

Coordinate Transforms Mediating Tactile Motion Representations with the Hand

Third-year Lunch Talk

Brain and Cognitive Sciences Department

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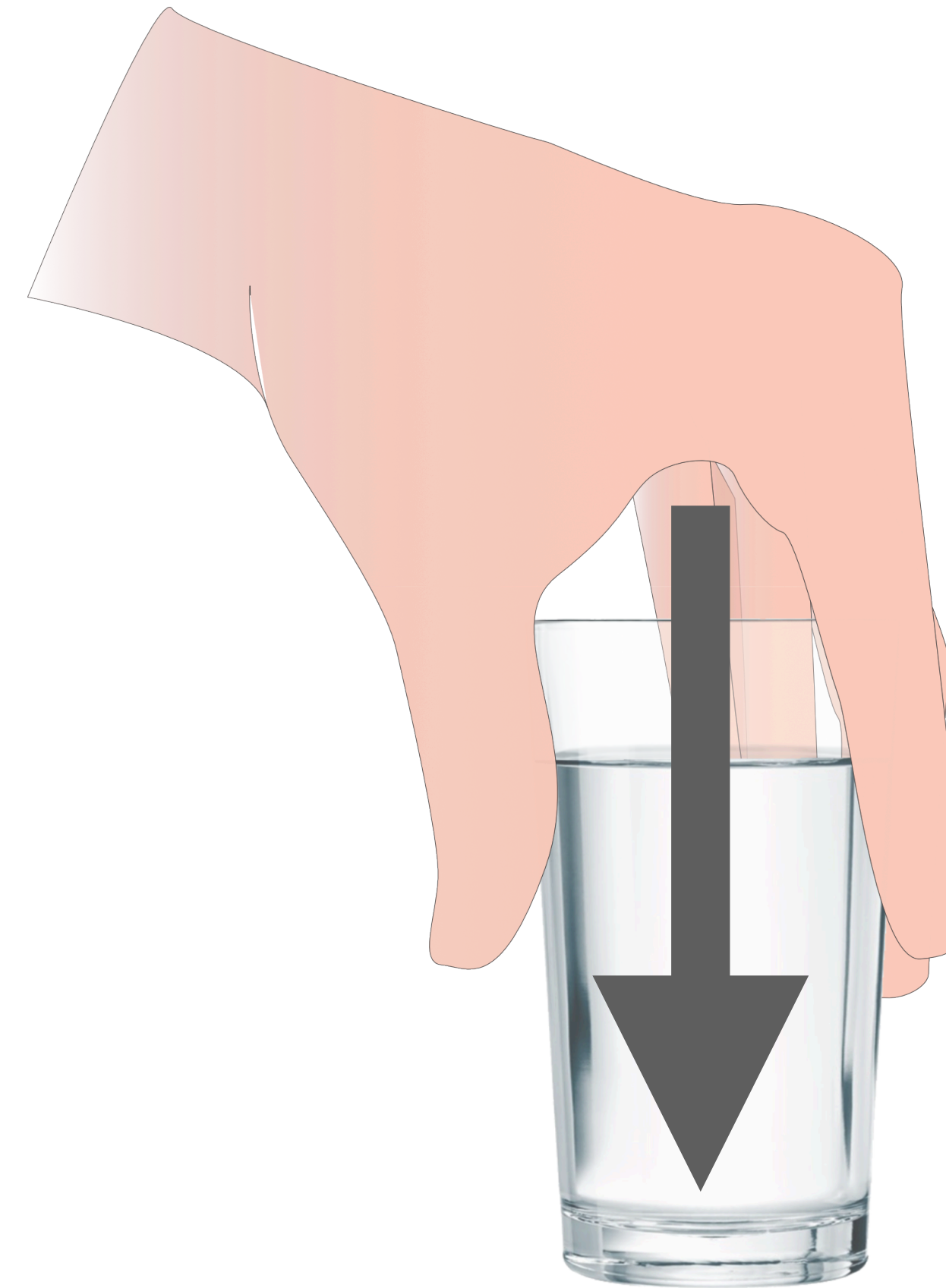
PI: Manuel Gomez-Ramirez

March 23rd, 2022

Is the object moving downwards or towards the palm?

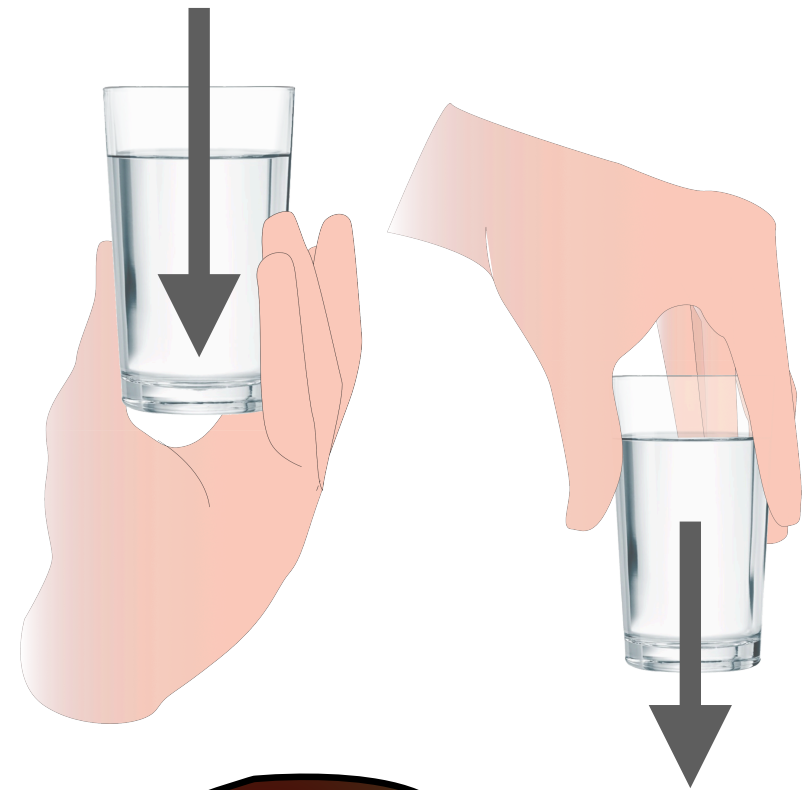


Downwards
Towards the palm



Downwards
Away from the palm

Is the object moving downwards or towards the palm?



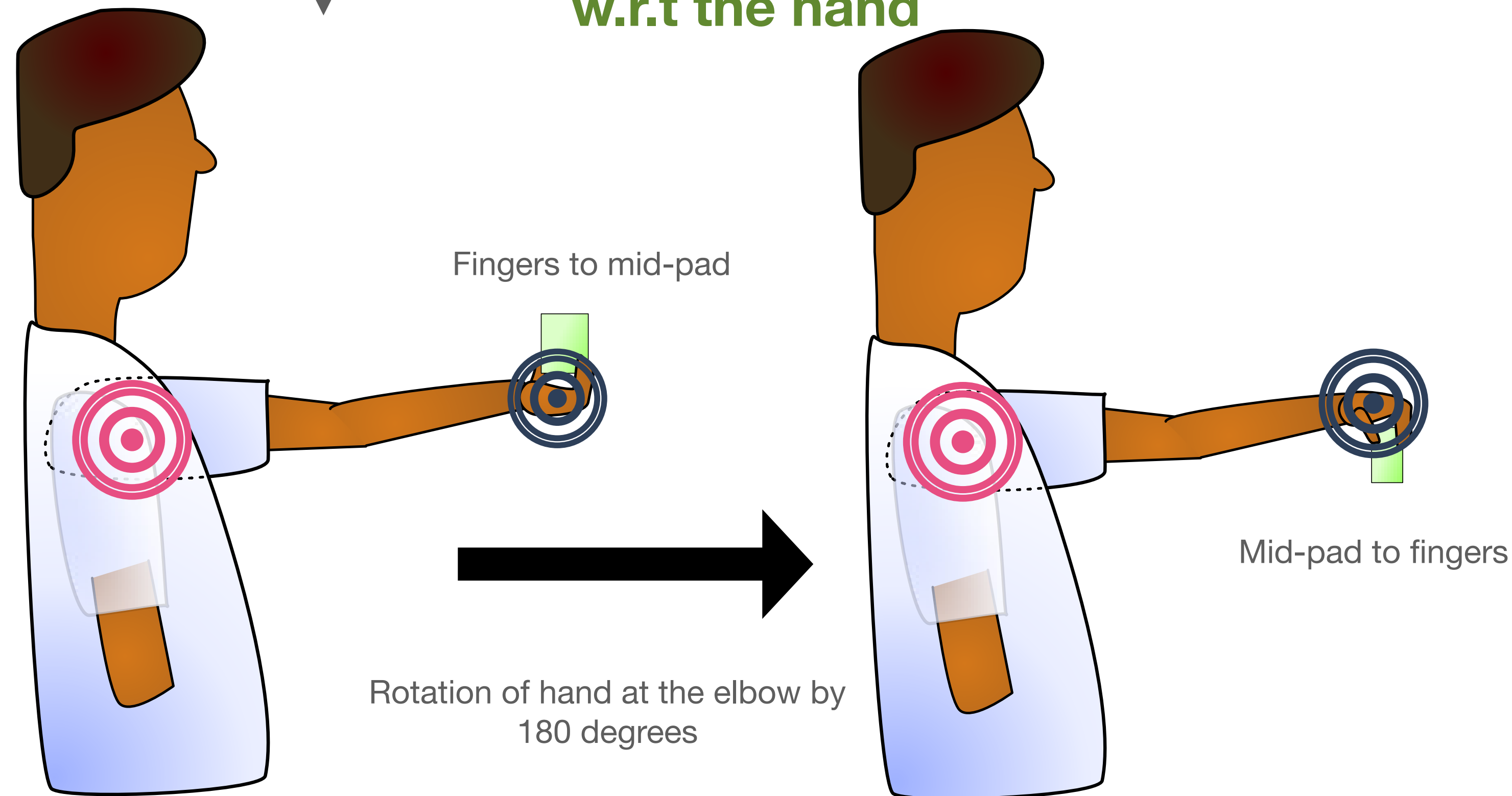
What changes between the two cases?

The posture of the hand

Motion direction on the fingers w.r.t the hand

= Proprioceptive state of the arm

= Cutaneous motion information

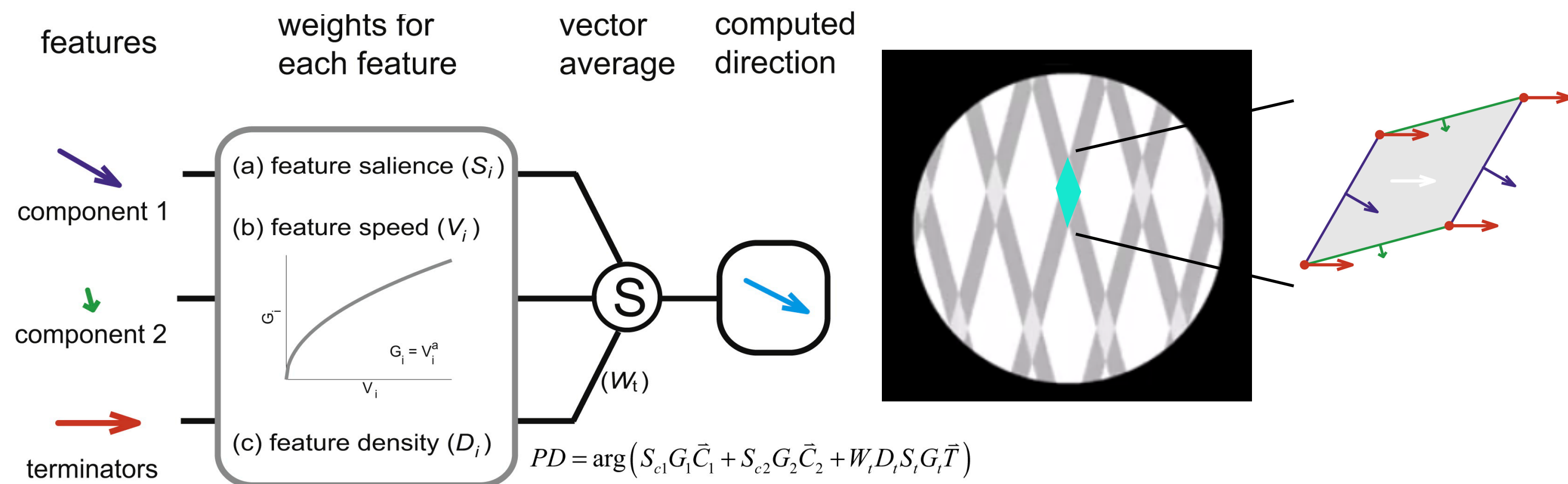


Motion in center-of-the-body reference frame stays the same

Motion in hand reference frame changes

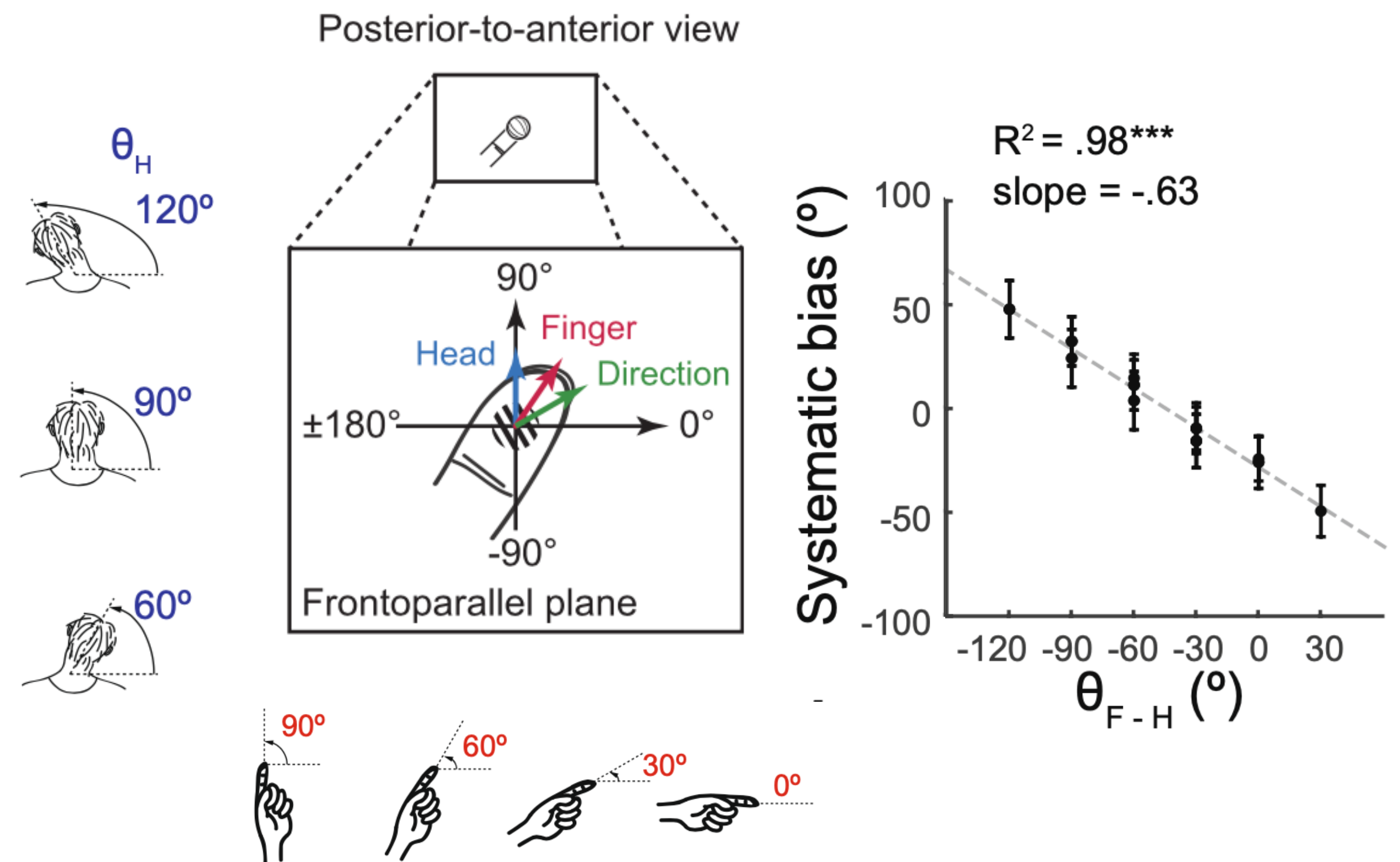
Analogous motion integration mechanisms in vision and tactile domains

- Local tactile motion signals are pooled together in **Area 1** (Analogous to MT for visual stimuli)
- Weighted vector average of edge and terminator directions
- **Tactile motion tuning function studied with the hand in a fixed posture**



Proprioceptive state biases tactile motion report

- Proprioception introduces systematic biases in tactile motion perception
- **No explicit reference frame instructed**
- **No theoretical framework for explaining the interaction of posture and tactile motion cues.**



Research questions of interest

Can humans flexibly perceive tactile motion in different proprioceptive states and reference frames?

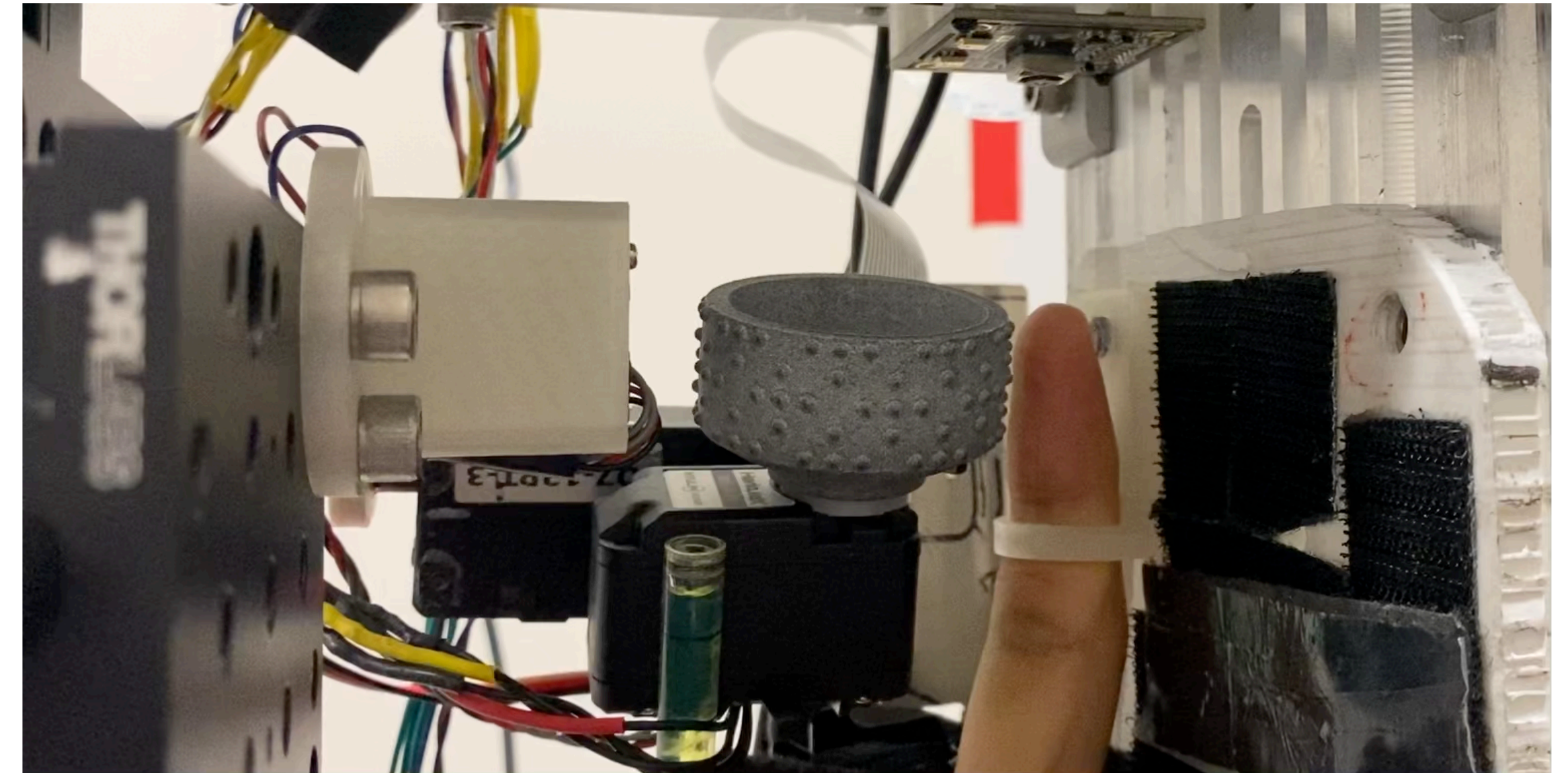
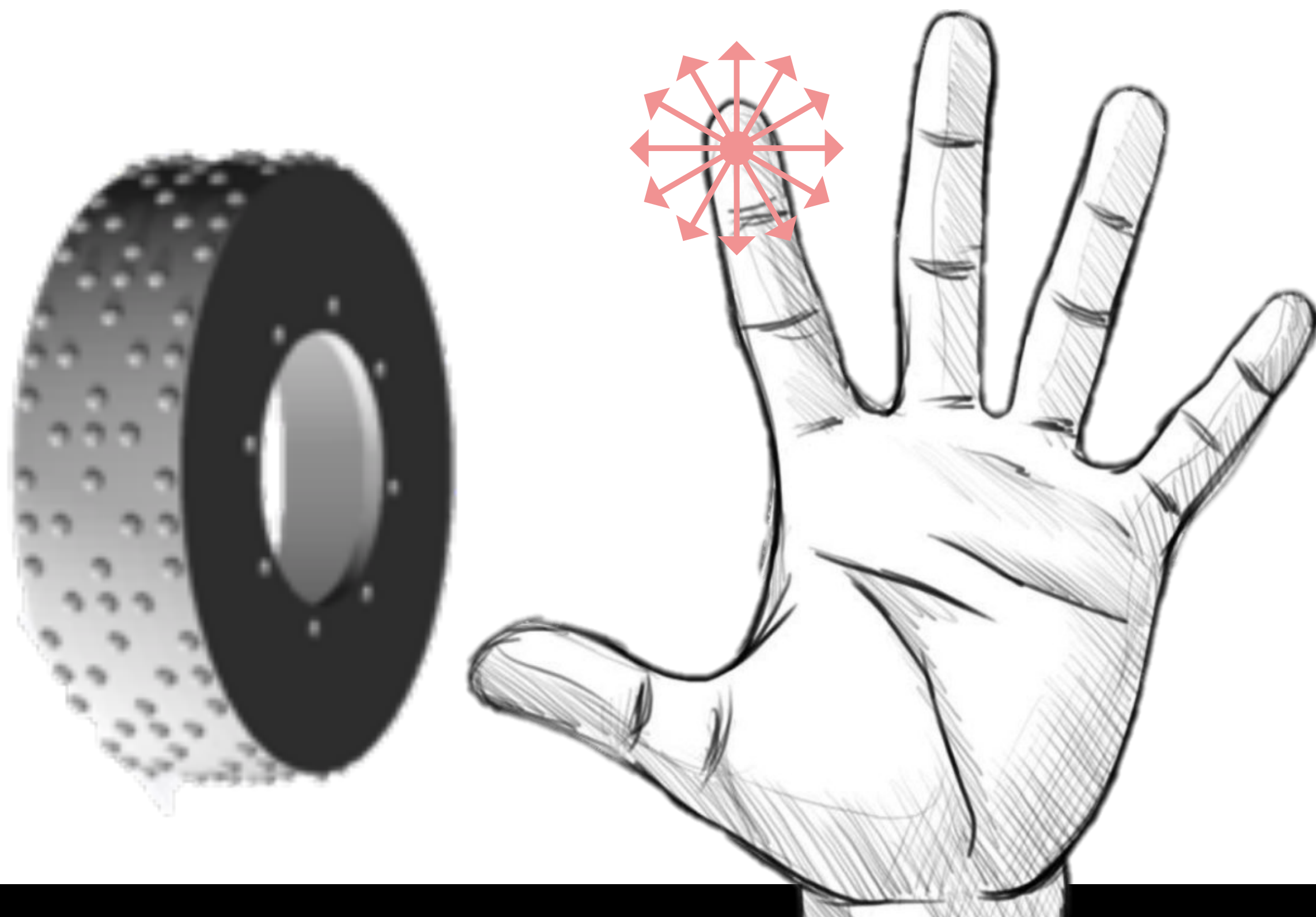
Develop a generalizable theoretical framework that explains human behavioral report.

Experiment Design: Stimulus Properties

Dot Motion Stimulus

Direction: 0-360°, steps of 30°

Point of Stimulation: Digit 2



Experiment Design: 2-AFC Motion Direction Discrimination

Two reference frames: Head-Centric and Hand-Centric

Two-Alternate Force Choice Motion Direction discrimination

LEFT vs RIGHT

w.r.t the center of the body



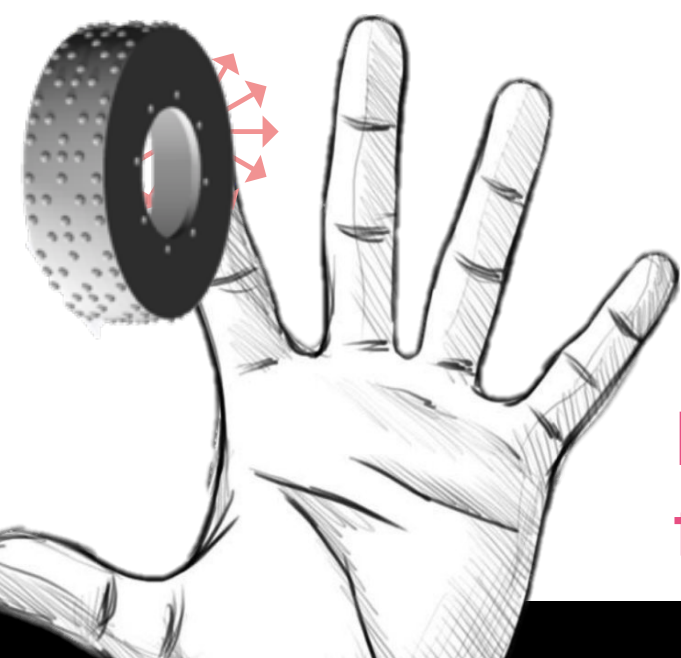
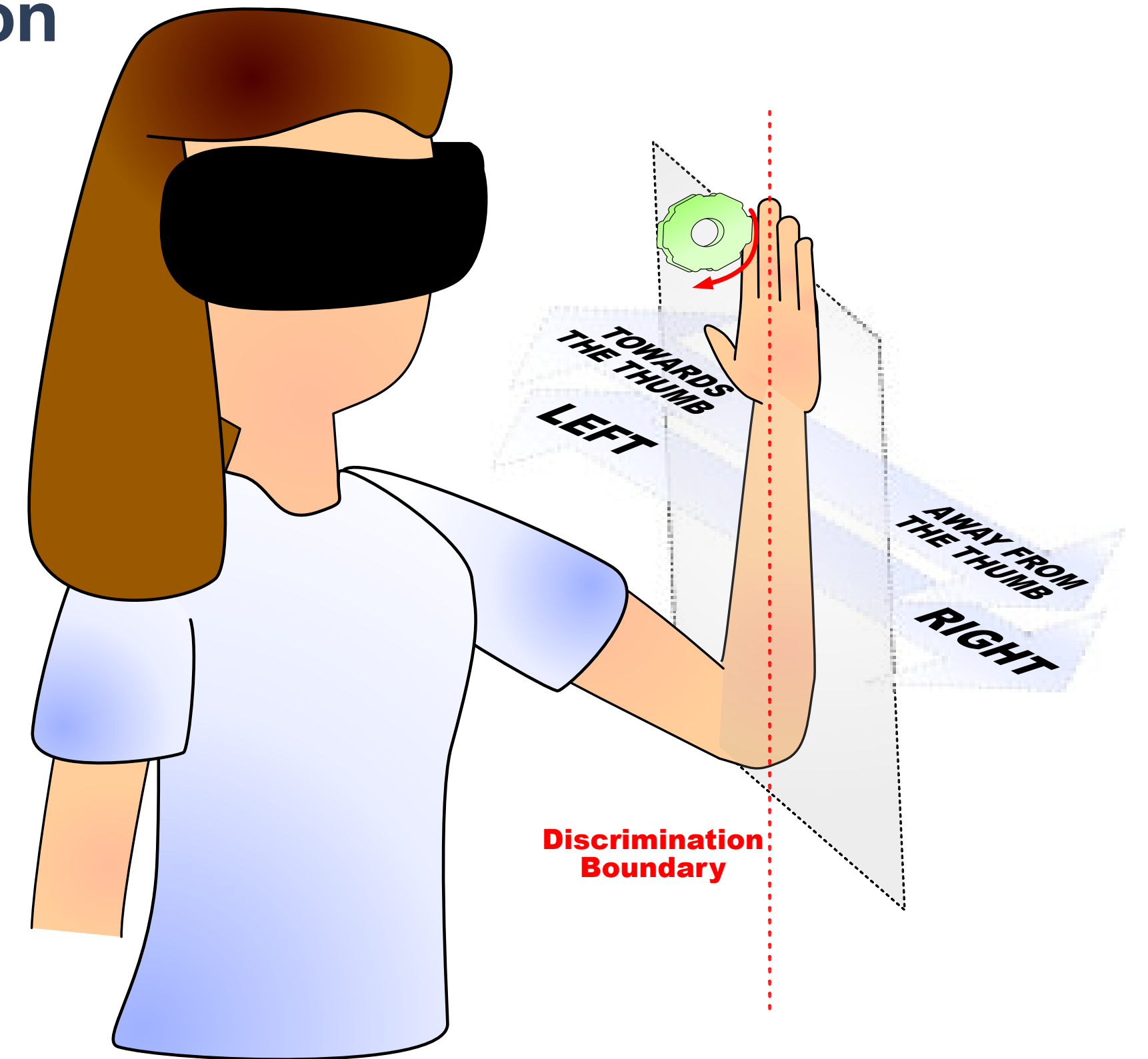
Sternum-Centric Reference Frame

AWAY vs TOWARDS

the thumb-edge of the palm



Finger-Centric Reference Frame



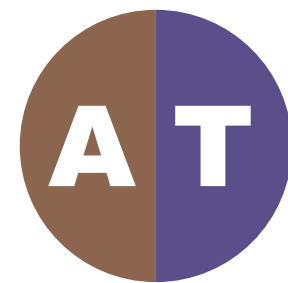
Dot Motion Stimulus at D2
for 2 seconds, steps of 30 degrees.

Experiment Design: Three Proprioceptive States

2-AFC Motion Discrimination Task

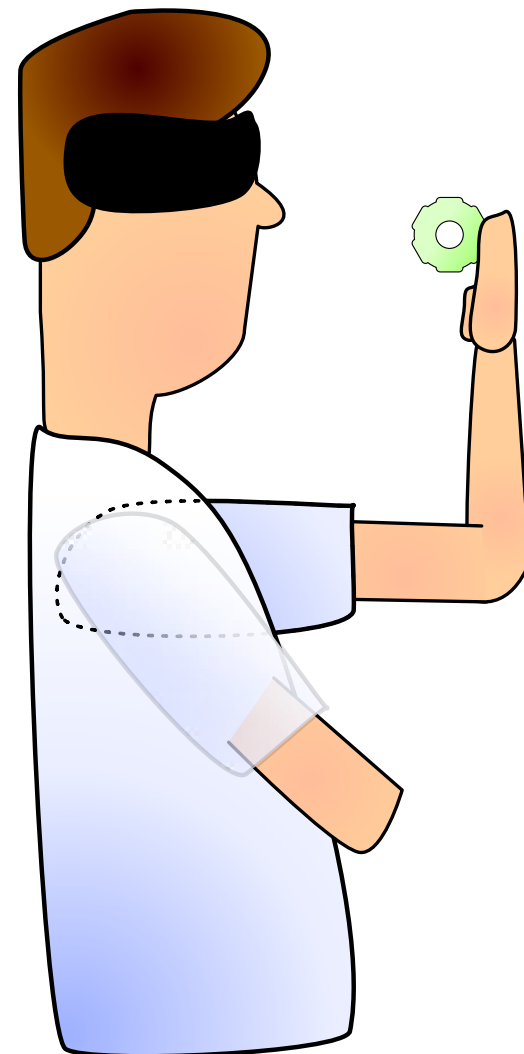


Sternum-Centric Reference Frame

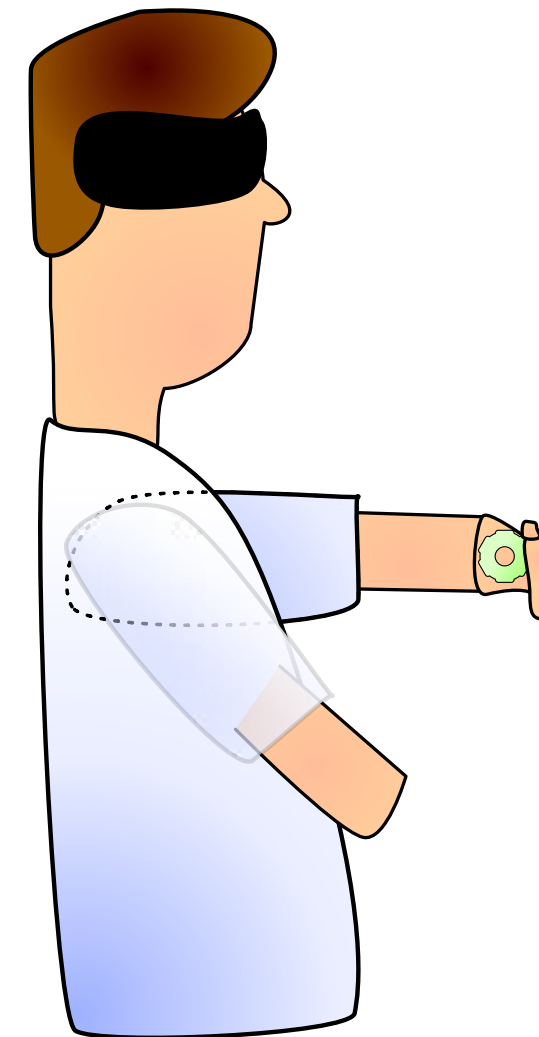


Finger-Centric Reference Frame

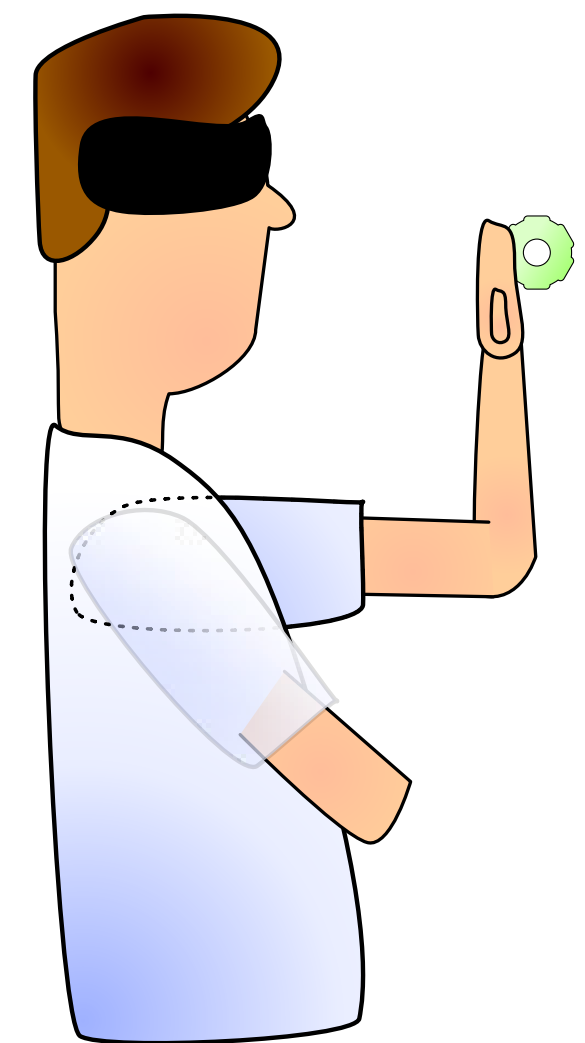
Vertical (V)



Horizontal (H)

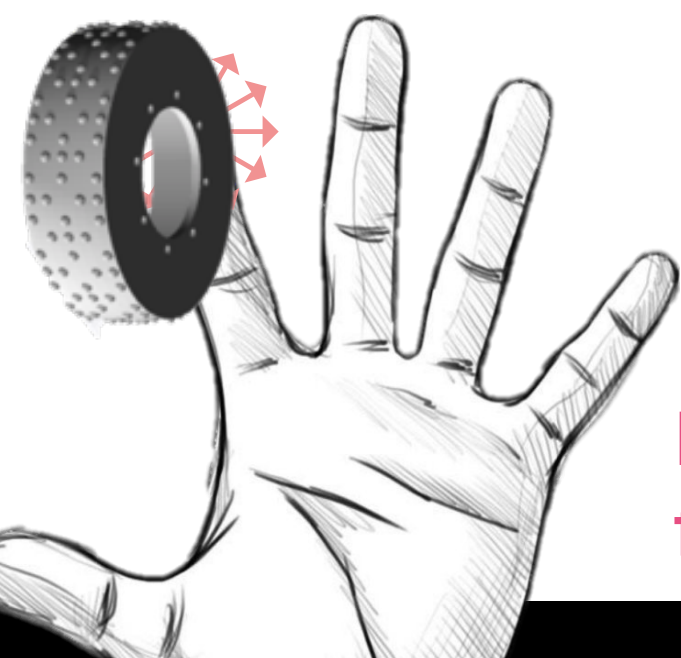


Inverted Vertical (I)



Three proprioceptive states (postures)

Dot Motion Stimulus at D2
for 2 seconds, steps of 30 degrees.



Experiment Design: Three Proprioceptive States

2-AFC Motion Discrimination Task

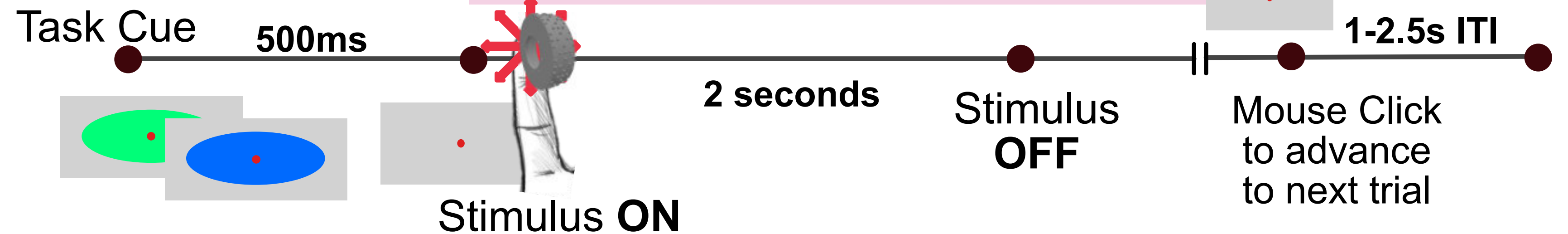


Sternum-Centric Reference Frame

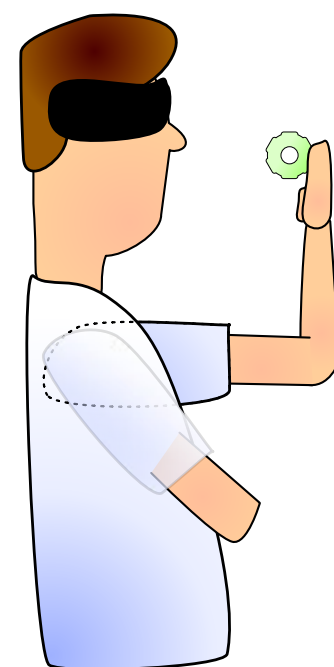


Finger-Centric Reference Frame

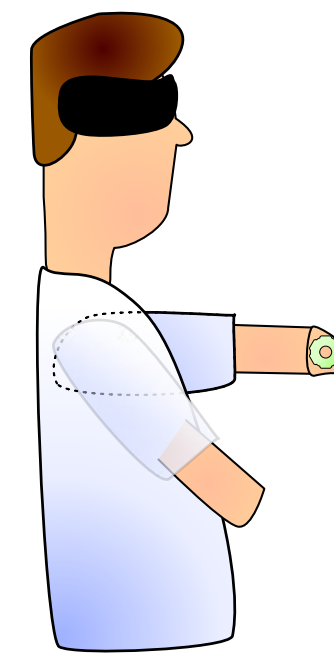
Sternum-Centric/ Finger-Centric



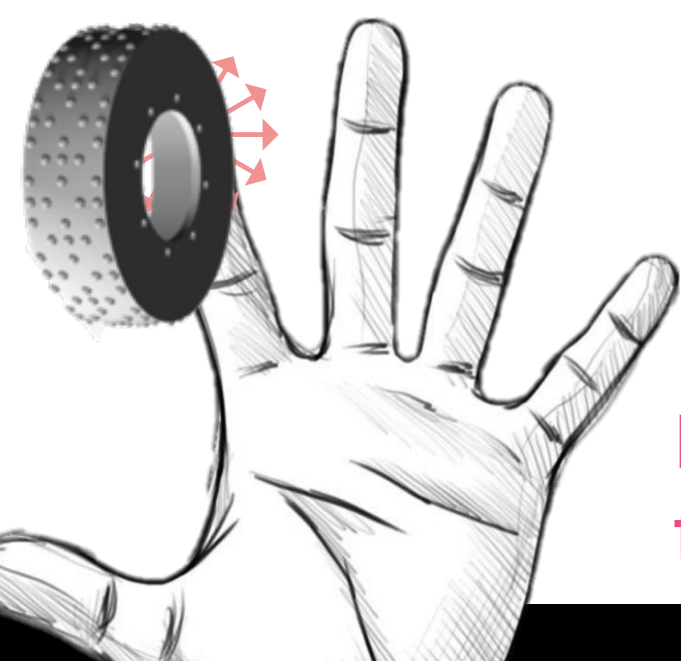
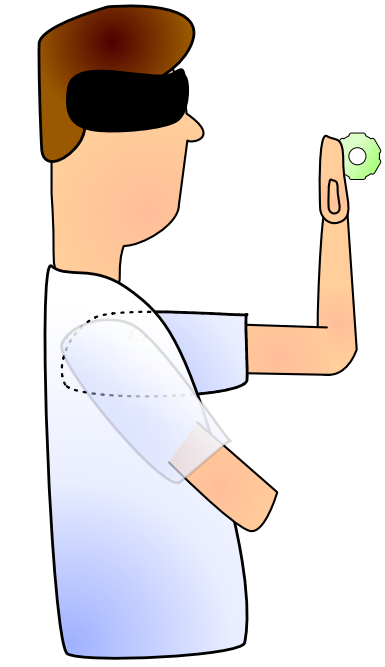
Vertical (V)



Horizontal (H)

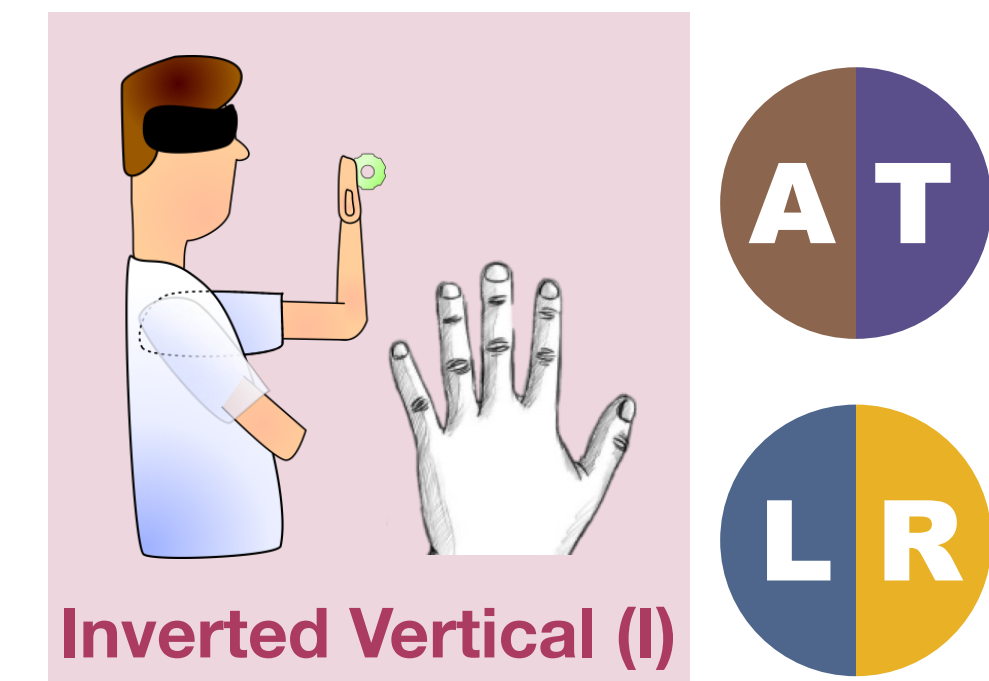
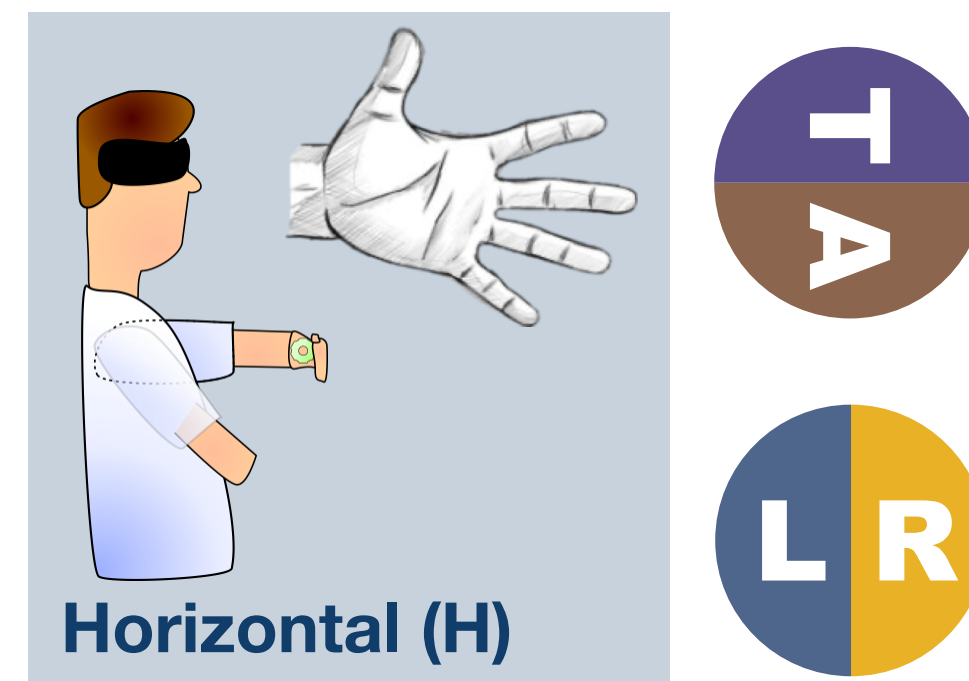
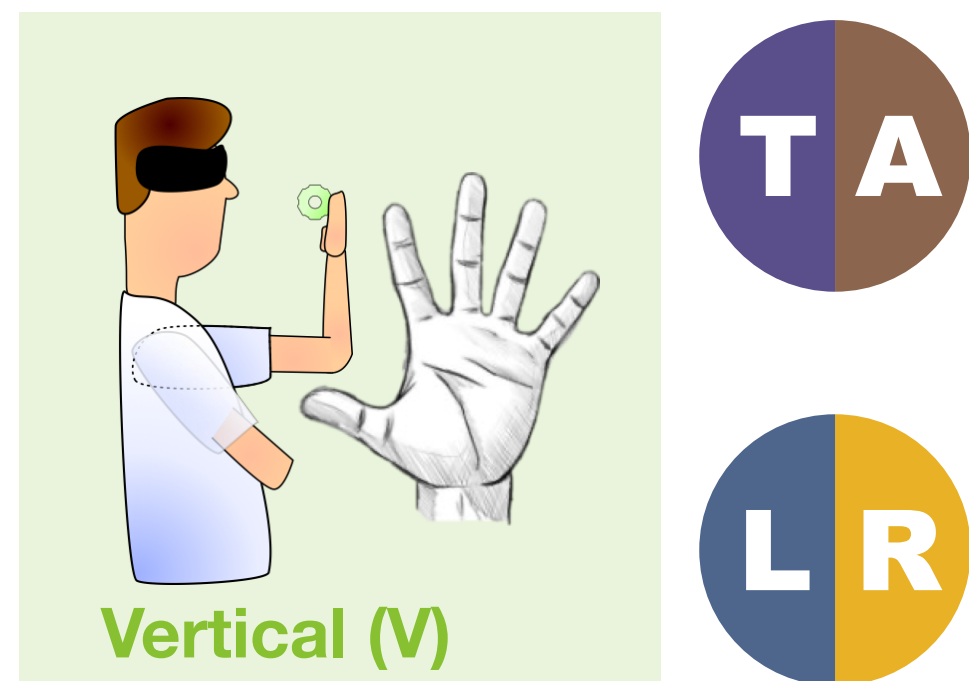
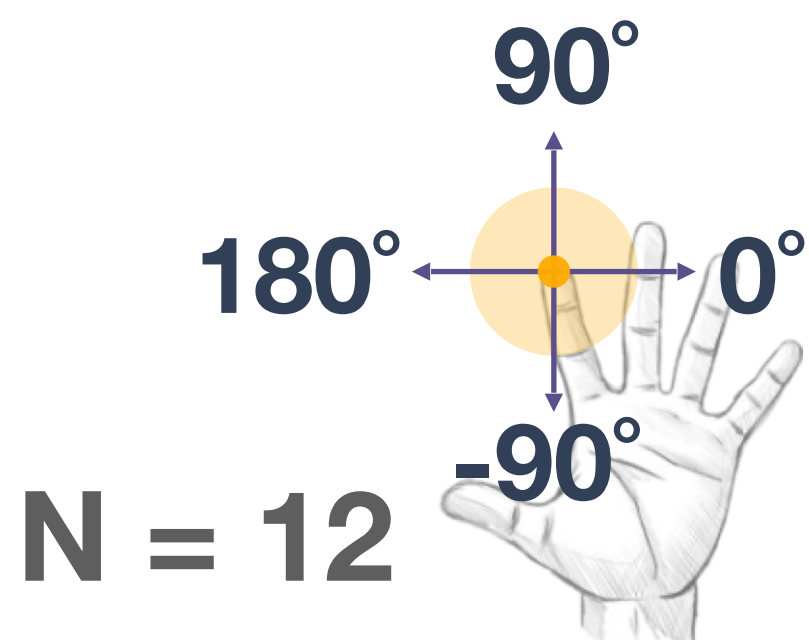
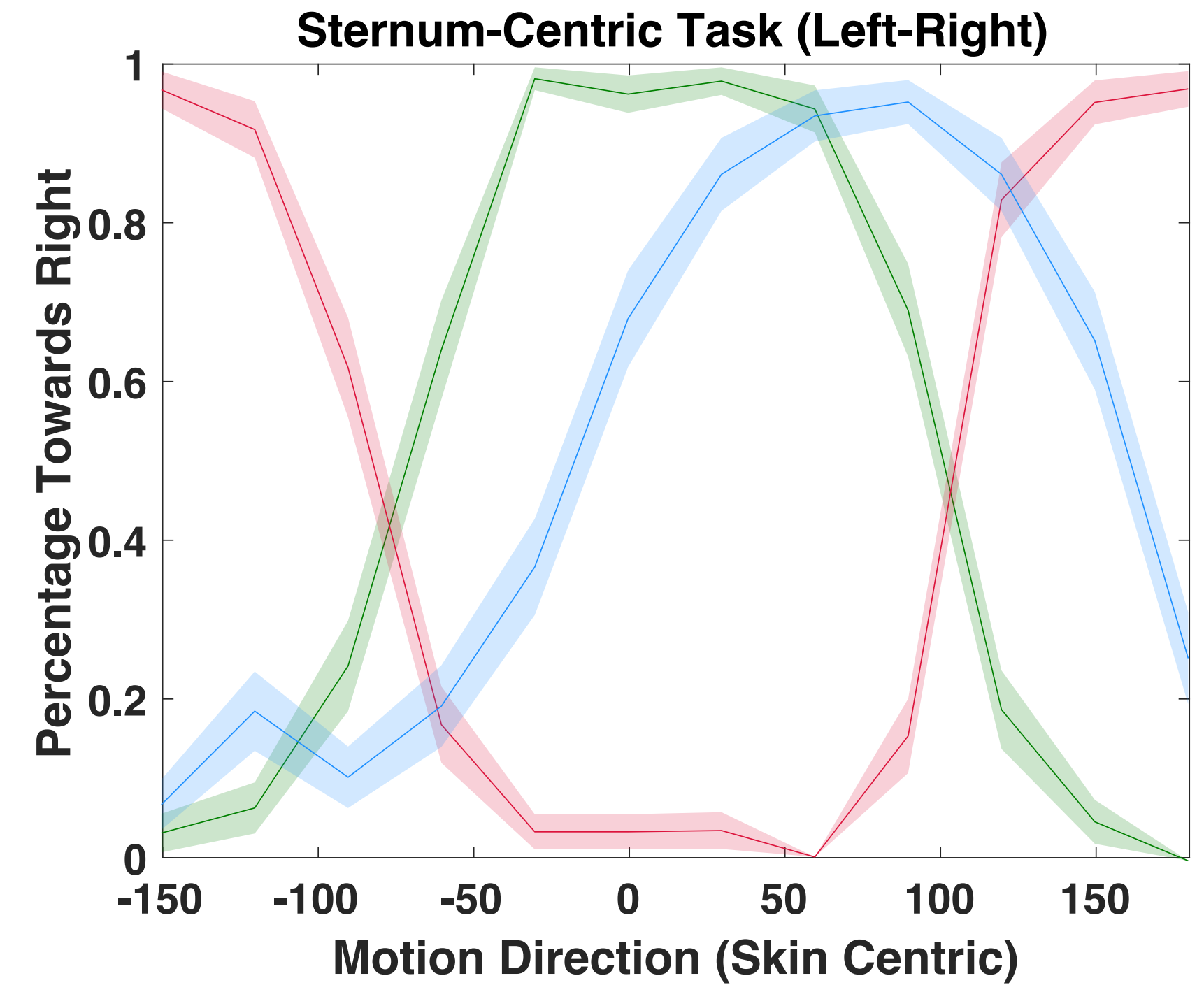
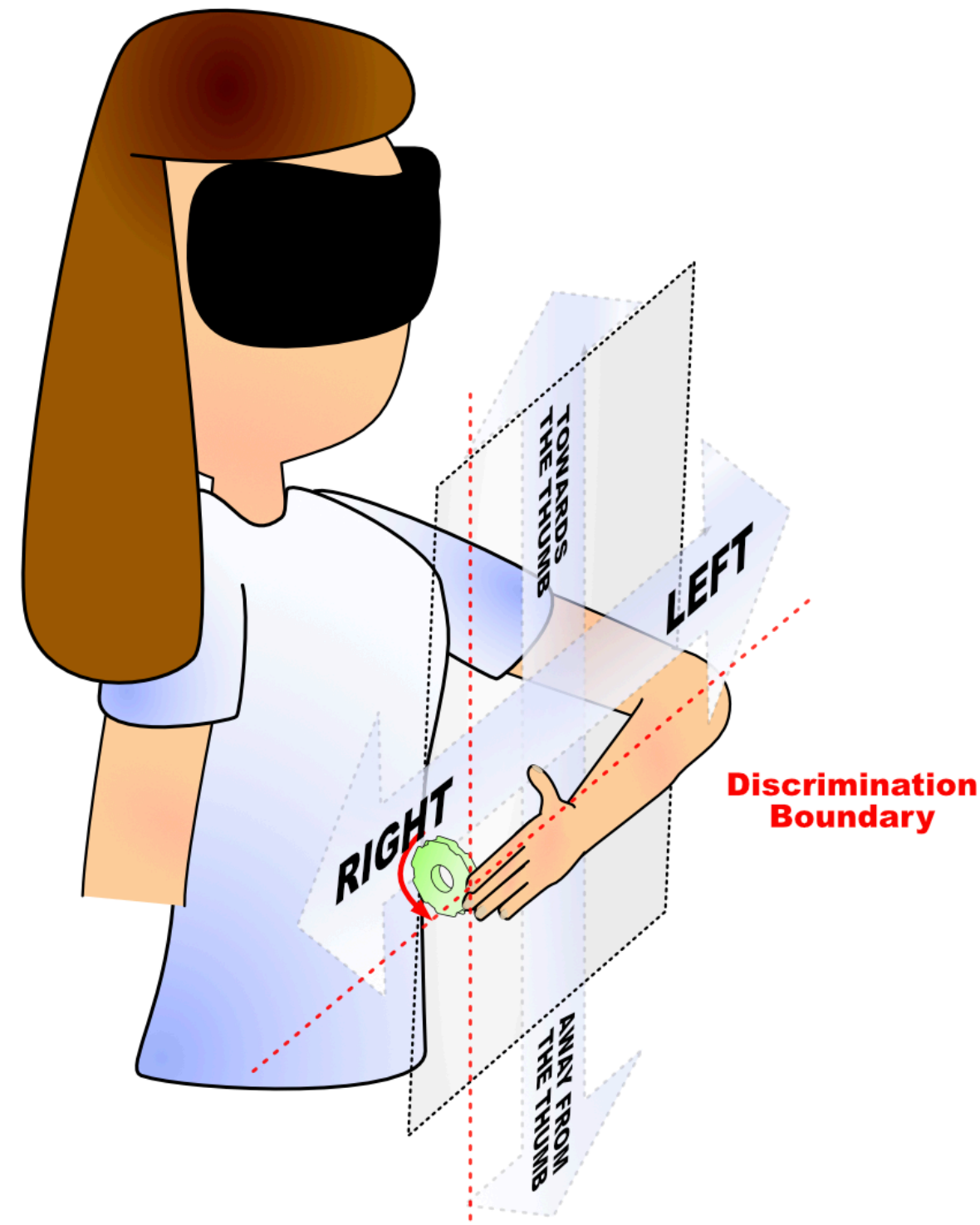
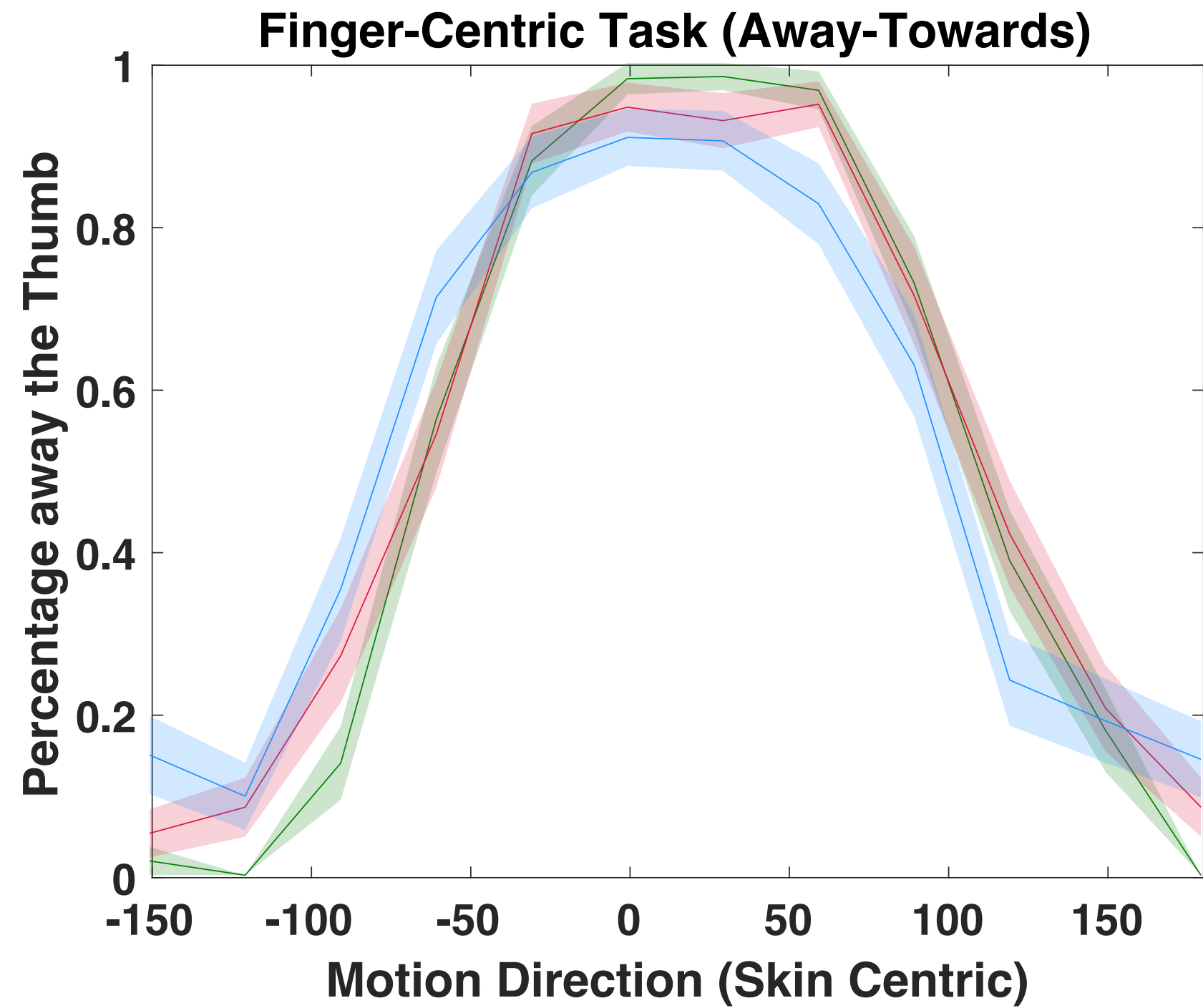


Inverted Vertical (I)



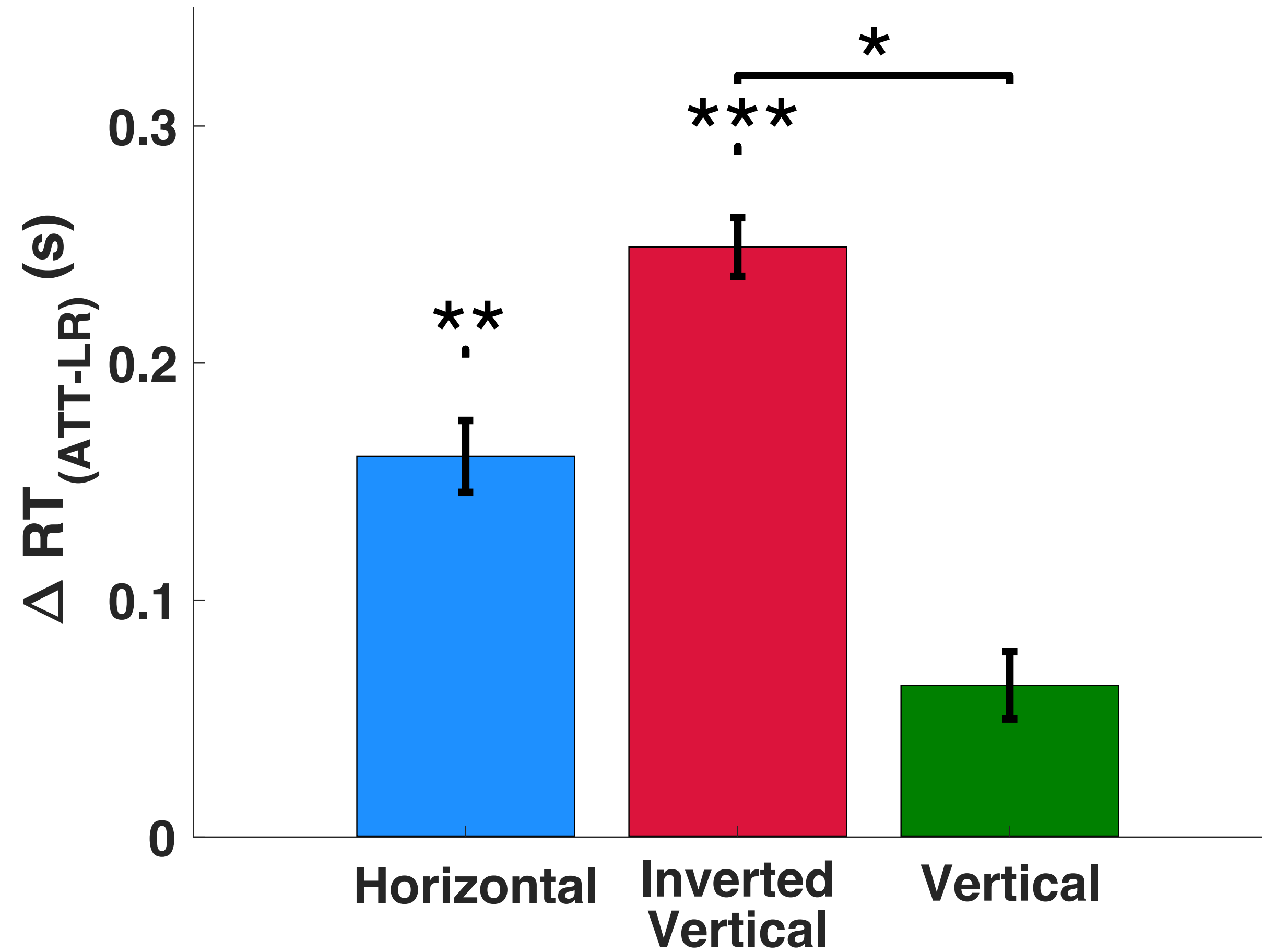
Dot Motion Stimulus at D2
for 2 seconds, steps of 30 degrees.

Subjects flexibly perceive motion in two coordinate systems

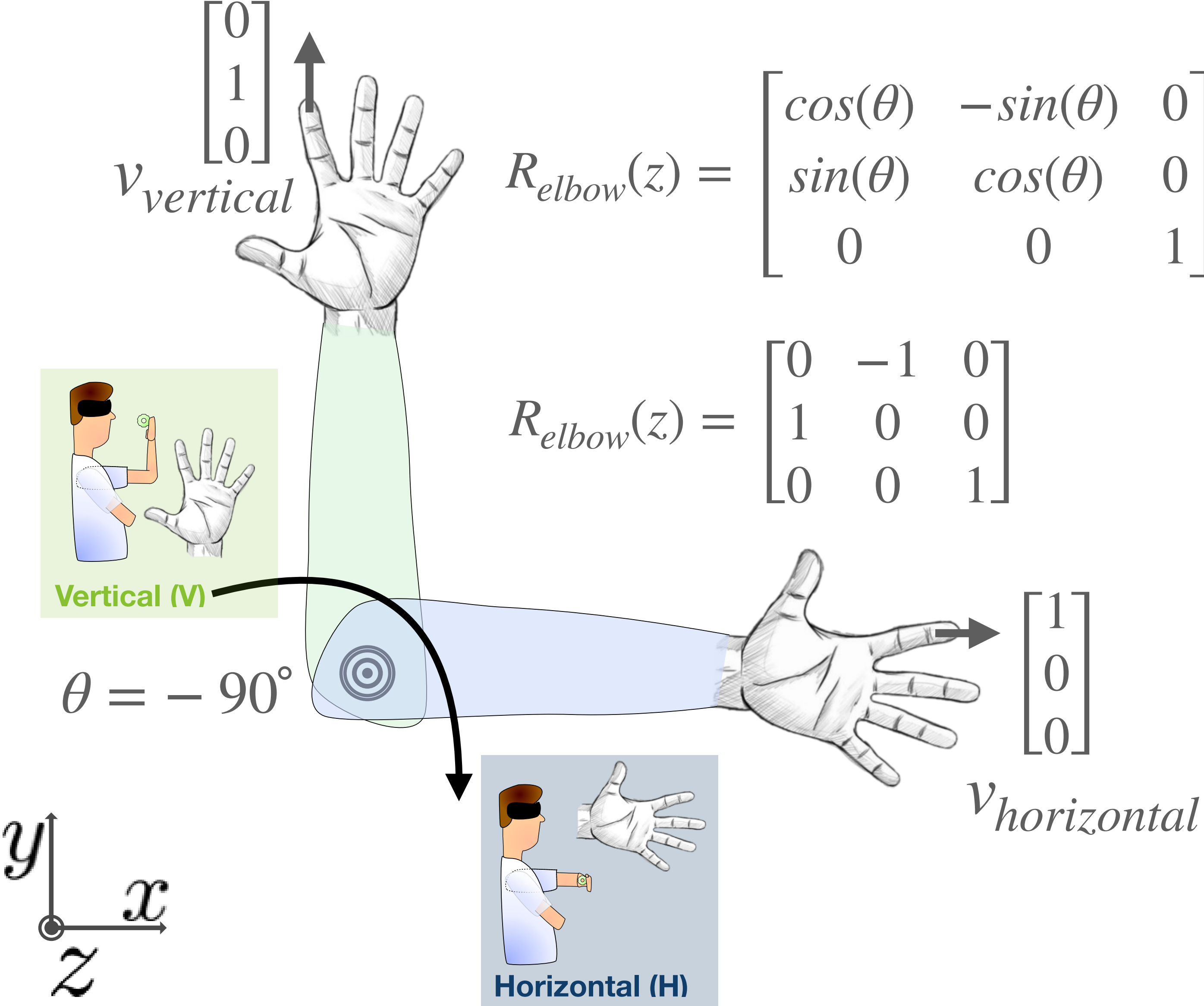


Faster response times in the sternum-centric task

Difference in Response Time
RT(Finger Centric) - RT(Sternum centric)



Euler Matrix Transformations explain tactile motion report



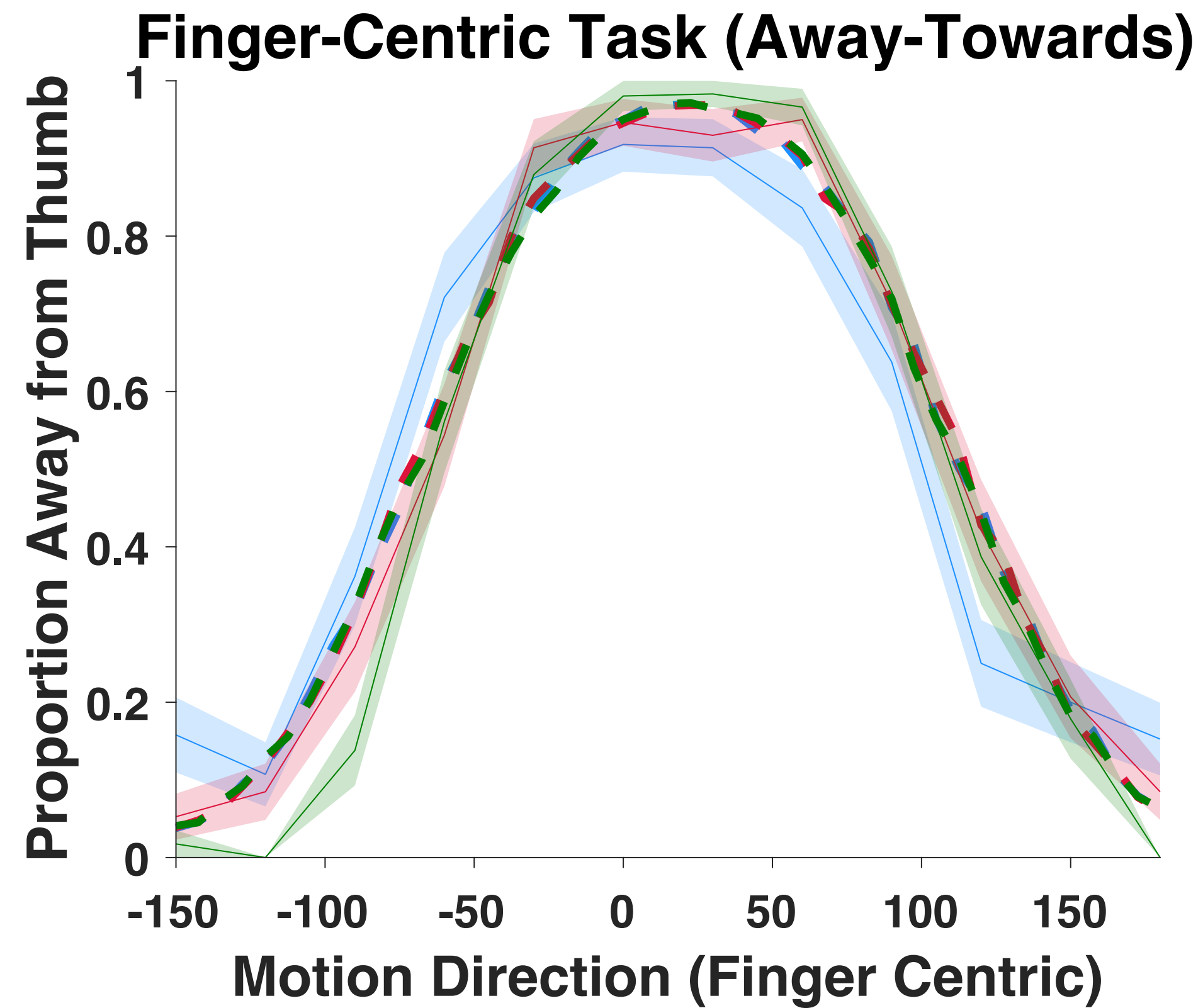
$$R_{elbow}(z) \cdot v_{vertical} = v_{horizontal}$$

$$\begin{bmatrix} 0 & 1 & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$

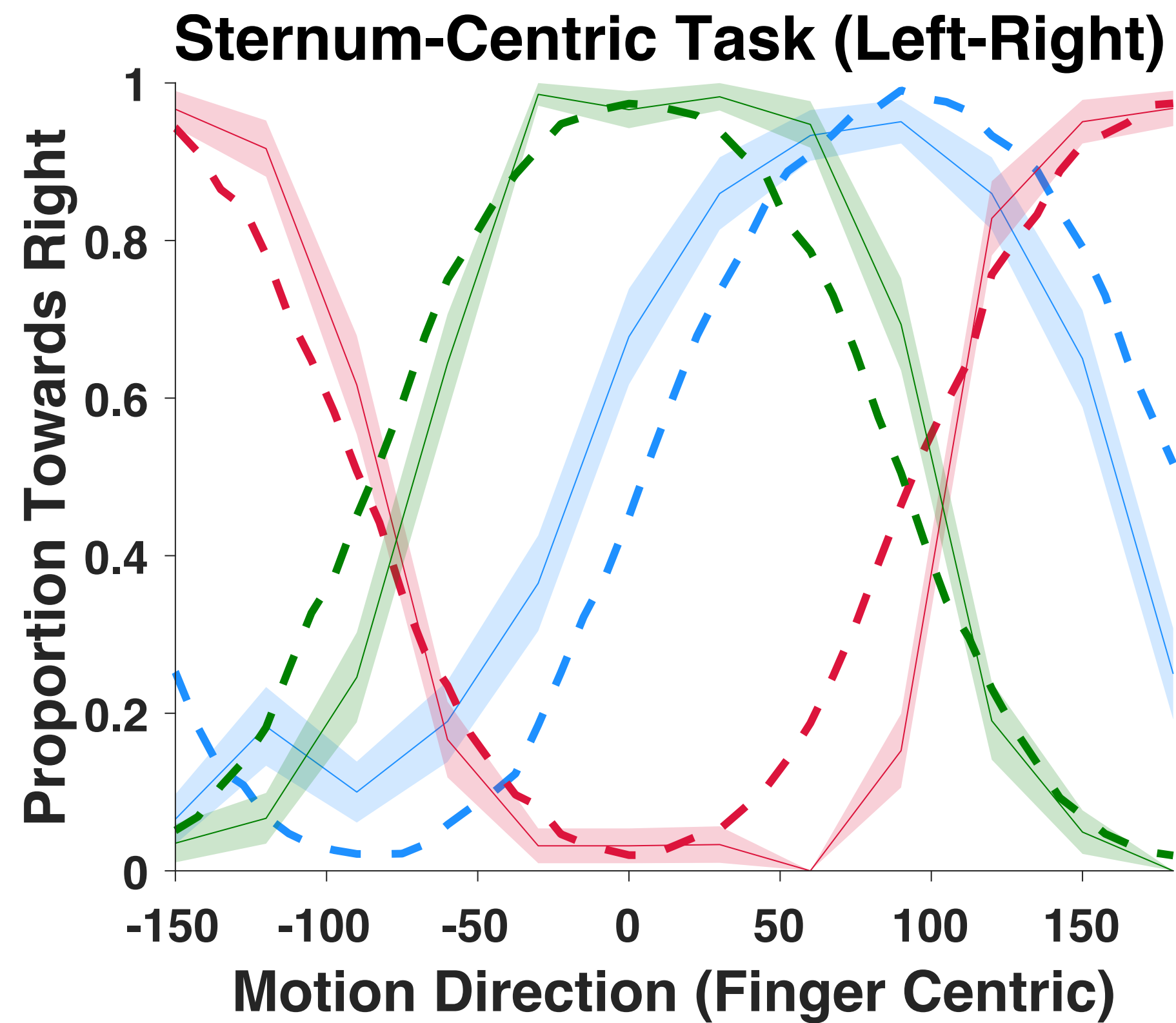
Similar matrix transformation can be performed at each proprioceptor joints between two reference frames

$$R_{shoulder}(x) \cdot \dots \cdot R_{elbow}(z) \cdot R_{wrist}(y) \cdot v = v'$$

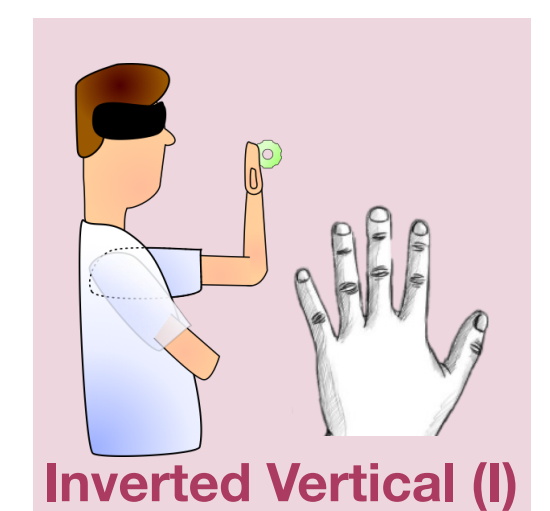
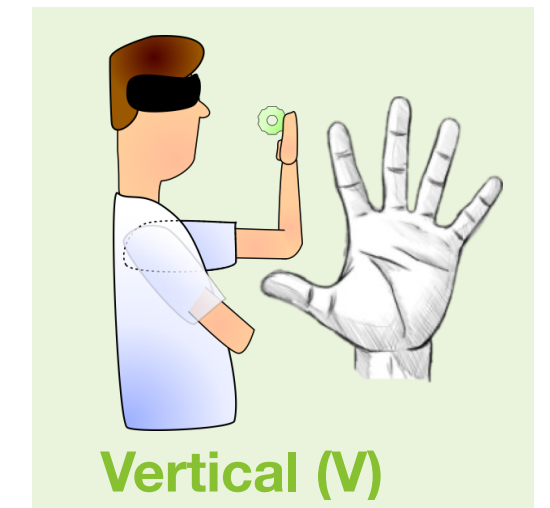
Euler-Matrix Transformation-based Generative model explains behavioral results



McFadden's $R^2 = 0.41$



McFadden's $R^2 = 0.45$

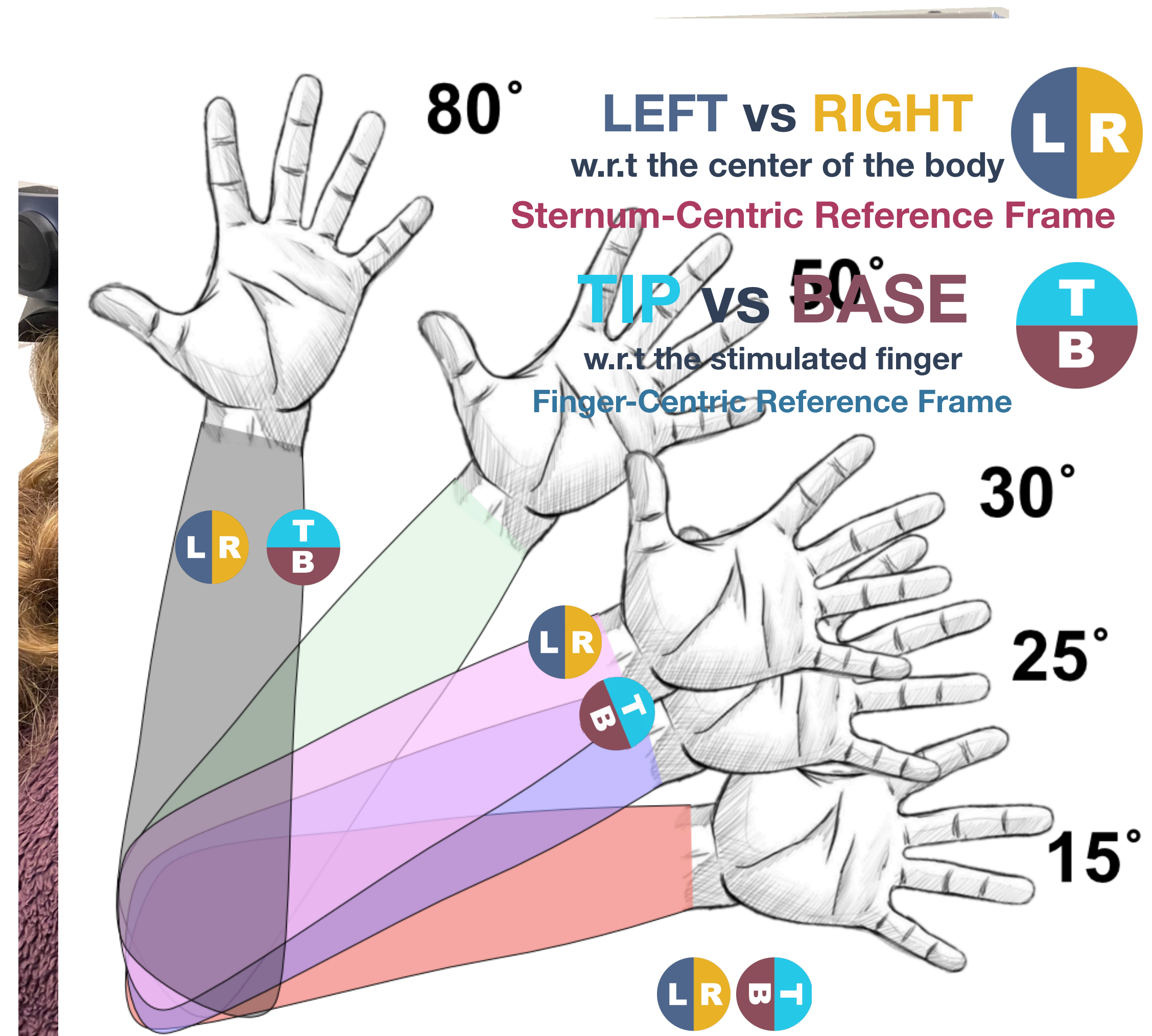


--- Model Fit

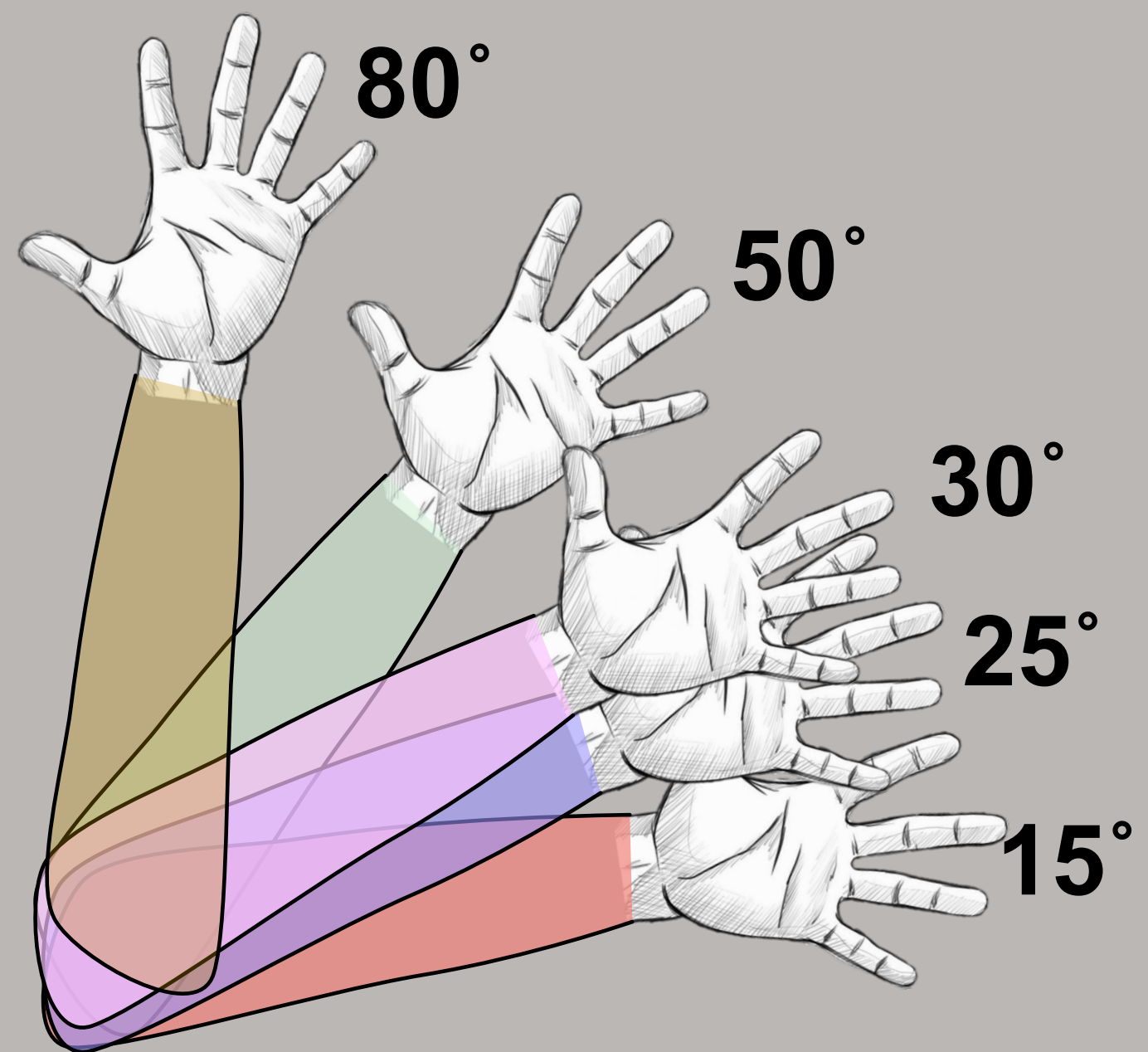
— Observed

Motivations for updating current experiment design

- Strategize associations between the discrimination boundaries at a blocked posture.
 - ➔ **Modulate proprioceptive state on each trial**
 - ➔ **Generalize the theoretical framework to other coordinate systems.**
- Low number of individual subject trials
 - ➔ **Sensitivity of motion discrimination in different coordinate systems**
 - ➔ **Systematic biases across coordinate systems and proprioceptive states.**

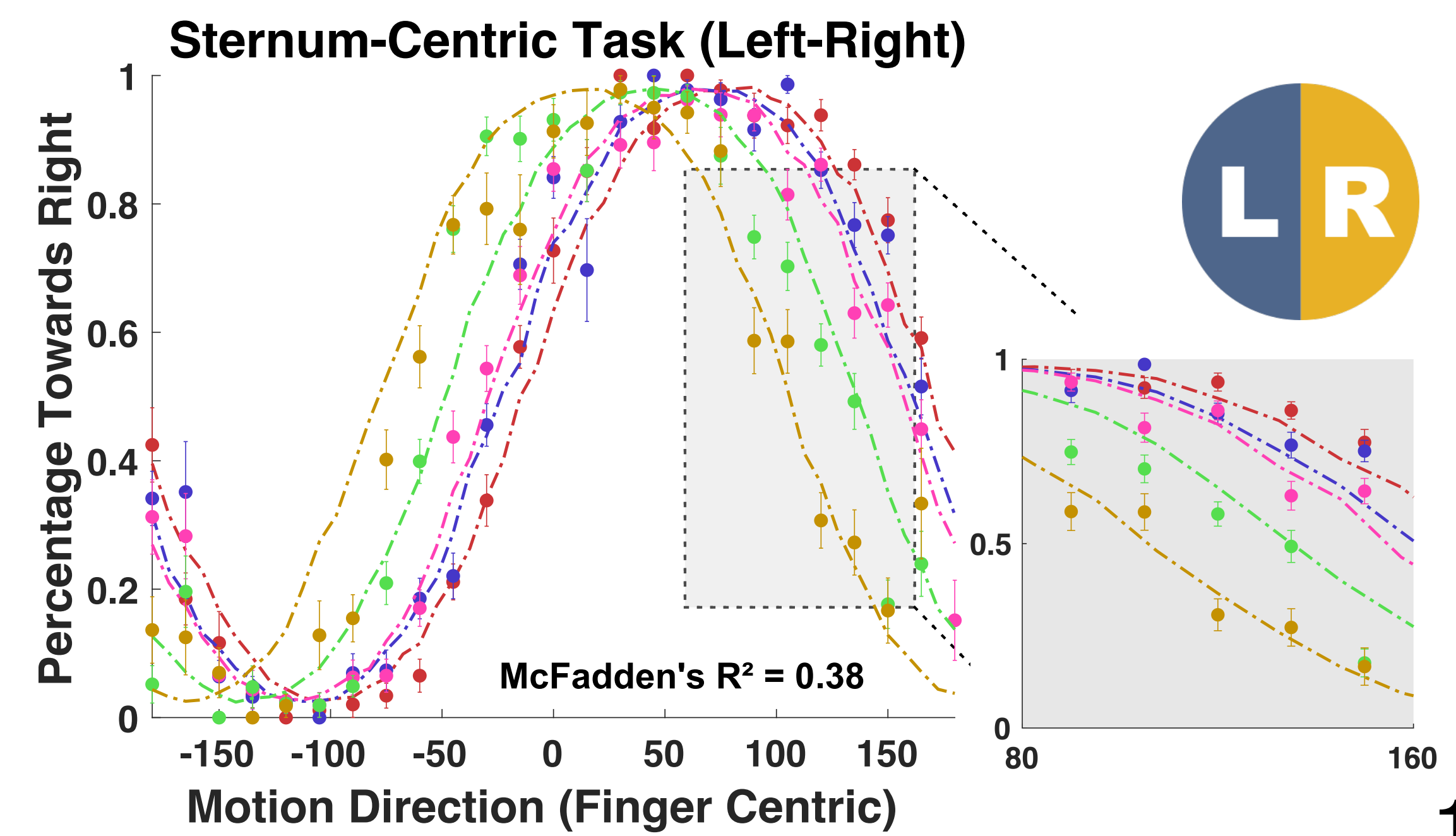
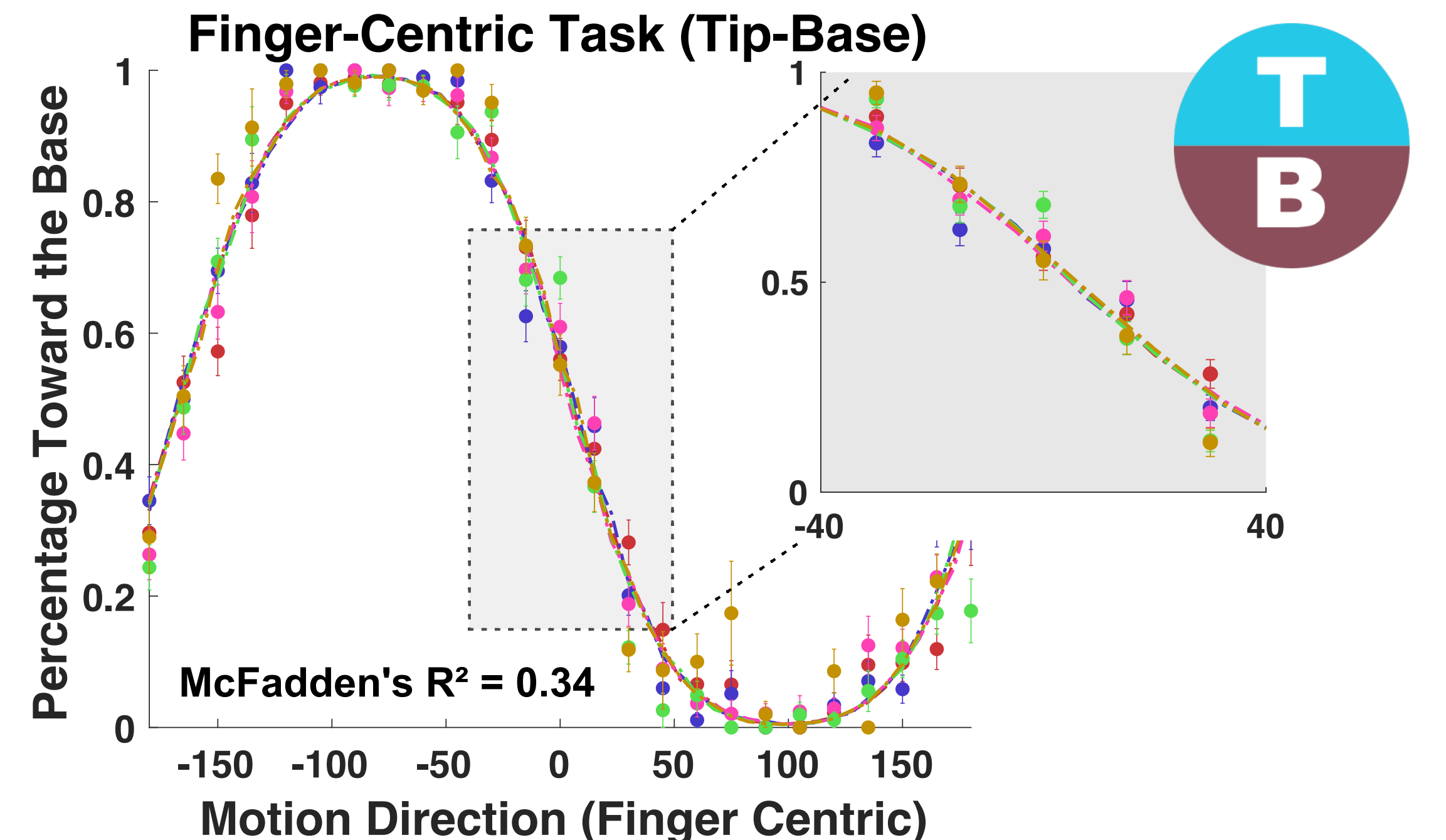


Proprioception modulates tactile motion perception in a reference frame-dependent manner

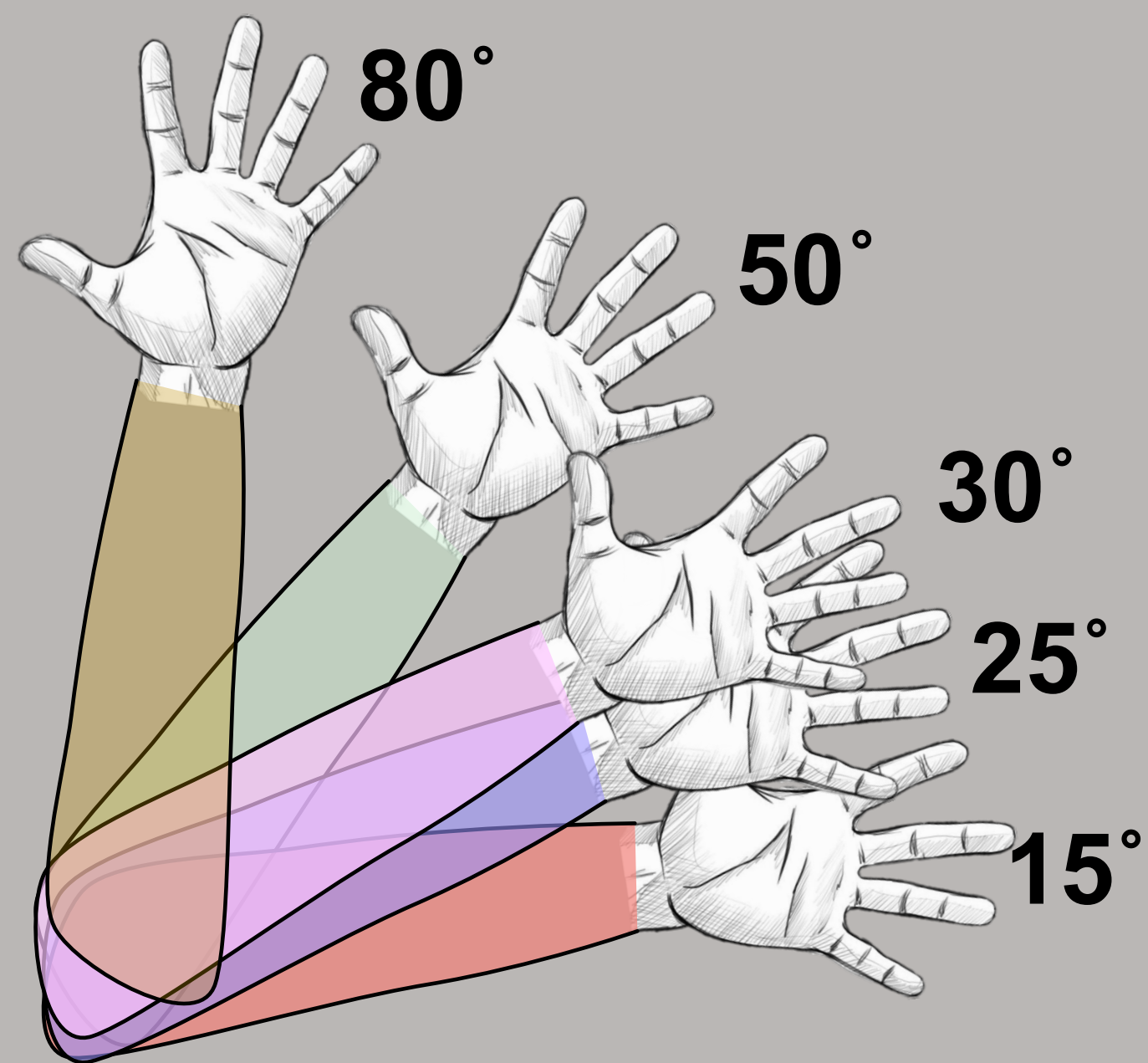


--- Model Fit
 ● | Observed Data

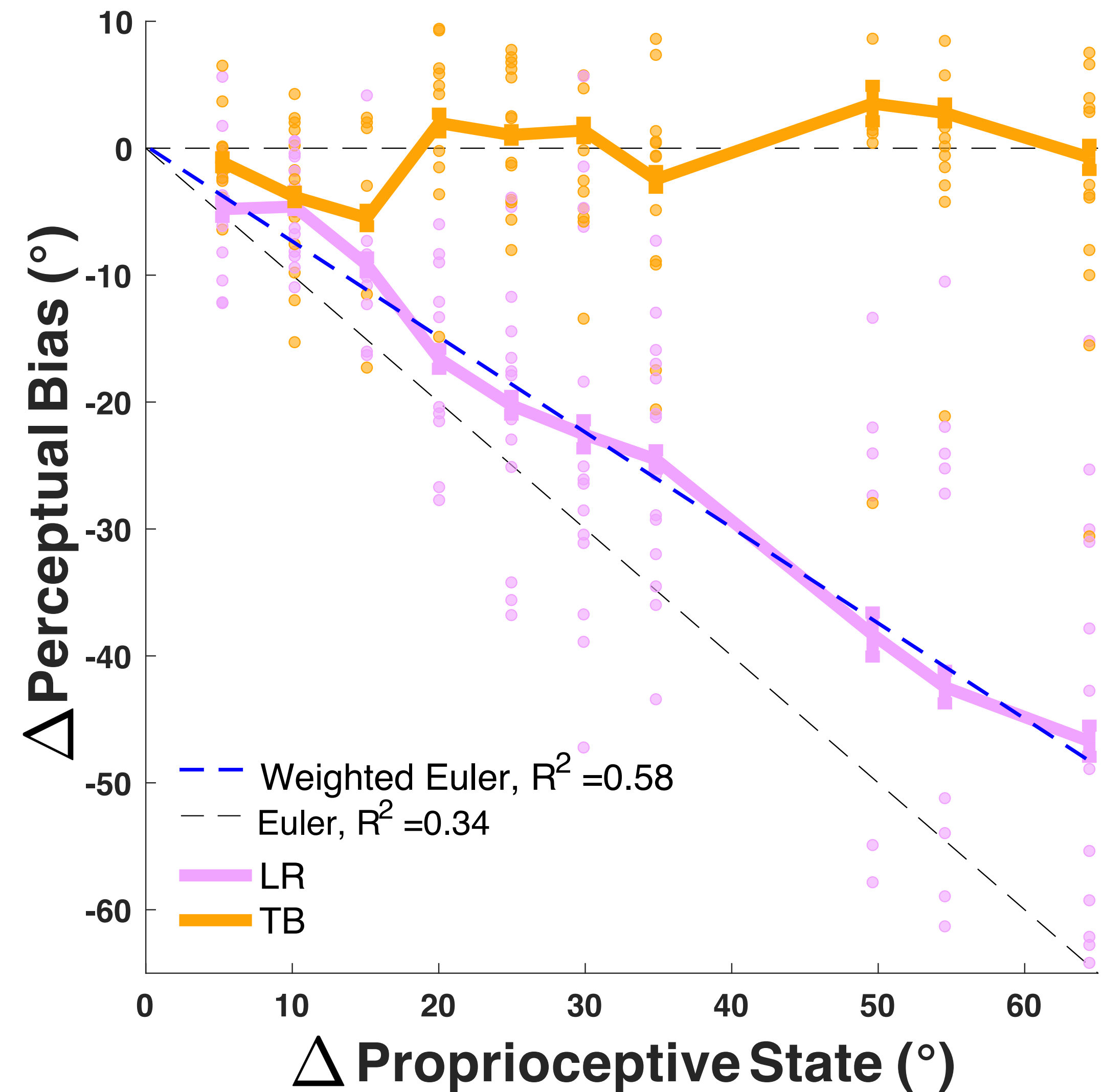
N = 14



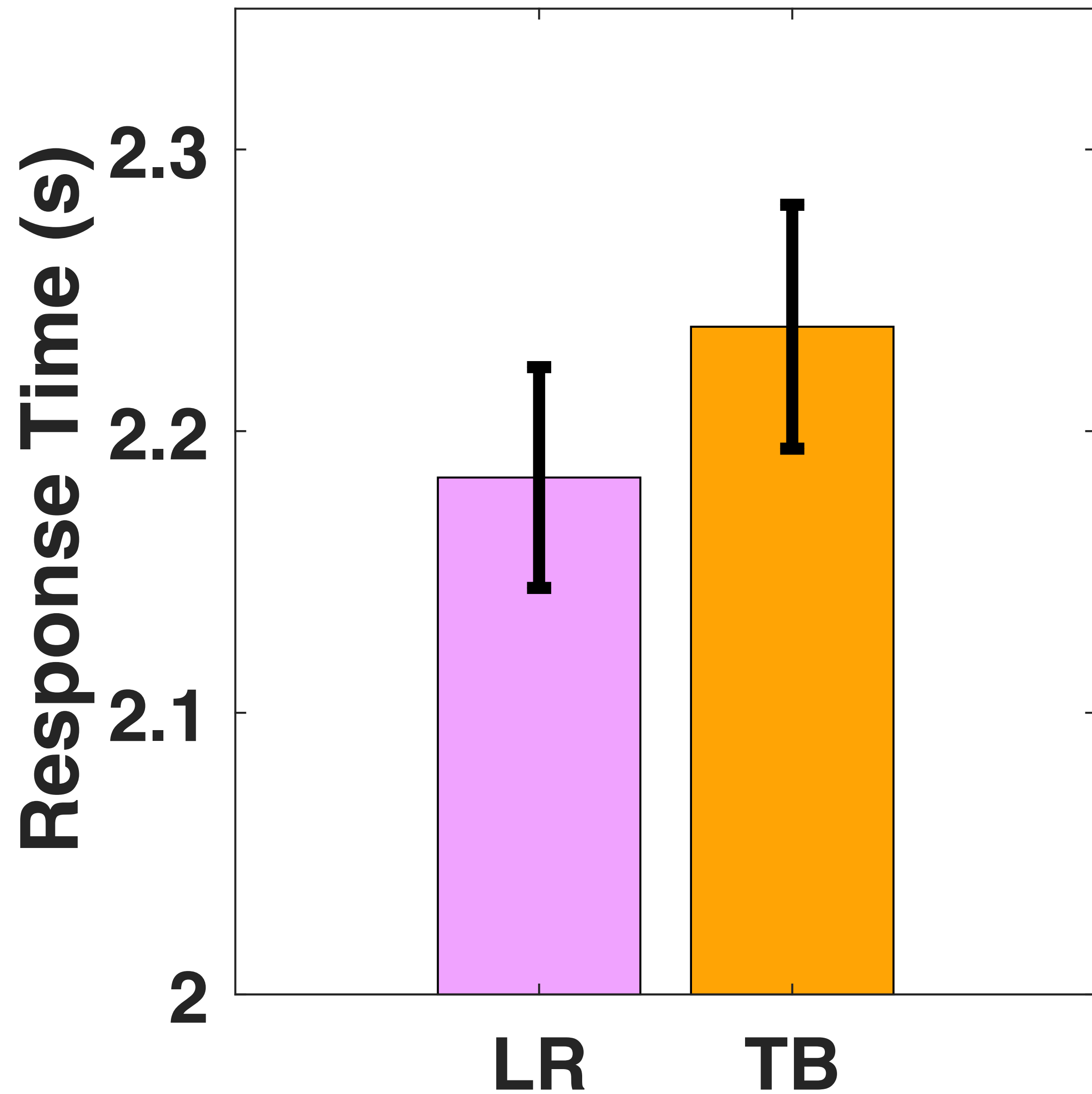
Proprioception systematically biases tactile motion report in the sternum-centric task



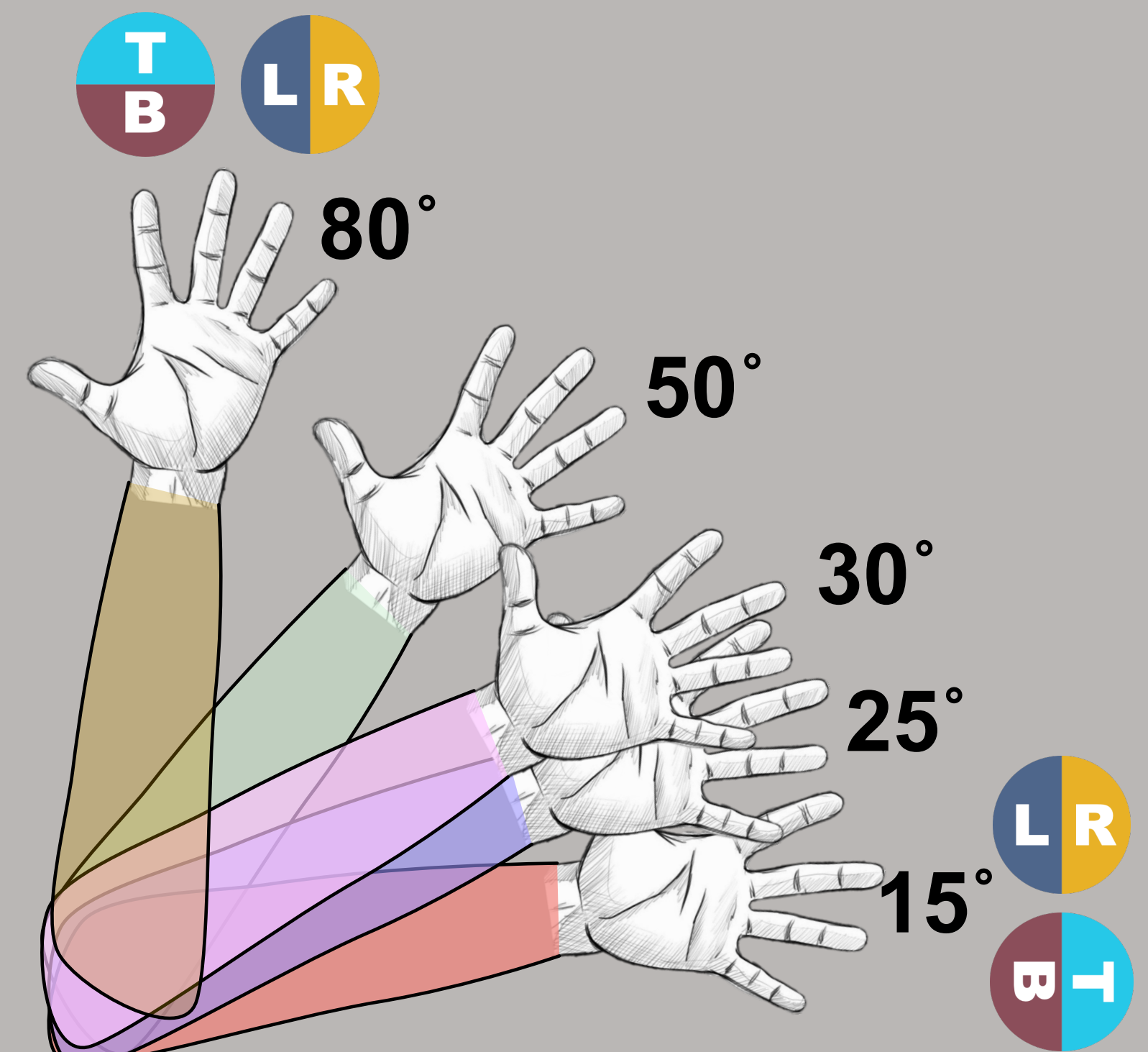
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Slower response times in sternum-centric task when discrimination spaces incongruent

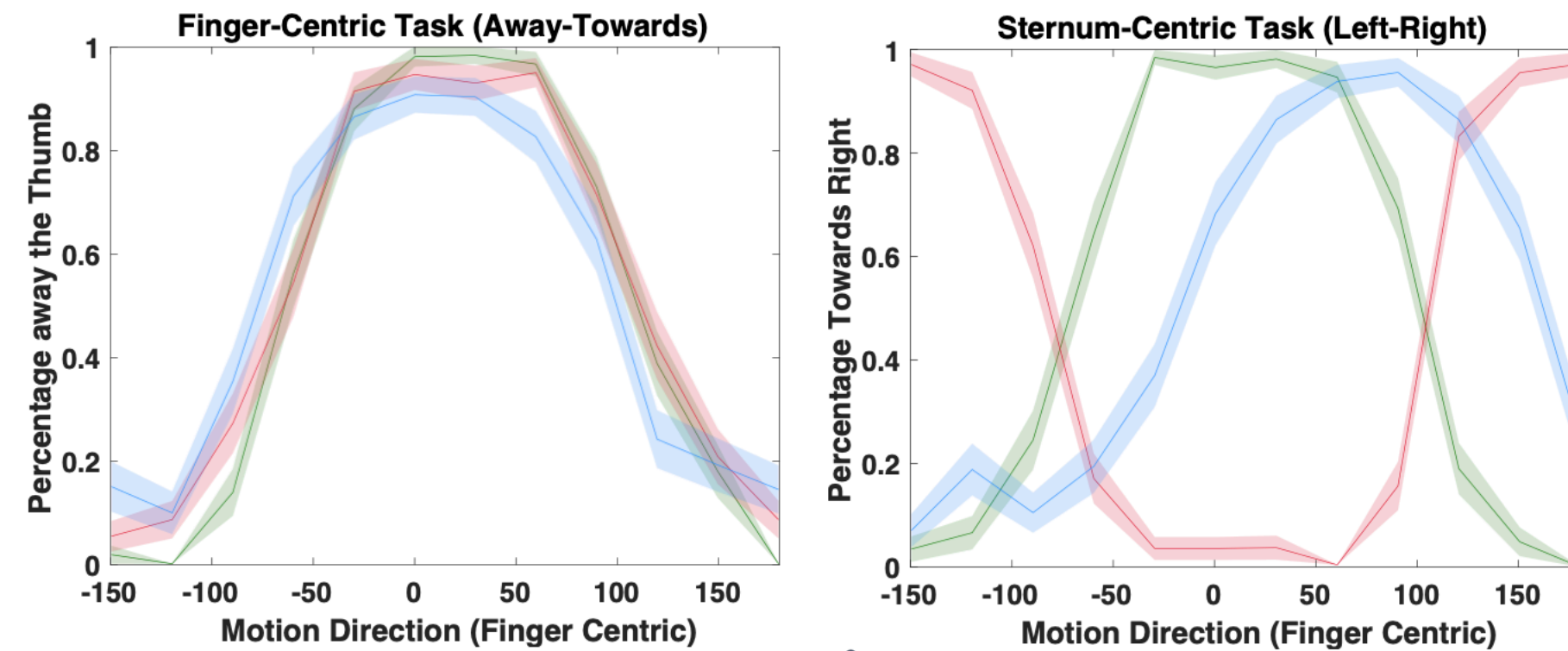


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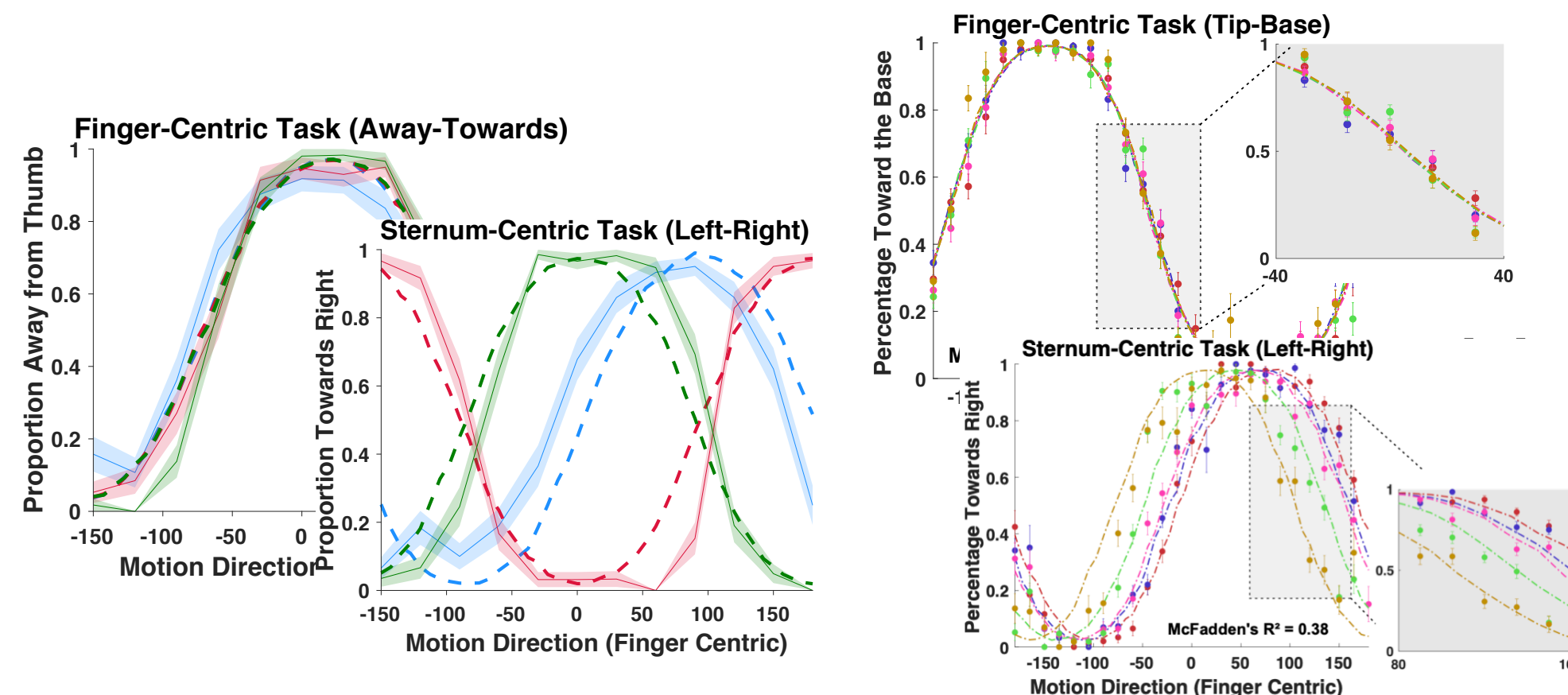


Summary

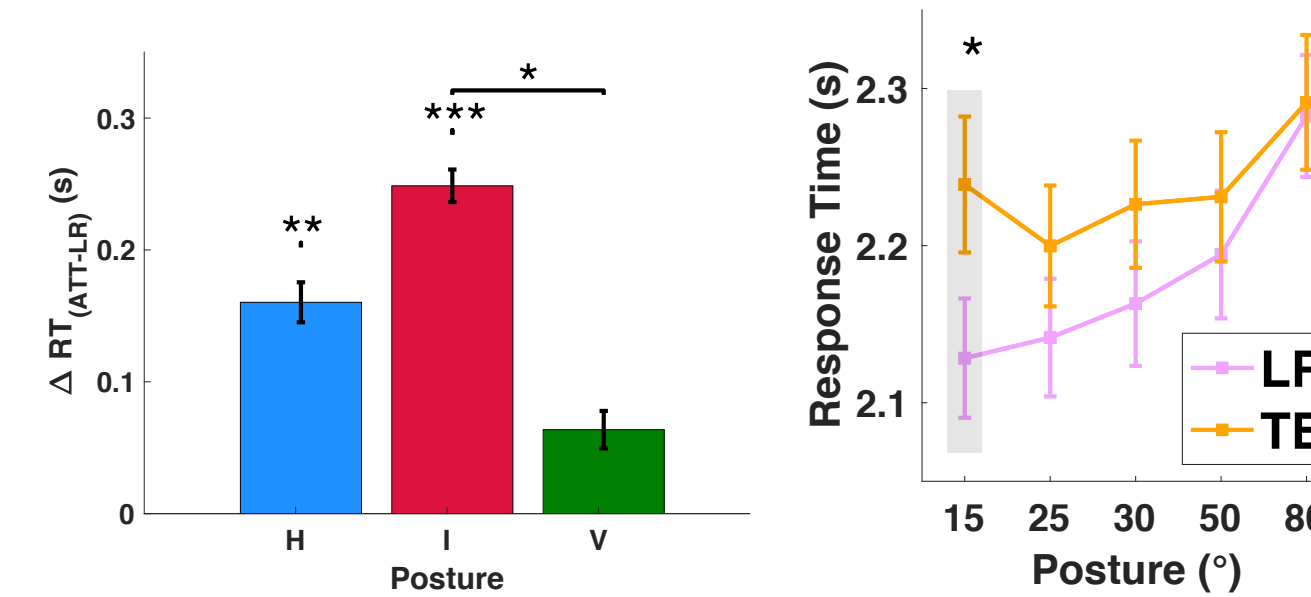
- We show that humans flexibly perceive tactile motion direction in different coordinate systems



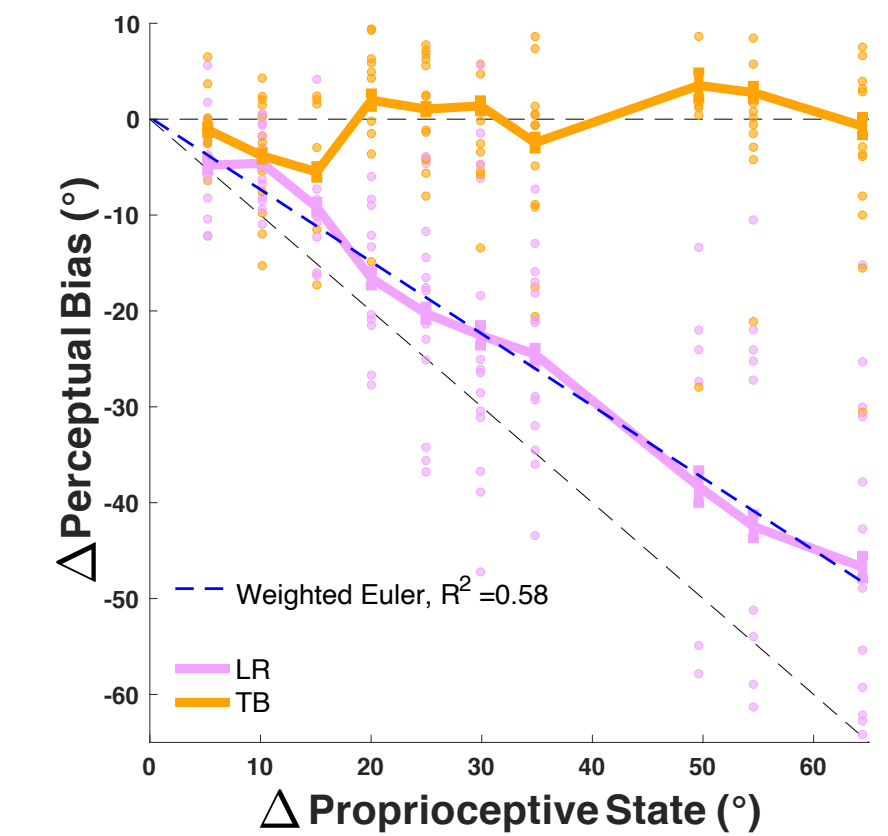
- A modified Euler-matrix based generative model explained behavioral report.



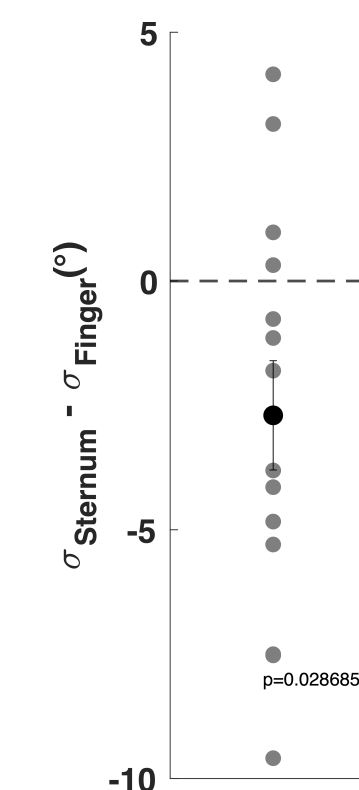
- Faster reaction times in the sternum-centric task.

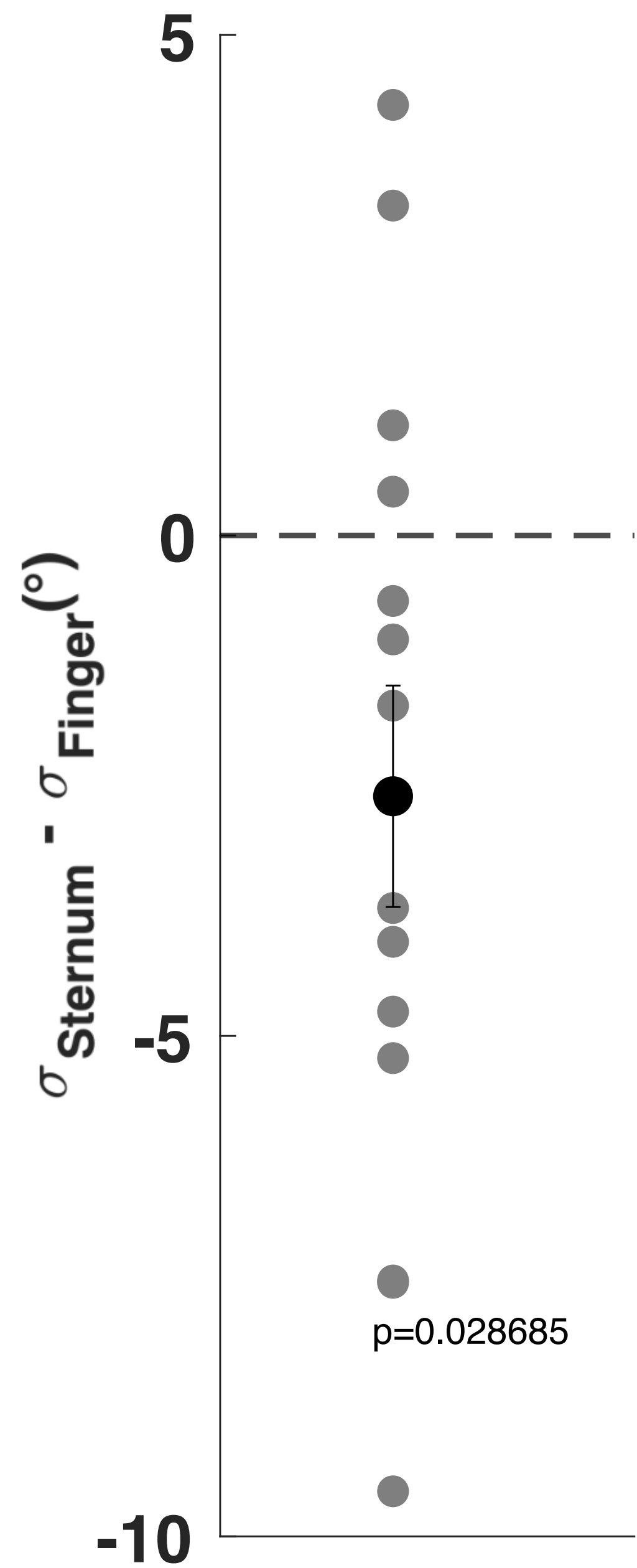
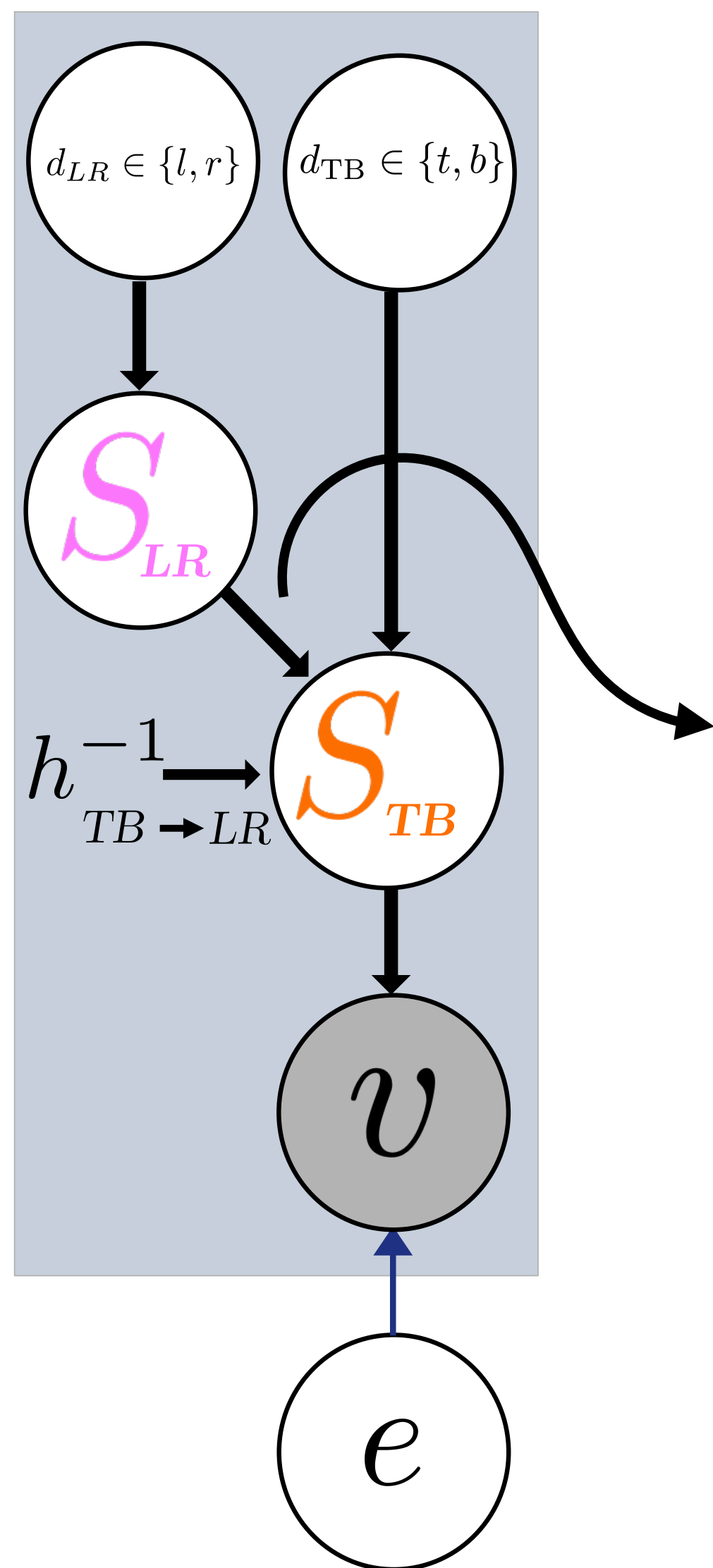


- The finger-centric task has a constant bias. The sternum-centric task has a posture dependent bias.



- Discrimination sensitivity higher in the finger-centric task

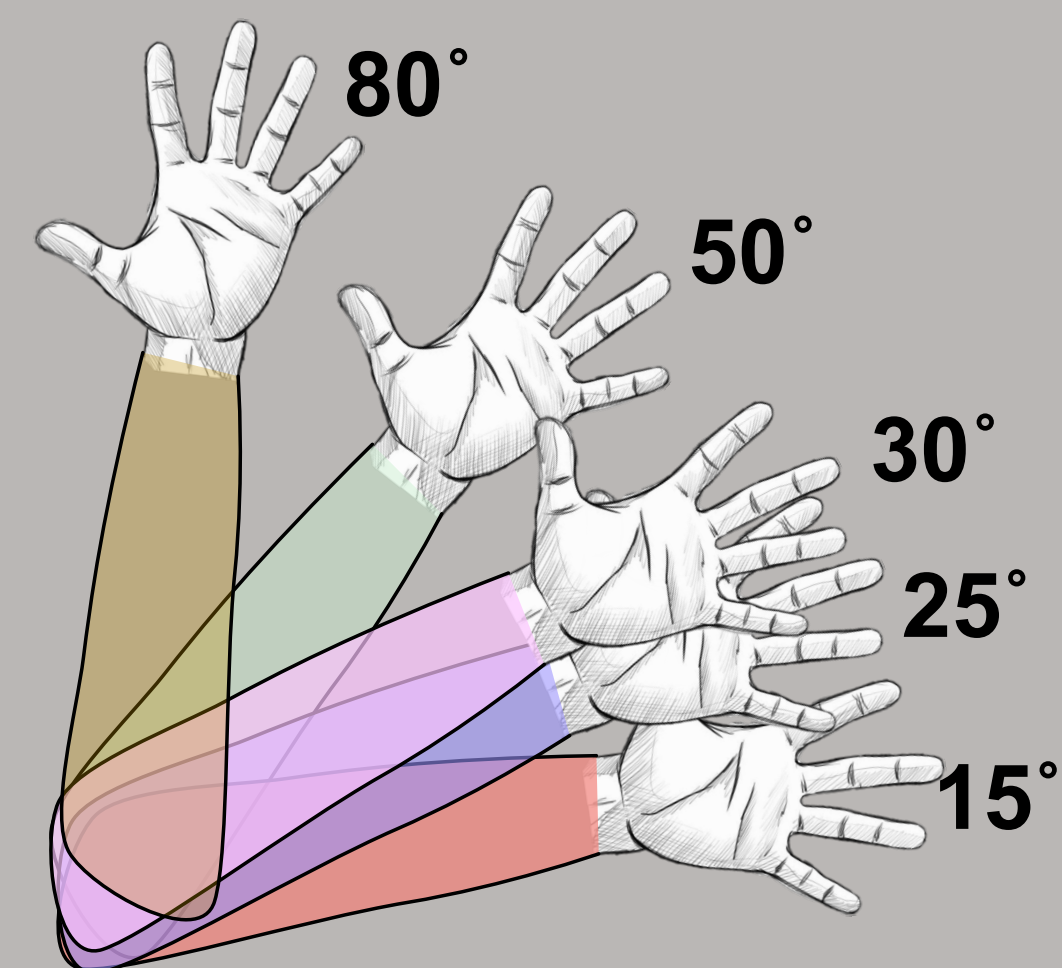




N = 14

Proprioceptive noise in the sternum-centric task

A positive difference implies transformation noise from finger-centric (S_{TB}) to sternum-centric coordinate system (S_{LR})



Acknowledgements

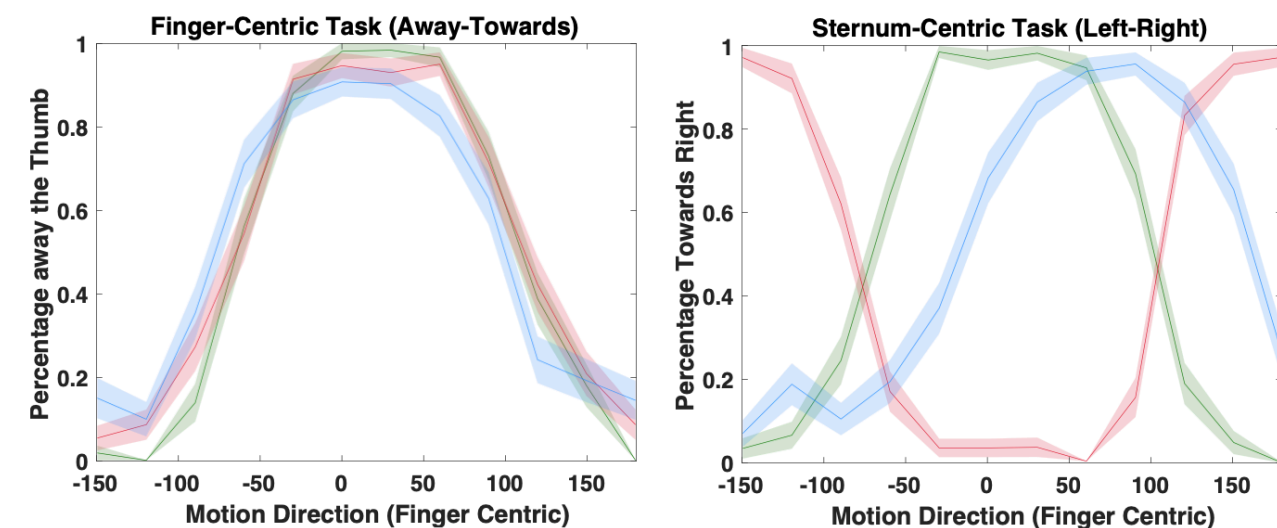


- ***Prof. Manuel Gomez-Ramirez, Prof. Ralf Haefner, Prof. Gregory DeAngelis*** for their continual guidance throughout the project.
- ***Sabyasachi Shivkumar***: For modeling and fitting the behavioral results
- ***Catalina Feistritzer, Amy Fuller, Yihan Xie***: Processing data and running human participants.
- ***Emily Murphy (Lab Manager), Michael Duhain (Fellow graduate student)*** and other lab members for their comments and support!

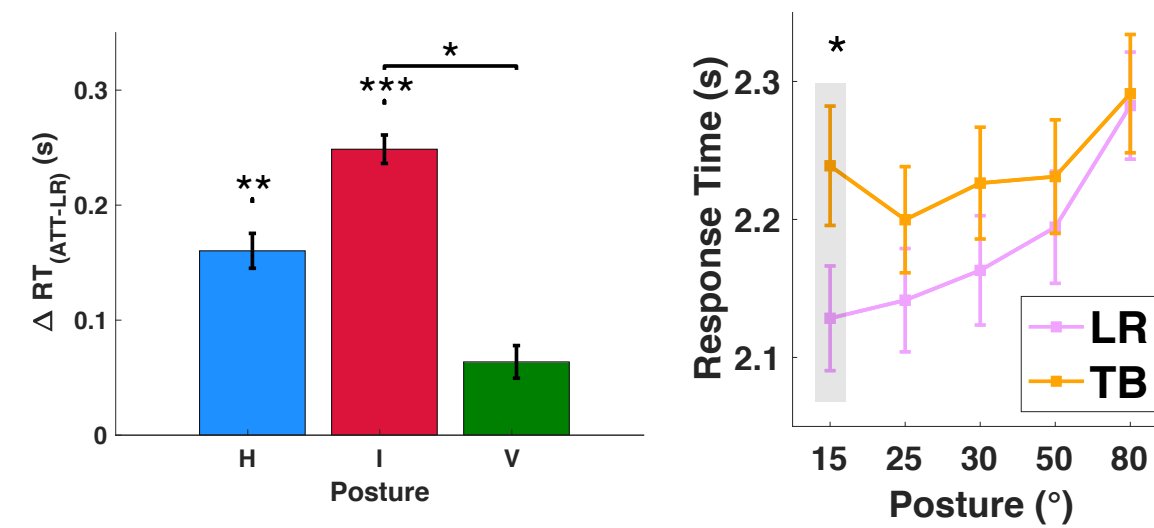


Questions and Comments

- We show that humans flexibly perceive tactile motion direction in different coordinate systems
- A modified Euler-matrix based generative model explained behavioral report.

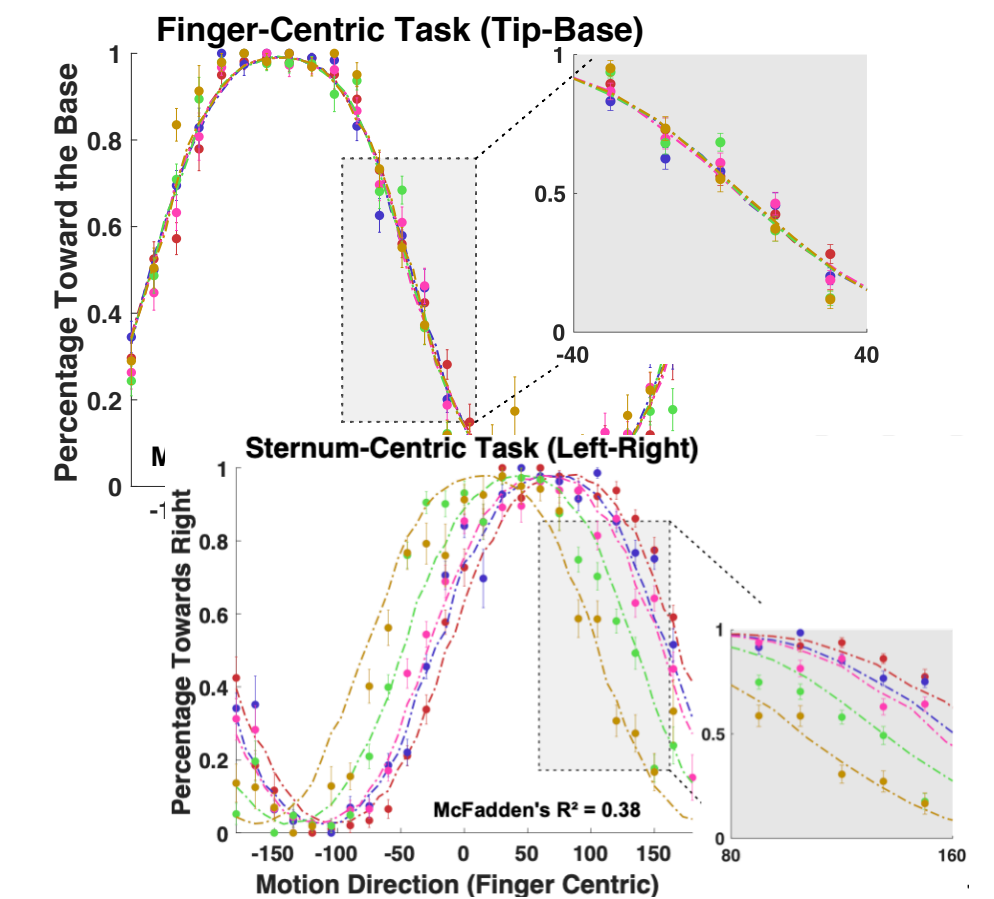
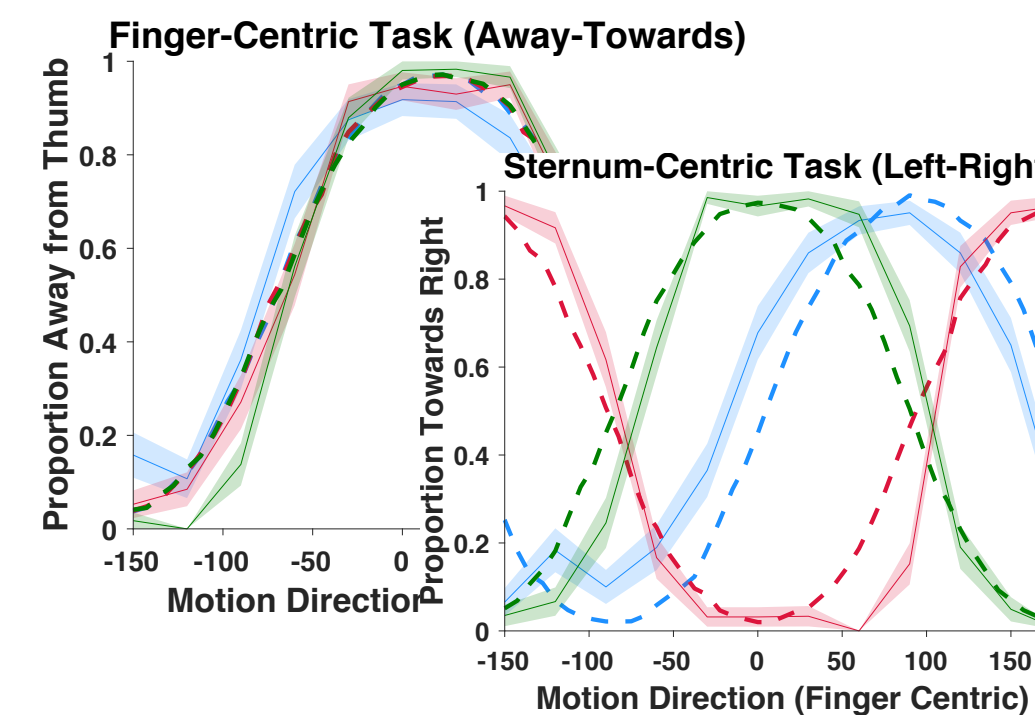


- Faster reaction times in the sternum-centric task.

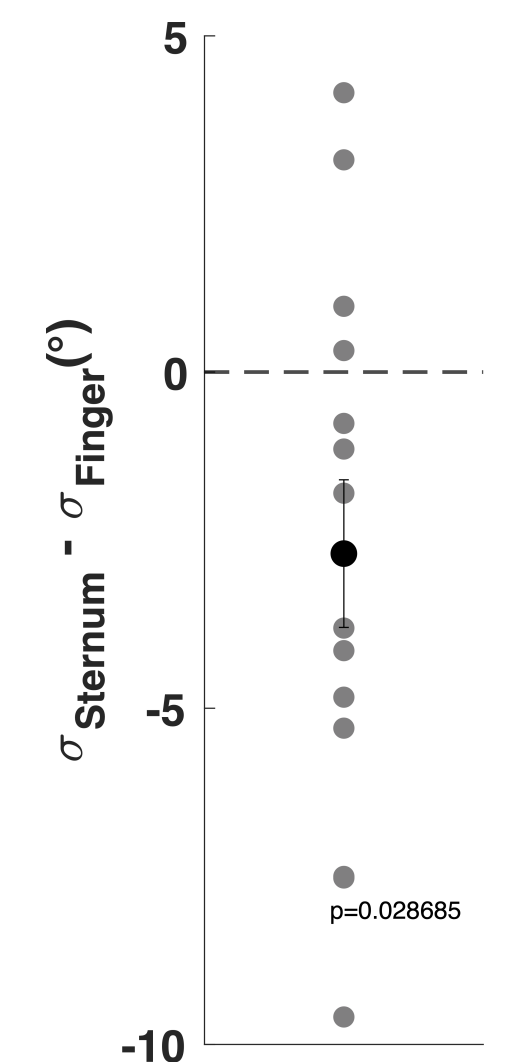
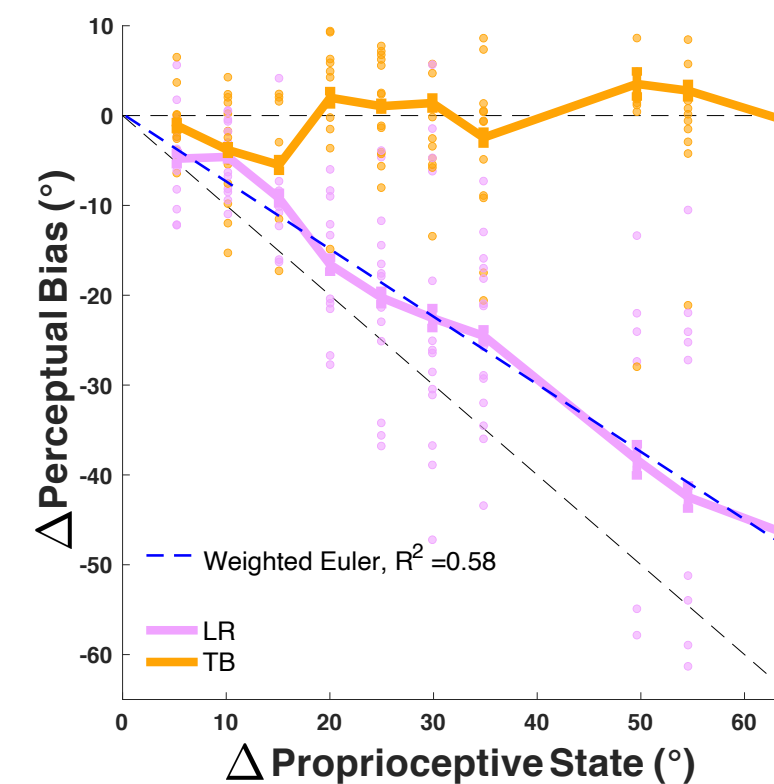


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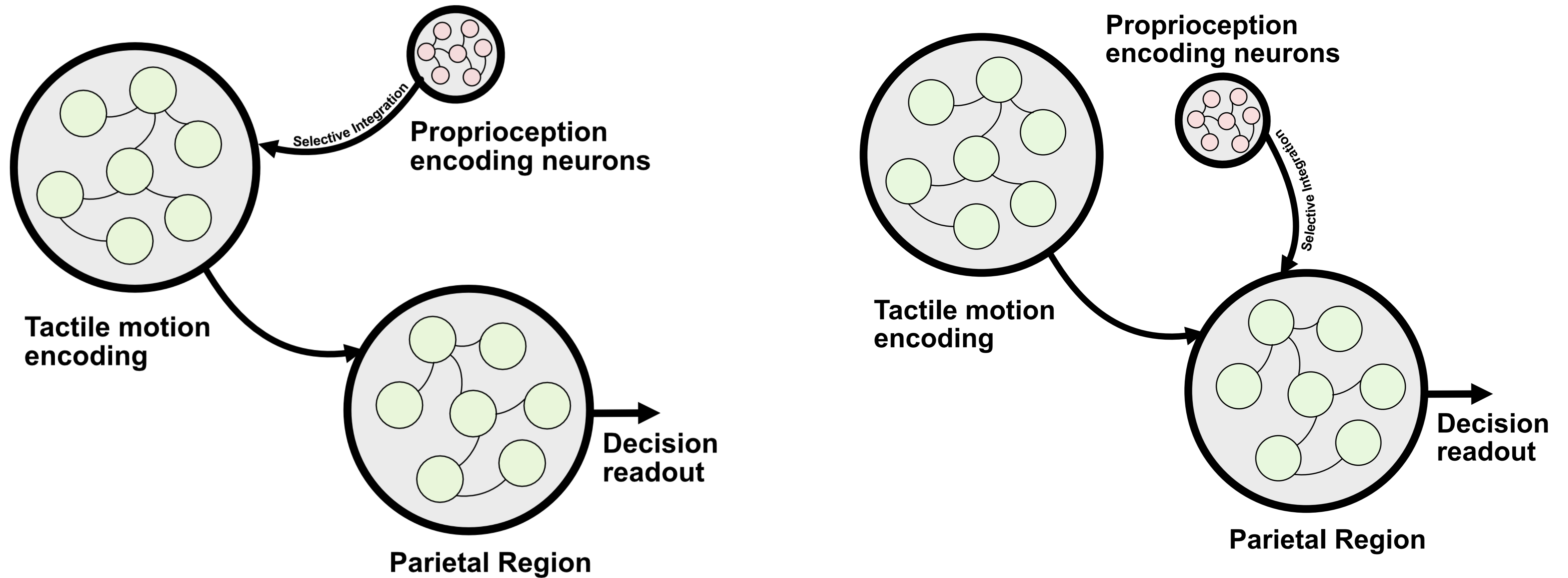


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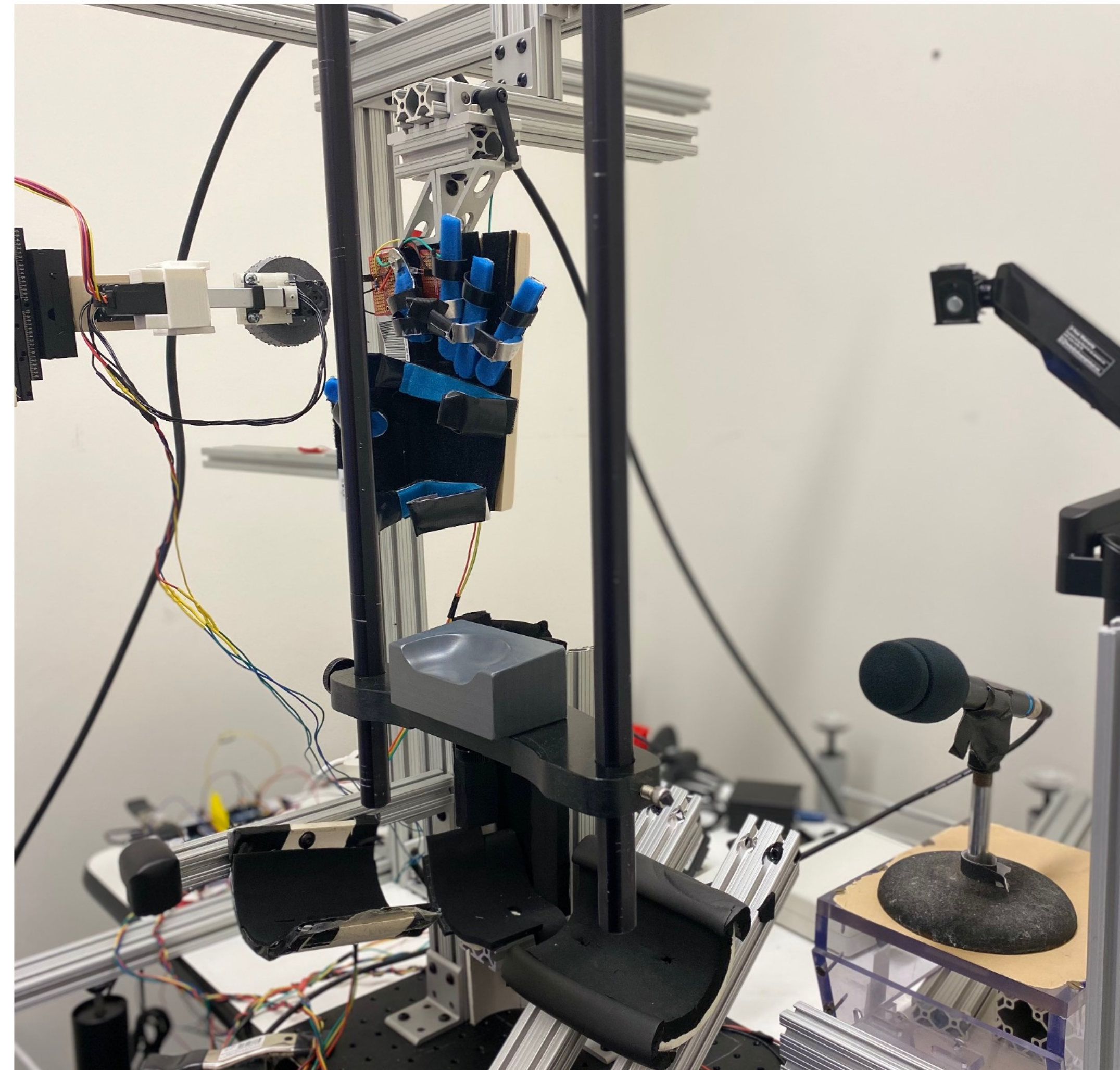
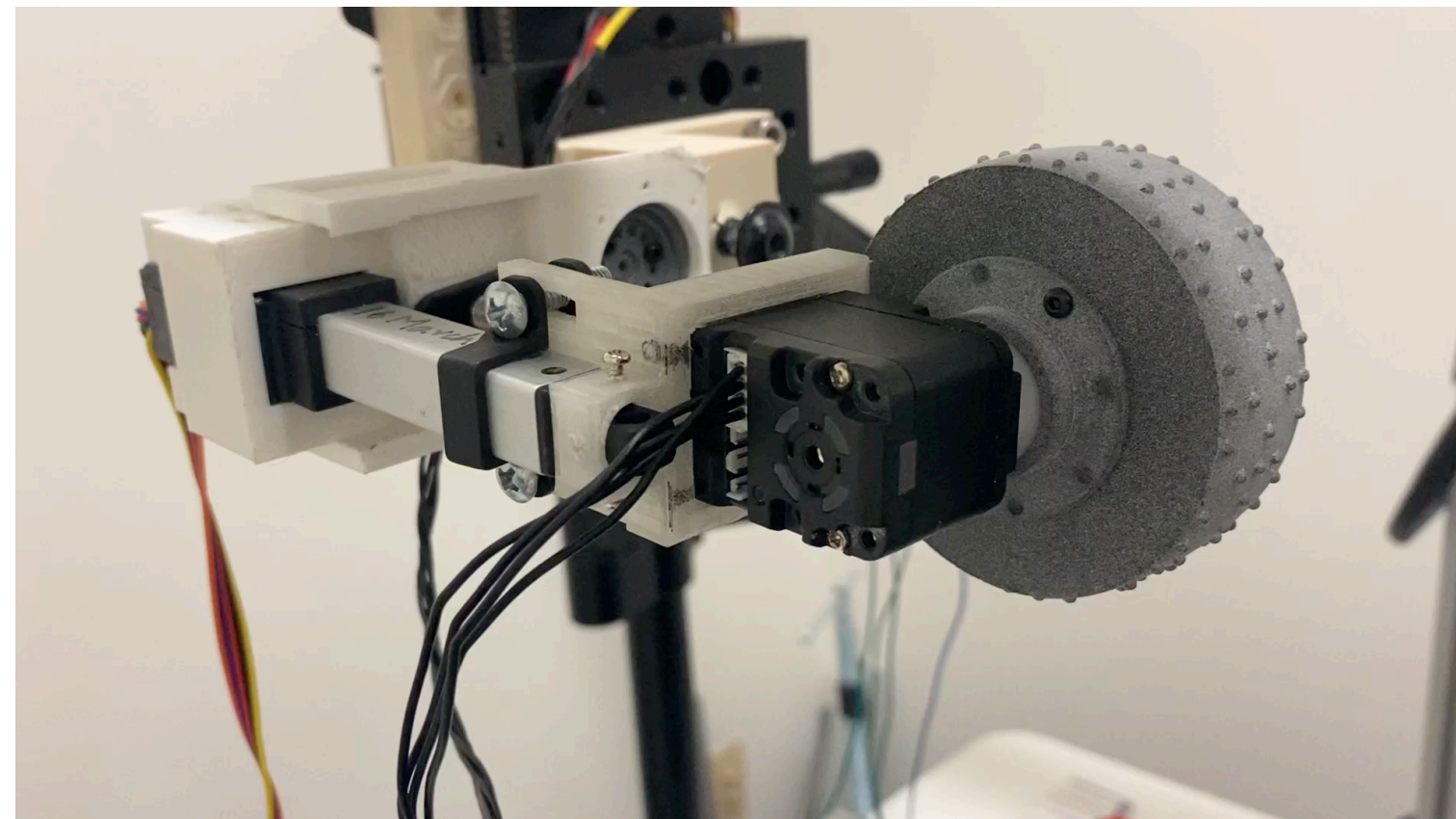
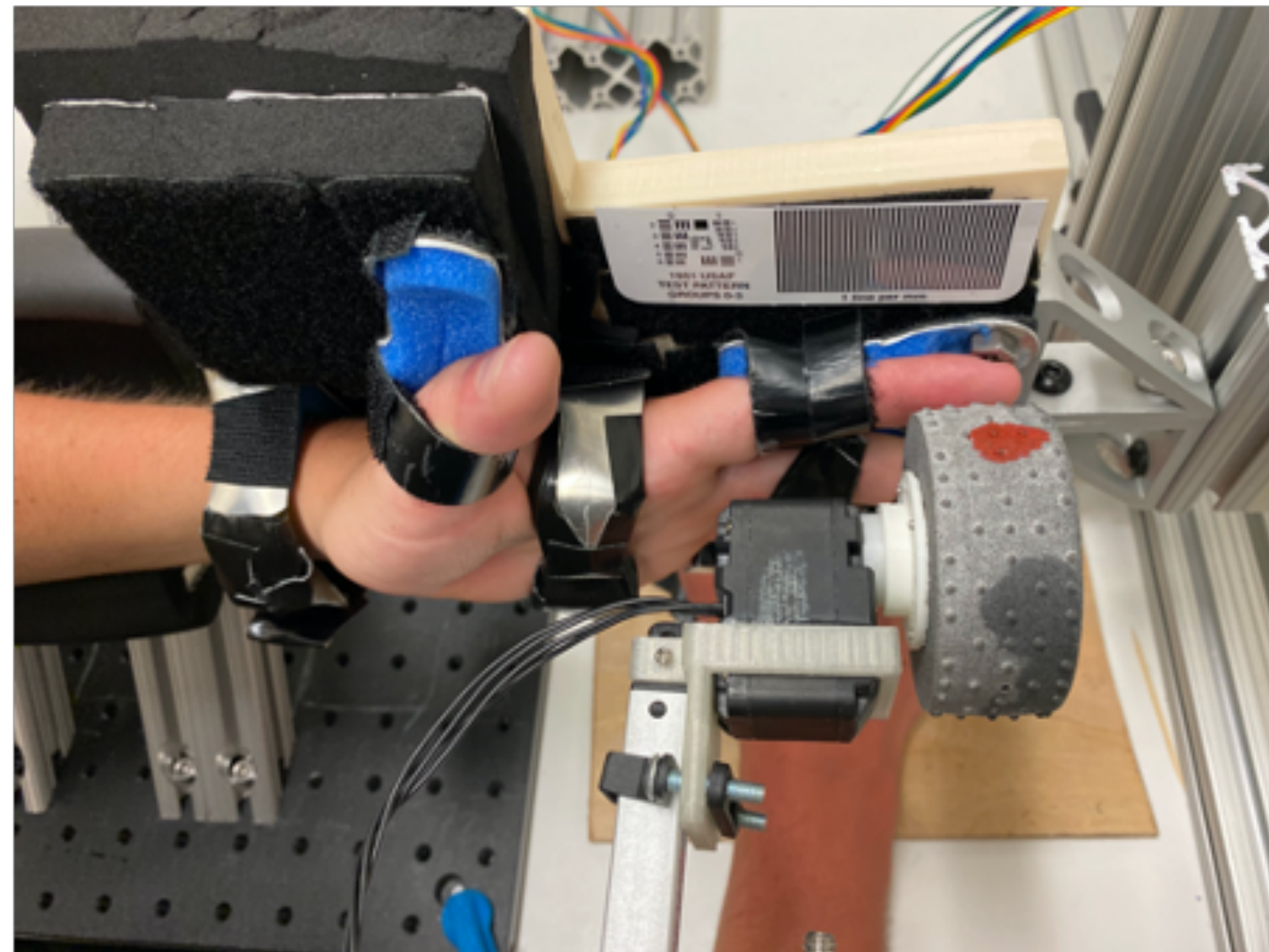


Supplementary Material

Neural implementation possibilities

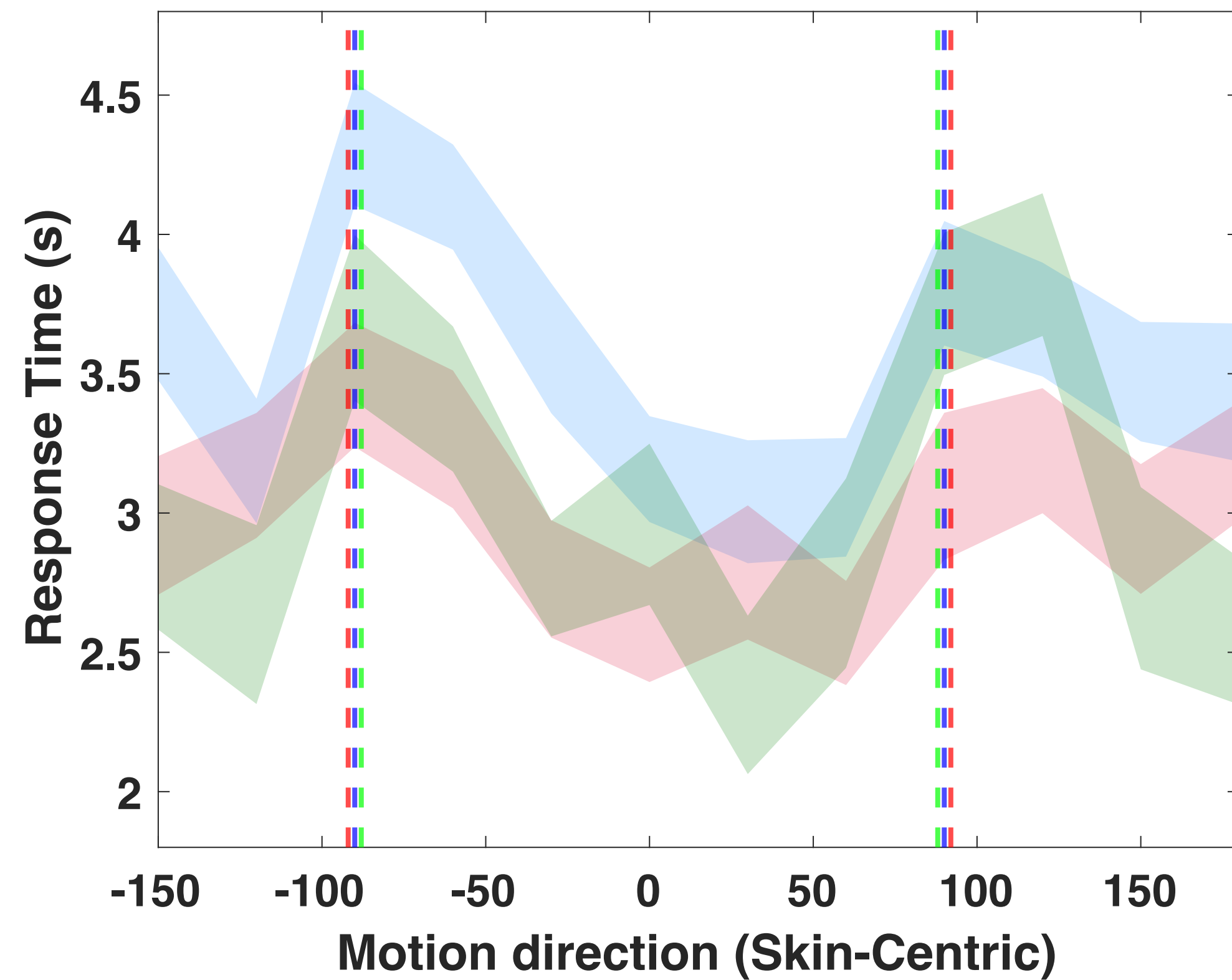


Old Experiment Design

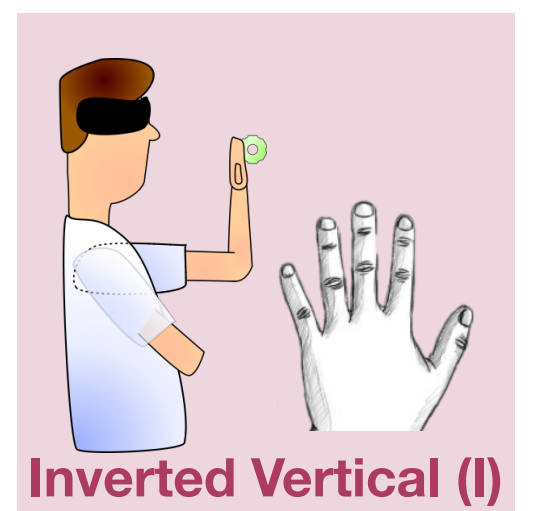
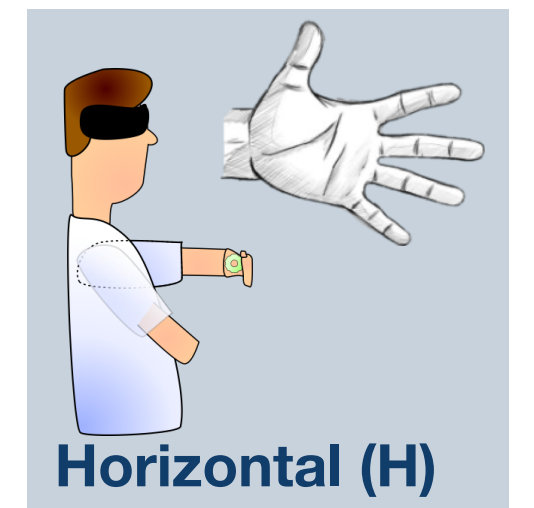
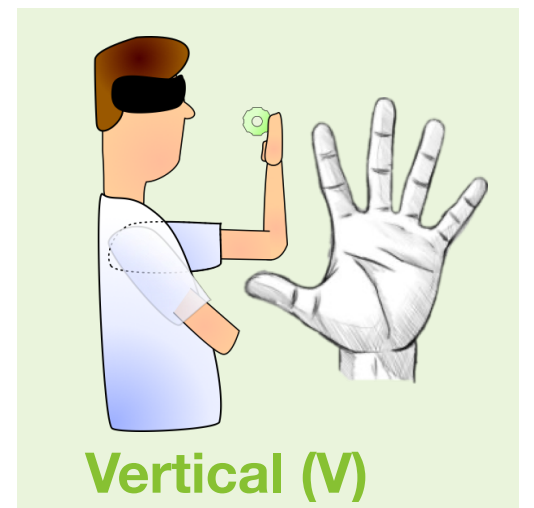
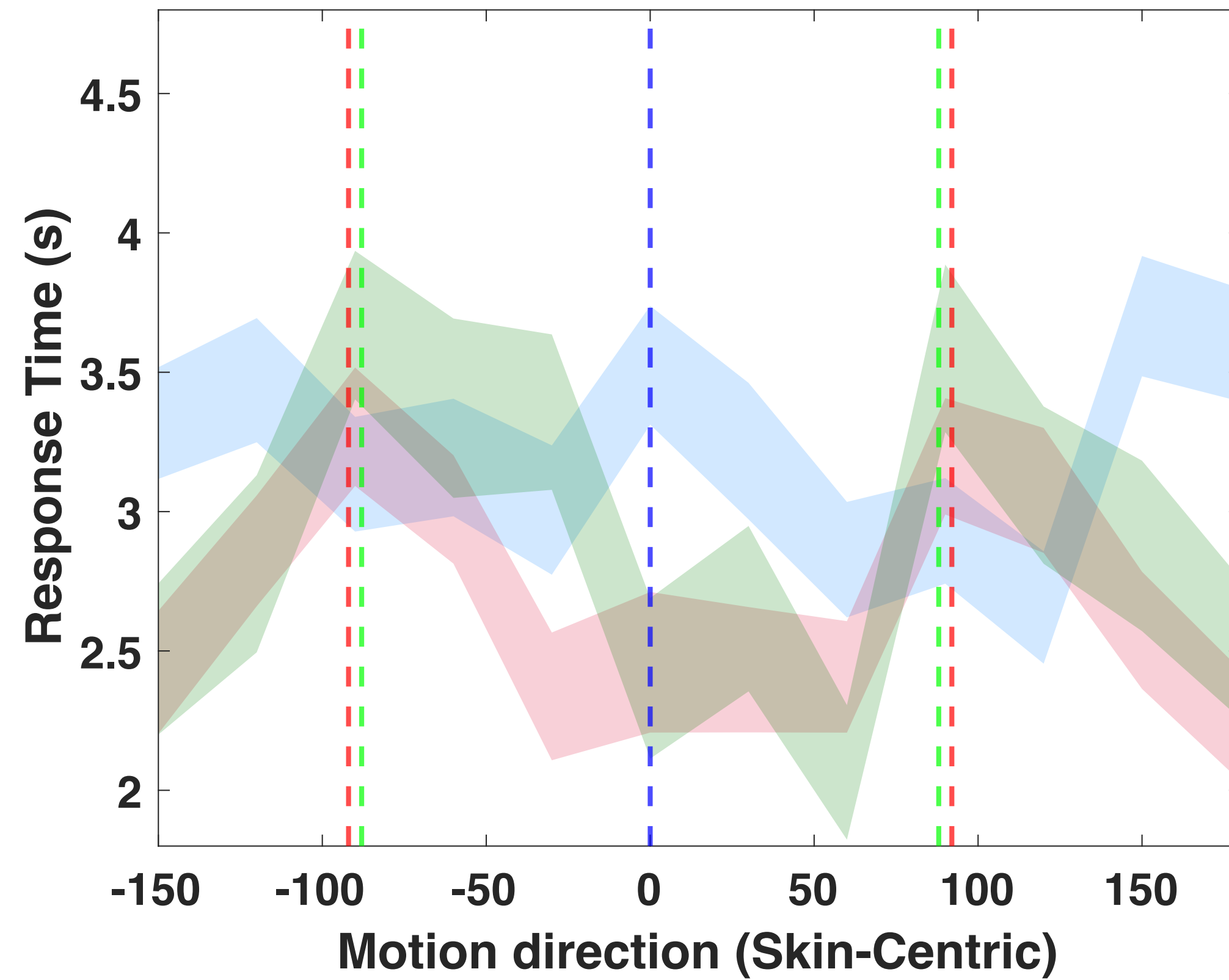


How the reaction time changes with the angle measure.

Away/ Towards the thumb

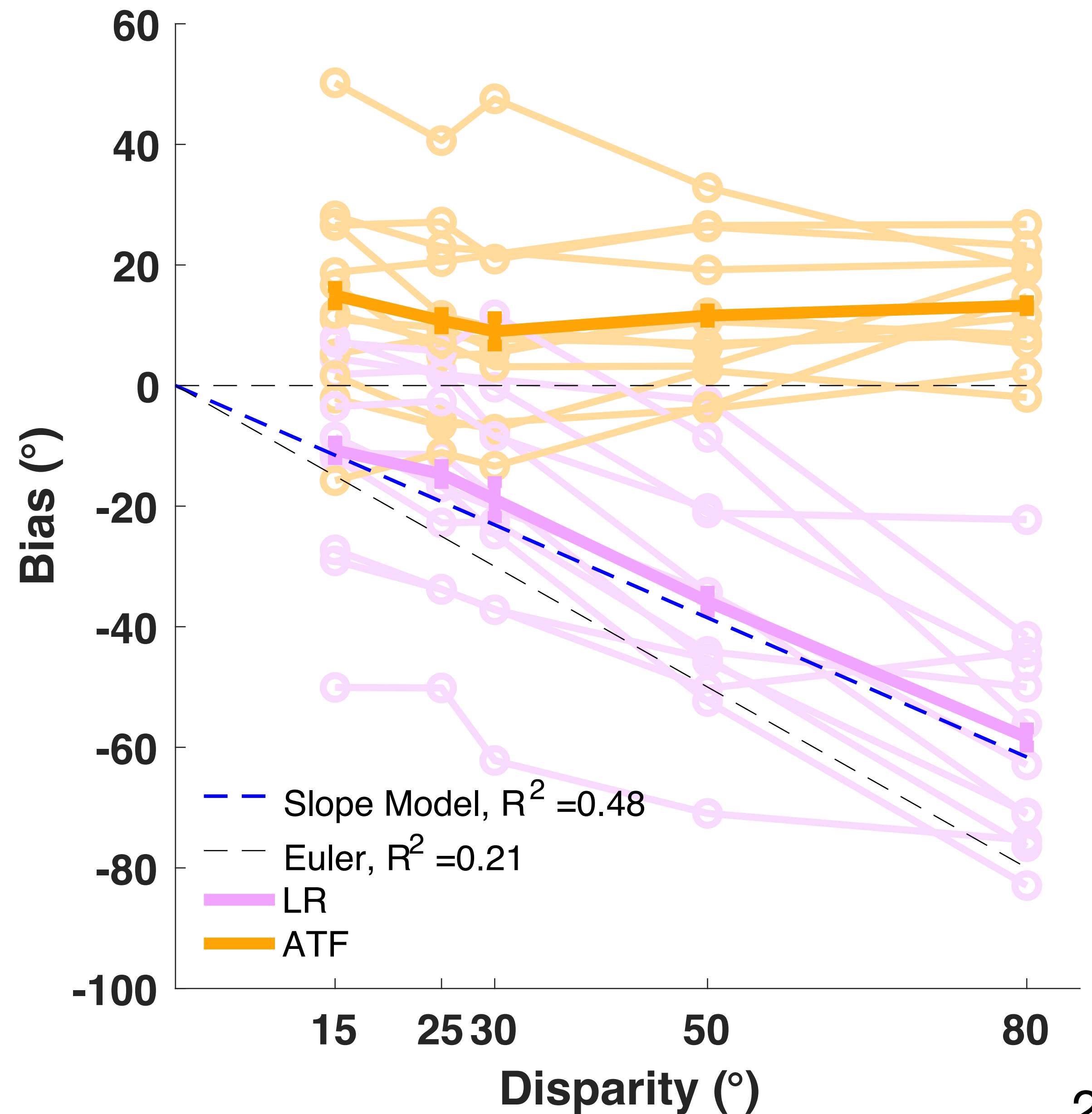


Left/ Right

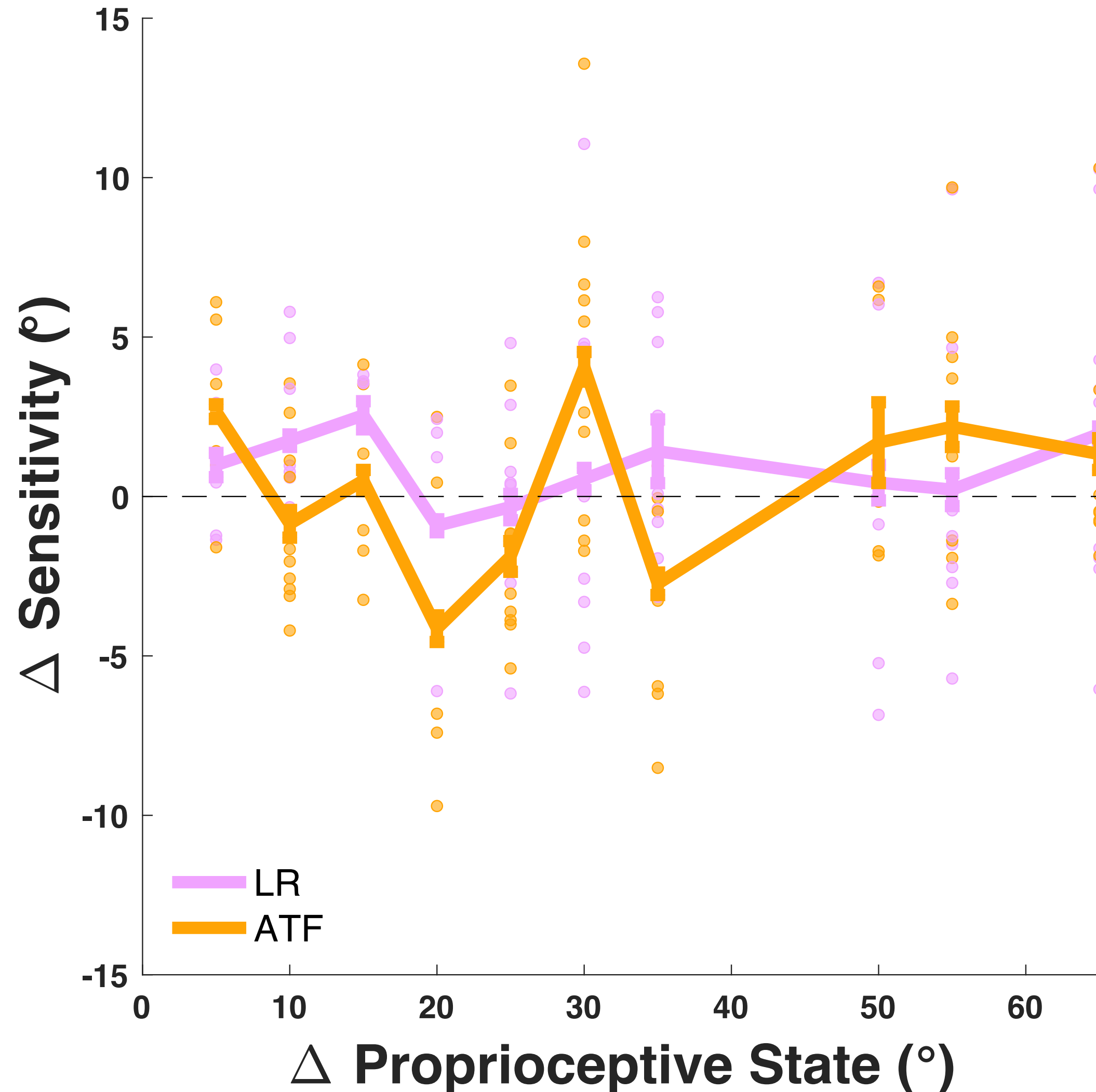


Proprioceptive bias in tactile motion report in the sternum-centric coordinate system.

No proprioceptive-dependent bias in the finger-centric reference frame.



Why do we choose only one sensitivity term to model our results?



Similar sensitivity difference across different proprioceptive states.

Responses of the population in two coordinate systems

