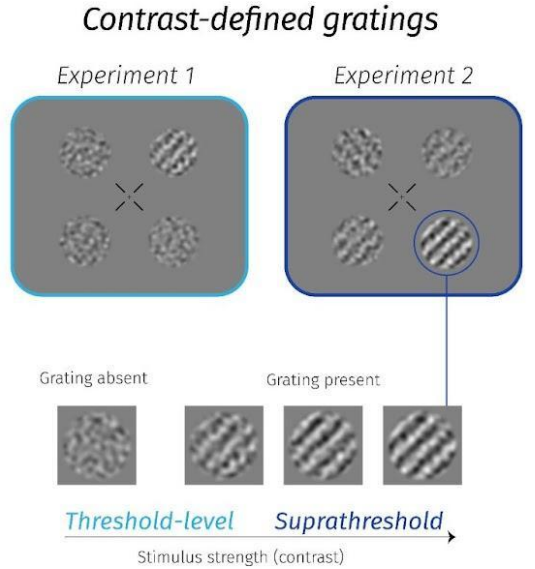
attentional manipulations

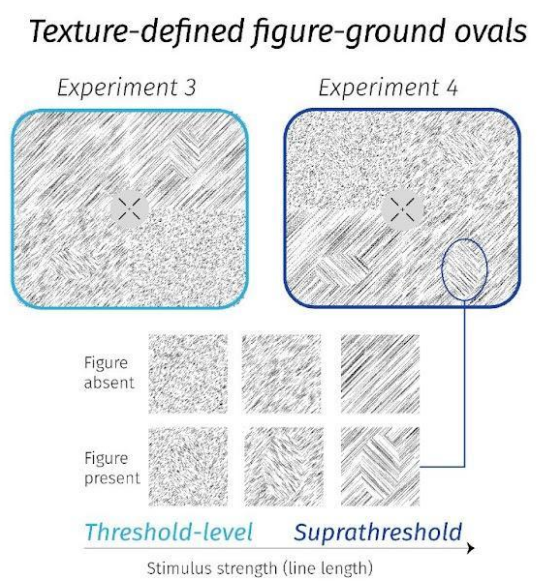
what happens to the subjective-objective RPF under different levels of attention?

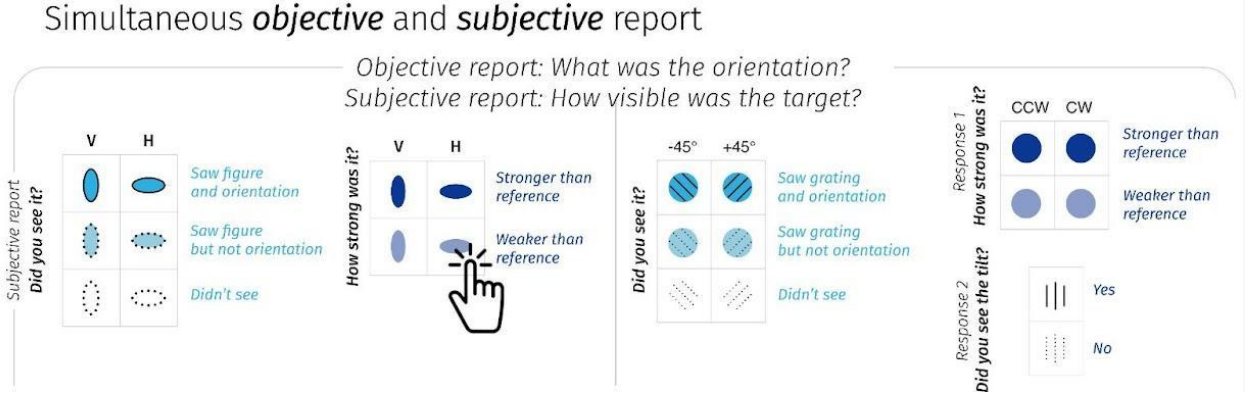
what we did

- **preregistered** on OSF
- simultaneous replication @ 2 sites
- 15 subjects/site/expt
- 3360 trials per subject/site/expt (~6 hrs)
- 30 subs * 4 expts * 6 hrs = 720 hrs!

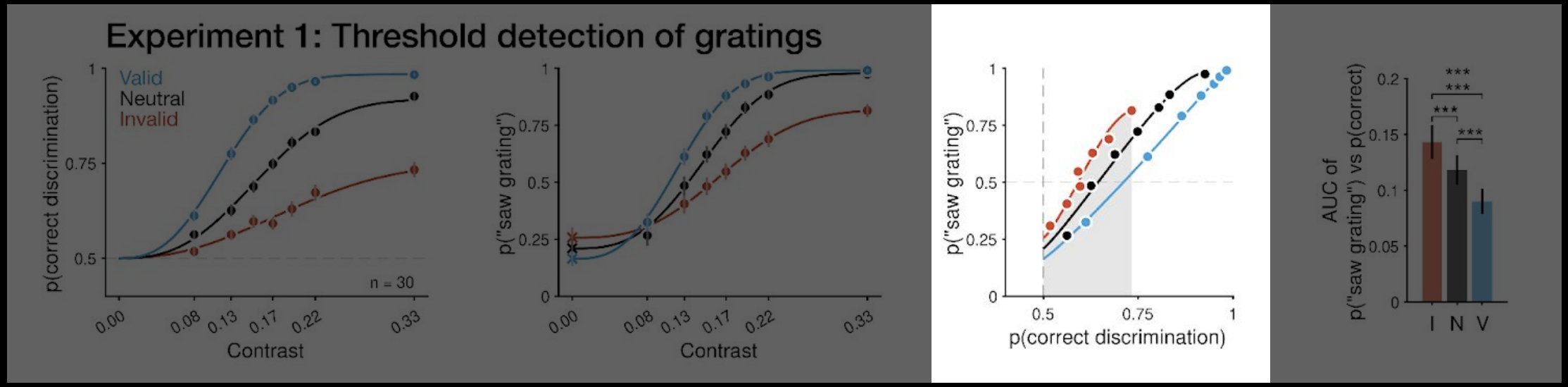


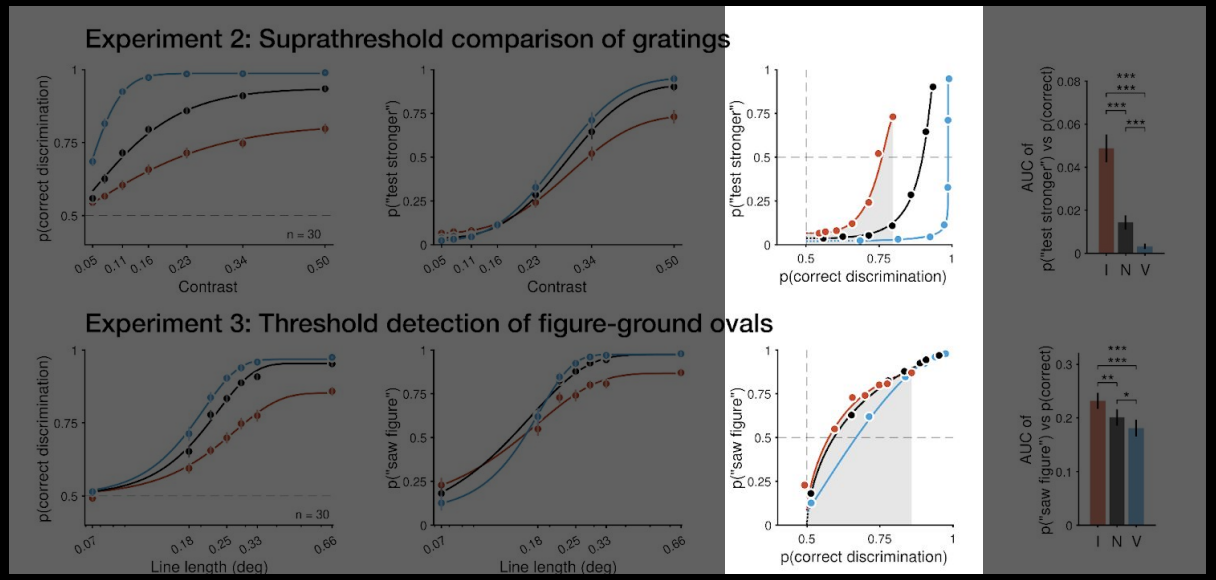


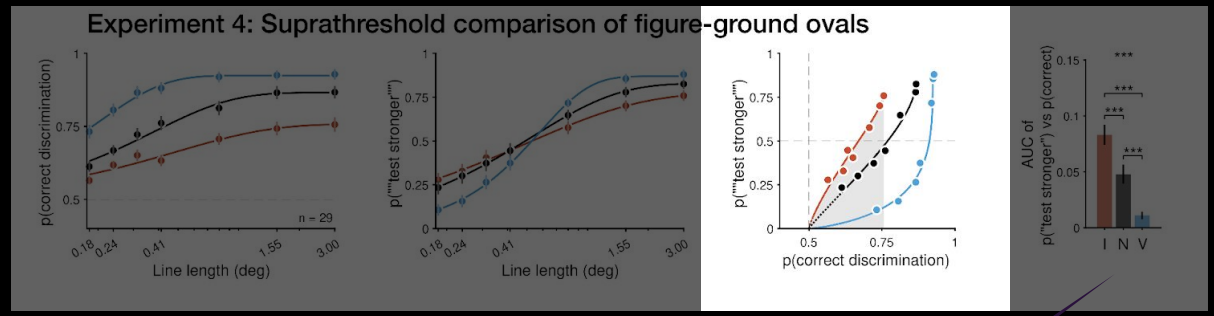


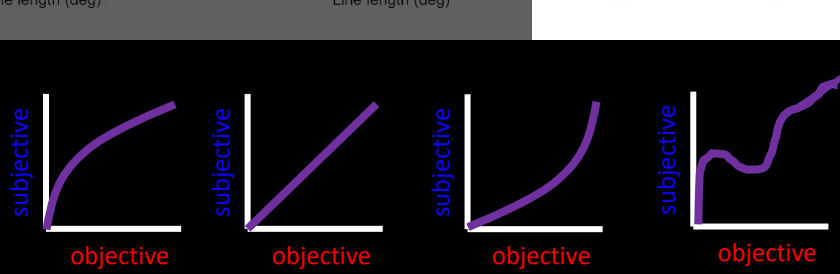


what we found





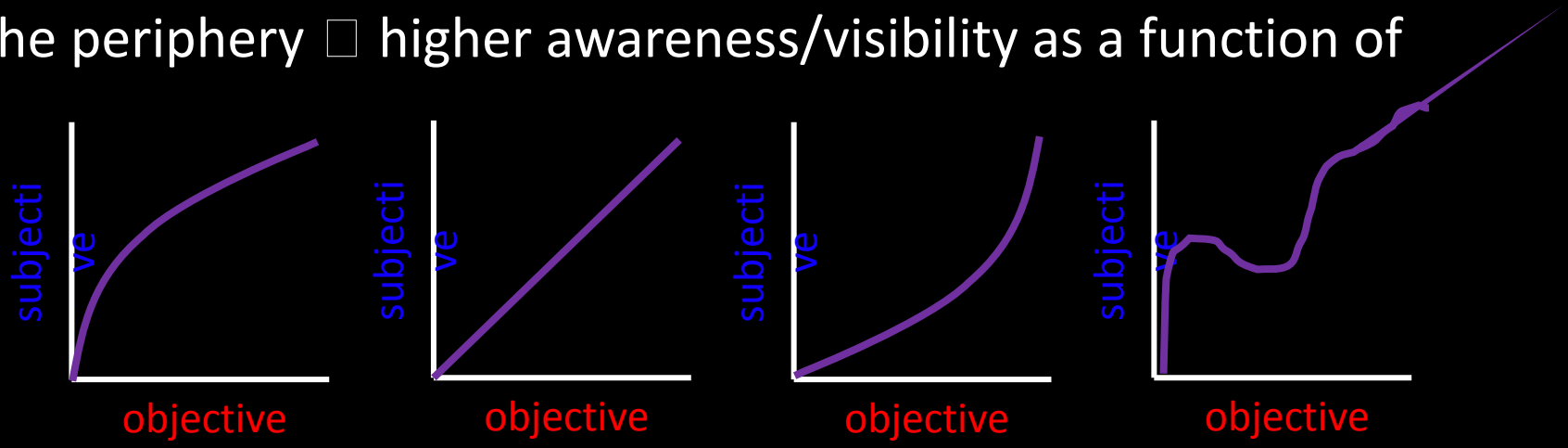




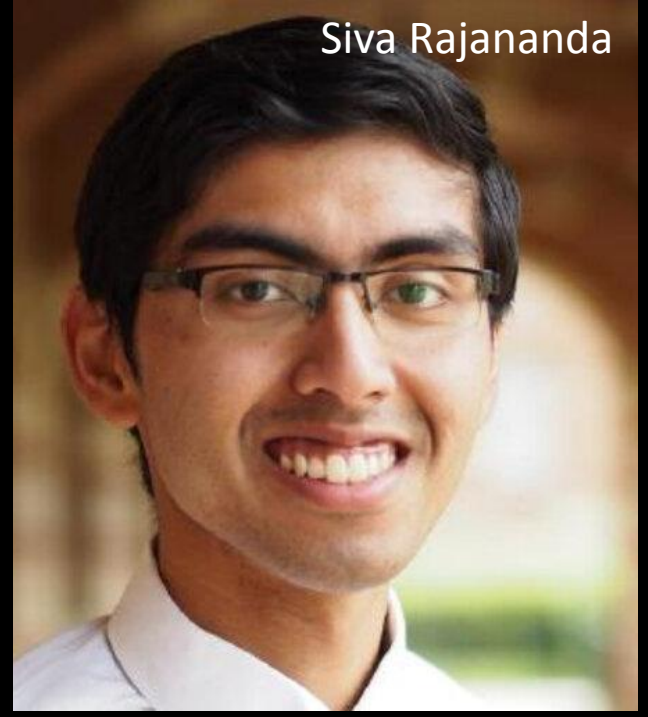
(Tian*, Maniscalco*, Epstein, Shen, Graham Castaneda, Arzu, Kurosawa, Motzer, Olsson, Romero, Russell, Walsh, Wang, Awrang Zeb, Brown, Lamme, Lau, He, Brascamp, Block, Chalmers, Peters†, & Denison†, in prep)

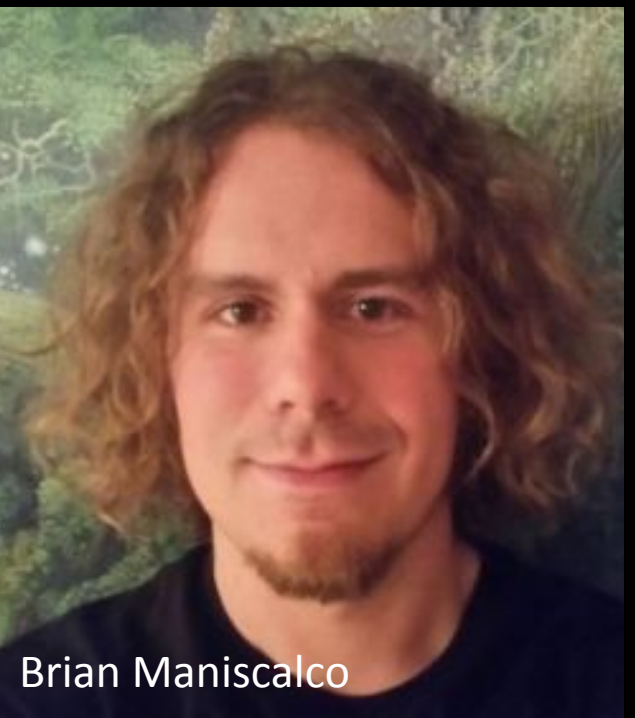
take-homes:

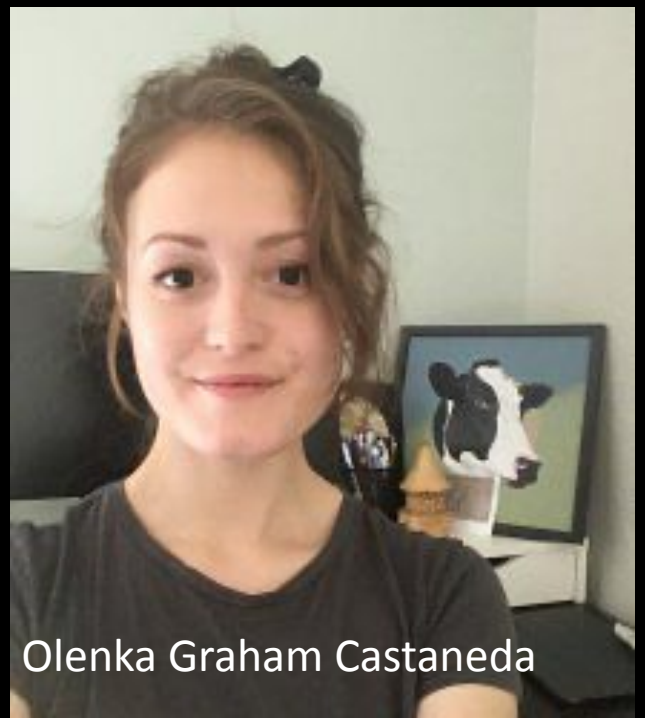
- stimulus manipulations:
  - higher dot density higher confidence as a function of performance
- visual field manipulations:
  - periphery, and especially upper visual periphery higher confidence as a function of performance under near-threshold noise & luminance
- attentional manipulations:
  - lower attention in the periphery higher awareness/visibility as a function of performance
  - RPF variability:



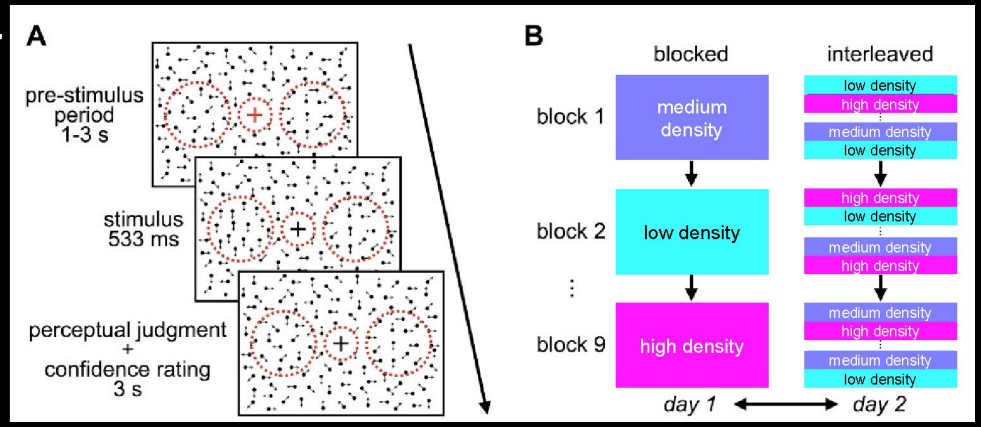
get data	stimulus manipulations
	visual field manipulations
	attentional manipulations
do analytic work	characterizing the relative psychometric function (RPF)
	thinking about how confidence “should” behave



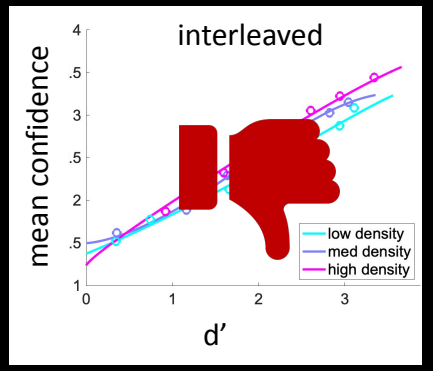




return to those stimulus manipulations as a case study…



(Maniscalco*, Graham Castaneda*, Odegaard, Morales, Rajananda, Denison, & Peters, 2020 *psyArxiv,* & just updated)



you can't just fit the RPF with a Weibull

unsolved area of statistics: nonlinear errors in variables problems have no MLE/OLS solution

but you can fit these with Weibulls!

stimulus vs [objective]

something objective
(% correct, RT, % choose "right", etc)

stimulus intensity

stimulus vs [subjective]

something subjective
(visibility, painfulness, confidence)

stimulus intensity

objective vs subjective

something subjective
(visibility, painfulness, confidence)

math!

something objective
(% correct, RT, % choose "right", etc)

standard Weibull functions for P_1 and P_2

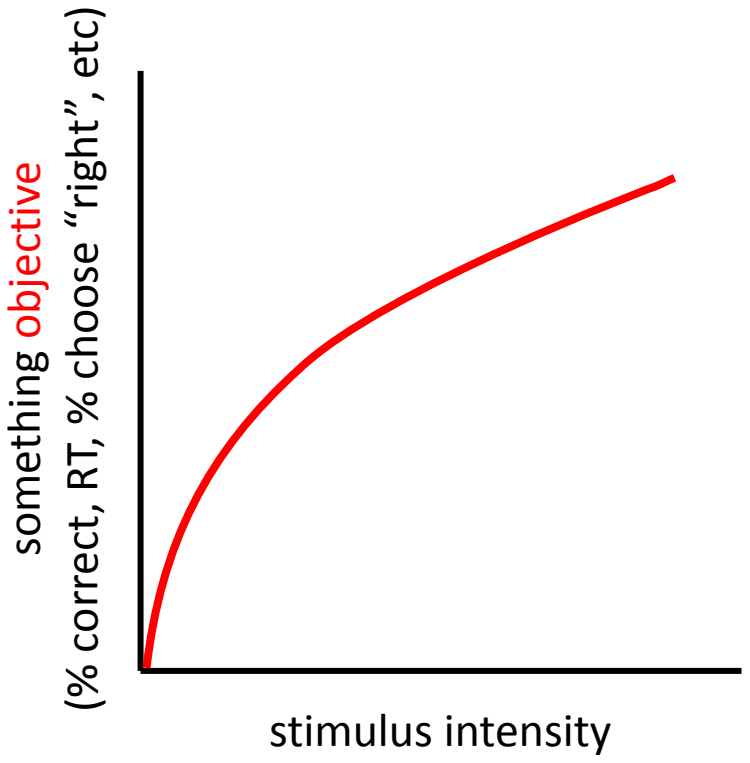
$$P_n = F_n(x) = \gamma_n + \left(1 - \lambda_n - \gamma_n\right)\left[1 - e^{-(x/\alpha_n)^{\beta_n}}\right]$$

math!

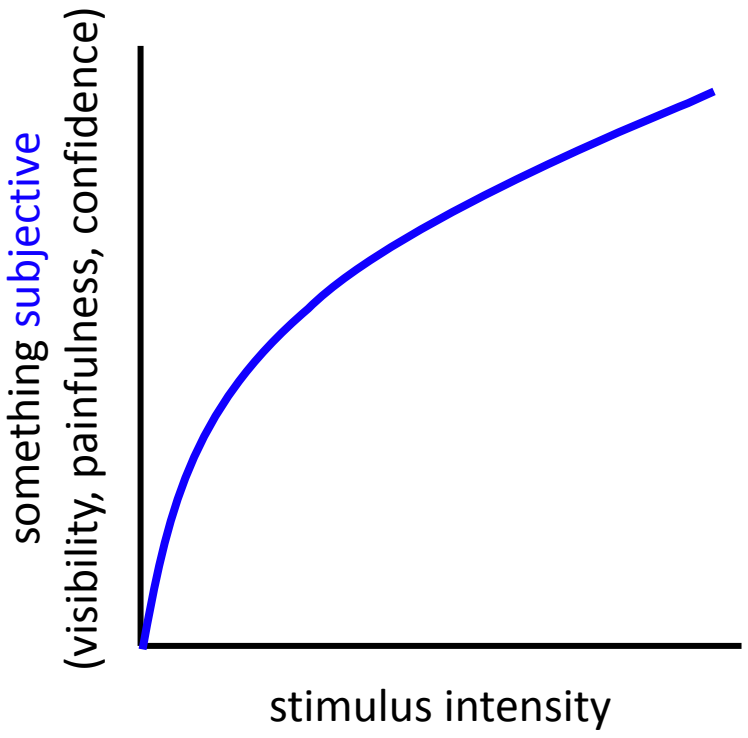
RPF under Weibull assumptions for P_1 and P_2

$$P_2 = R(P_1) = \gamma_2 + \left(1 - \lambda_2 - \gamma_2\right)\left[1 - e^{-\left(\left(\frac{\alpha_2}{\alpha_1}\right)^{-\beta_2}\left(\ln\left(\frac{1-\lambda_1-\gamma_1}{1-\lambda_1-P_1}\right)\right)^{\frac{\beta_2}{\beta_1}}\right)}\right]$$

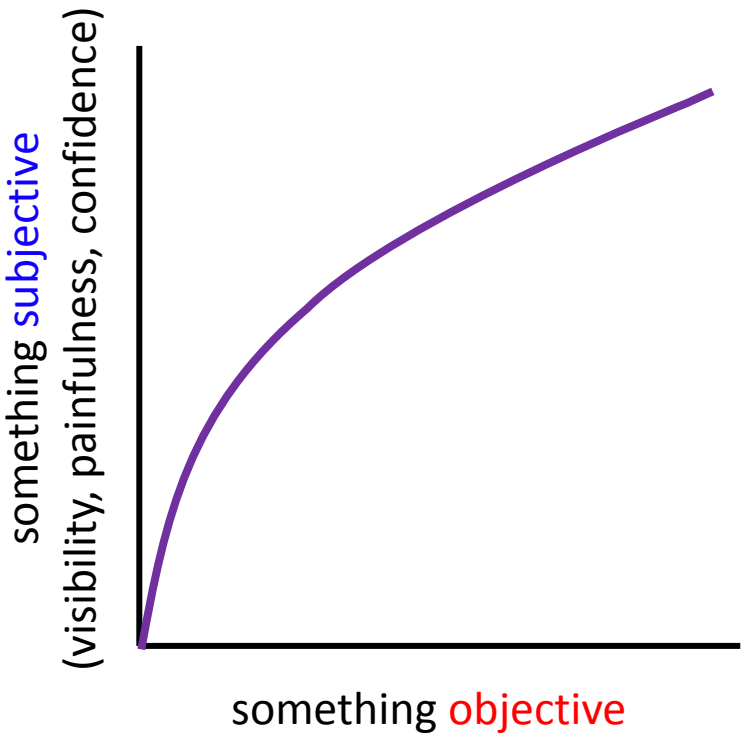
stimulus vs [objective]



stimulus vs [subjective]



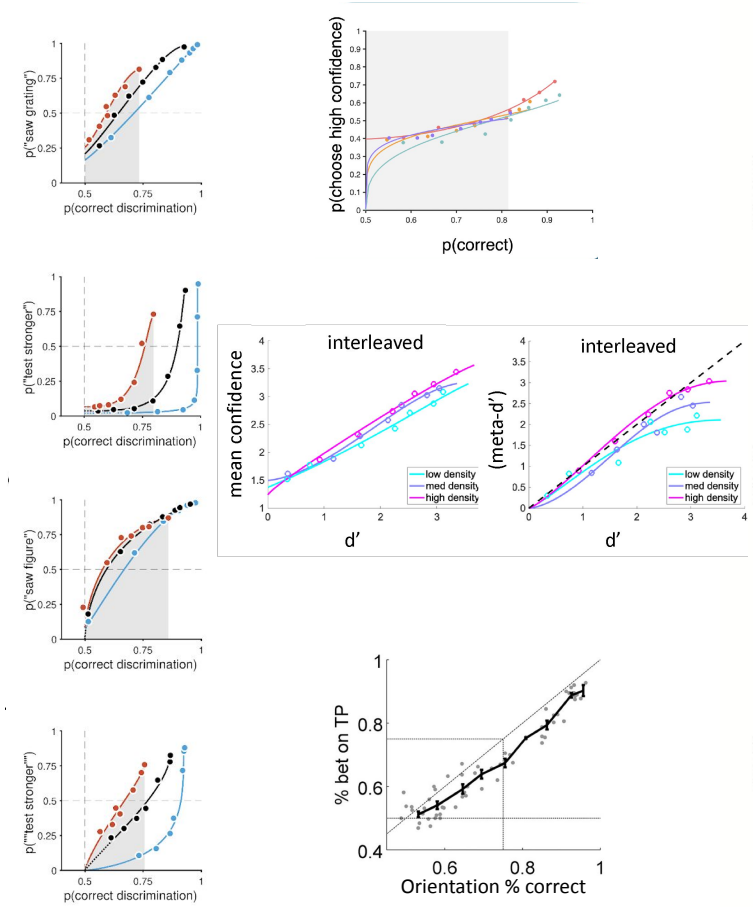
objective vs subjective

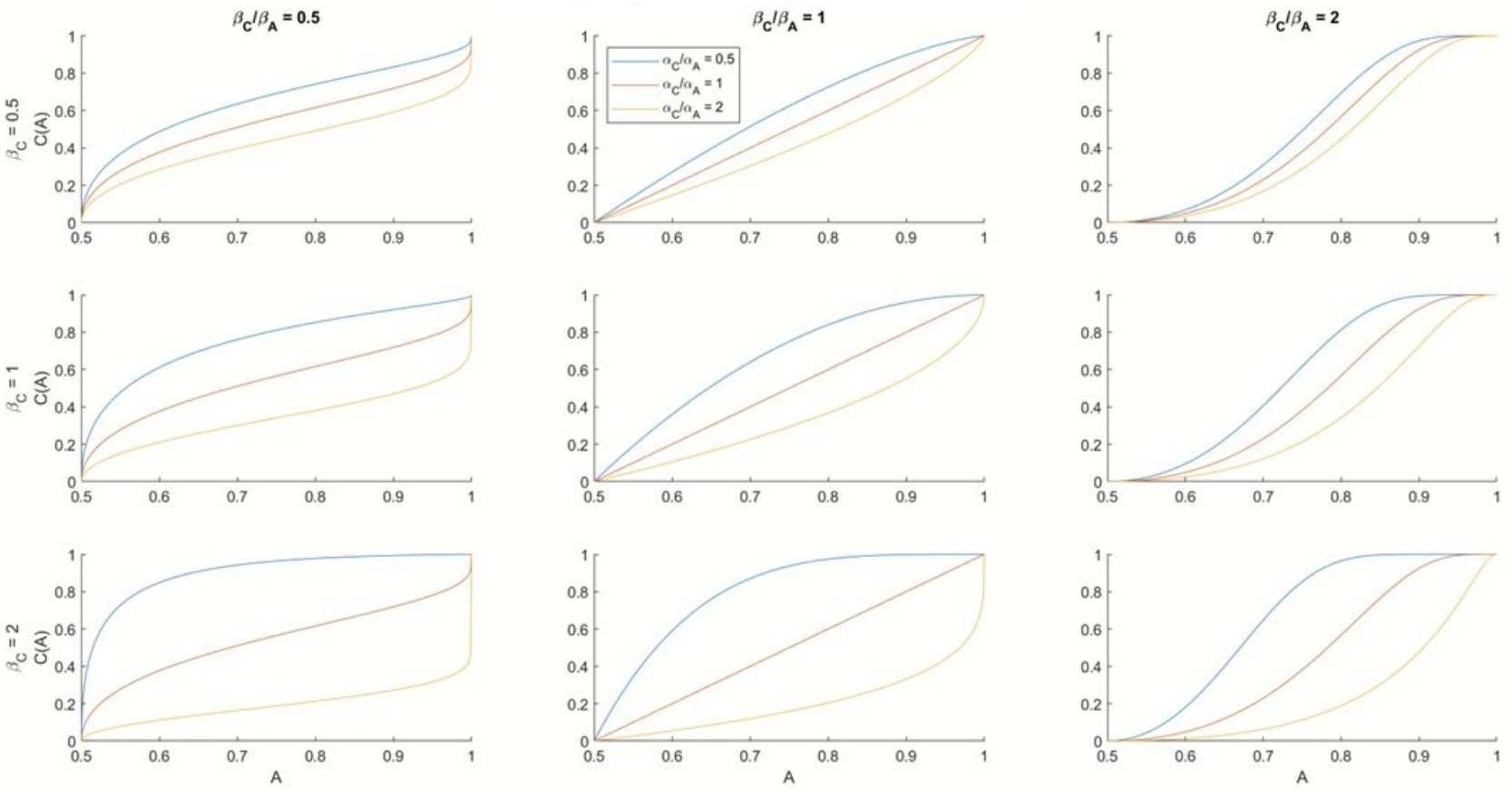


RPF under Weibull assumptions for P_1 and P_2

behavior of the RPF under Weibull assumptions

$$P_2 = R(P_1) = \gamma_2 + (1 - \lambda_2 - \gamma_2)\left[1 - e^{-\left(\left(\frac{\alpha_2}{\alpha_1}\right)^{-\beta_2}\left(\ln\left(\frac{1-\lambda_1-\gamma_1}{1-\lambda_1-P_1}\right)\right)^{\frac{\beta_2}{\beta_1}}\right)}\right]$$





why am I so excited about “2nd generation psychometric functions”??

(and why you should be excited too…)

get data	stimulus manipulations
	visual field manipulations
	attentional manipulations
do analytic work	characterizing the relative psychometric function (RPF)
	thinking about how confidence “should” behave

Hierarchically-dependent system:

1. $\hat{x}$ and $x \sim f(S, \theta)$

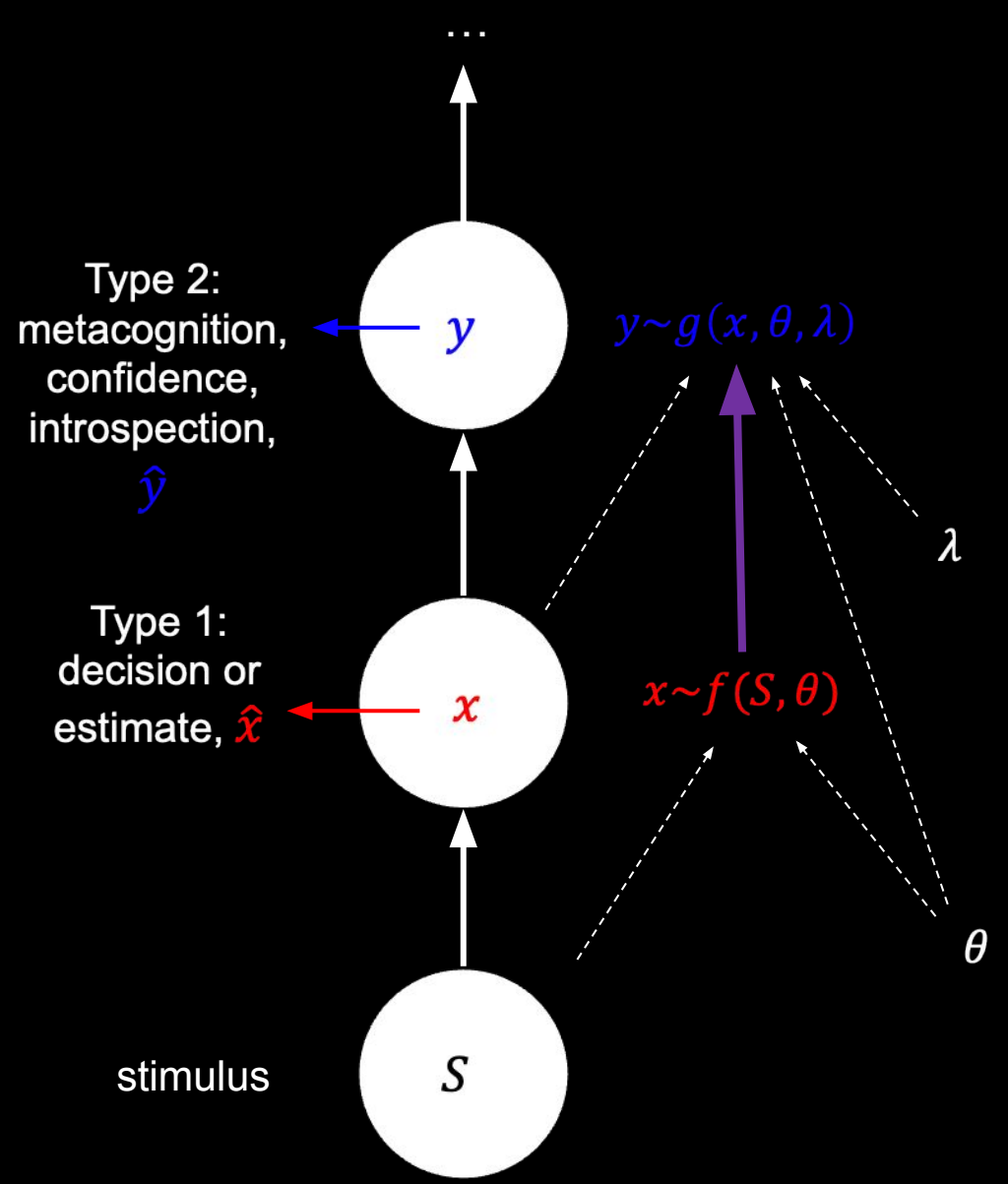
2. $\hat{y}$ and $y \sim g(f(S, \theta), \theta, \lambda) = g(x, \theta, \lambda)$

3. definition of $g(\cdot)$ depends on definition of $f(\cdot)$

building an **ideal observer model** of this system is **really hard**
(lots of ways for it to "go wrong")

type 2 psychophysics

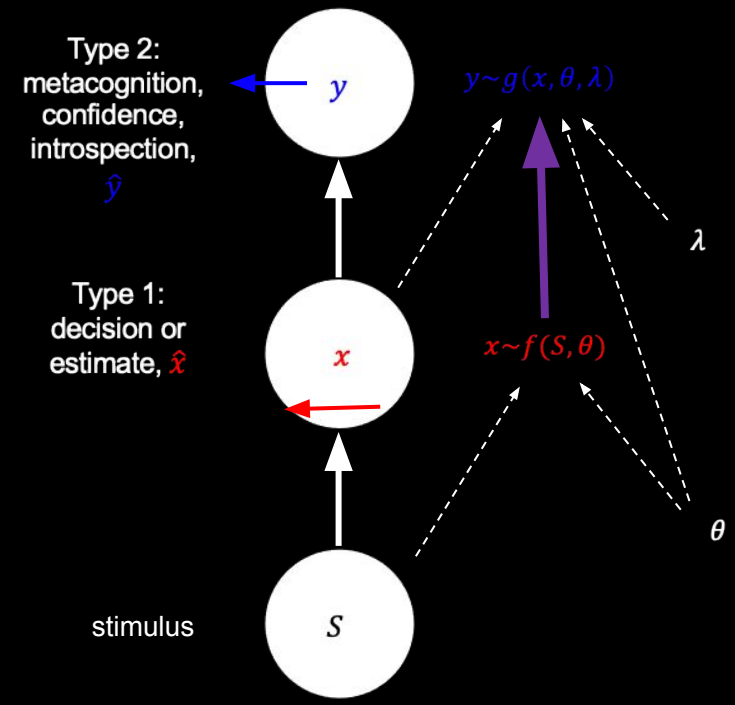
type 1 psychophysics



but if we can…

(Peters, 2022, *Neuro & Biobeh Rev*; Peters, 2024, *psyArxiv*)

Hierarchically-dependent anchors:
1. $\hat{x}$ and $x \sim f(S, \theta)$
2. $\hat{y}$ and $y \sim g(f(S, \theta), \theta, \lambda) = g(x, \theta, \lambda)$
3. definition of $g(\cdot)$ depends on definition of $f(\cdot)$



… we will formalize the study of introspection via

the next generation of psychophysics

factorize inputs | specify functional form(s) | characterizing distributions x & y | specify decision policies | closing the feedback loop

we have a lot of work to do

(Peters, 2022, *Neuro & Biobeh Rev*; Peters, 2024, *psyArxiv*)

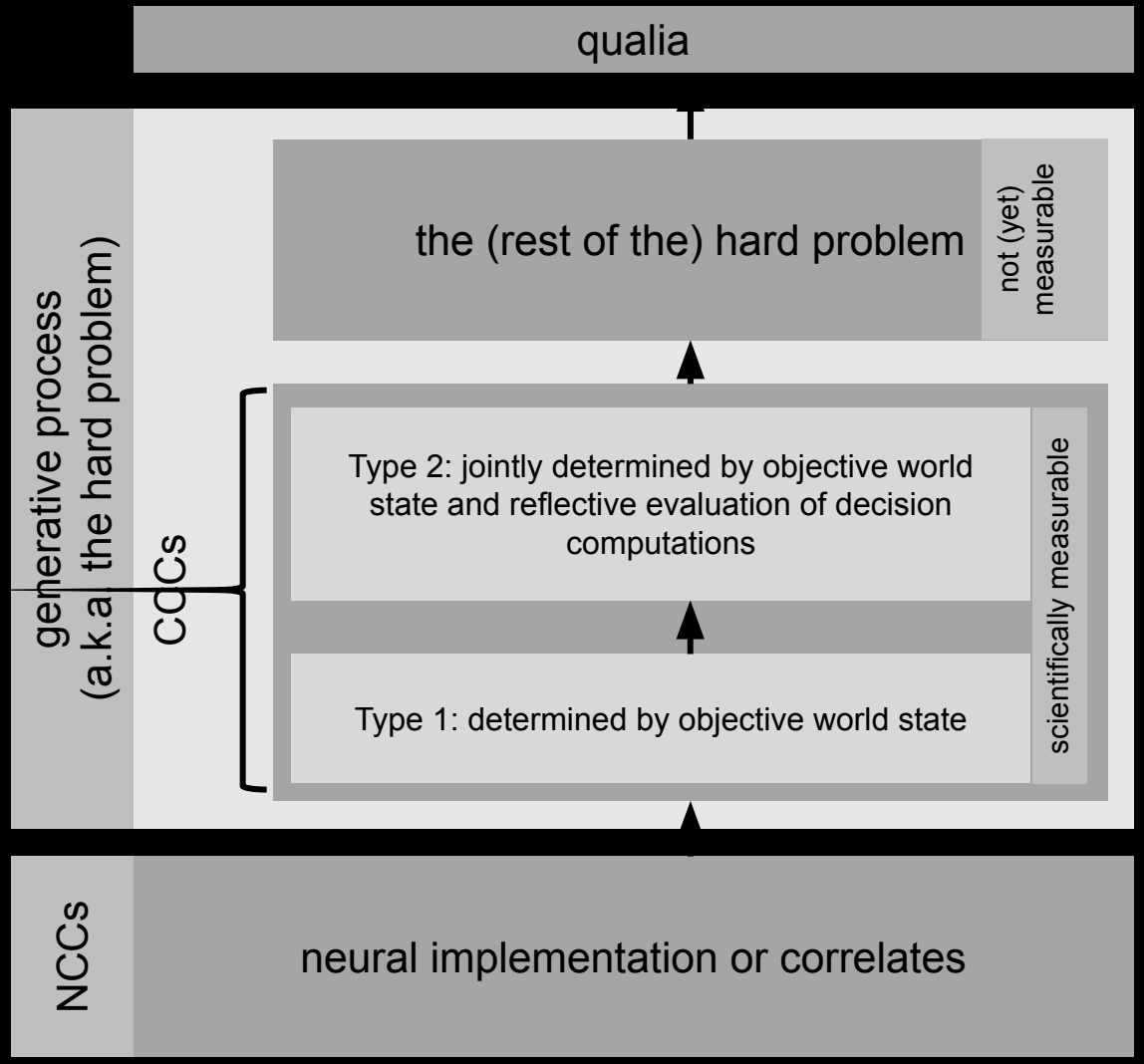
the “M-STEP approach”

metacognition as a step towards explaining phenomenology

(Peters 2022, *Neuro & Biobeh Rev*)

the next generation of psychophysics – introspective/metacognitive psychophysics (including ideal observer models of how it “ought to behave) – may help us understand the functions associated with and facilitated by consciousness, and maybe how those functions – & consciousness itself? – may arise

(Peters in press, *Cerebral Cortex*)



NCCs – Neural Correlates of Consciousness
CCCs – Computational Correlates of Consciousness

you have subjective experiences

introspective/metacognitive psychophysics may help
start to reveal the relevant (neural) computations

Optimal Metacognitive Decision Strategies in Signal Detection Theory

Brian Maniscalco[1*], Lucie Charles[2*], & Megan A. K. Peters[1]

[1] Department of Cognitive Sciences, University of California Irvine, Irvine, CA 92697

[2] Institute of Cognitive Neuroscience, University College London, Alexandra House, 17 Queen Square, London WC1N 3AZ, UK

[*] These authors contributed equally.

Psychonomic Bulletin & Review

A Journal of the Psychonomic Society

in press

shameless plug

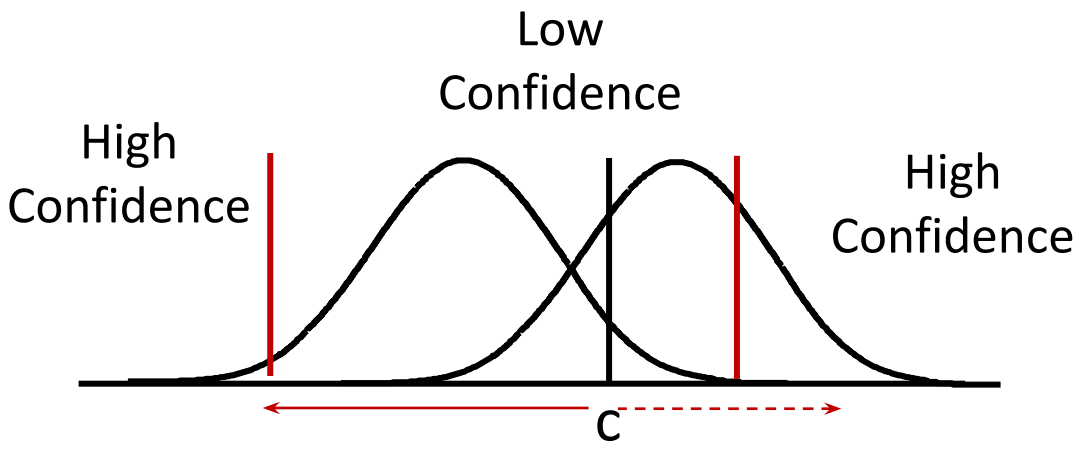
how metacognition "ought to behave"

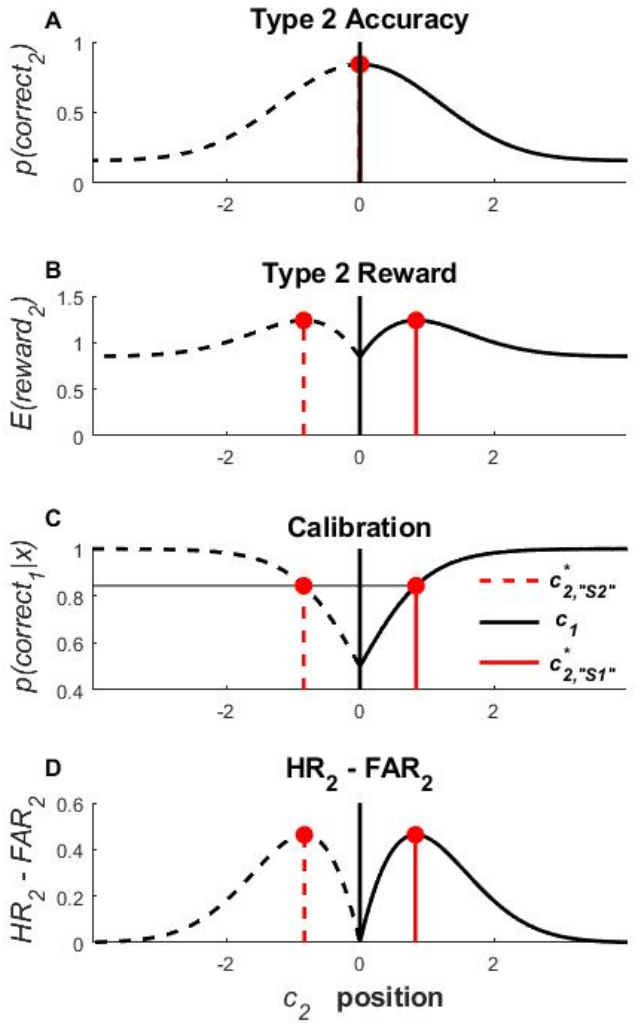
Brian Maniscalco

Lucie Charles

Optimal confidence criterion: where does it go?

how confident “should” you feel from one trial or condition to the next?



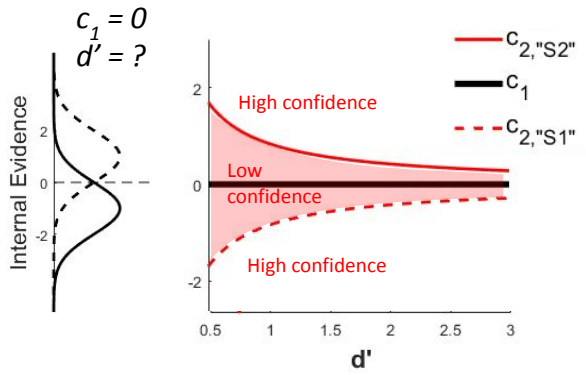


(Maniscalco*, Charles*, & Peters *in press*, *Psychonomic Bull & Rev*)

Optimal confidence criterion: where does it go?

Calibrate confidence threshold

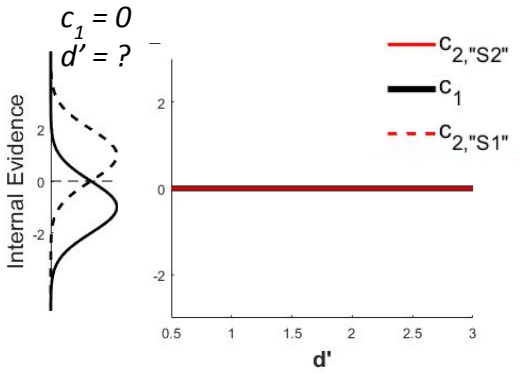
*Respond **high confidence** when you have more than **85% chance** of being correct.*



Maximize Type 2 accuracy

Response	Correct	Incorrect
High Confidence	**Hit_2**	False $Alarm_2$
Low confidence	$Miss_2$	**Correct $Rejection_2$**

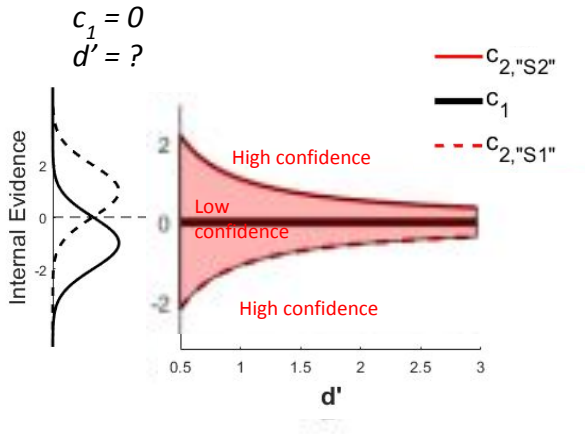
$p_{corr1} * HR_2 + p_{incorr1} * CR_2$



Respond **high confidence** all the time!

Maximize Type2 reward

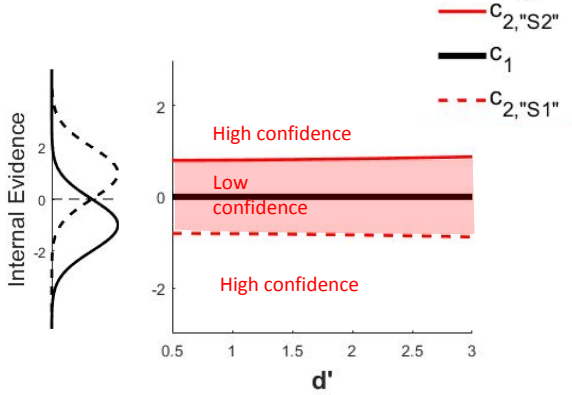
Response	Correct	Incorrect
High Confidence	**+£1**	**£0**
Low confidence	**£0**	**+£5.32**



Maximize Type 2 discriminability

Response	Correct	Incorrect
High Confidence	**Hit_2**	**False $Alarm_2$**
Low confidence	$Miss_2$	Correct $Rejection_2$

$Max(HR_2 - FAR_2)$

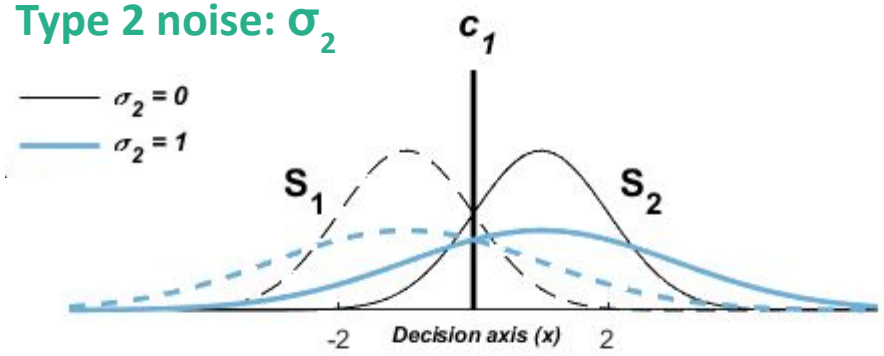


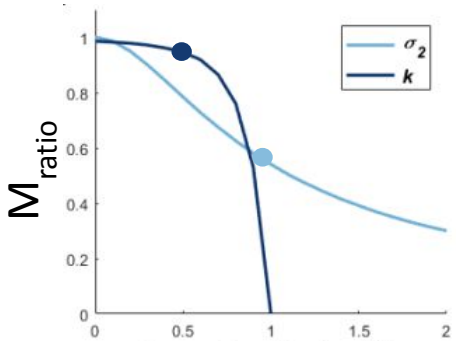
Equivalent to being **calibrated** on actual accuracy

(Maniscalco*, Charles*, & Peters *in press*, *Psychonomic Bull & Rev*)

Suboptimal metacognitive efficiency

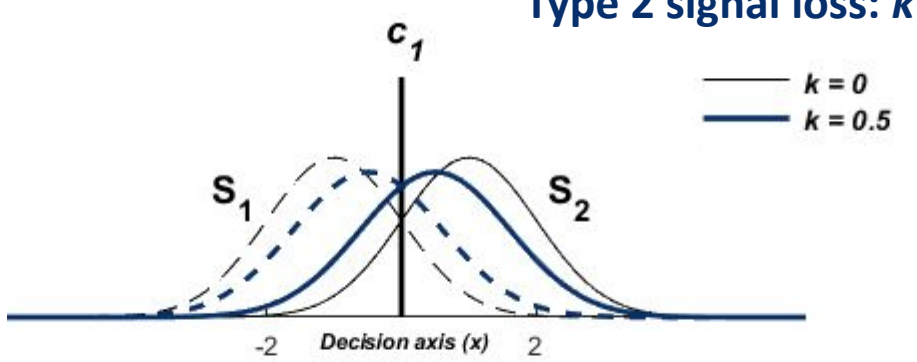
Type 2 noise: σ_2



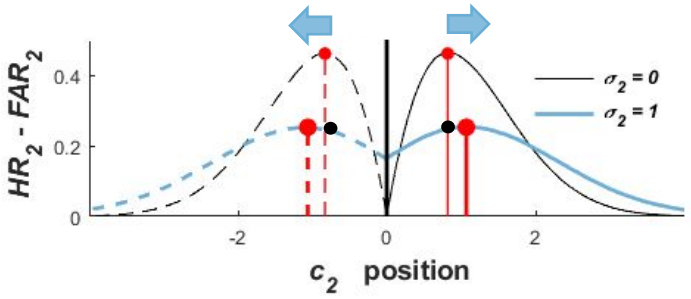


Parameter value
(σ_2 or k)

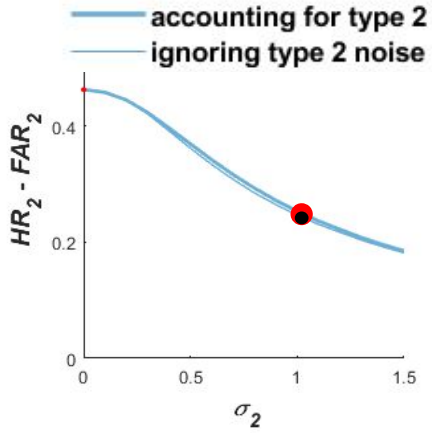
Type 2 signal loss: k

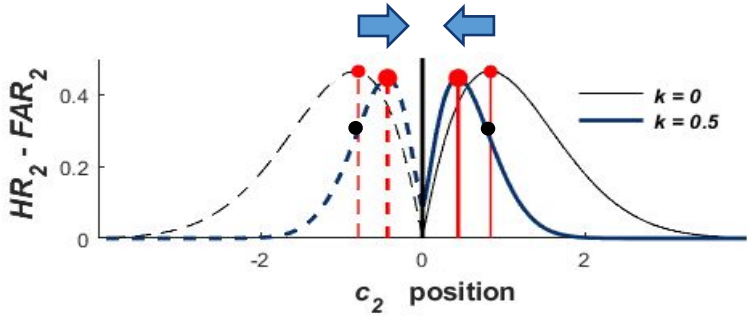


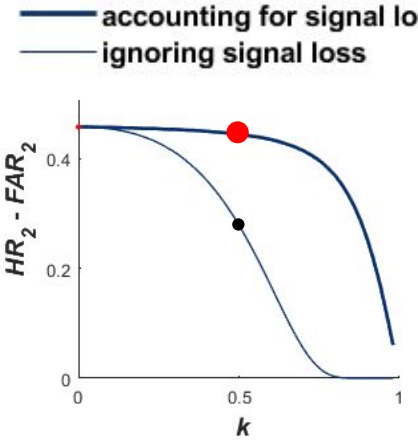
Maximize Type 2 discriminability



Ignoring Type 2 noise might not lead to different outcomes







Ignoring Type 2 signal loss leads to large difference in outcomes

noise signal loss

(Maniscalco*, Charles*, & Peters *in press*, *Psychonomic Bull & Rev*)

all of this does relate to neuroscience!

how does the *brain* compute confidence?

how does the *brain* create phenomenology?

how does the *brain* do introspection?

see also

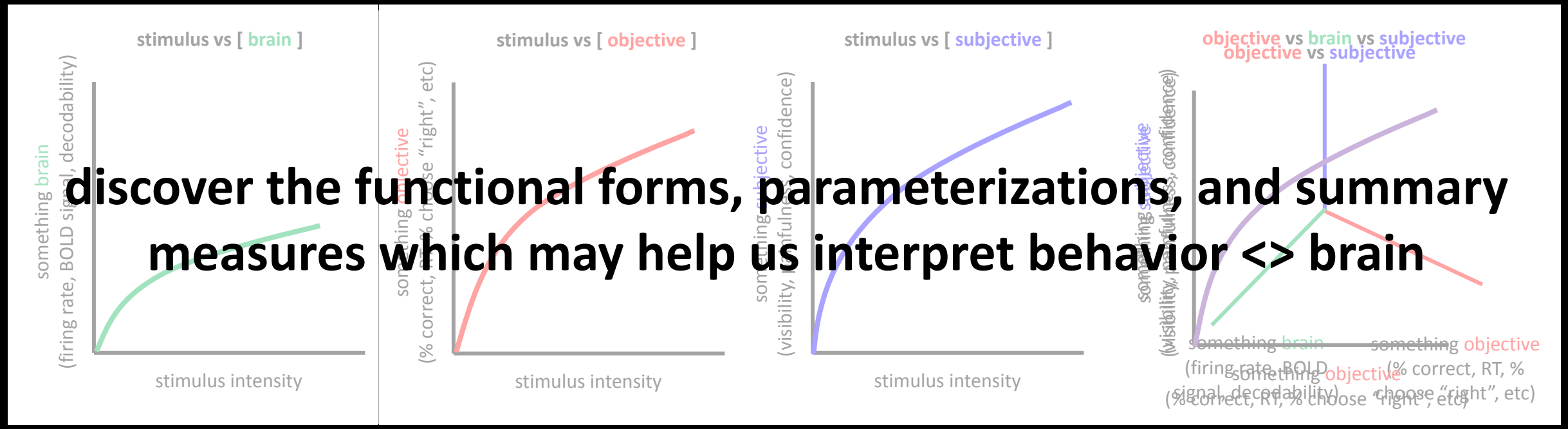
PNAS RESEARCH ARTICLE | PSYCHOLOGICAL AND COGNITIVE SCIENCES OPEN ACCESS

A unified framework for perceived magnitude and discriminability of sensory stimuli

Jingyang Zhou [a,b,1], Lyndon R. Duong [b], and Eero P. Simoncelli [a,b,c,1]

Edited by Roberta Klatzky, Carnegie Mellon University, Pittsburgh, PA; received July 18, 2023; accepted April 25, 2024

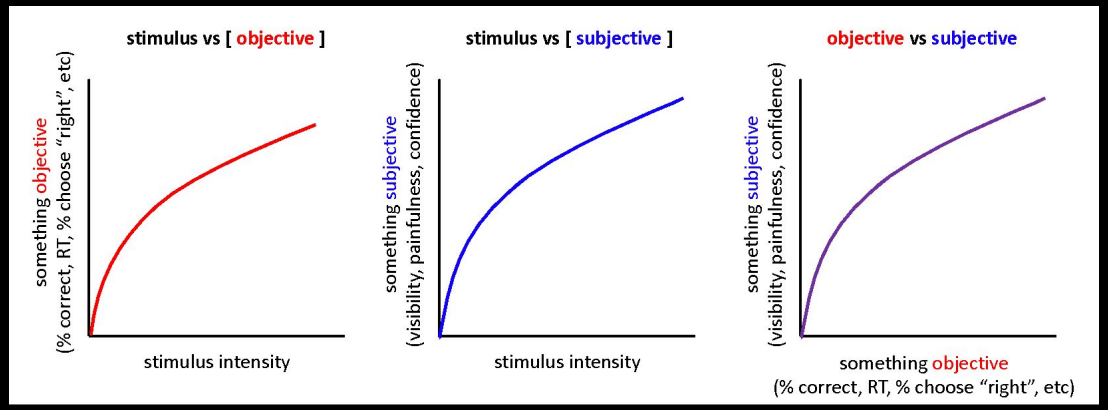
June 10, 2024 | 121 (25) e2312293121 | https://doi.org/10.1073/pnas.2312293121



discover the functional forms, parameterizations, and summary measures which may help us interpret behavior <> brain

do <u>you</u> want to do type 2 psychophysics?

with Brian Maniscalco



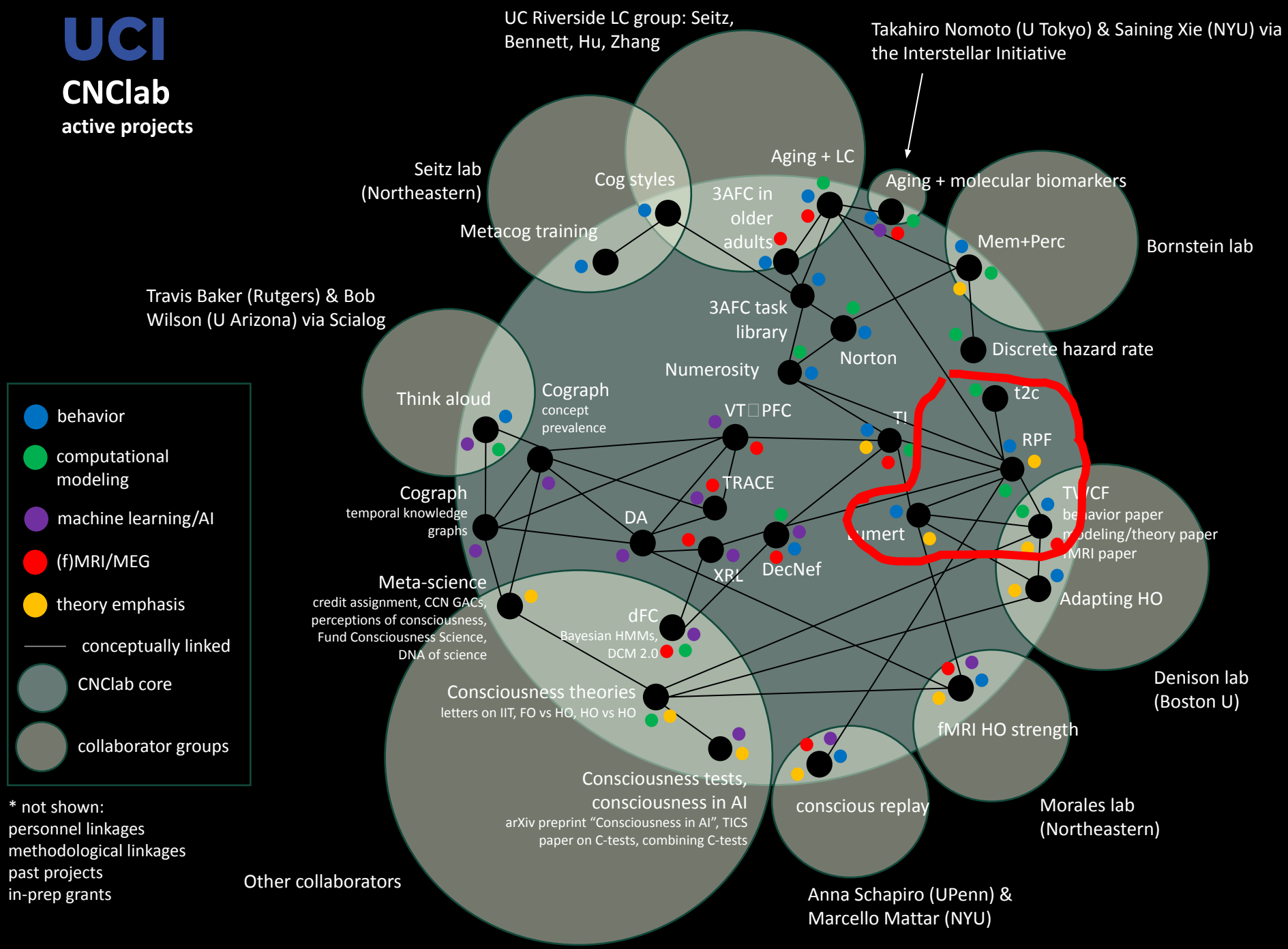
RPF toolbox

https://github.com/CNClaboratory/RPF

UCI

CNClab

active projects



- behavior
- computational modeling
- machine learning/AI
- (f)MRI/MEG
- theory emphasis
- conceptually linked
- CNClab core
- collaborator groups

* not shown:
personnel linkages
methodological linkages
past projects
in-prep grants

other random stuff i think about that somehow isn't on this map:

multisensory integration & cognitive penetrability of it

cognitive penetrability of beliefs in general

core beliefs & models of the world

belief updating based on *subjective* vs *objective* evidence quality

thank you

@meganakpeters

meganakpeters.org

RPF toolbox
https://github.com/CNClaboratory/RPF

UCI University of California, Irvine

Brian Maniscalco **Emil Olsson**

Shaida Abachi | Hojjat Azimi | Nora Bradford | Vanessa Ceja | Andrew Hansen | Ari Khoudary | Mehdi Orouji | **Angela Shen**

Alumni: **Olenka Graham Castaneda** | Kenny Nelson | Nalani Lando | Tammi Tang | Jarrett Winter | Fan Zhang | Isaac Menchaca | Sana Hussain | Kimia Yaghoubi | Yingqi Rong

*including friends of the lab and alumni!

collaborators:
Hakwan Lau | **Brian Odegaard** | Mitsuo Kawato | Cody Cushing | Mouslim Cherkaoui | **Rachel Denison** | **Jorge Morales** | **Lucie Charles** | Aaron Bornstein | Barbara Sarnecka | Mark Steyvers | Konrad Kording | Gunnar Blohm | Paul Schrater | Brad Wyble | Sean Escola | Kathryn Bonnen | Aaron Seitz | Xiaoping Hu | Ilana Bennett | Weiwei Zhang | Bob Wilson | Travis Baker | Michele Guindani | Neuromatch | and so many more

TEMPLETON WORLD CHARITY FOUNDATION

Japan Agency for Medical Research and Development
AMED

CIFAR

The New York Academy of Sciences

NIH

AFOSR
AIR FORCE OFFICE OF SCIENTIFIC RESEARCH

RESEARCH CORPORATION for SCIENCE ADVANCEMENT