Metacognition of visually guided action

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Sensory and sensory-motor integration

- Sensory cue integration behavior often consistent with an ideal Bayesian observer
- Observers take into account prior information and each cue's relative uncertainty
- This is found with single modalities and multisensory stimuli
- (Near) optimality is also seen in sensory-motor tasks, combining uncertain sensory and prior information to guide motor action
- Motor behavior also optimally combines uncertainty in movement with outcome costs and benefits

Metajudgments: Sensory and motor confidence

- We can also judge the quality of our decisions and actions
- This is most often studied with perceptual decisions
- In both perceptual decisions and sensory-motor contexts, confidence involves information integration

Perceptual metacognition

- Awareness vs. performance
- Mainly retrospective
- Typically 2AFC tasks
- Confidence as an estimate of probability correct or other subjective sense of the correctness of a perceptual decision
- Leads to confidence metrics such as meta-*d'*
- May involve some motor awareness, e.g., responding "low confidence" after a Type-1 response lapse

Metacognition for action

- Motor awareness vs. performance vs. agency
- Both prospective and retrospective information available
- Typically continuous tasks (e.g., reaching toward a target, tracking)
- Motor awareness and planning can include knowledge of one's motor uncertainty, which can serve as a prospective cue for confidence in an action

Putting it all together: Sensorimotor confidence

- Allows for more natural, real-world tasks
- Must comprise all three elements: Perception, action and goal
- Motor awareness, affordance, etc. can act as prospective cues. Errors can arise from any combination of sensory noise, motor error or incorrect goal.
- Motor awareness may or may not be essential for such judgments.

Integration of prospective and retrospective information in sensory-motor confidence

Marissa Fassold

Shannon Locke

Fassold, Locke & Landy, *PLoS Comp. Biol.*, in press

Temporally Distinct Cues

Prospective Cues - available prior to the action

- Sensory information
- Prior experience with task
- Knowledge of motor noise

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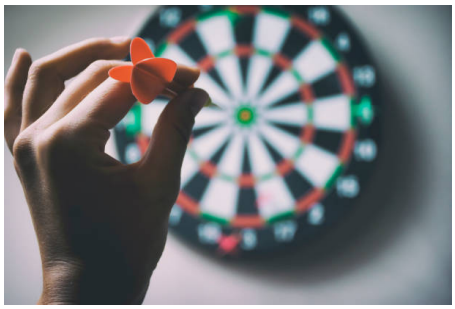
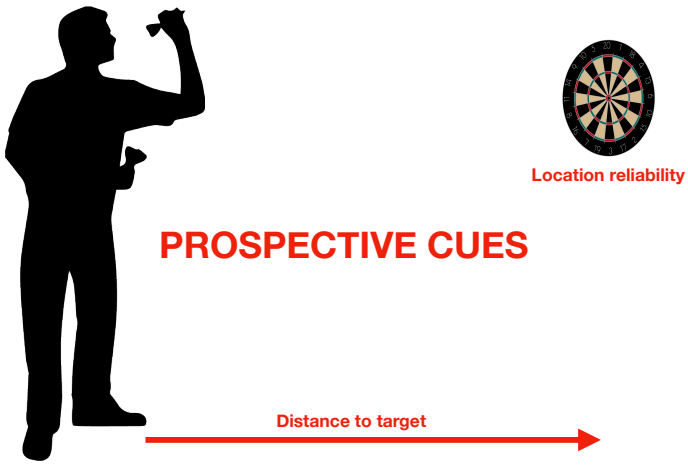
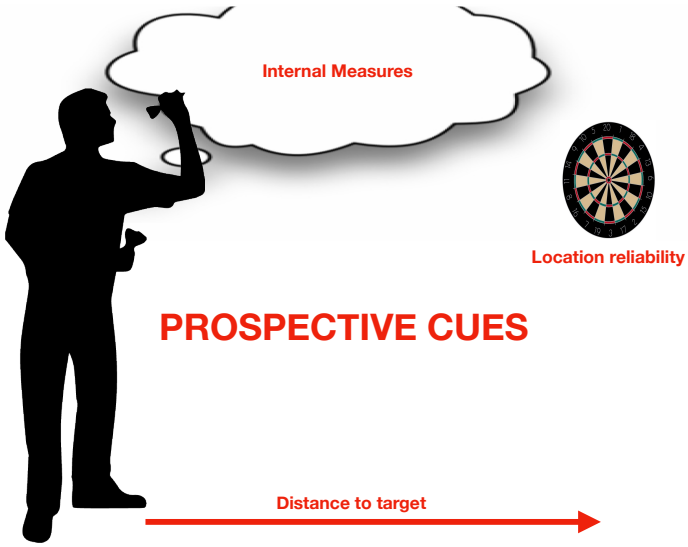
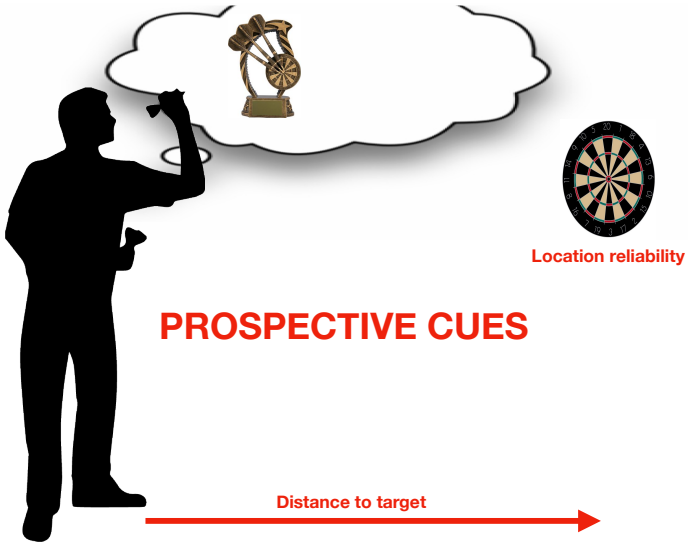
Retrospective Cues - depend on information available after the action and specific to the action itself

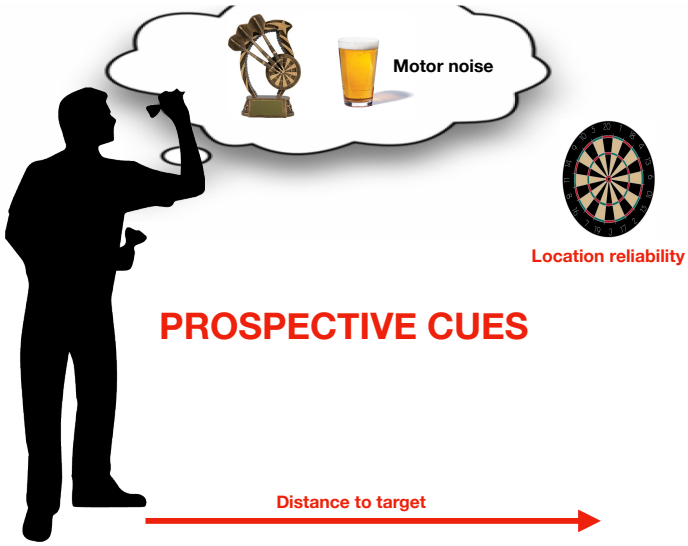
- Proprioception
- Knowledge of proprioceptive noise
- Visual feedback (when available)



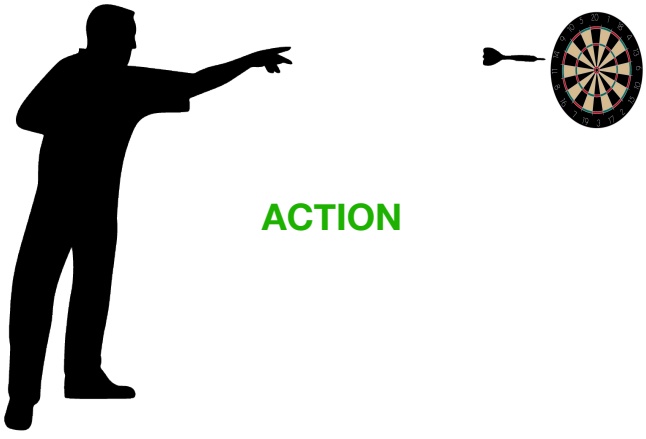

Location reliability
PROSPECTIVE CUES
Distance to target

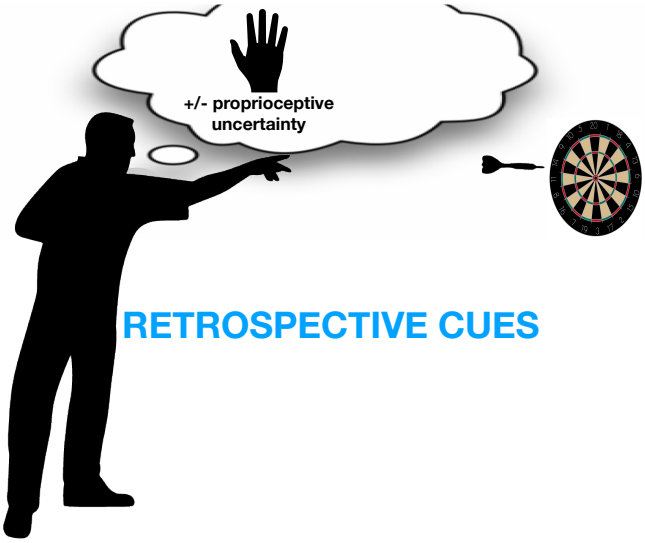

Internal Measures
Location reliability
PROSPECTIVE CUES
Distance to target


Location reliability
PROSPECTIVE CUES
Distance to target

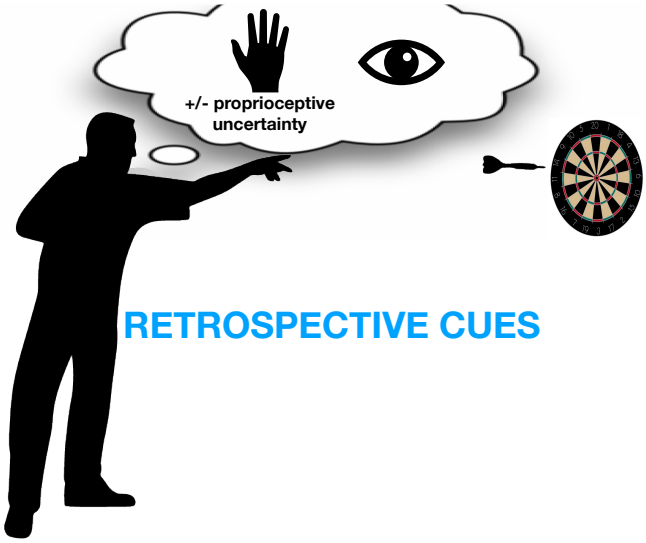

Motor noise
Location reliability
PROSPECTIVE CUES
Distance to target


ACTION

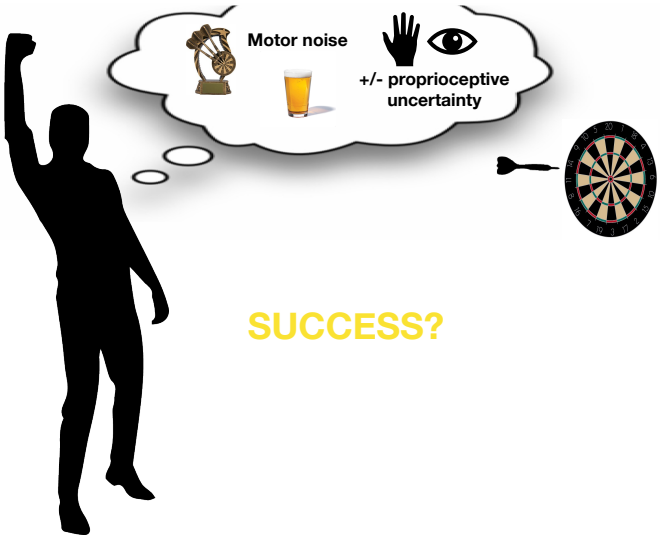

ACTION



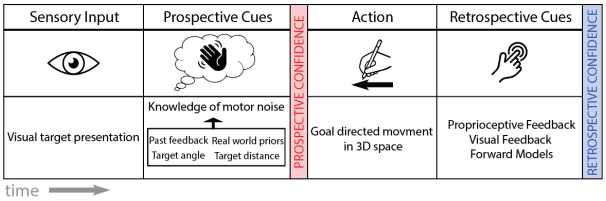
RETROSPECTIVE CUES



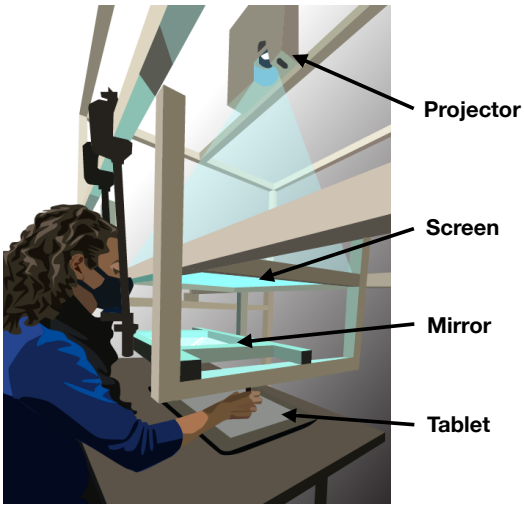
RETROSPECTIVE CUES



SUCCESS?



- How do the cues at these two time points contribute to the final sensorimotor confidence judgment?
- Are they always incorporated together or do observers depend only on one or the other set of cues?



Motor Awareness Task

How well can you estimate the location of your hand in space?

Purpose: To independently measure the participant's proprioceptive noise.

Motor Awareness Task

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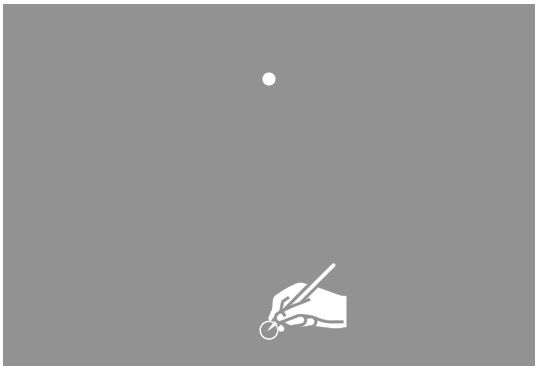
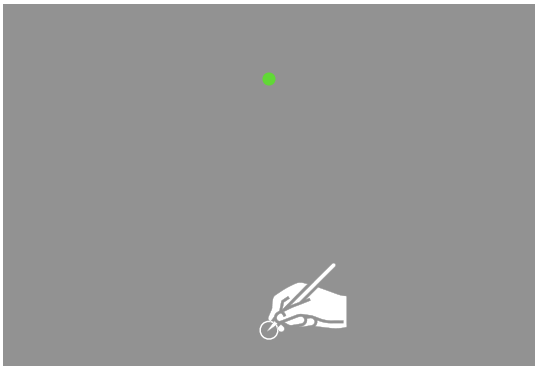


Motor Awareness Task



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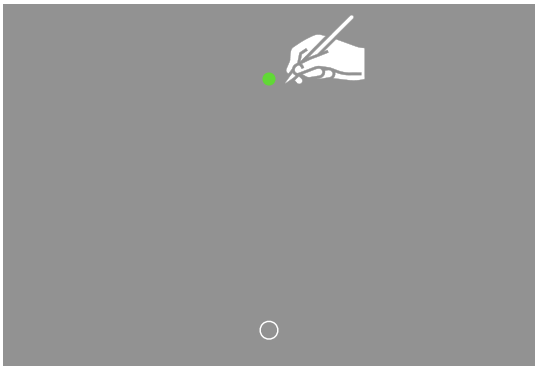

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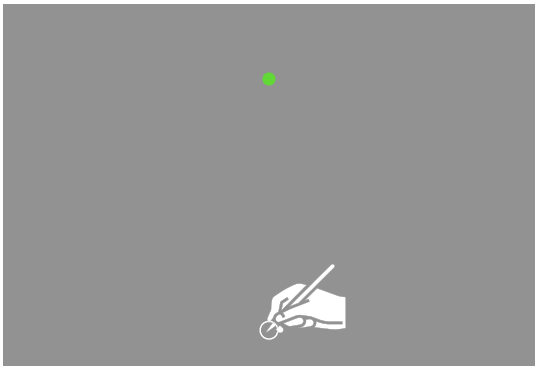

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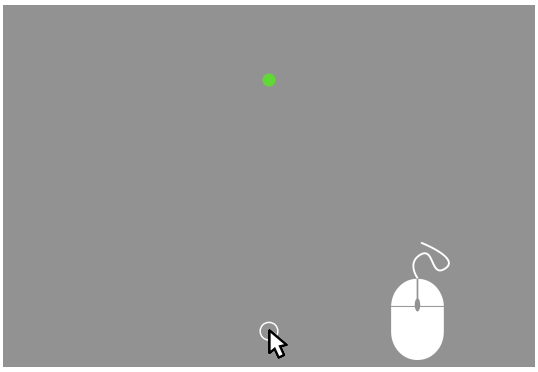

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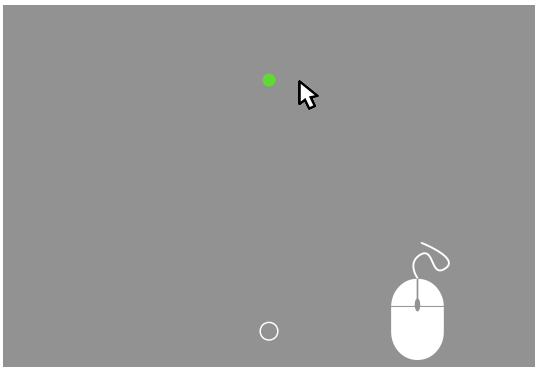
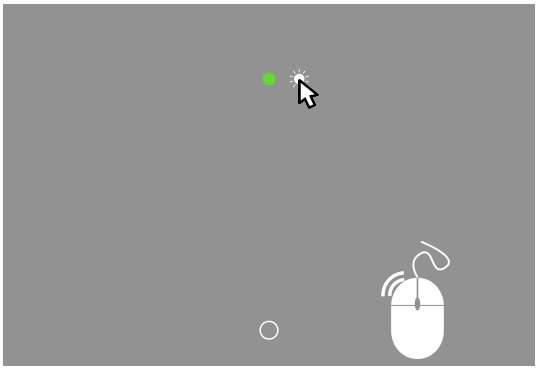


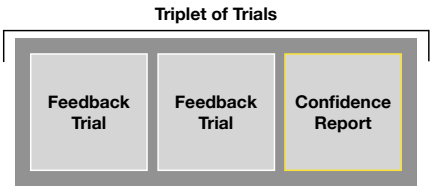
Motor Awareness Task



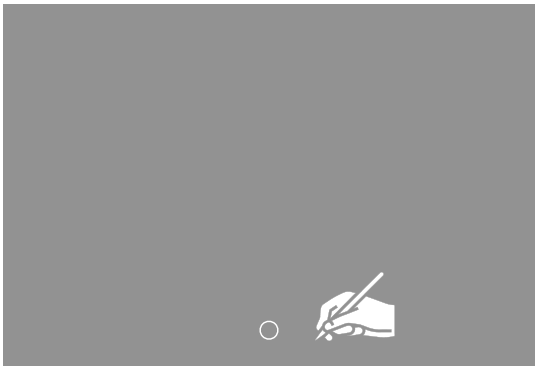
Confidence-Judgment Experiment

Task: Report confidence on unseen reaches to a visually cued target location.

Endpoint Feedback: Presented only on the two trials prior to each confidence judgement.



Experimental Paradigm



Experimental Paradigm

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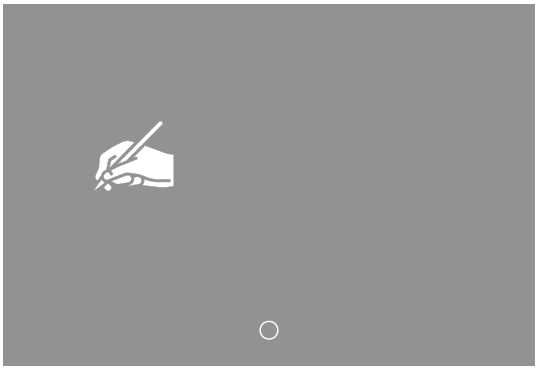

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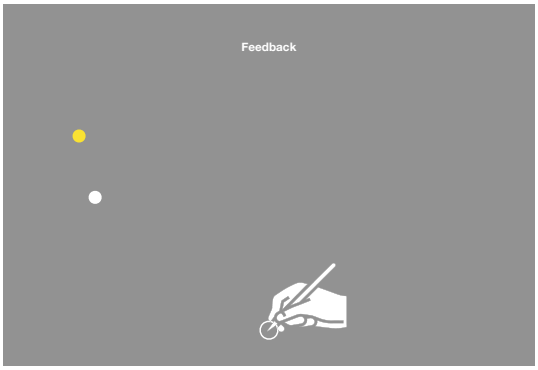

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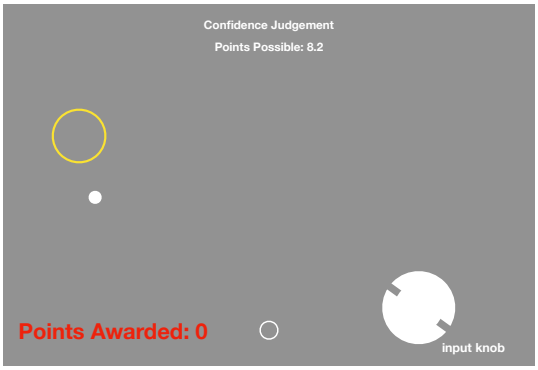

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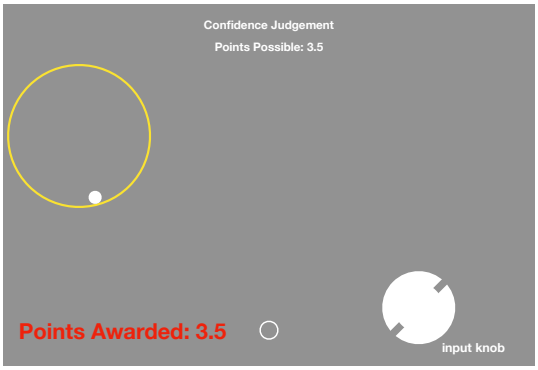
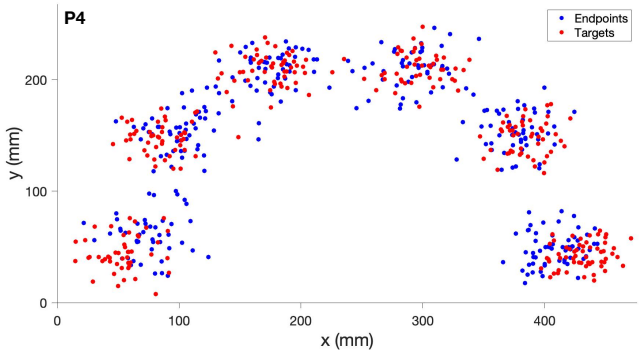
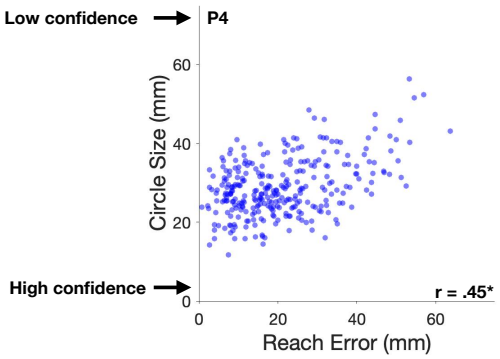


Behavioral Results

Endpoints on Tablet



Confidence Performance Correlation



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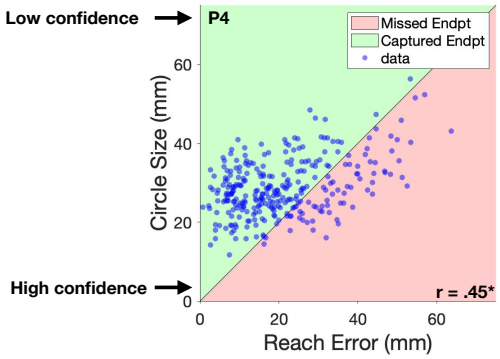

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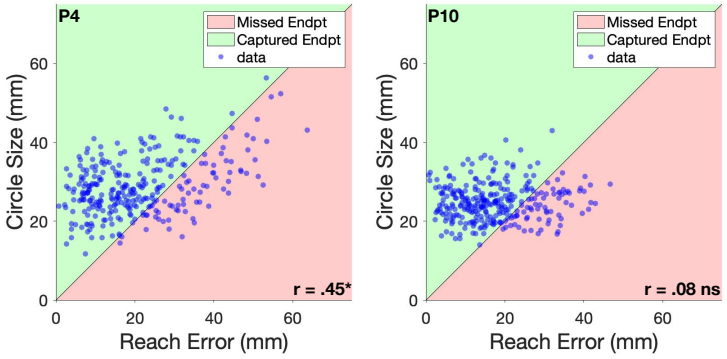
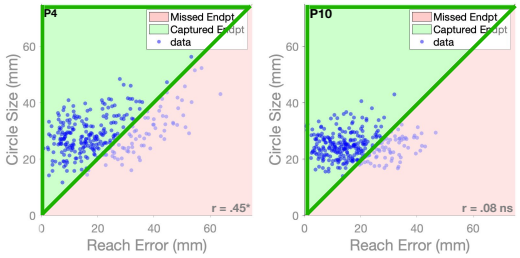


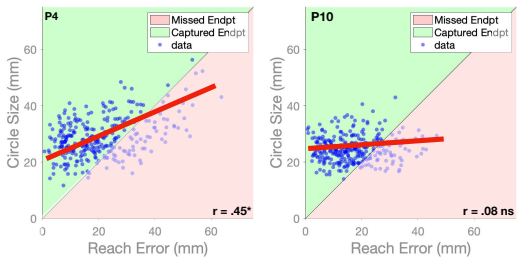
Confidence Performance Correlation

- Participants capture the majority of their endpoints to successfully earn points



Confidence Performance Correlation

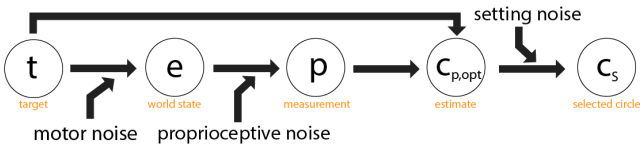
- Participants capture the majority of their endpoints to successfully earn points
- Some participants' confidence reports significantly correlated with performance, while others' are not



MODEL PARAMETERS

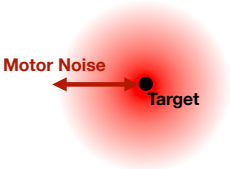
MODELS	Prospective Cues	Retrospective Cues	Setting Noise
Ideal Observer	✓	✓	✓
Retrospective Observer	✗	✓	✓
Prospective Observer	✓	✗	✓

Generative Model



Ideal Observer Model

Ideal Observer Model



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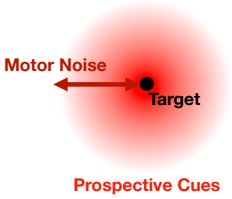

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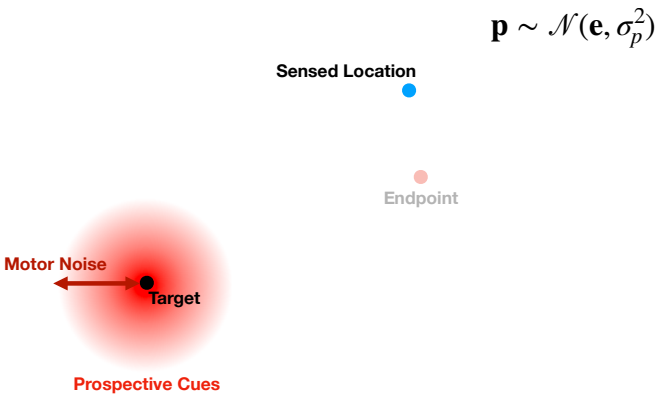

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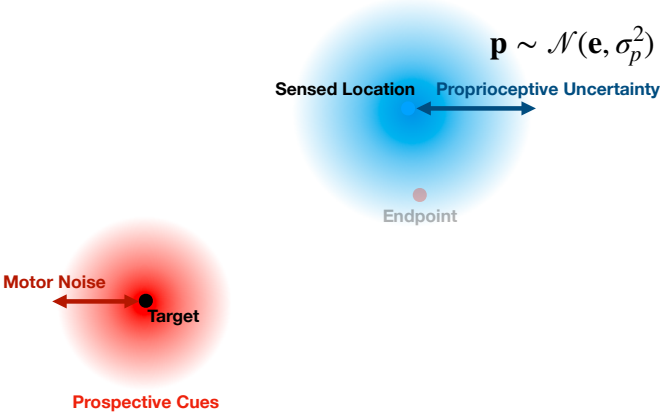

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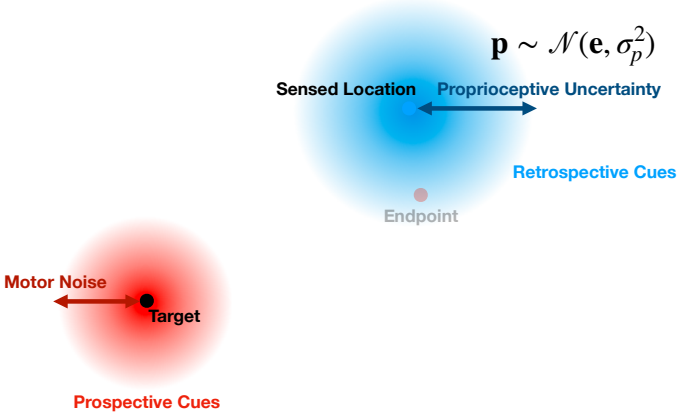

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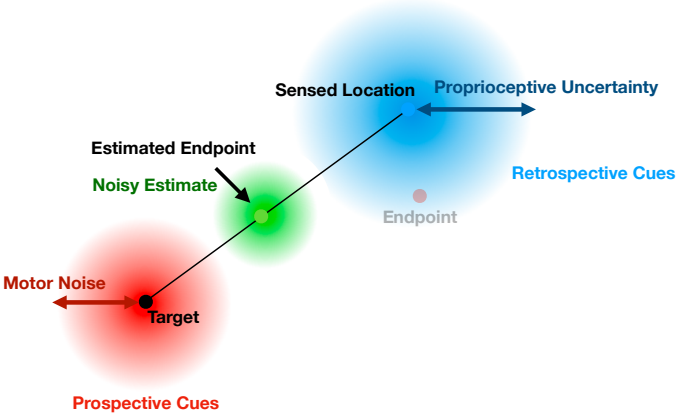

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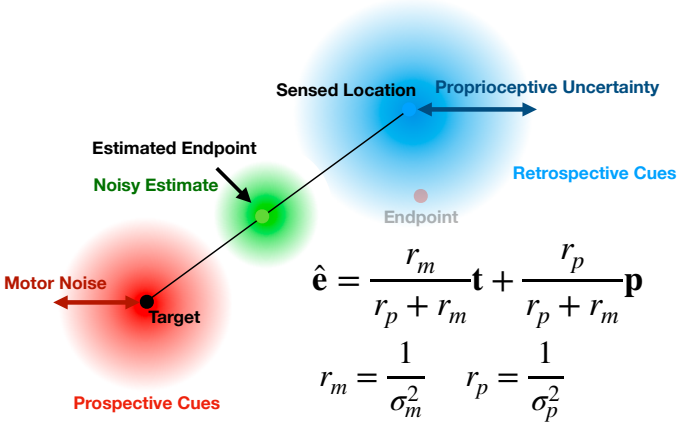

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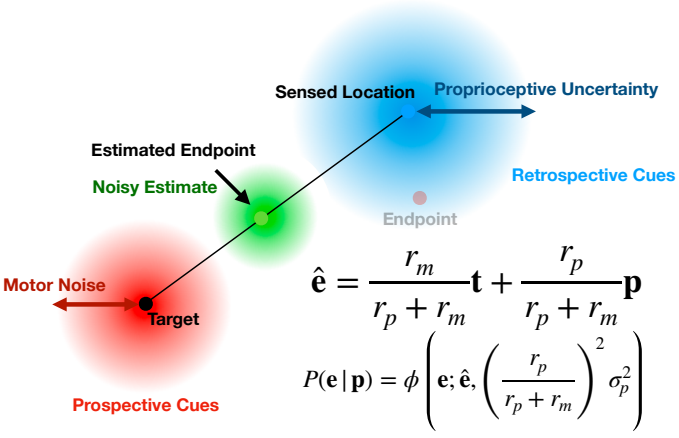

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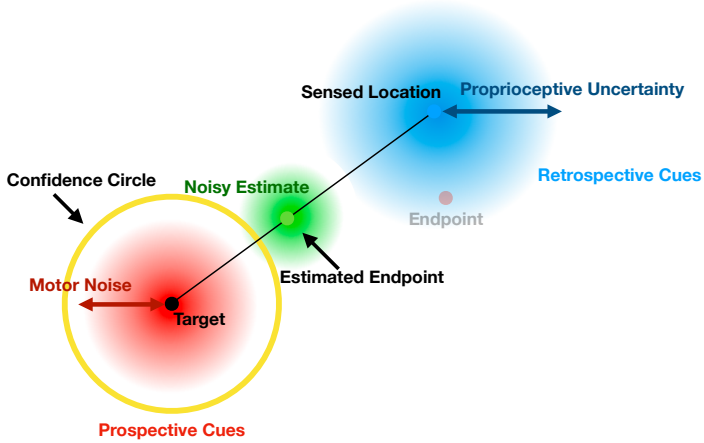


Ideal Observer Model

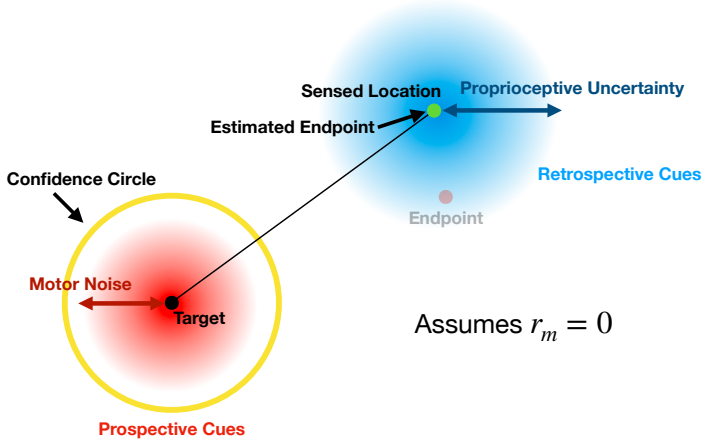
$$P(\mathbf{e}\,|\,\mathbf{p}) = \phi\left(\mathbf{e};\hat{\mathbf{e}},\left(\frac{r_p}{r_p+r_m}\right)^2\sigma_p^2\right)$$

$$EG(s_c\,|\,\mathbf{p}) = f(s_c)\iint_{C(\mathbf{t},s_c)} p(\mathbf{e}=(x,y)\,|\,\mathbf{p})dxdy$$

$$c_{s,opt} = \arg\max_{c_s} EG(s_c\,|\,\mathbf{p})$$

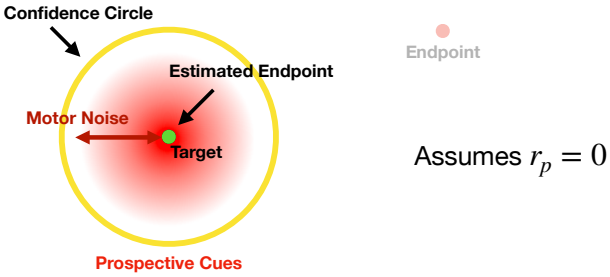
$$c_s \sim \mathcal{N}(c_{s,opt},\sigma_s^2)$$

Retrospective Observer Model



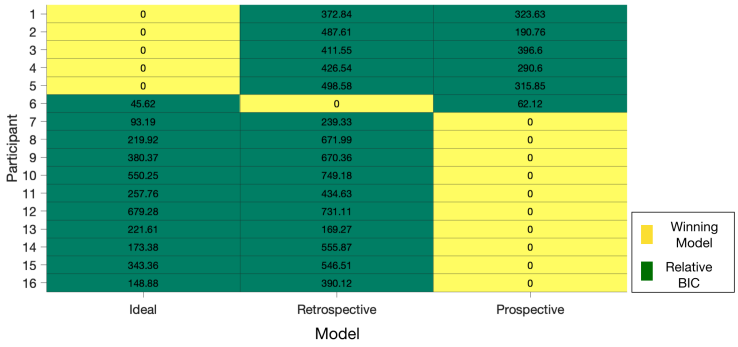
Assumes $r_m = 0$

Prospective Observer Model



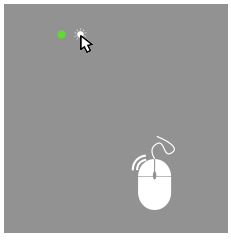
Assumes $r_p = 0$

BIC Model Comparison

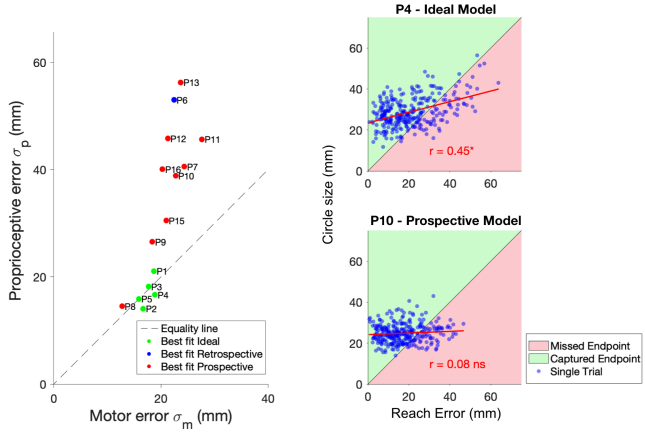


Summary of Model Fits

- Observers can use proprioception when prompted
- But, proprioceptive information is not always used when making a sensorimotor confidence judgment



Best Fit Model Parameters



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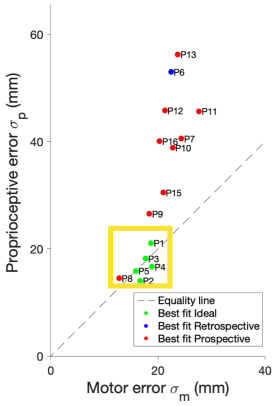
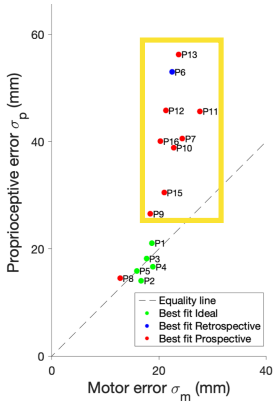


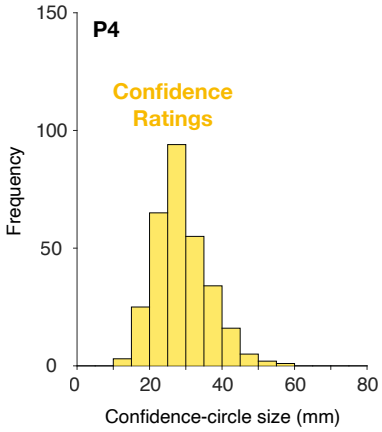
Proprioceptive information is used during confidence judgment when proprioceptive uncertainty is low

Best Fit Model Parameters



Proprioception is not used during confidence judgment when uncertainty is high

Model Predictions of Confidence



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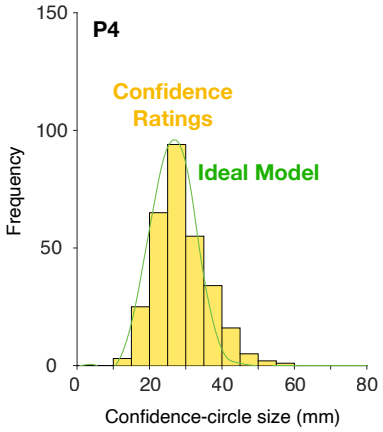

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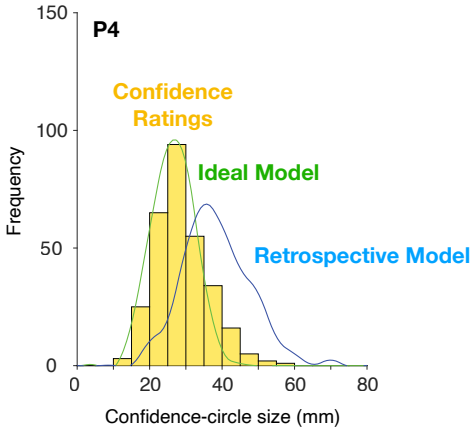

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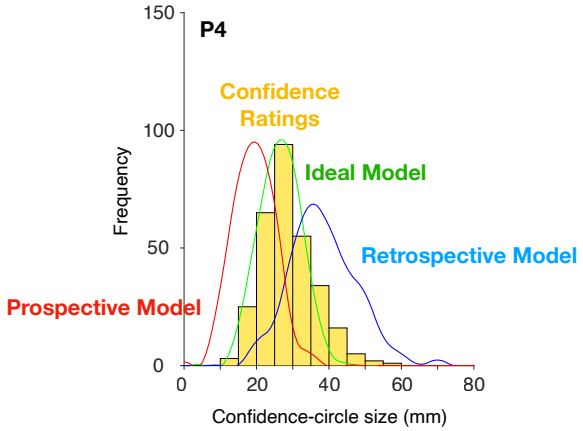
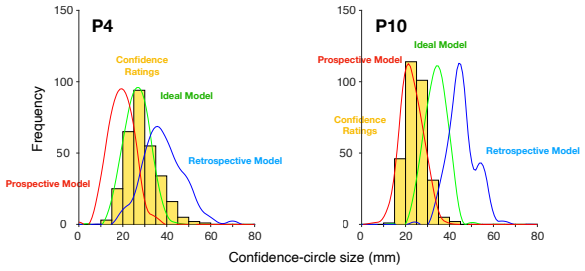
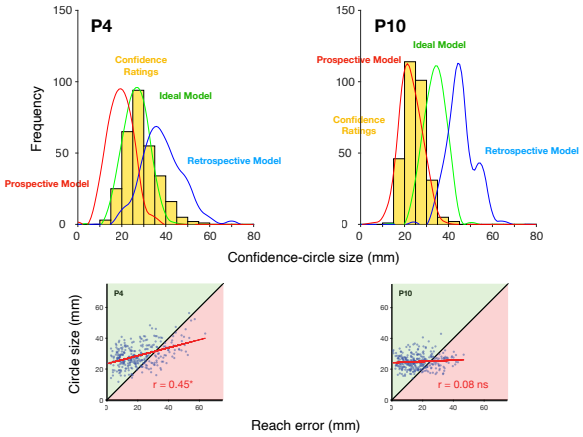
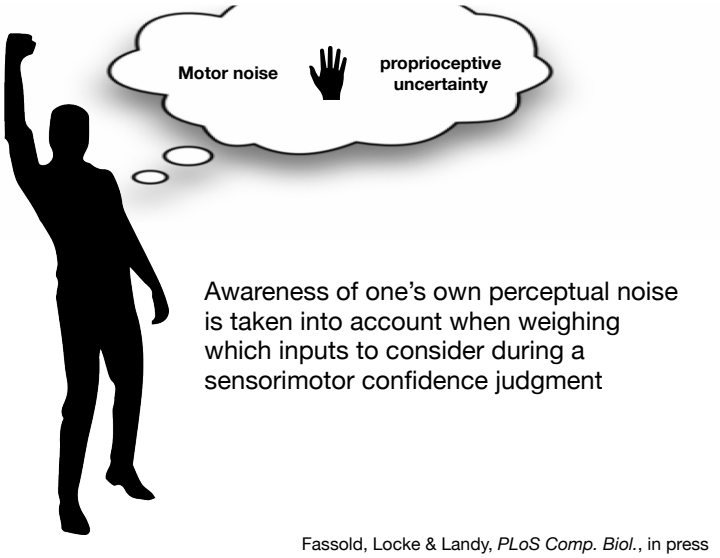


Model Predictions of Confidence



Model Predictions of Confidence





Awareness of one's own perceptual noise is taken into account when weighing which inputs to consider during a sensorimotor confidence judgment

Fassold, Locke & Landy, *PLoS Comp. Biol.*, in press

Future plans and ideas

- Look at the dynamics of evidence and of confidence formation
- Do so with possible ongoing decisions that logically depend on confidence (e.g., "scoping")
- Do so in contexts in which motor uncertainty varies (e.g., visuomotor adaptation)

Thank you!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