

# Coordinate Transforms Mediating Tactile Motion Representations with the Hand

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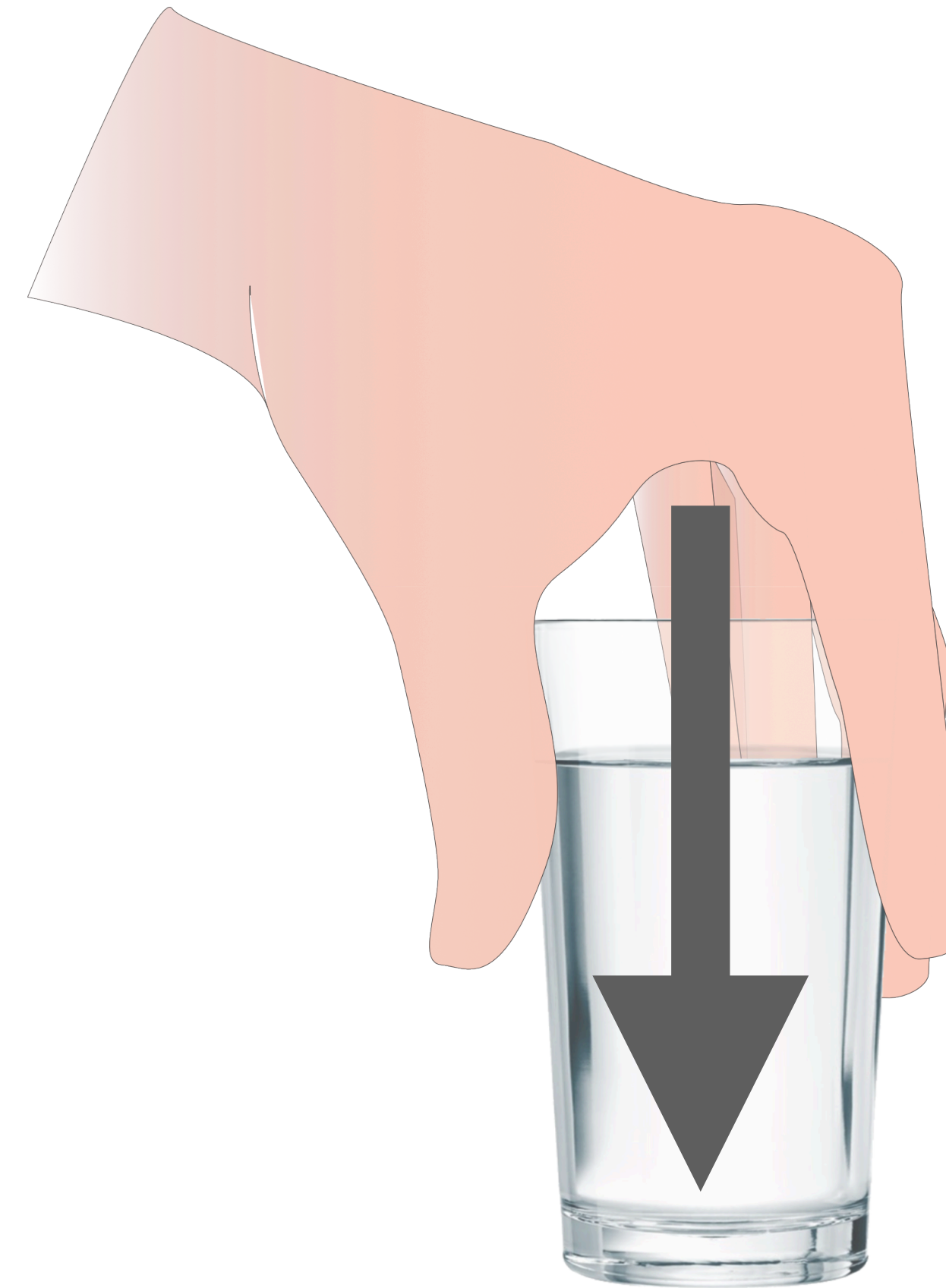
PI: Manuel Gomez-Ramirez

July 5th, 2022

**Is the object moving downwards or towards the palm?**

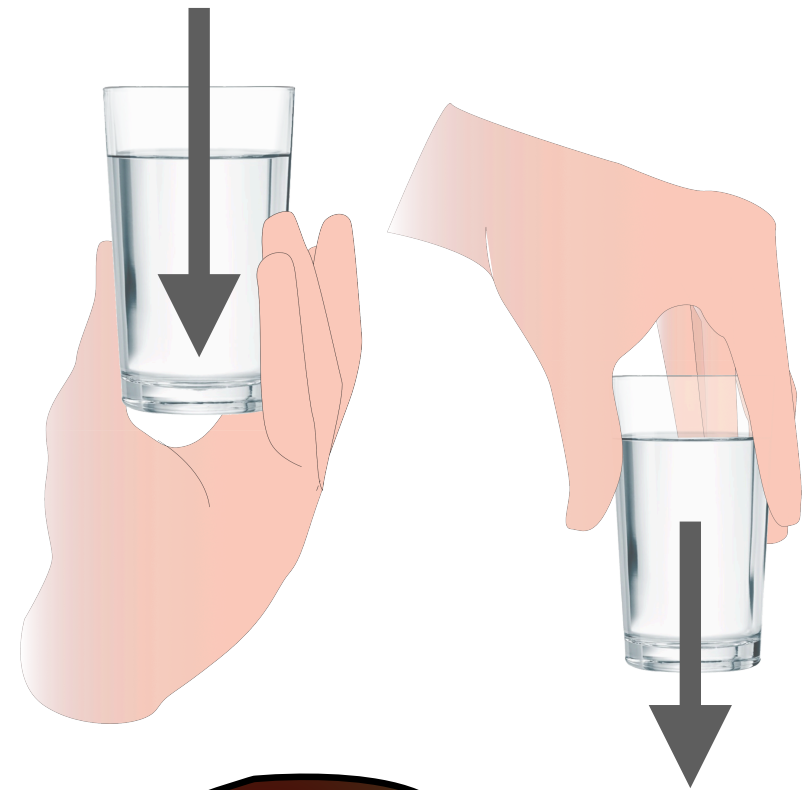


**Downwards**  
**Towards the palm**



**Downwards**  
**Away from the palm**

# Is the object moving downwards or towards the palm?



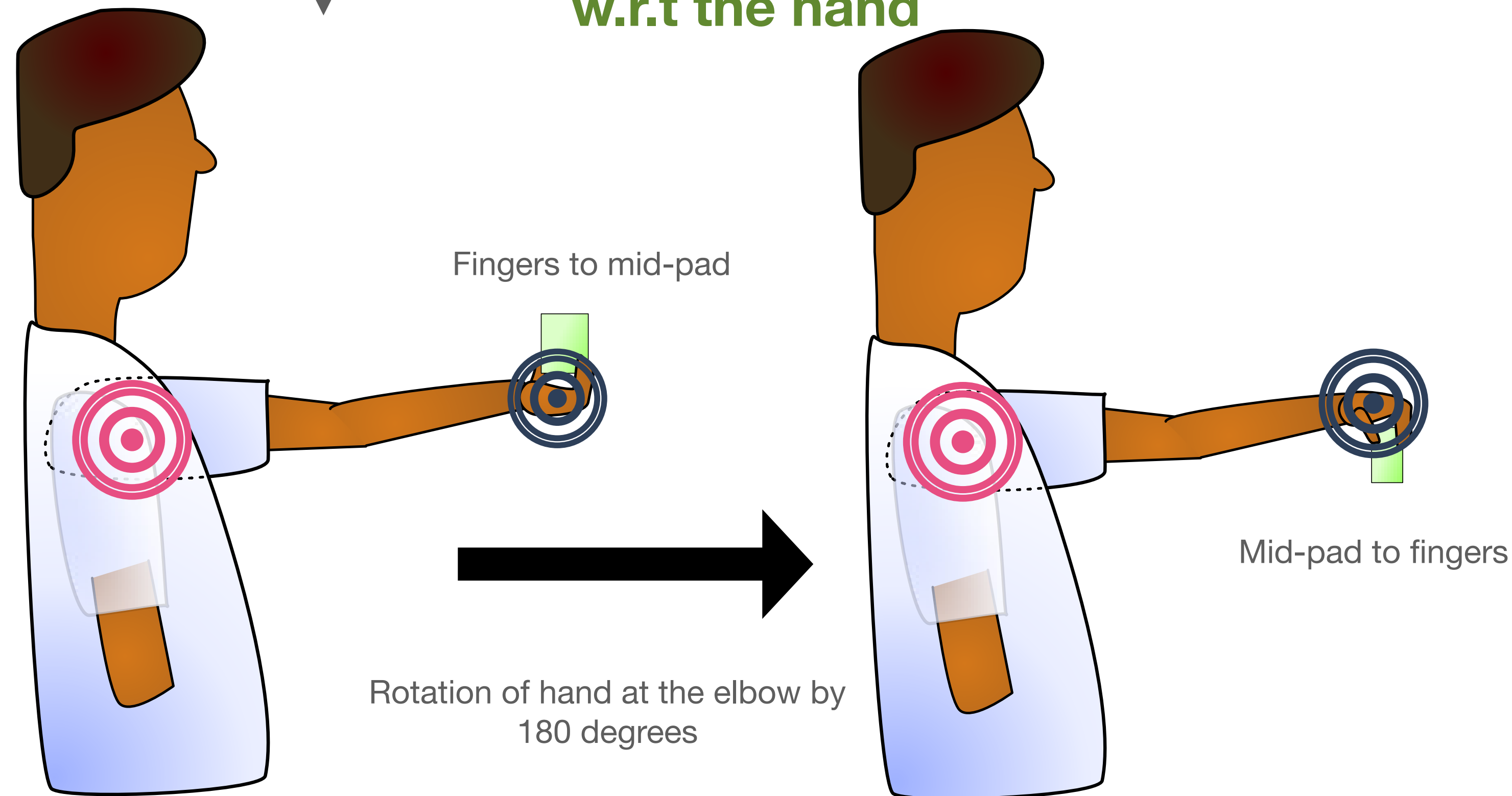
What changes between the two cases?

The posture of the hand

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

= Proprioceptive state of the arm

= Cutaneous motion information

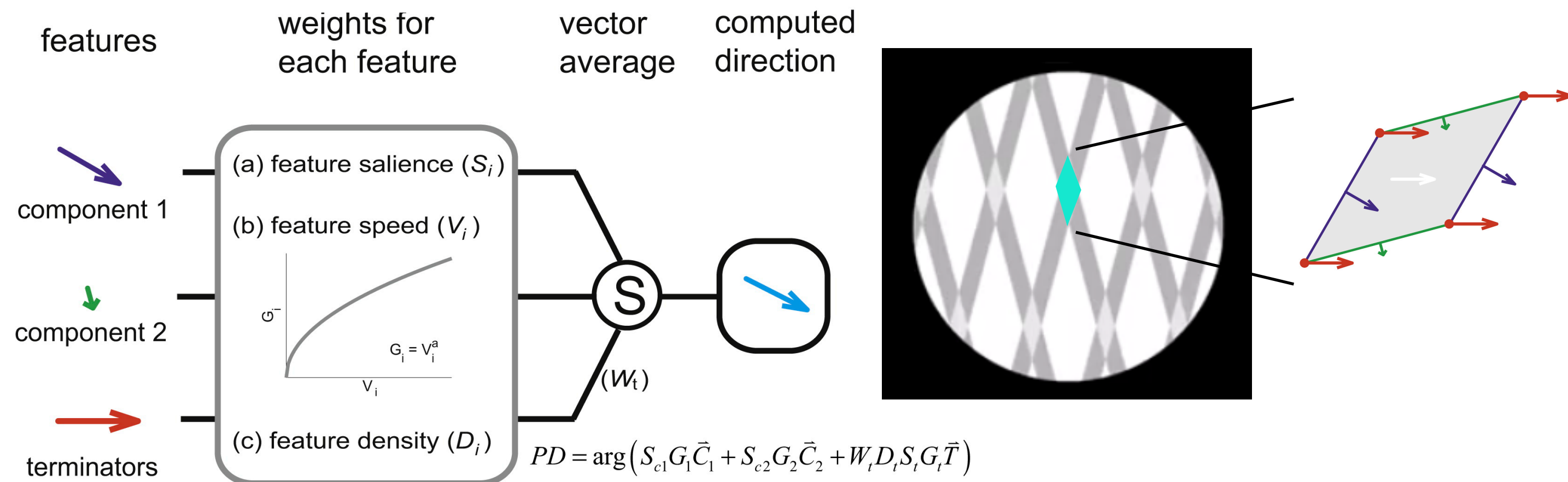
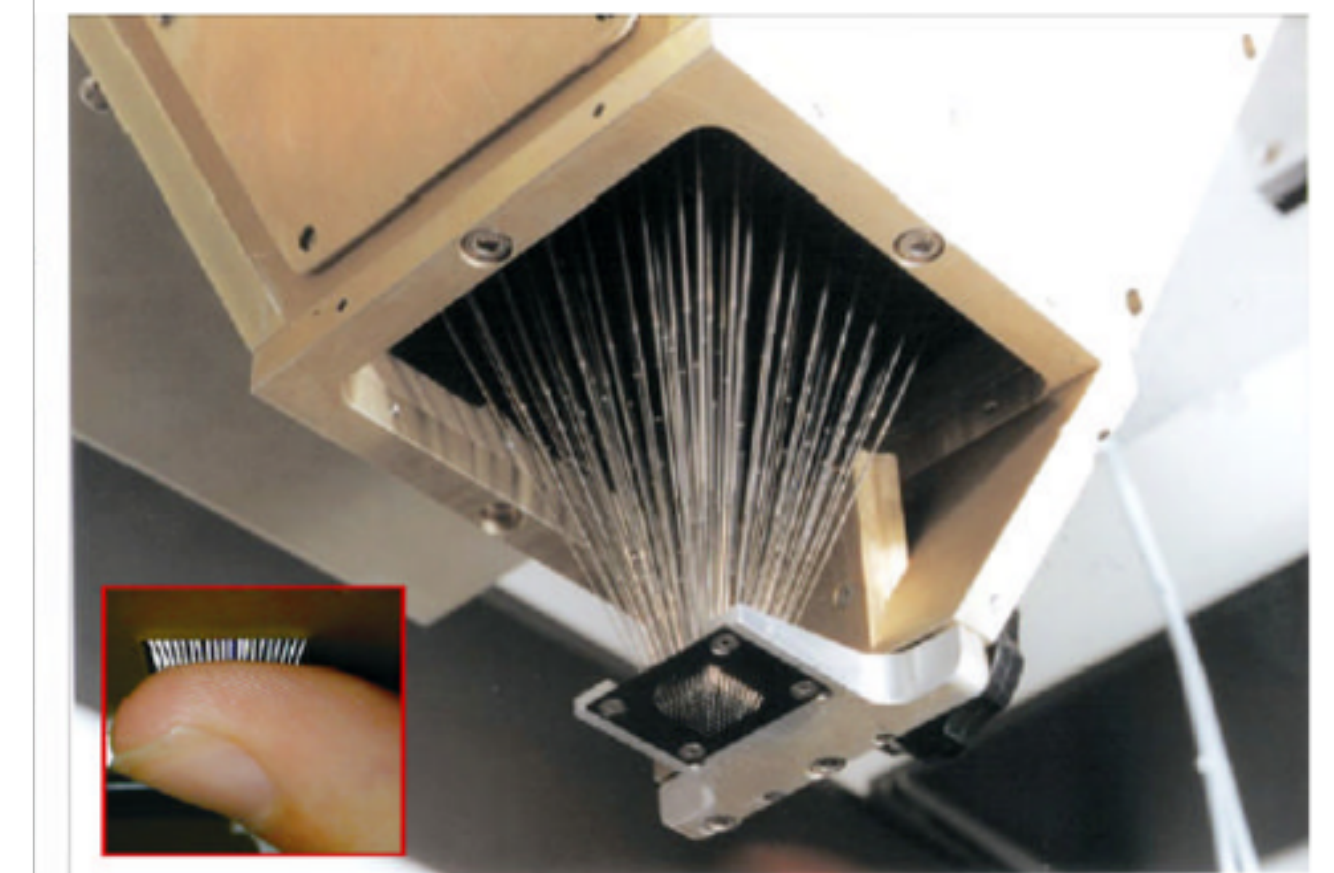


Motion in center-of-the-body reference frame stays the same

Motion in hand reference frame changes

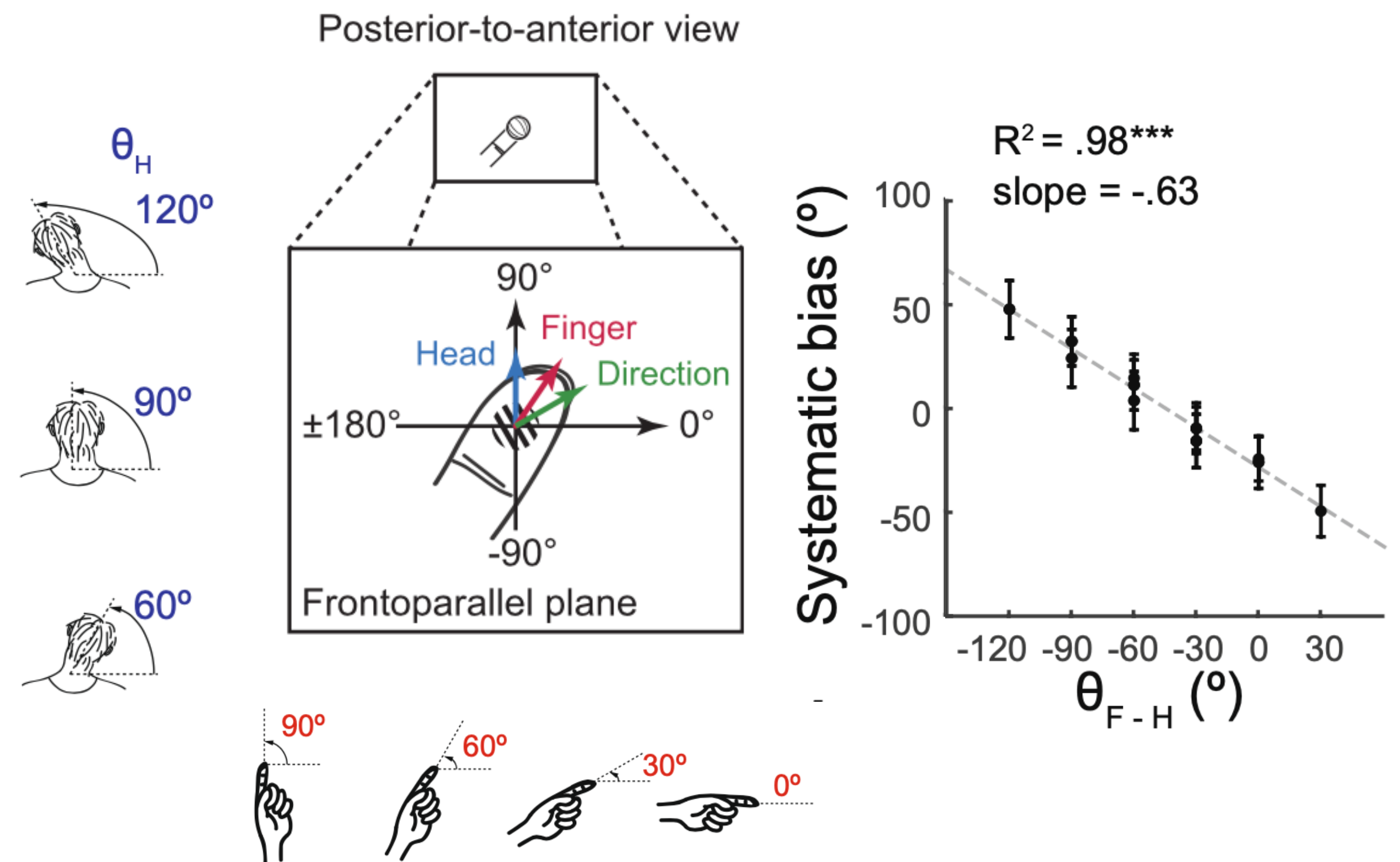
# Analogous motion integration mechanisms in vision and tactile domains

- 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?

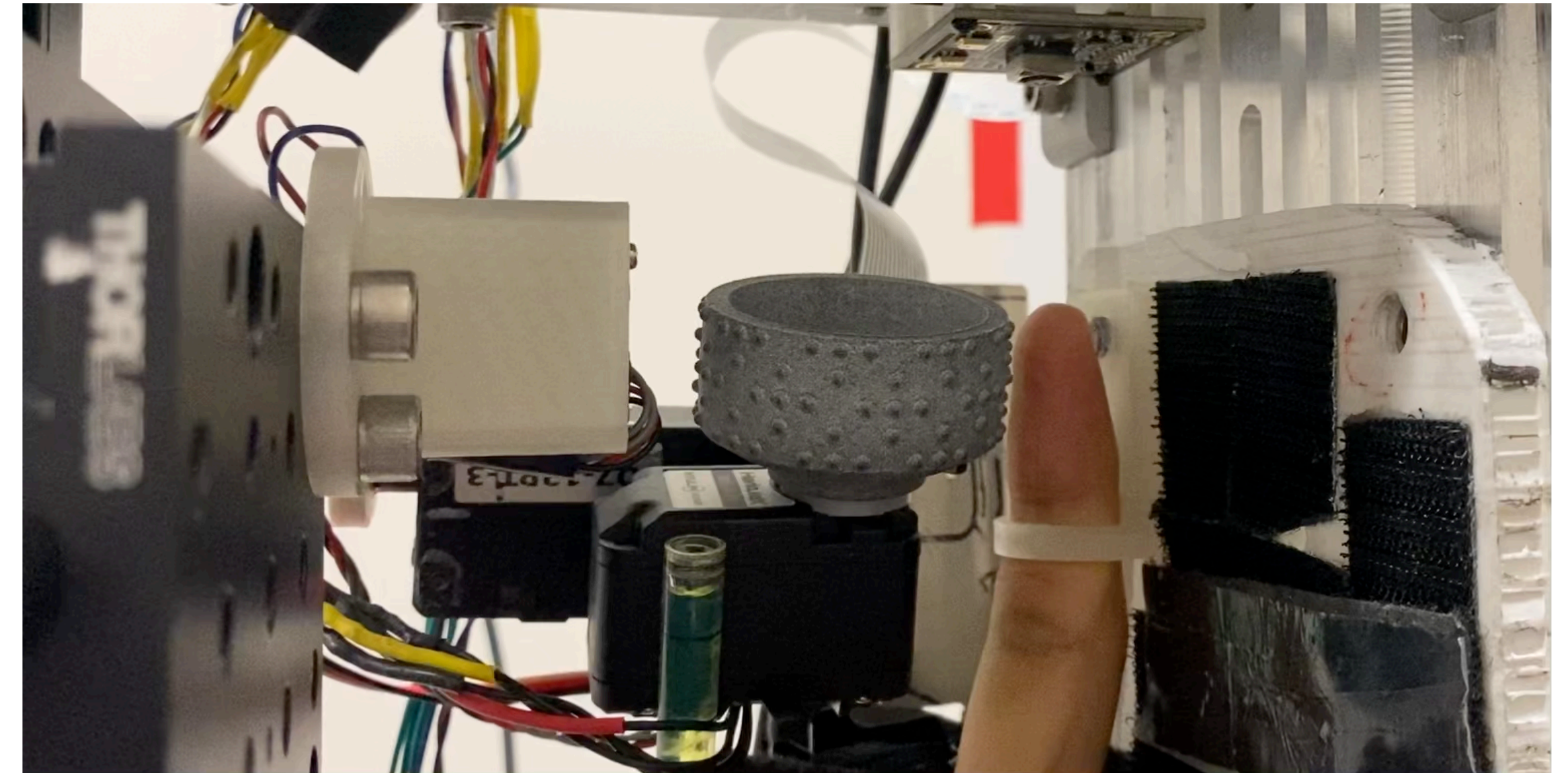
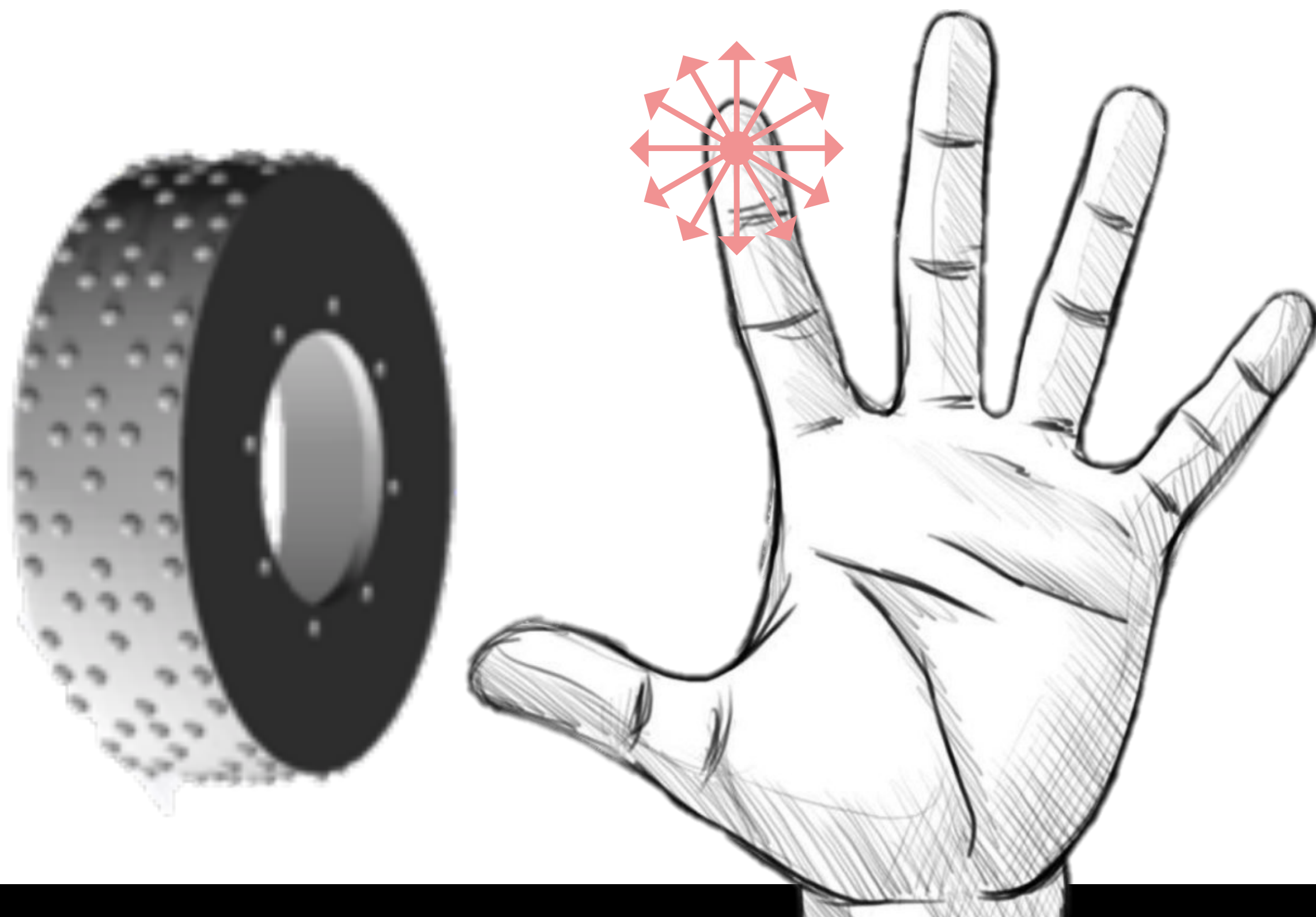
Develop a generalizable theoretical framework that explains human behavioral report.

# 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



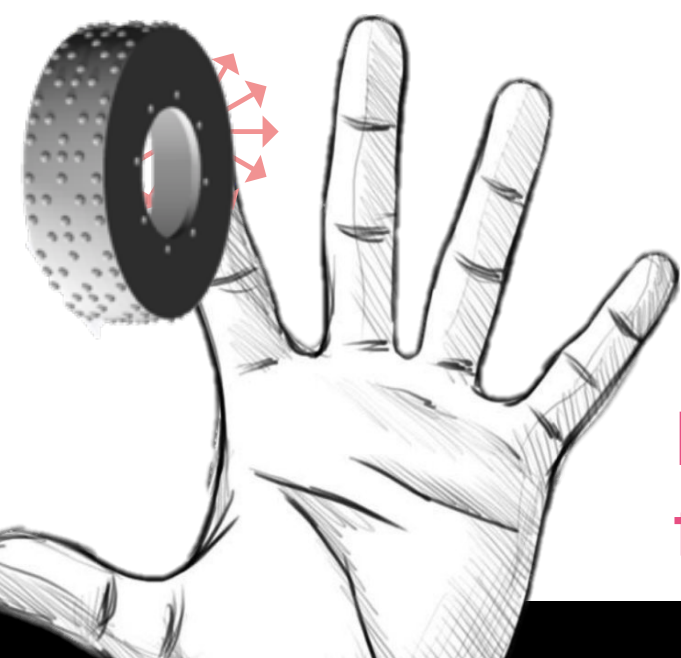
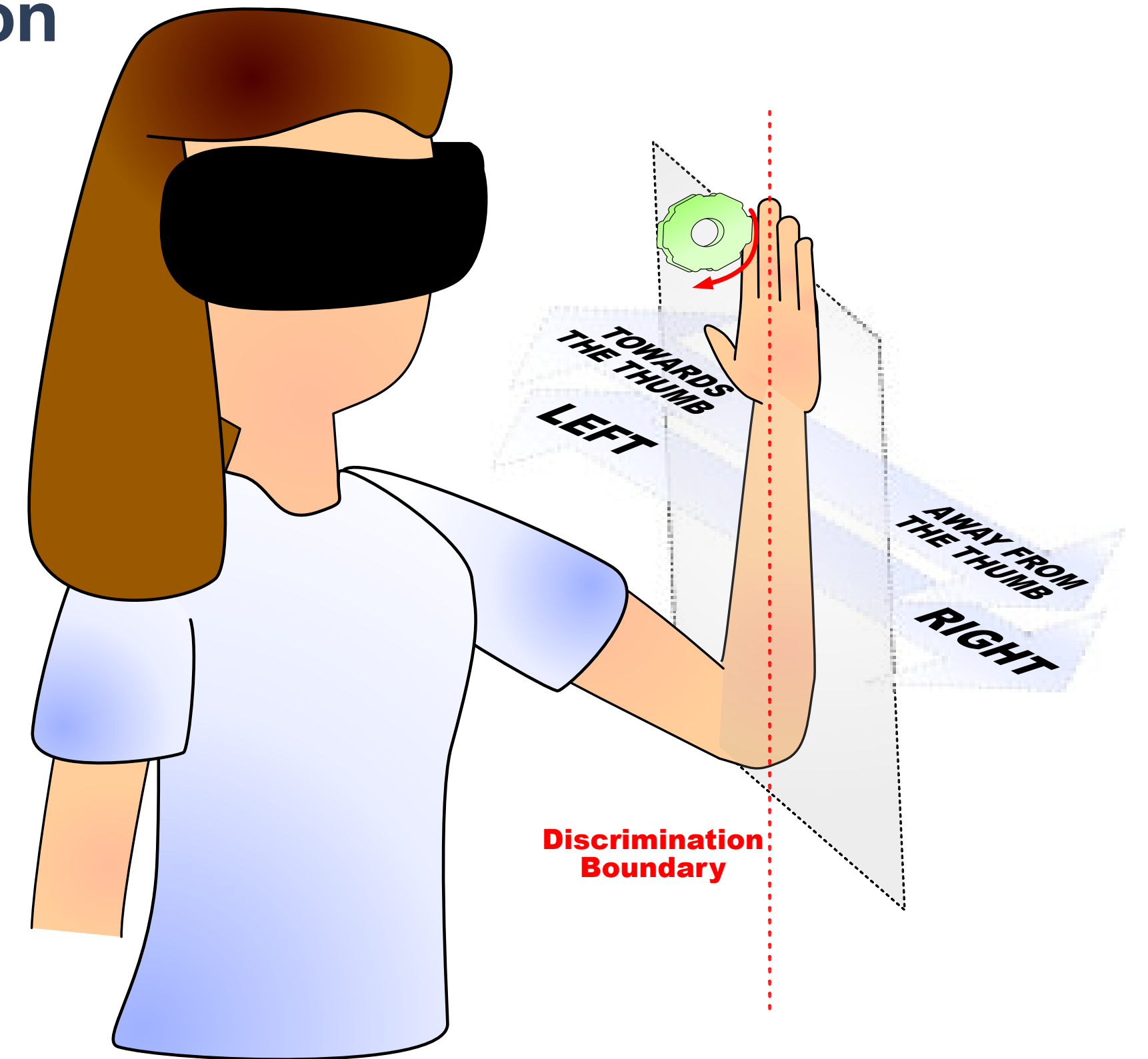
**Sternum-Centric Reference Frame**

**AWAY vs TOWARDS**

the thumb-edge of the palm



**Finger-Centric Reference Frame**



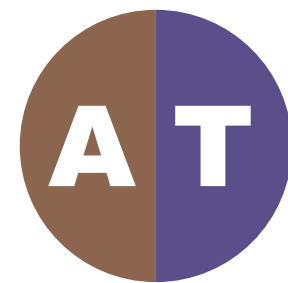
Dot Motion Stimulus at D2  
for 2 seconds, steps of 30 degrees.

# Experiment Design: Three Proprioceptive States

## 2-AFC Motion Discrimination Task

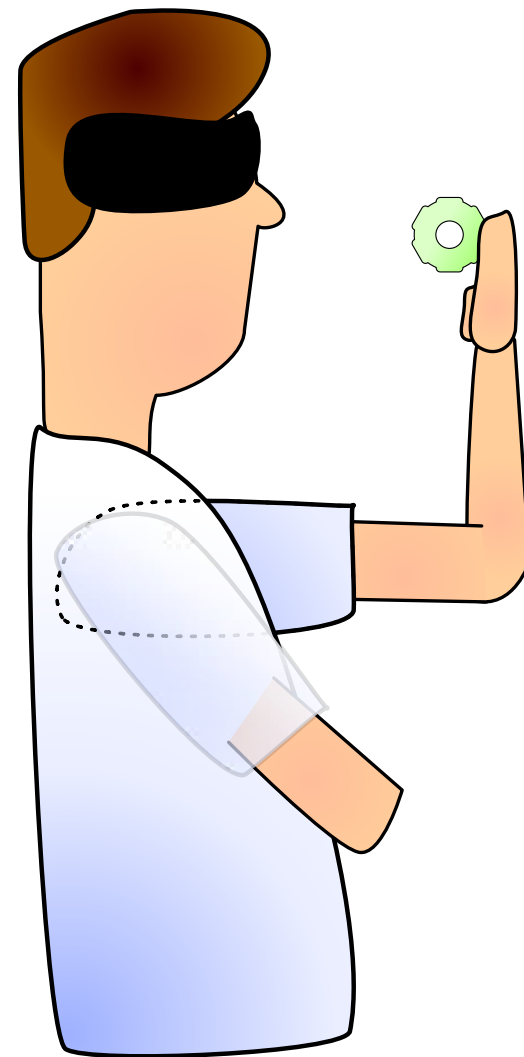


Sternum-Centric Reference Frame

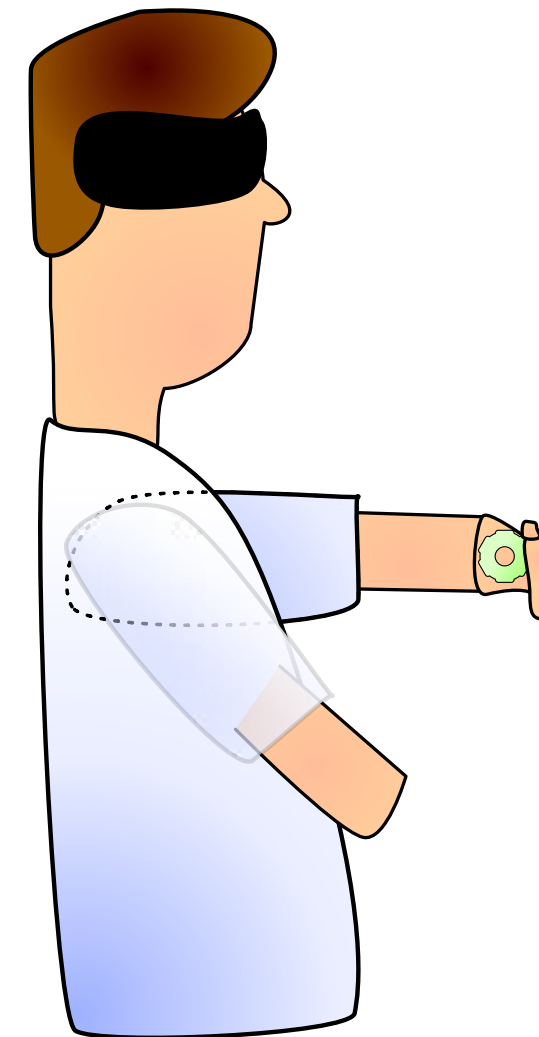


Finger-Centric Reference Frame

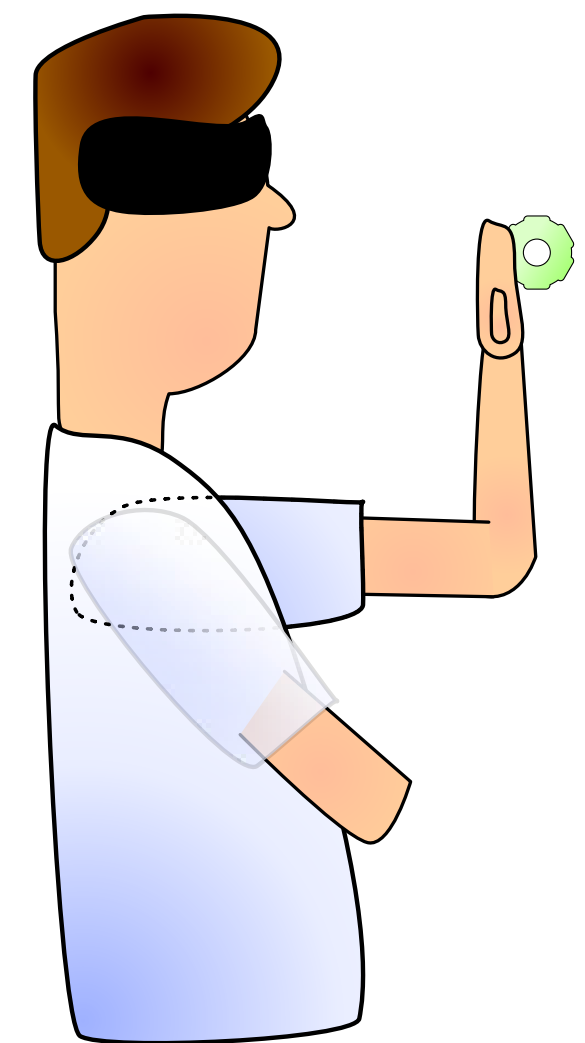
Vertical (V)



Horizontal (H)

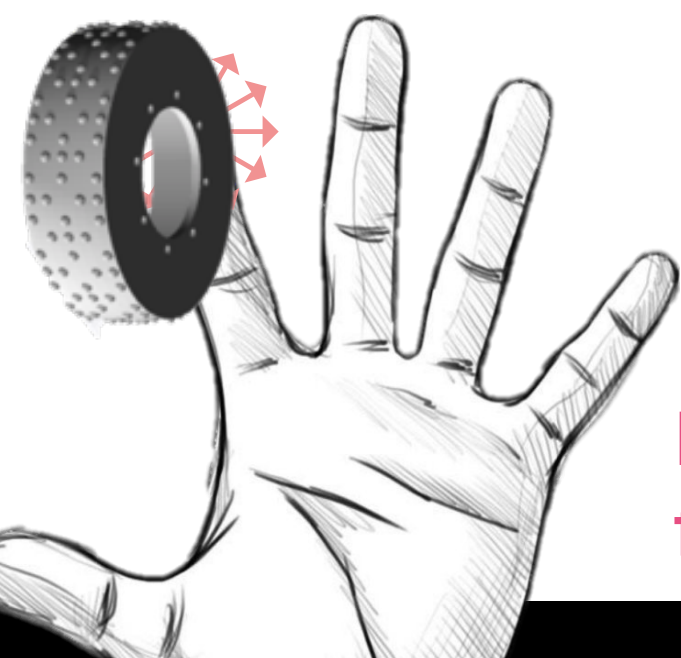


Inverted Vertical (I)



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

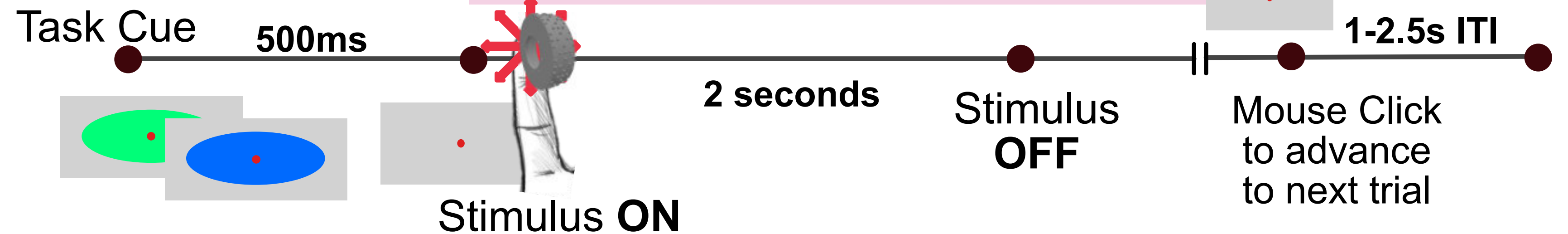


Sternum-Centric Reference Frame

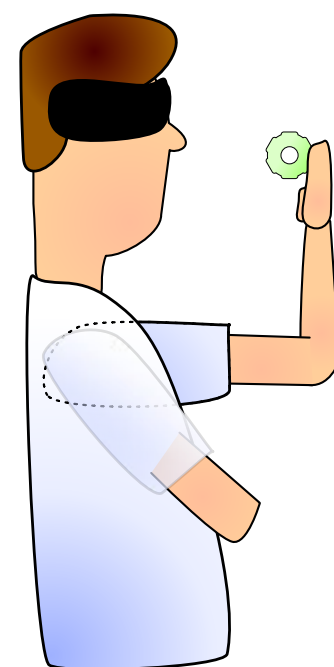


Finger-Centric Reference Frame

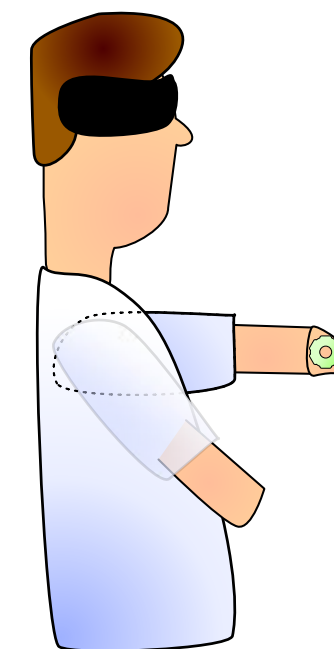
**Sternum-Centric/  
Finger-Centric**



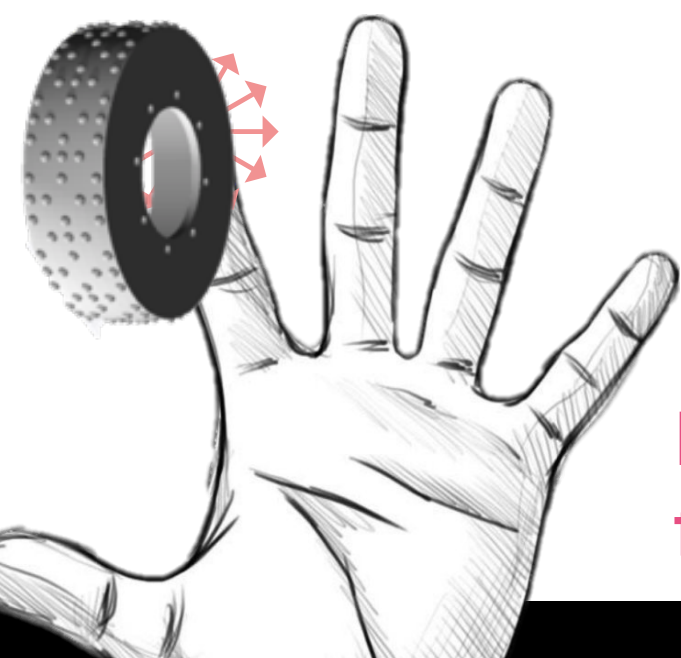
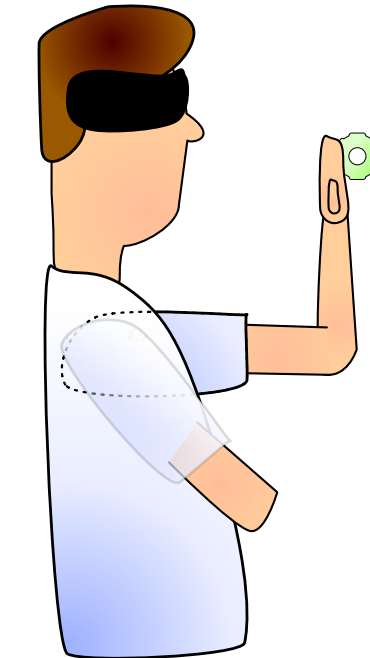
**Vertical (V)**



**Horizontal (H)**

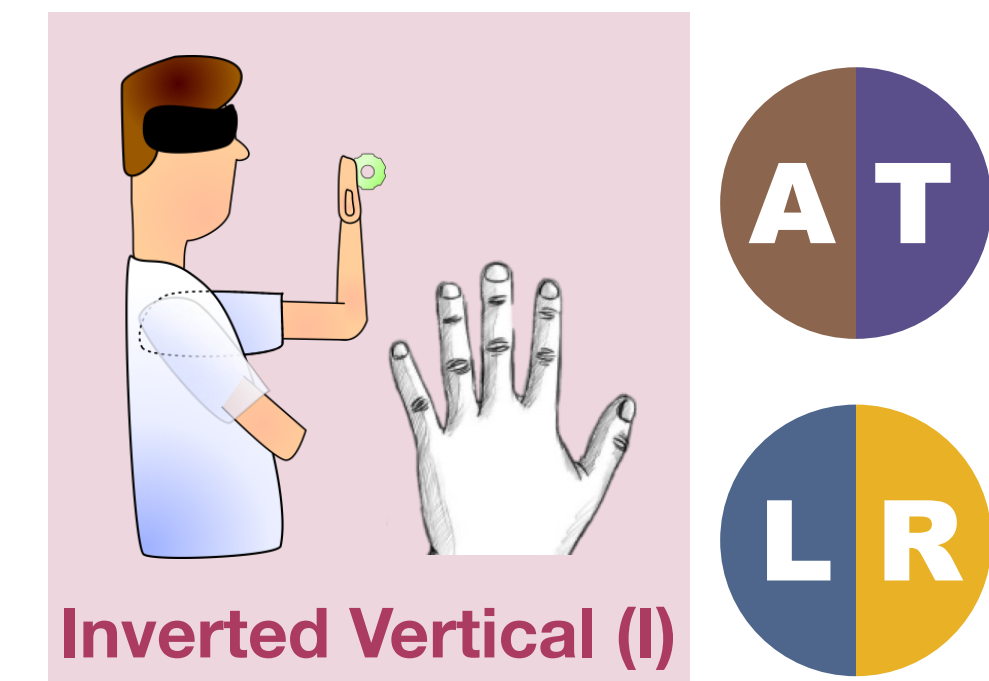
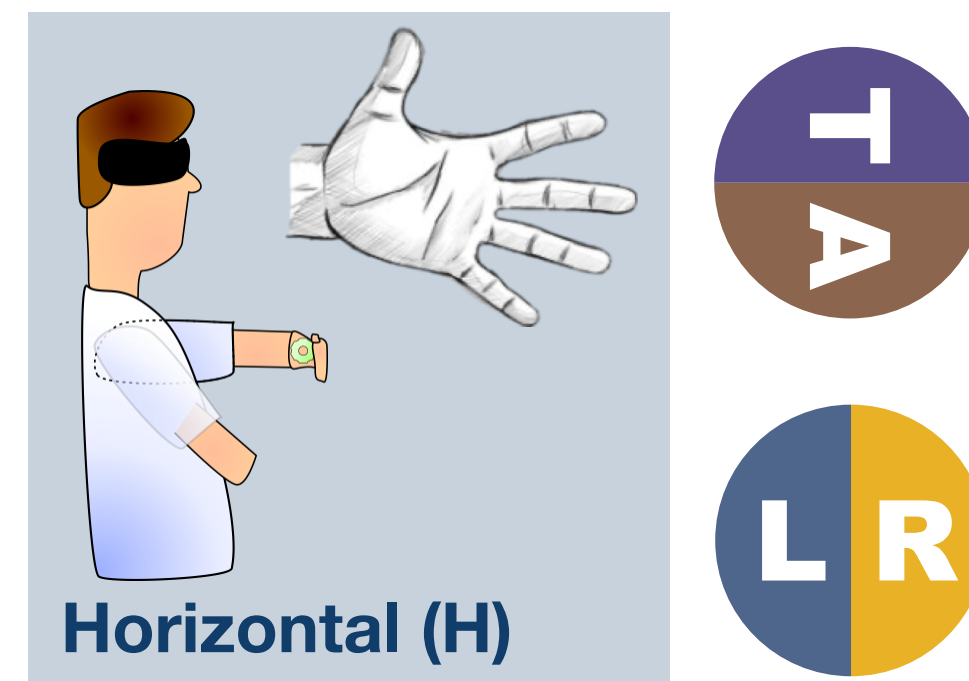
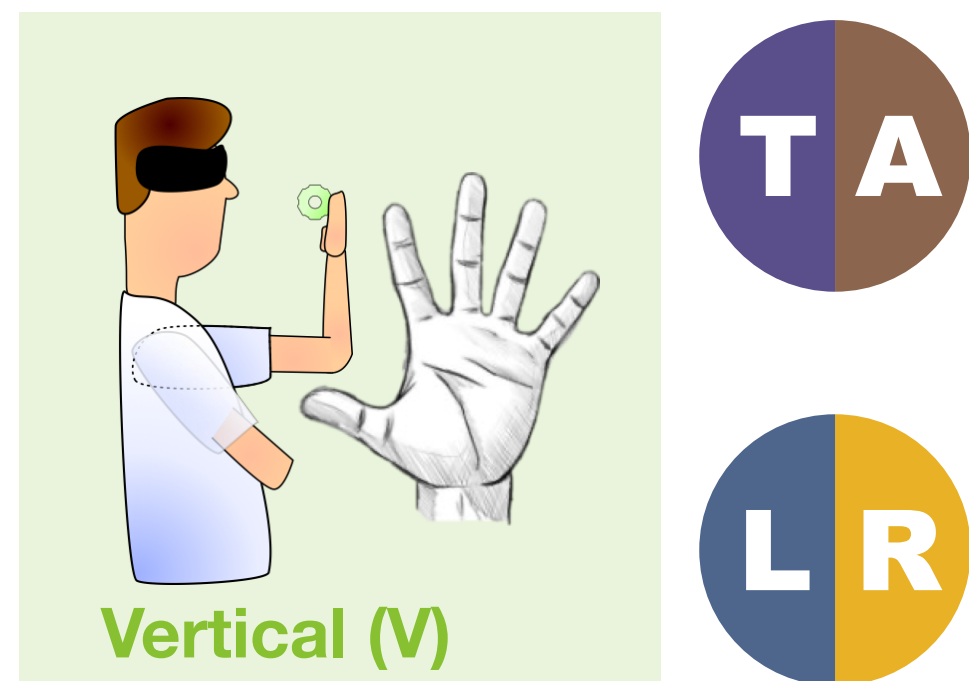
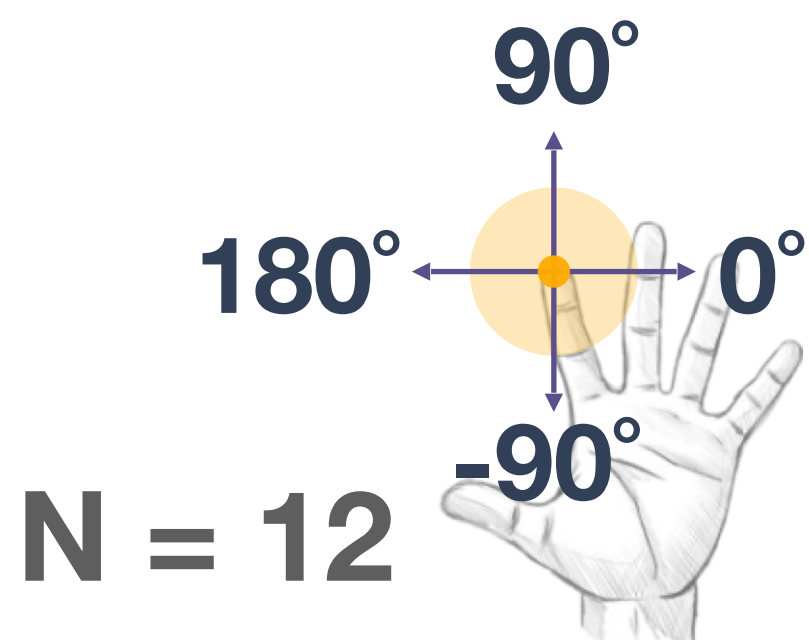
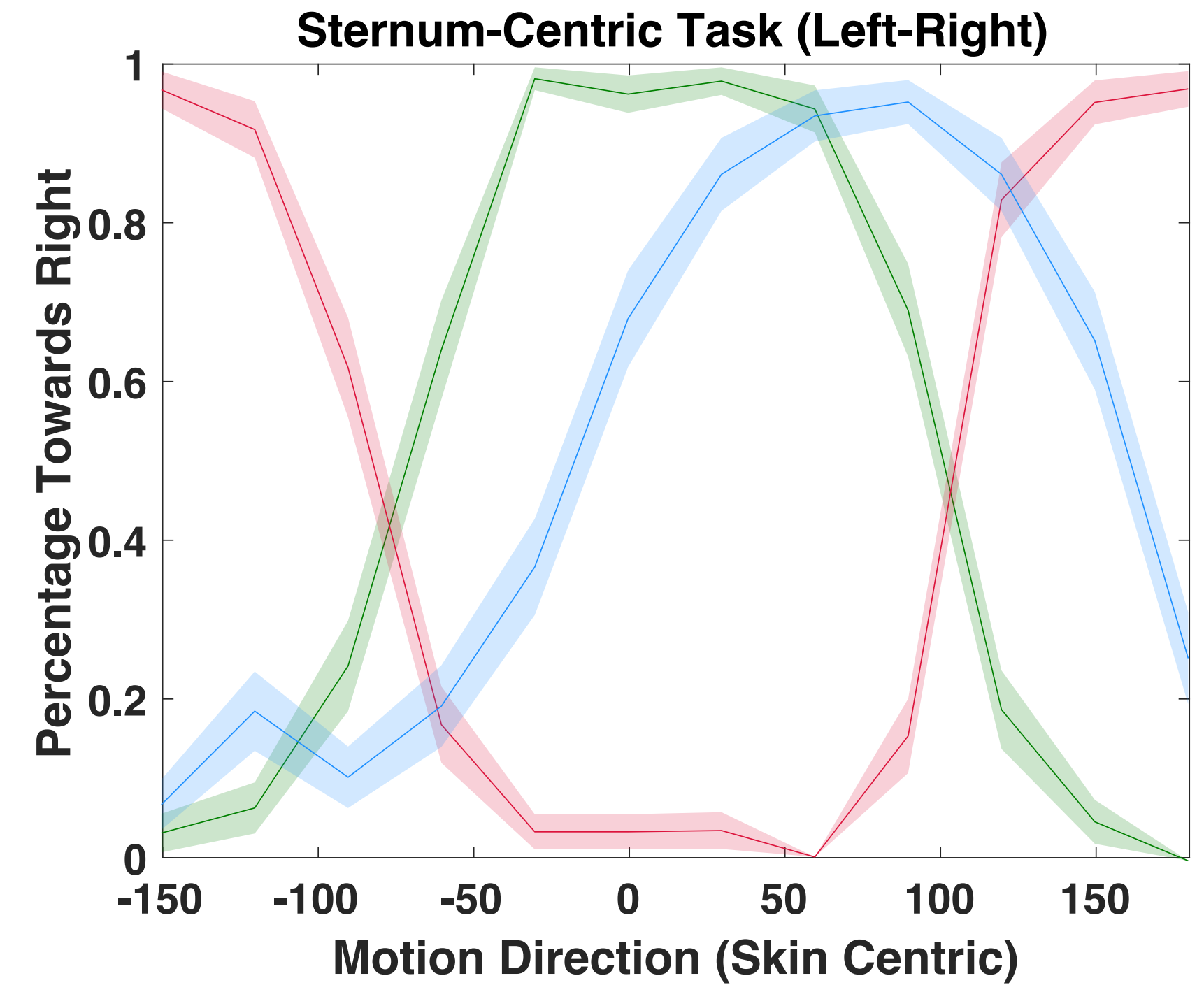
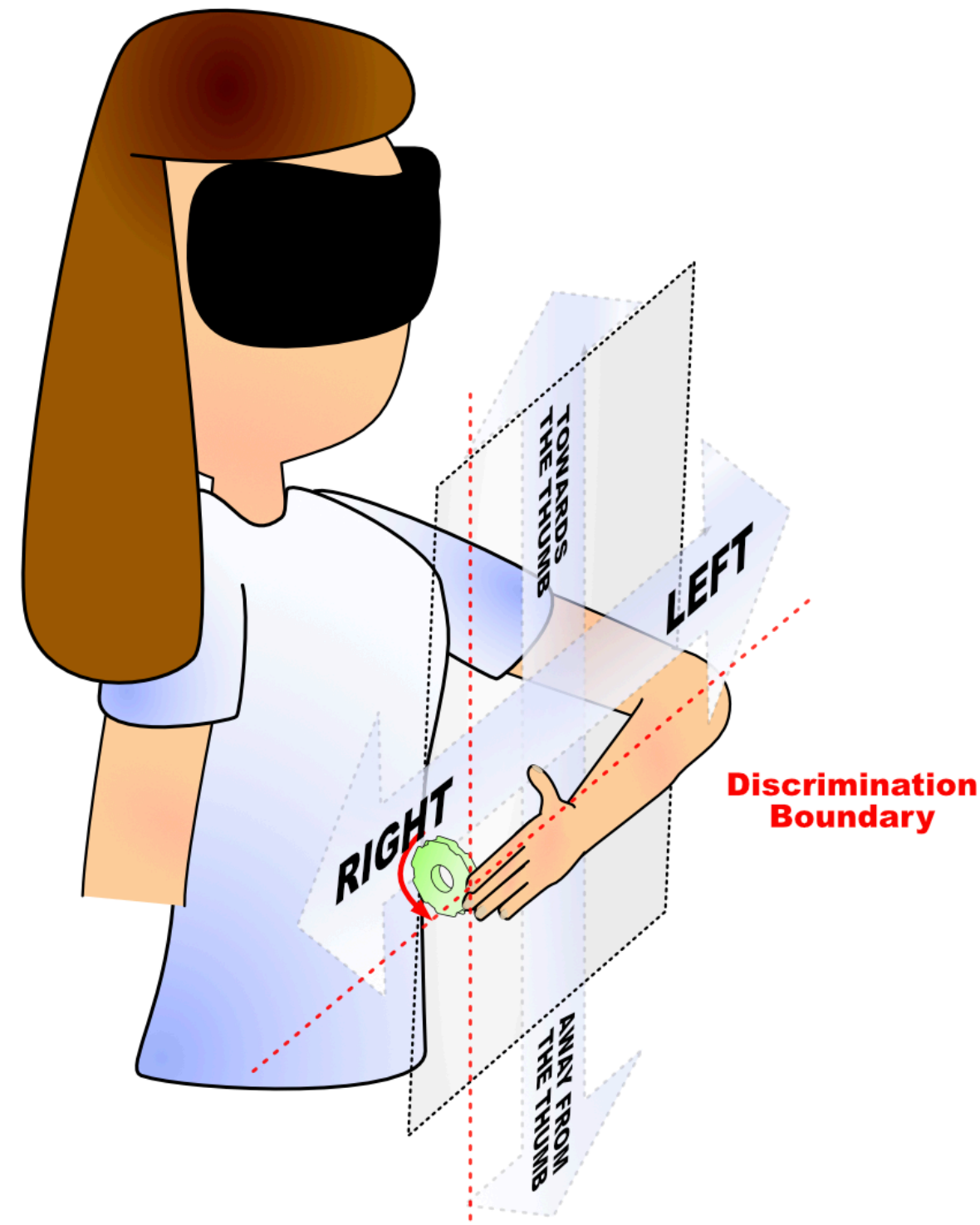
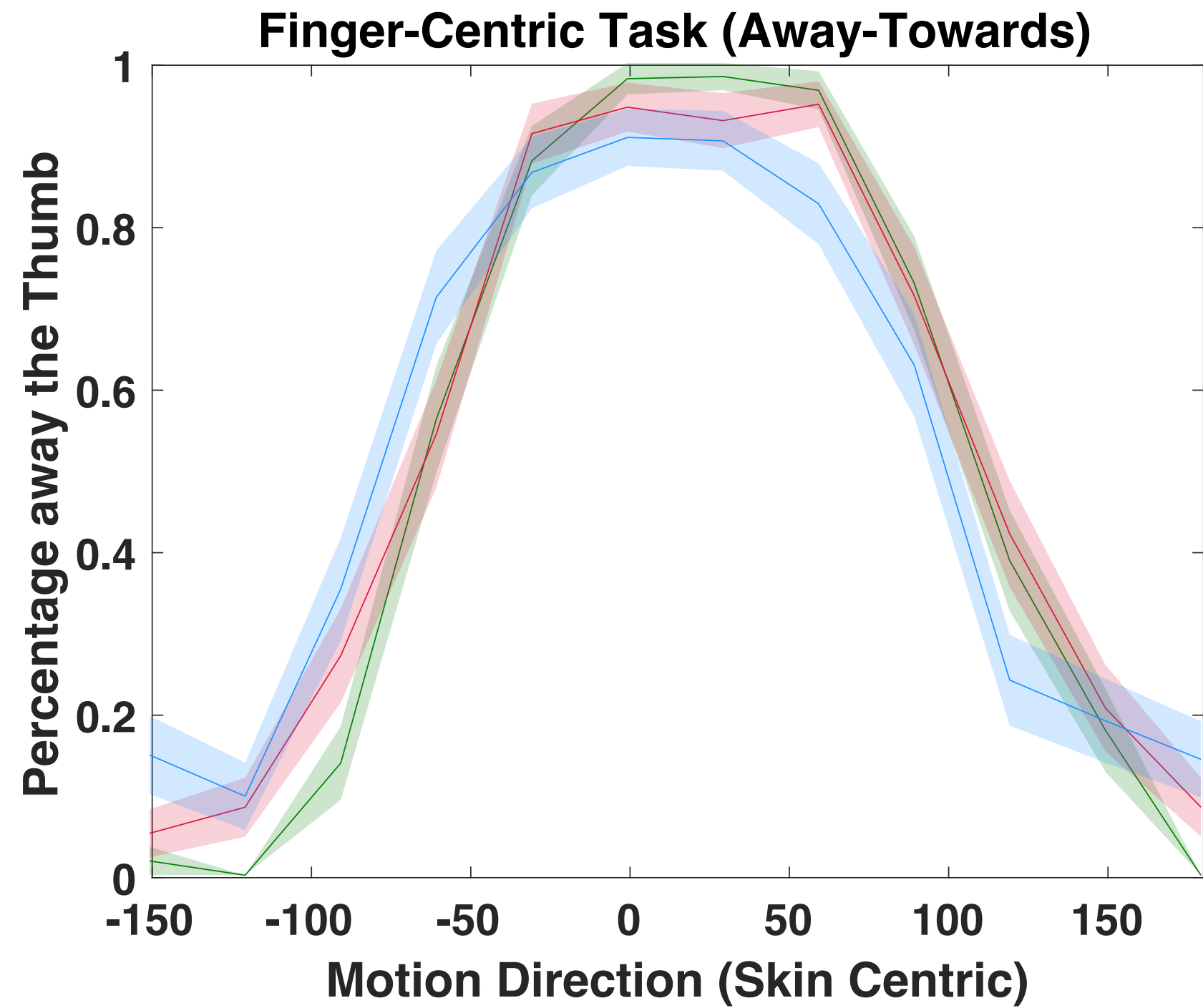


**Inverted Vertical (I)**



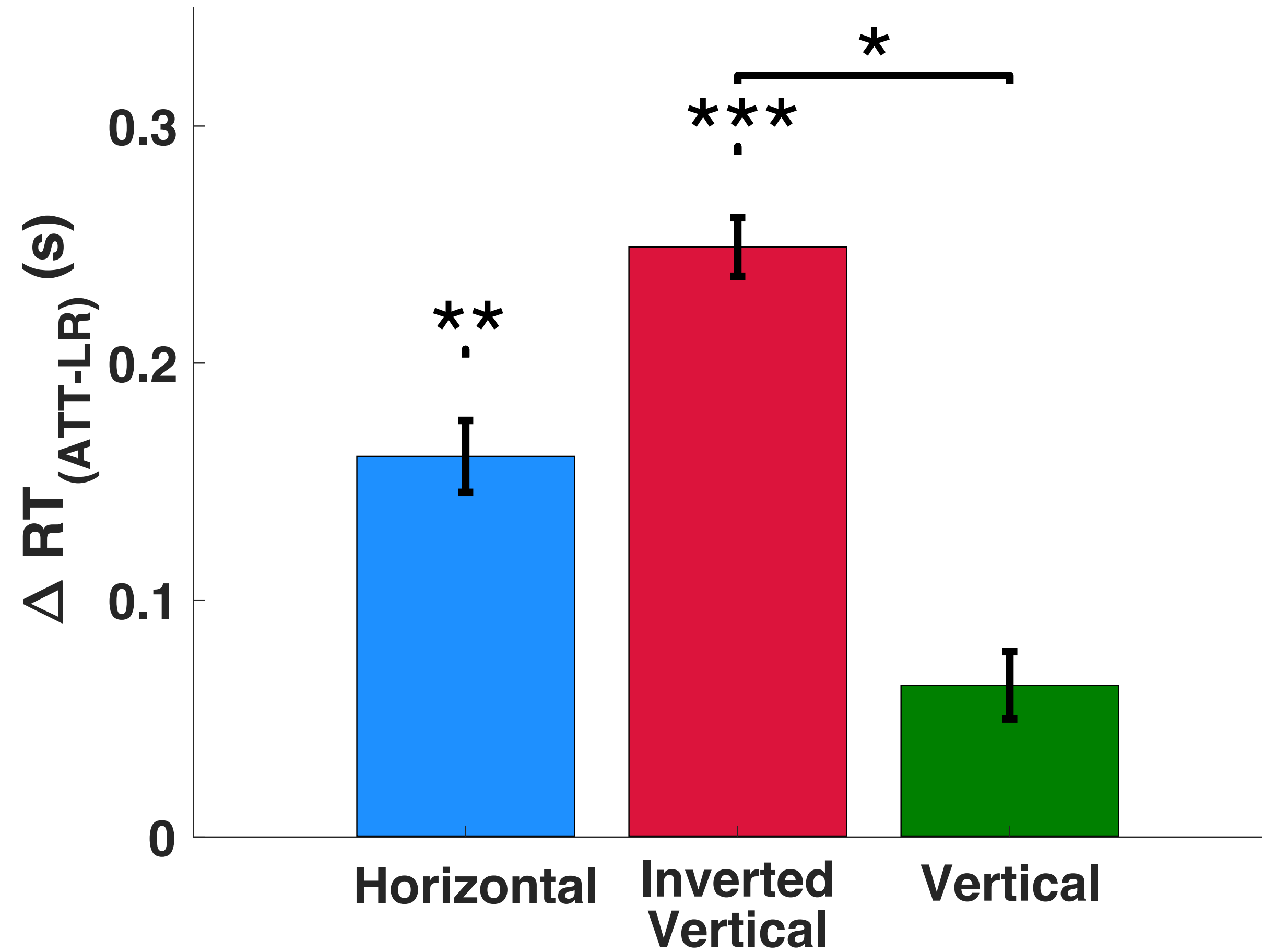
Dot Motion Stimulus at D2  
for 2 seconds, steps of 30 degrees.

# Subjects flexibly perceive motion in two coordinate systems

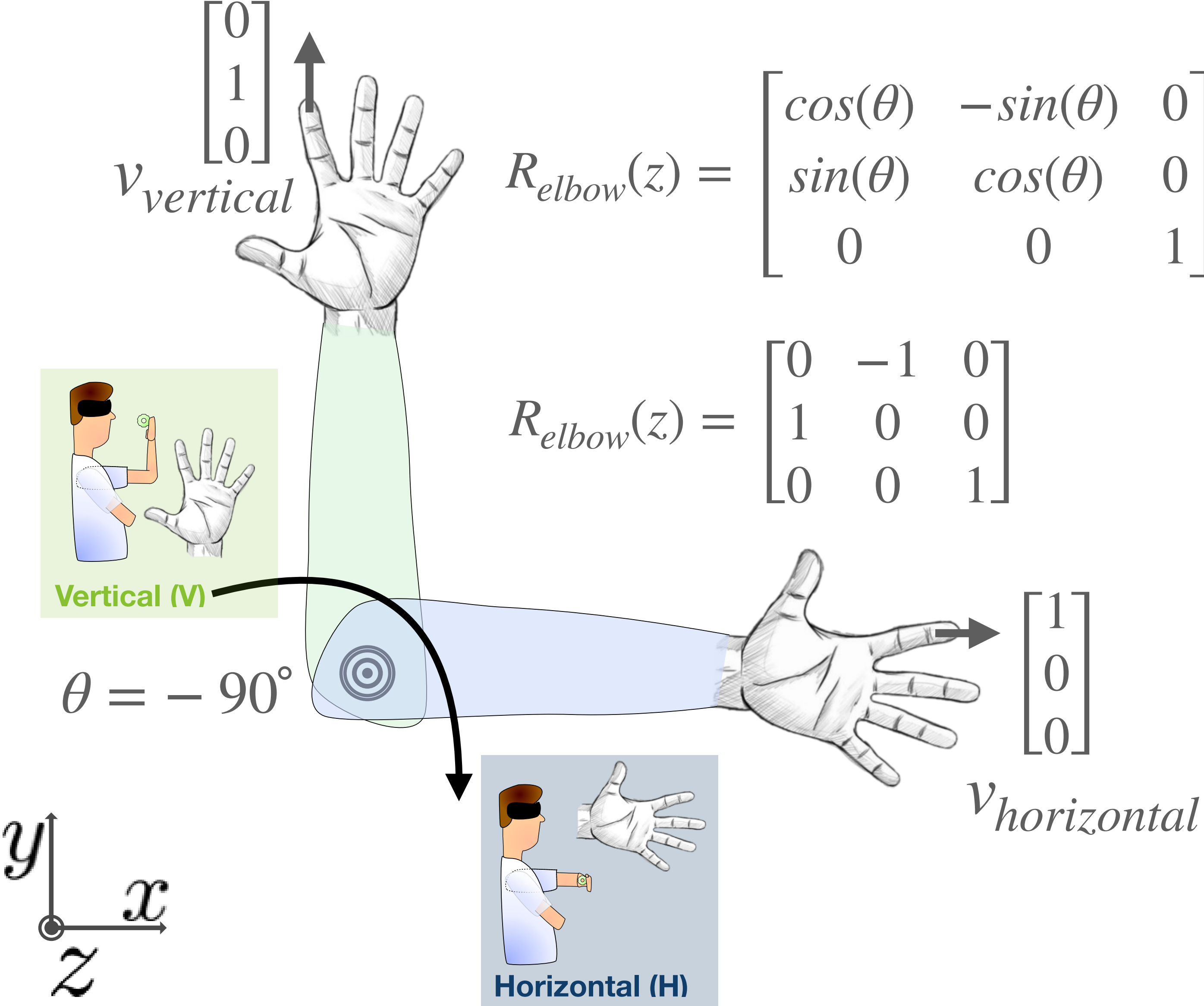


# Faster response times in the sternum-centric task

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



# Euler Matrix Transformations explain tactile motion report



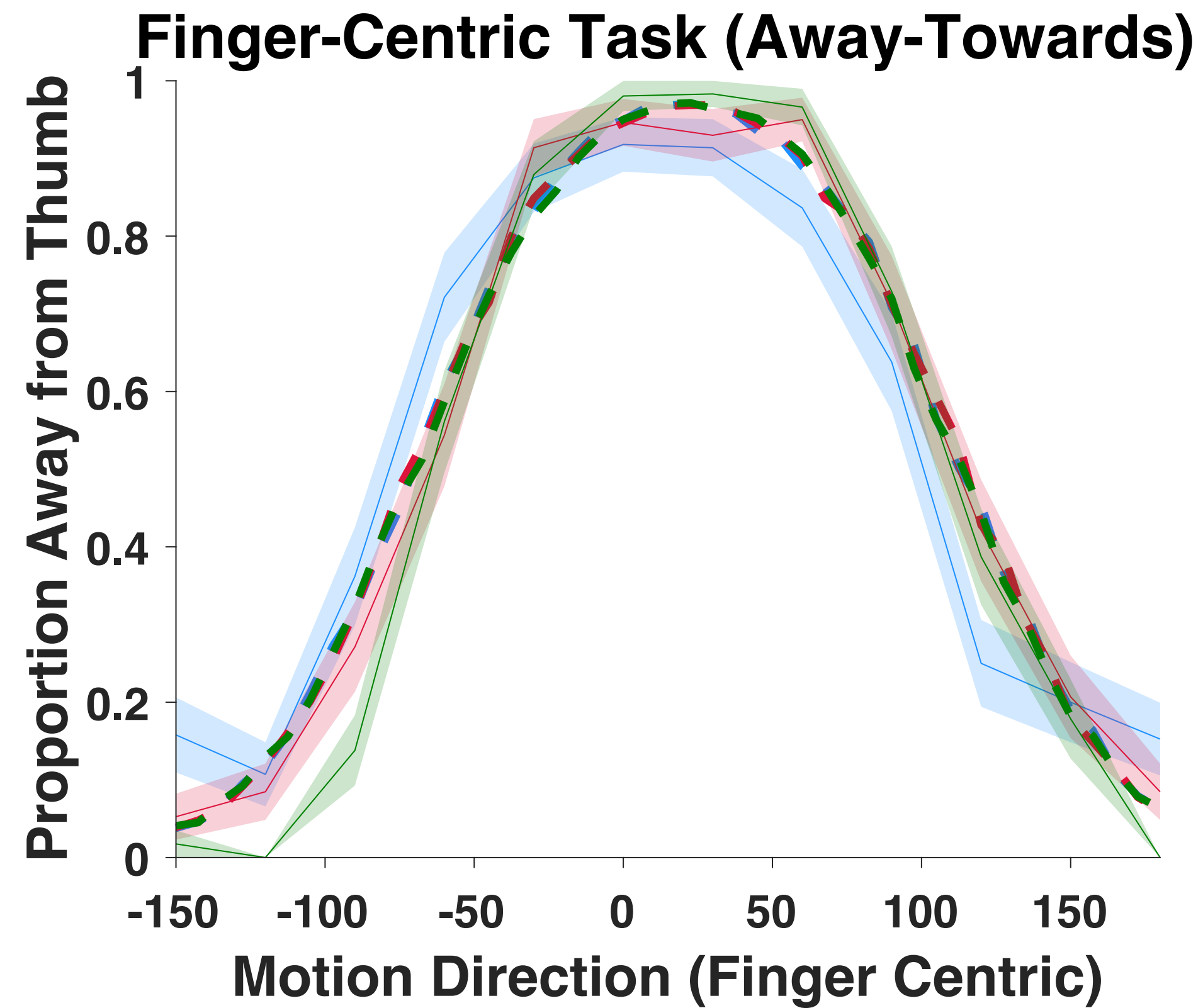
$$R_{elbow}(z) \cdot v_{vertical} = v_{horizontal}$$

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

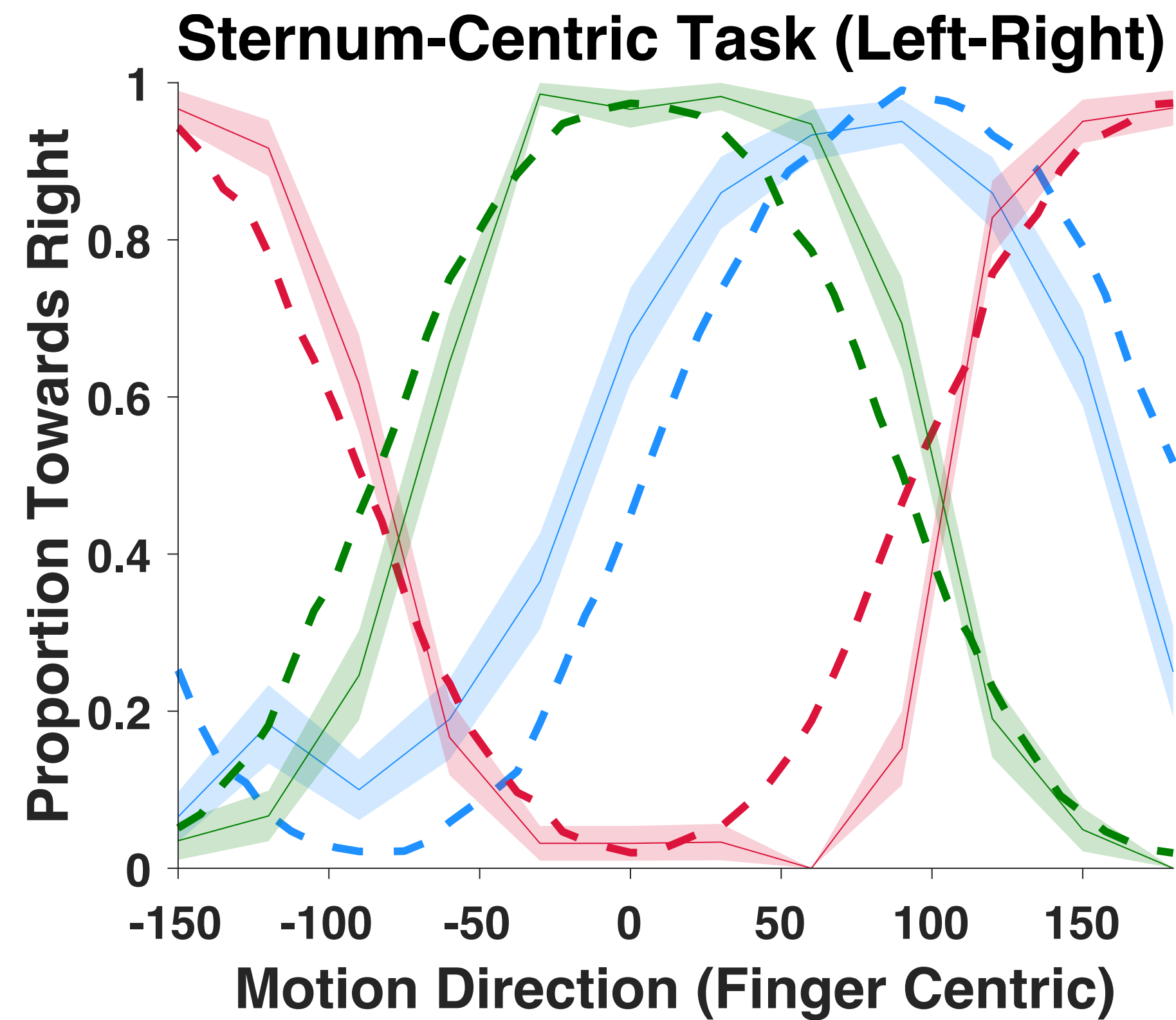
**Similar matrix transformation can be performed at each proprioceptor joints between two reference frames**

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

# Euler-Matrix Transformation-based Generative model explains behavioral results



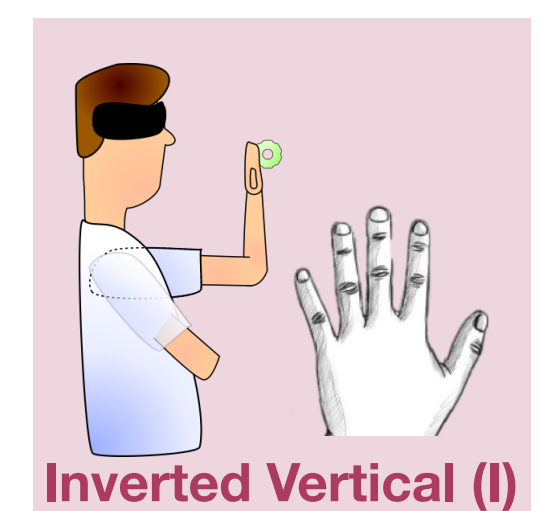
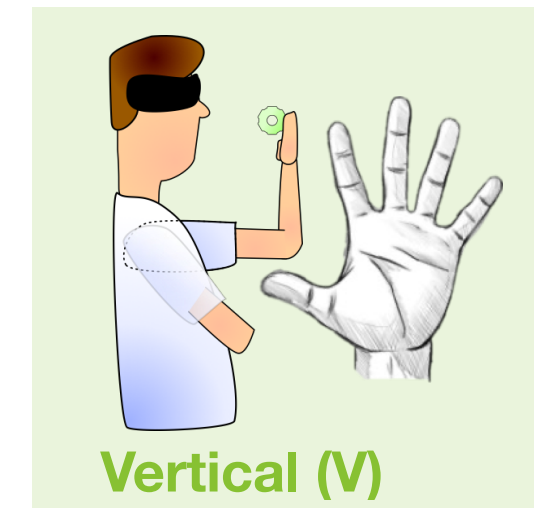
McFadden's  $R^2 = 0.41$



McFadden's  $R^2 = 0.45$

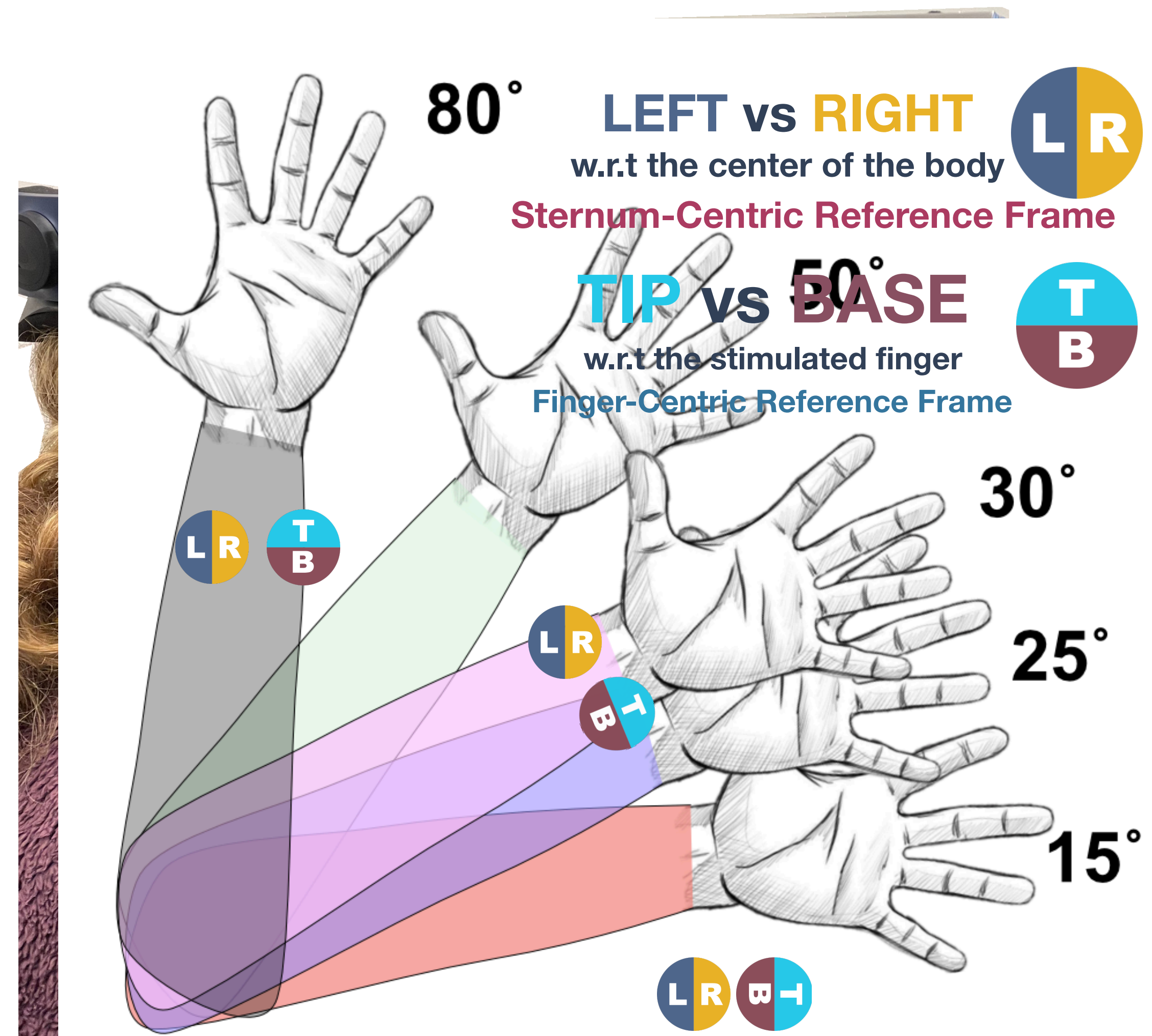
--- Model Fit

— Observed

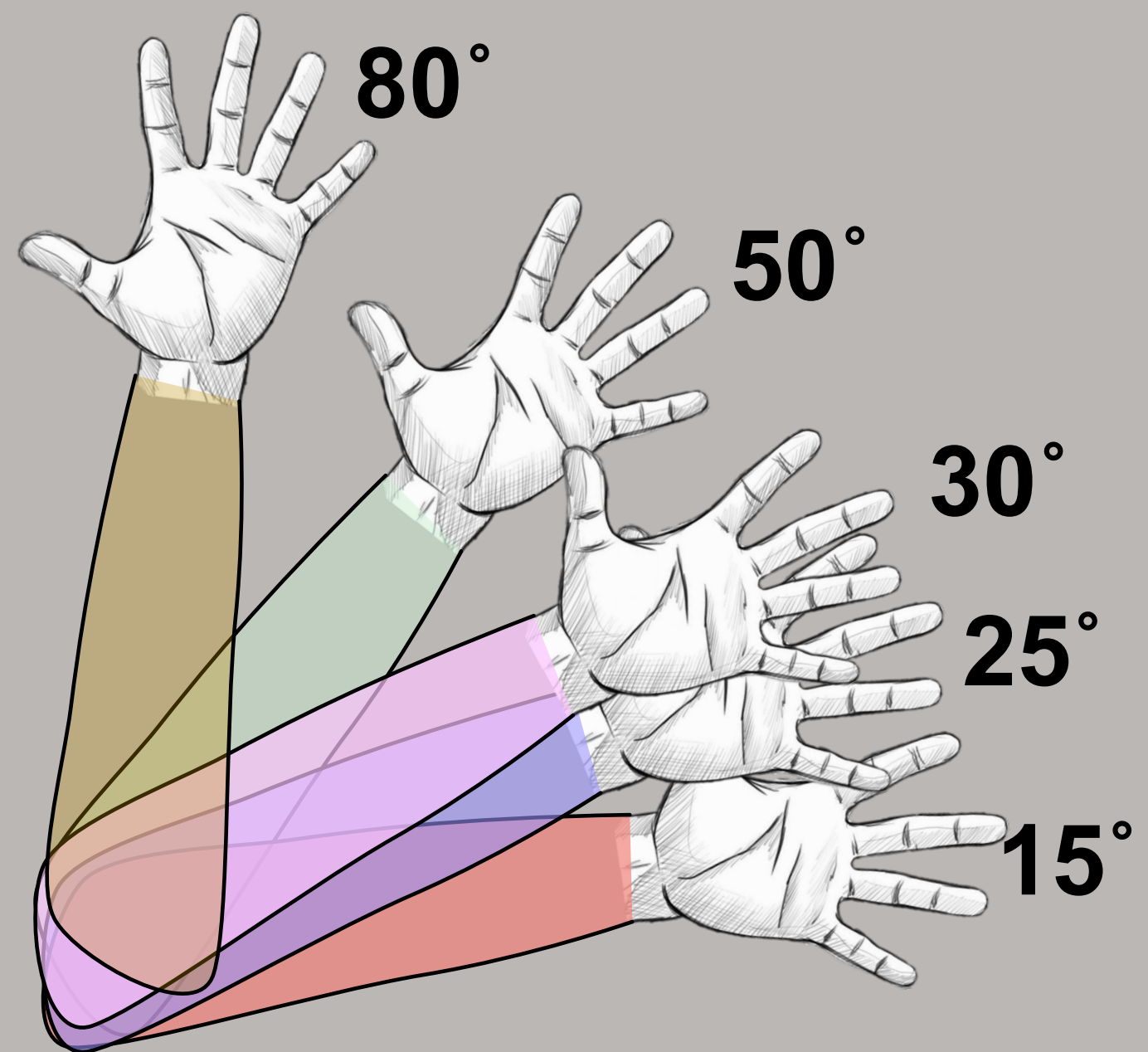


# Motivations for updating current experiment design

- 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.**

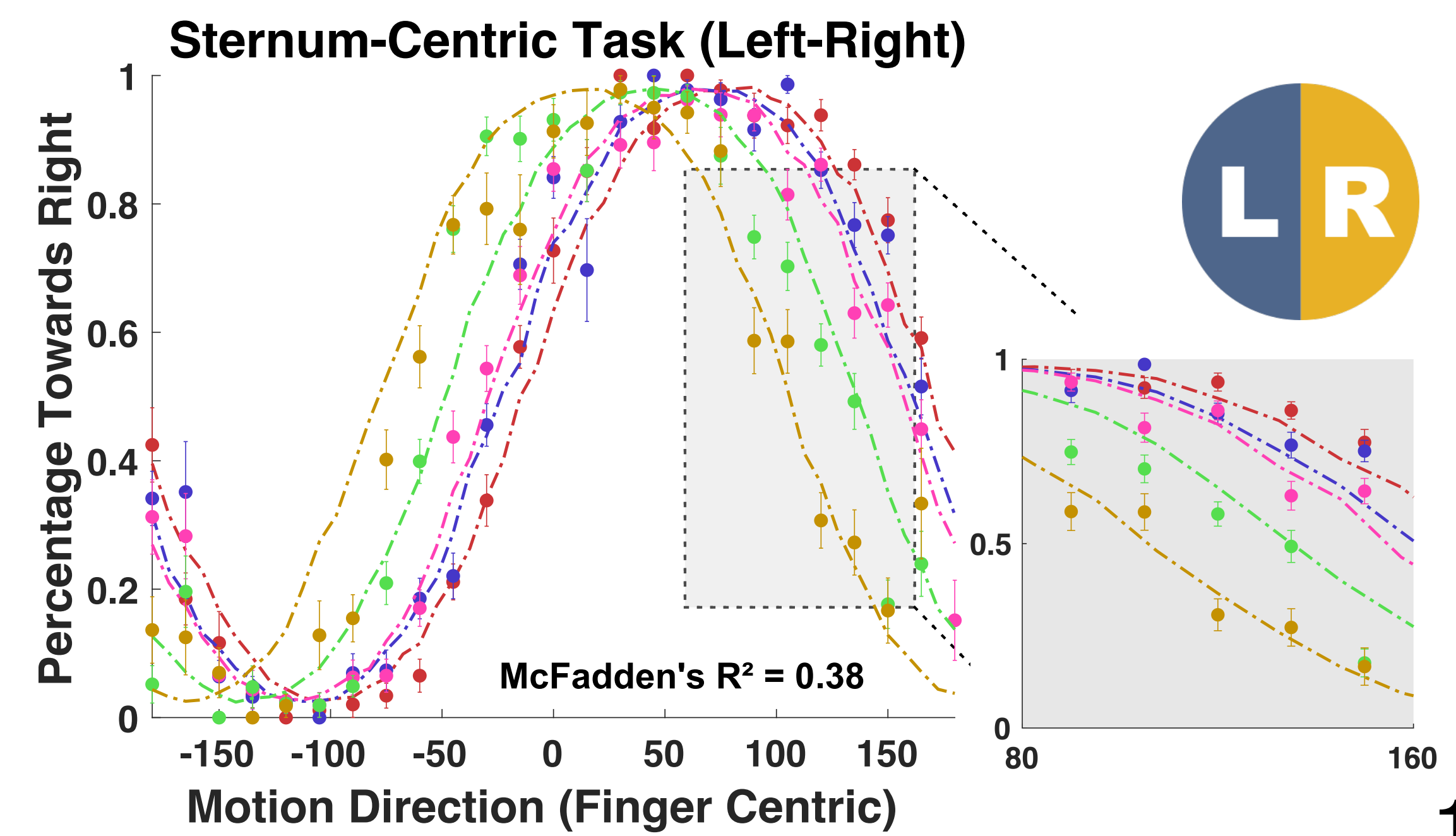
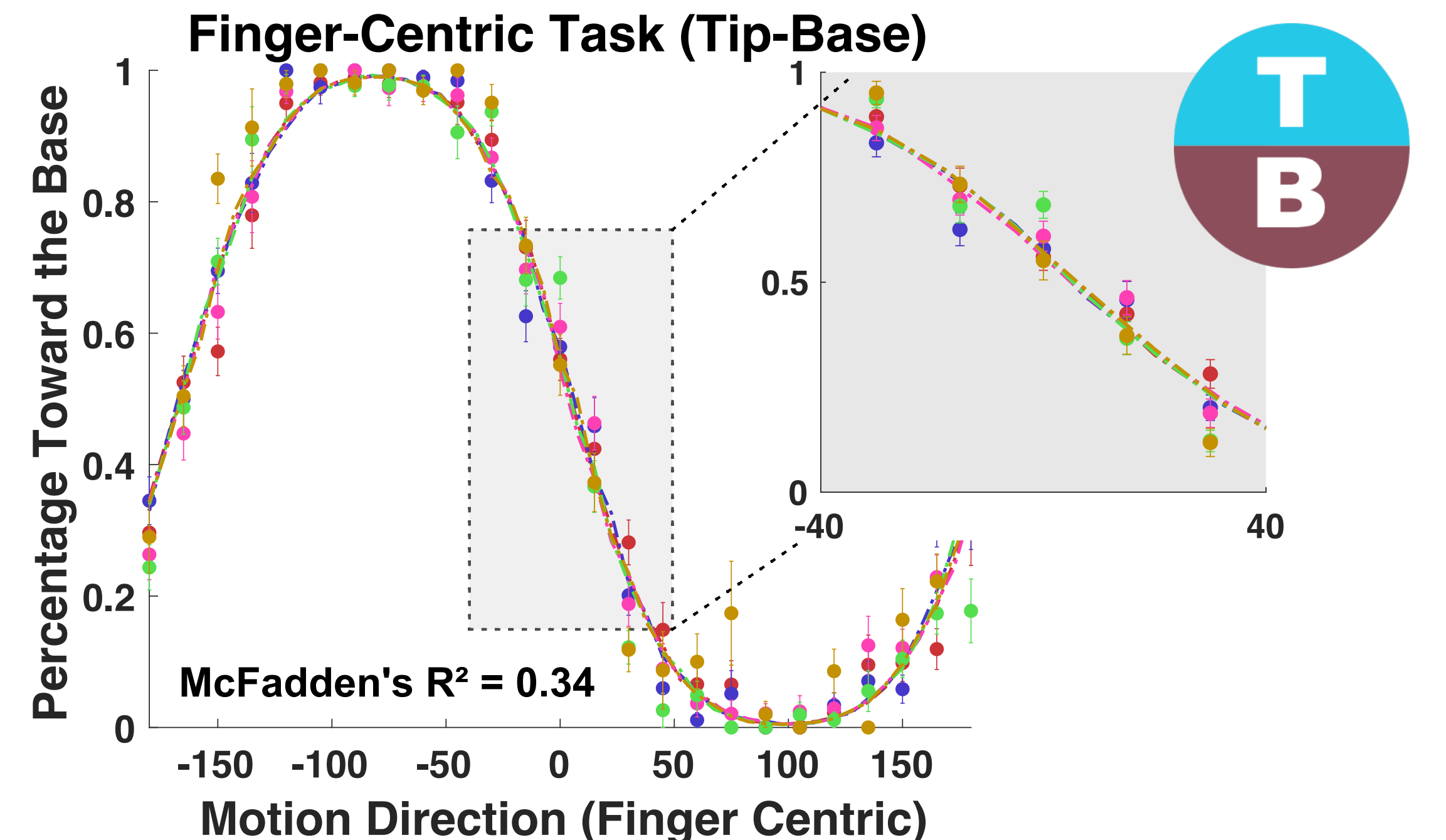


# Proprioception modulates tactile motion perception in a reference frame-dependent manner

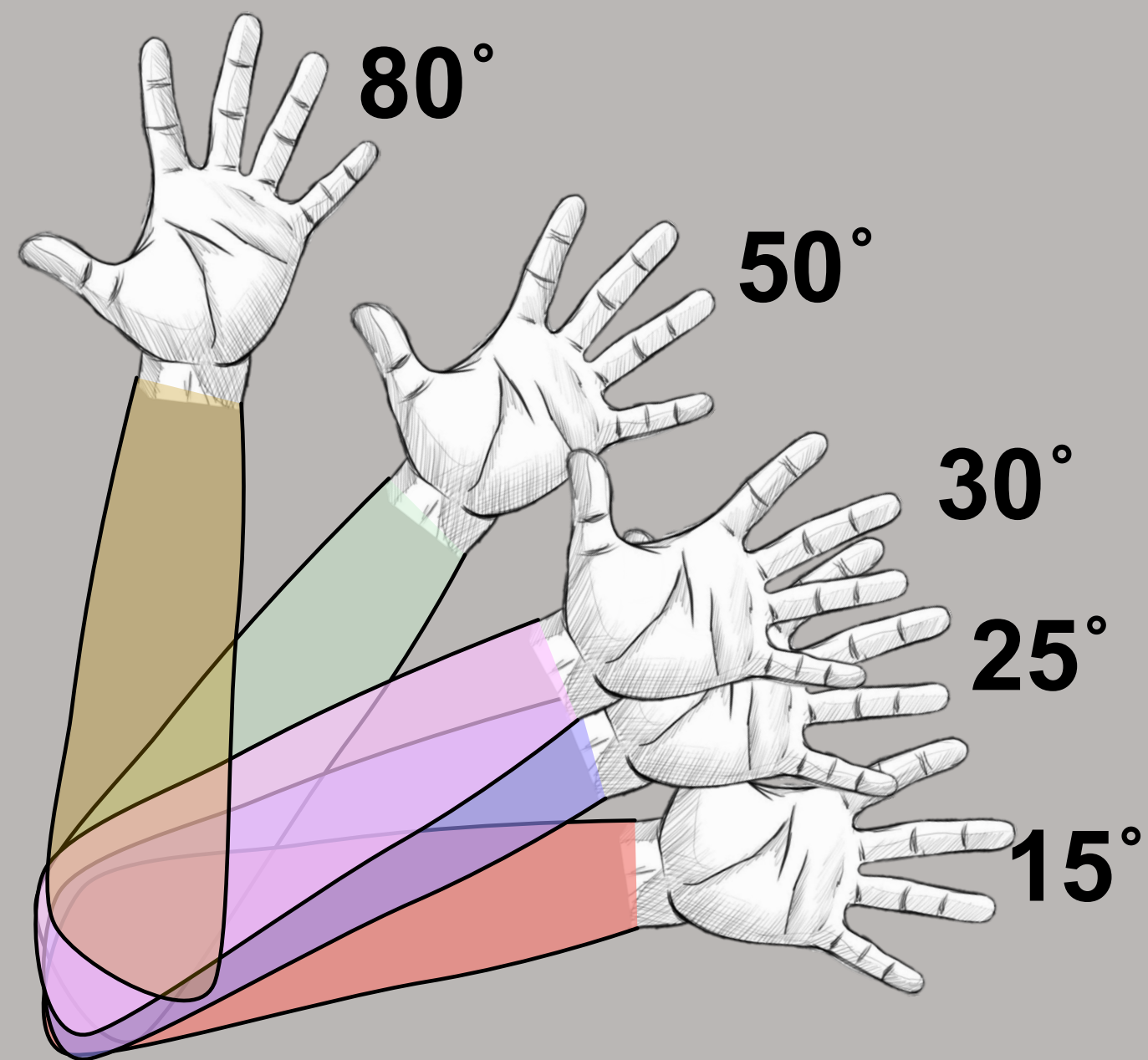


--- Model Fit  
 ● | Observed Data

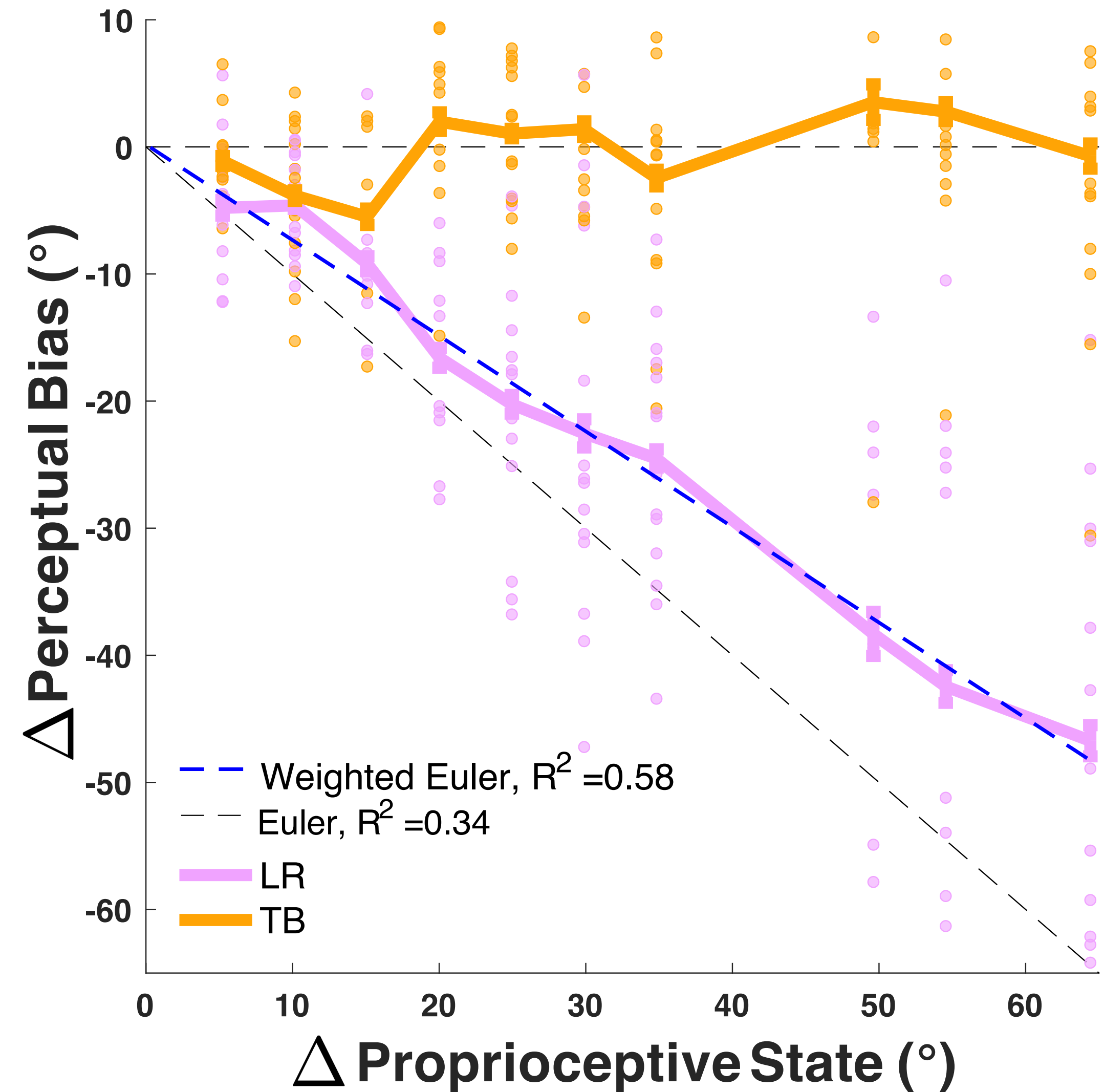
N = 14



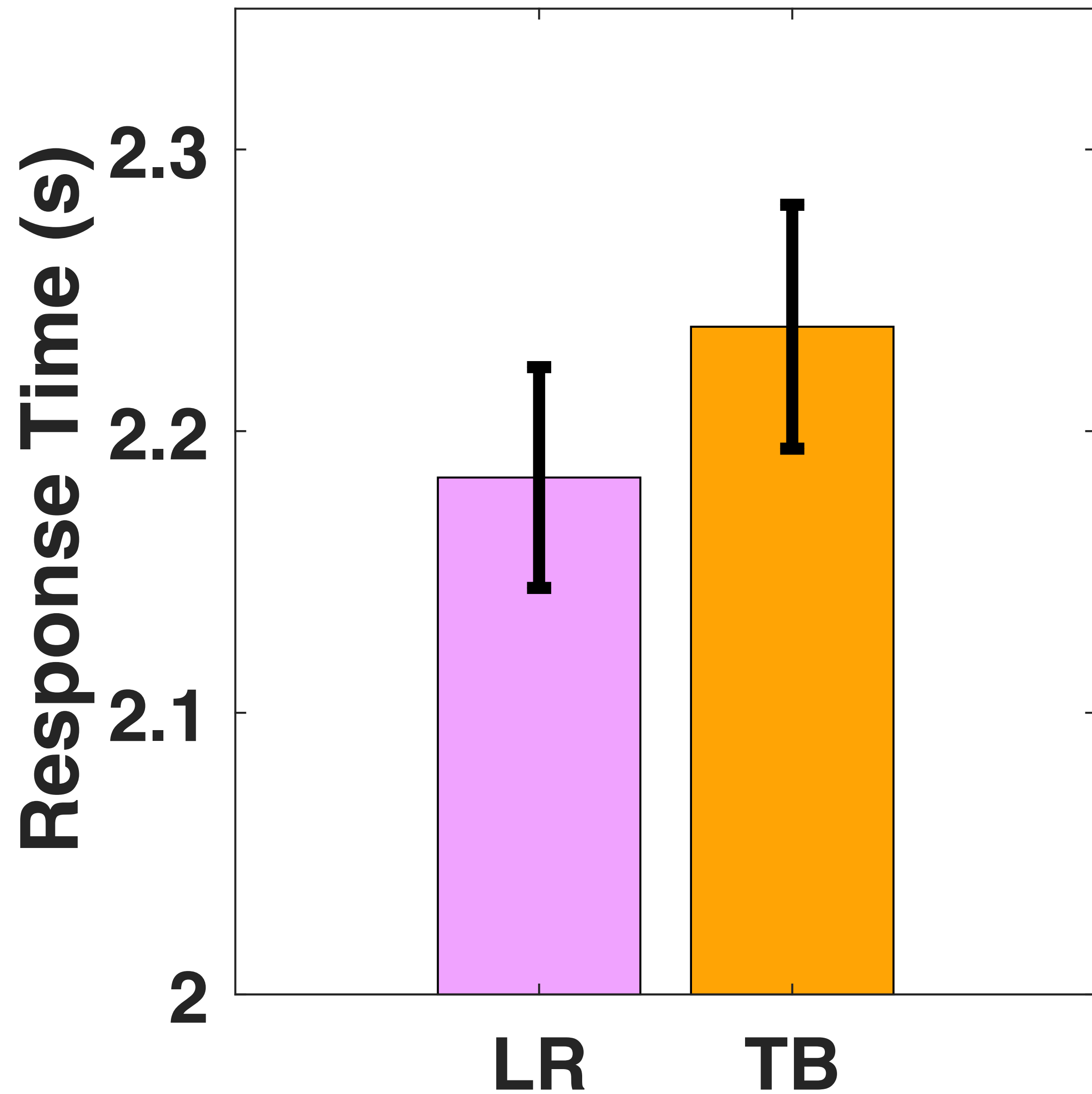
# Proprioception systematically biases tactile motion report in the sternum-centric task



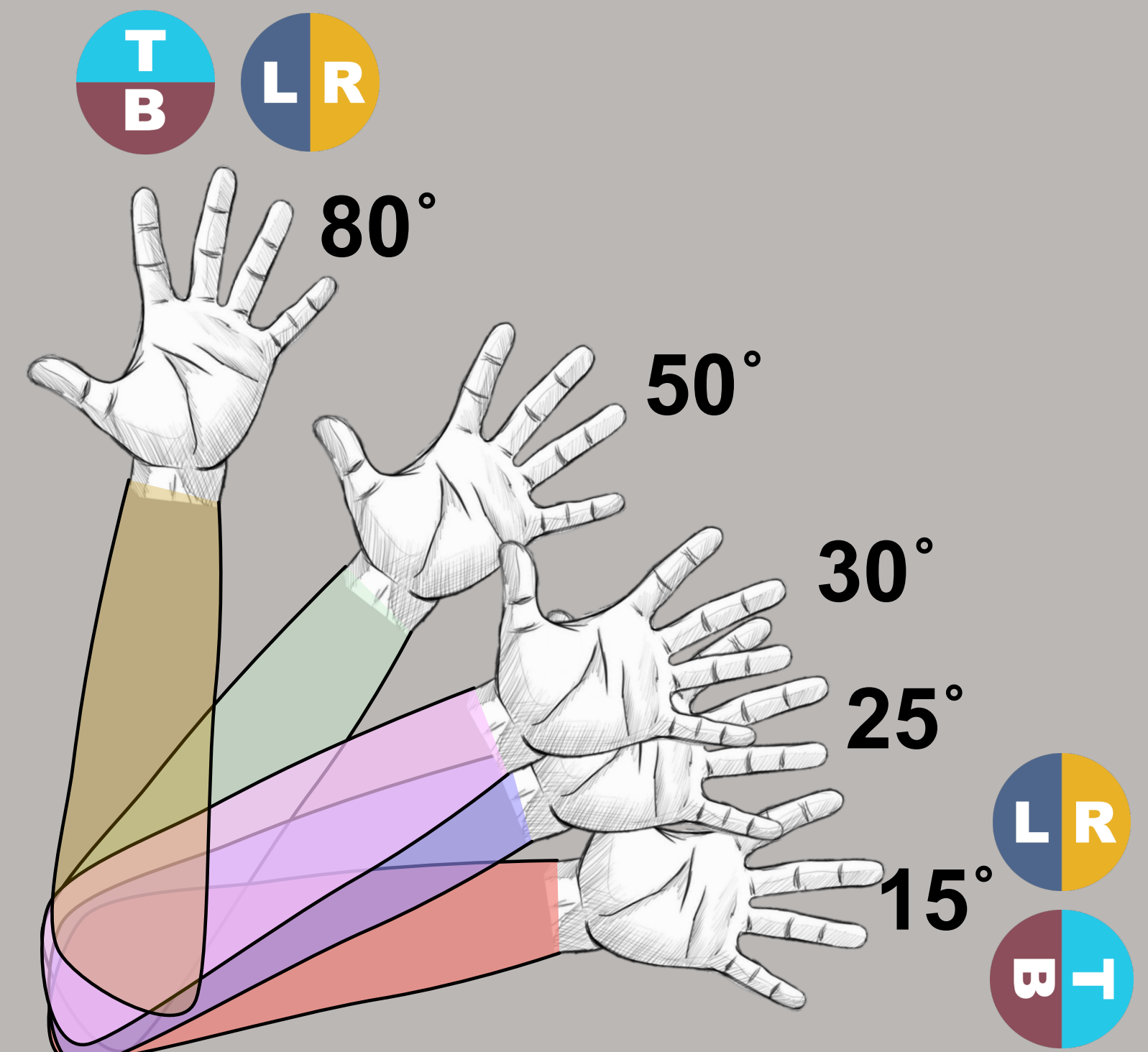
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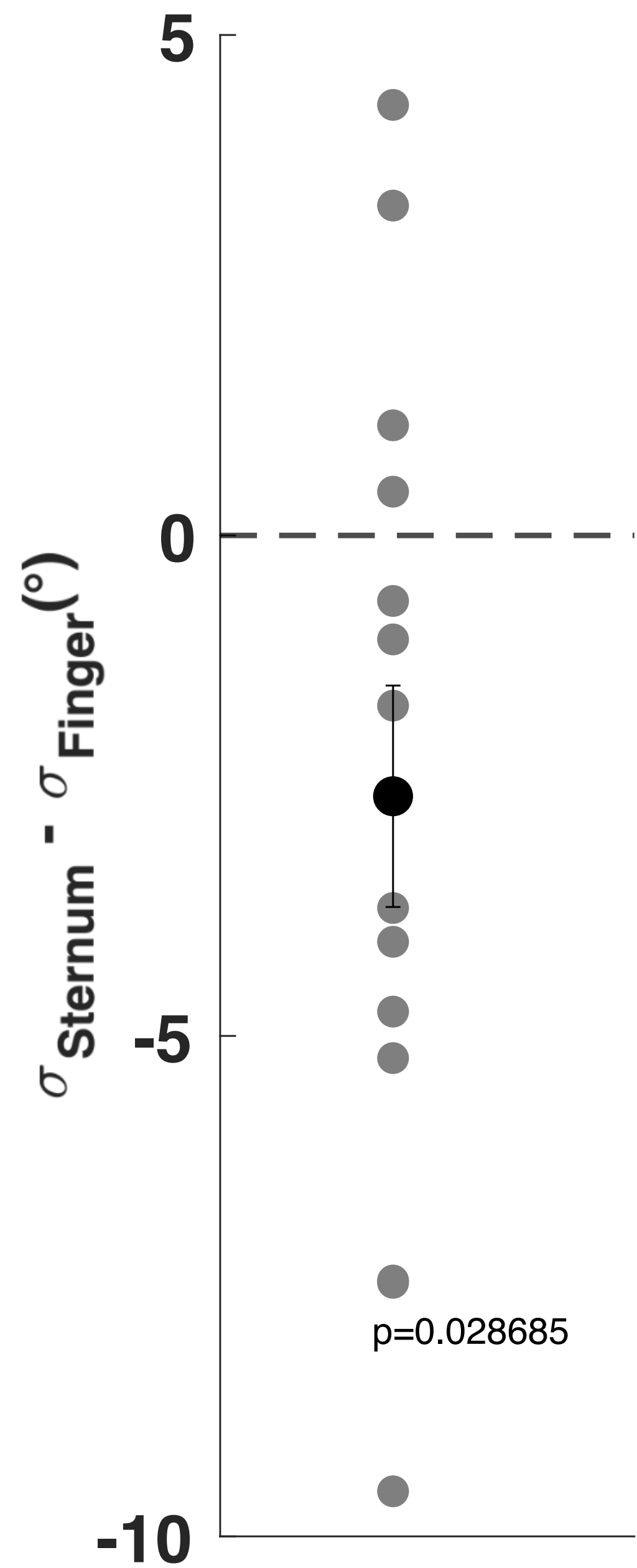
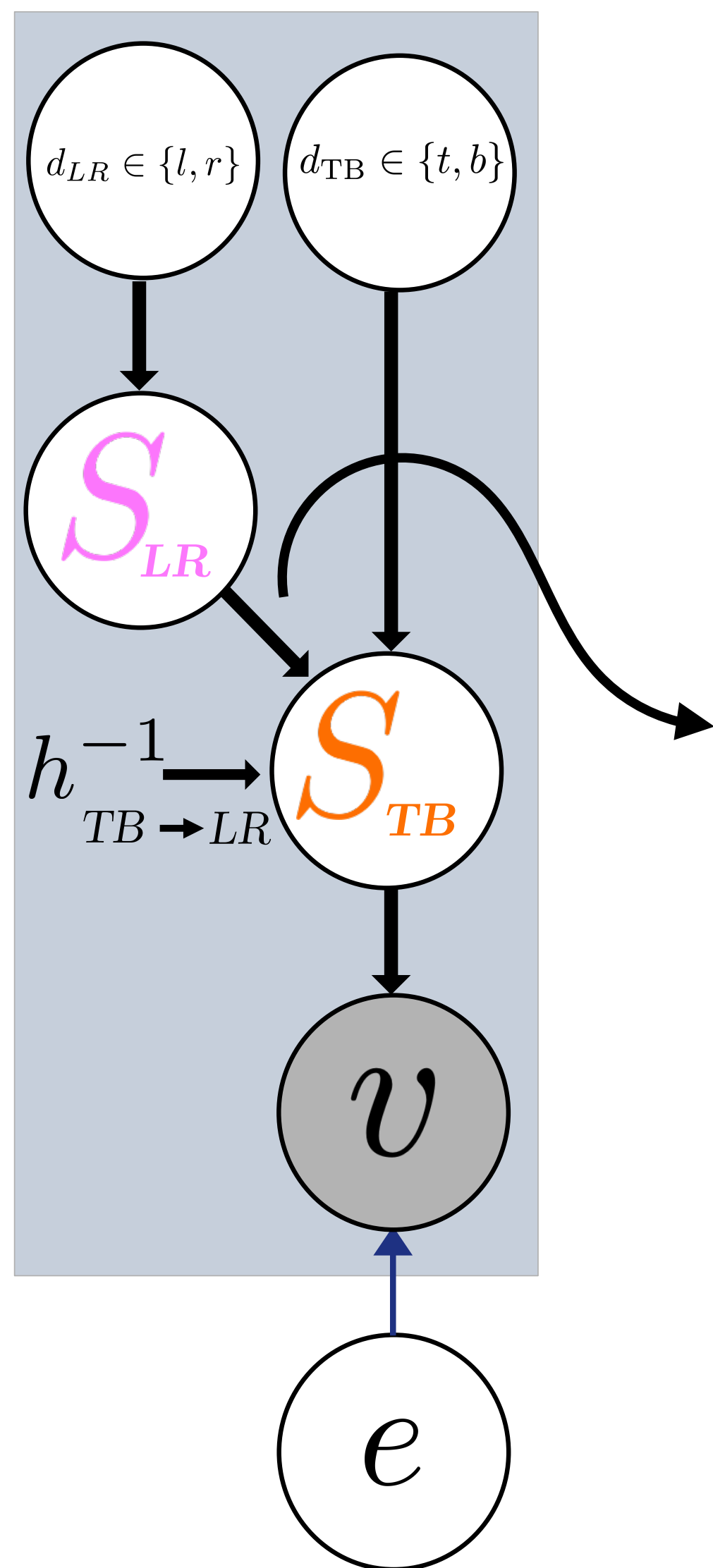


# Slower response times in sternum-centric task when discrimination spaces incongruent



N = 14

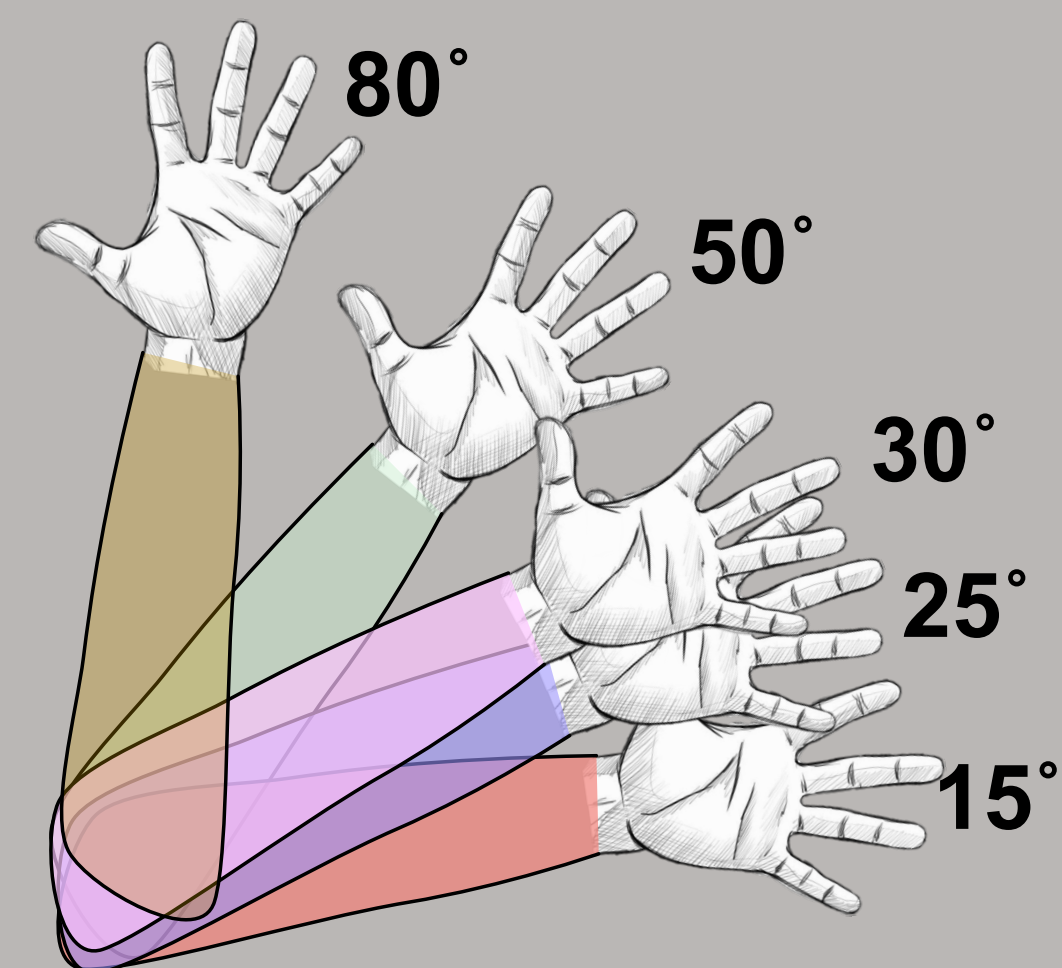




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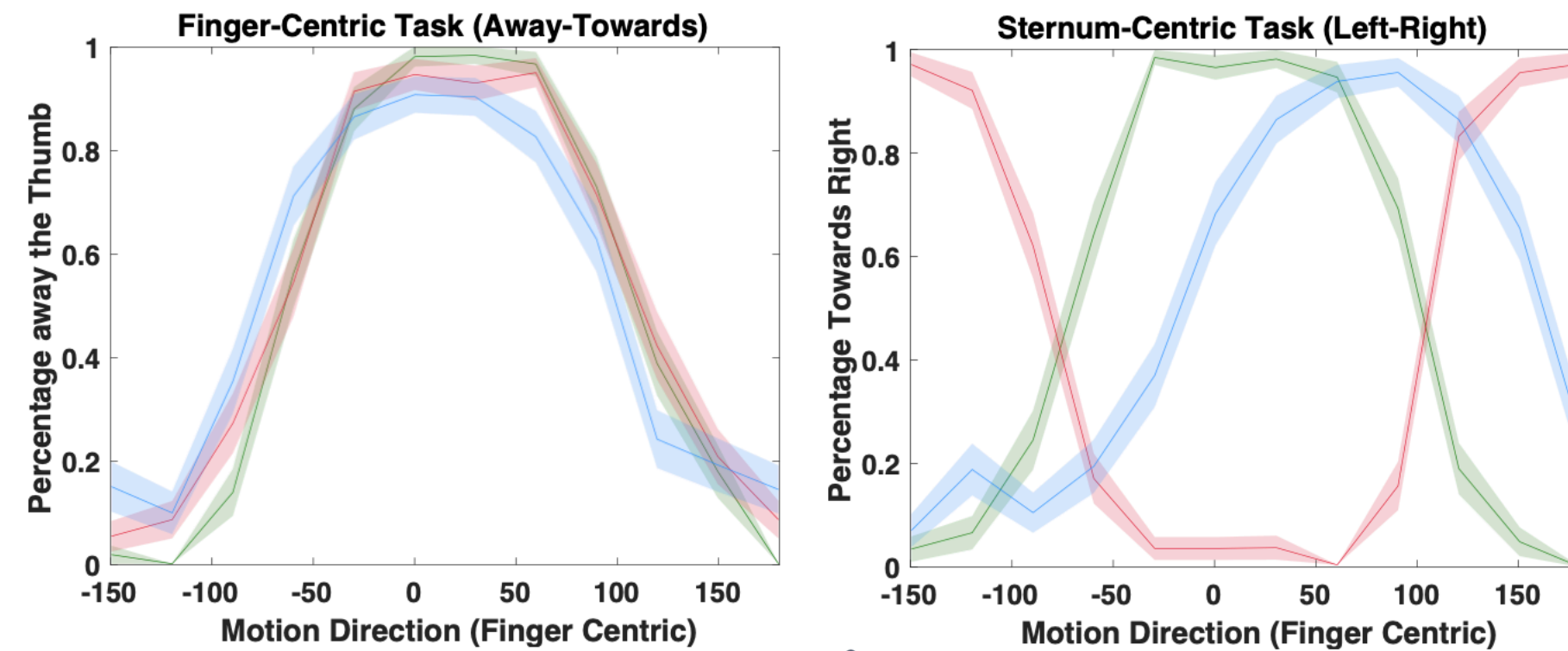
# Proprioceptive noise in the sternum-centric task

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

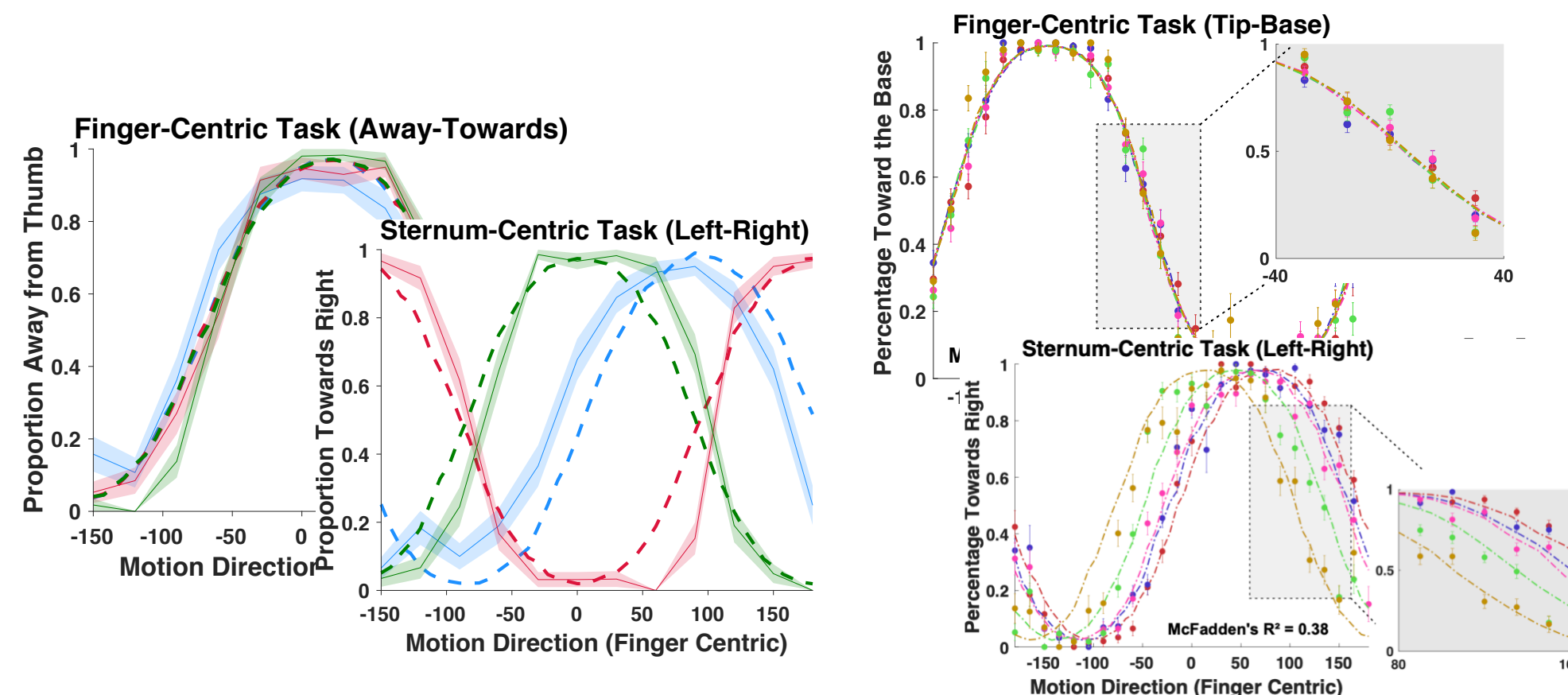


# Summary

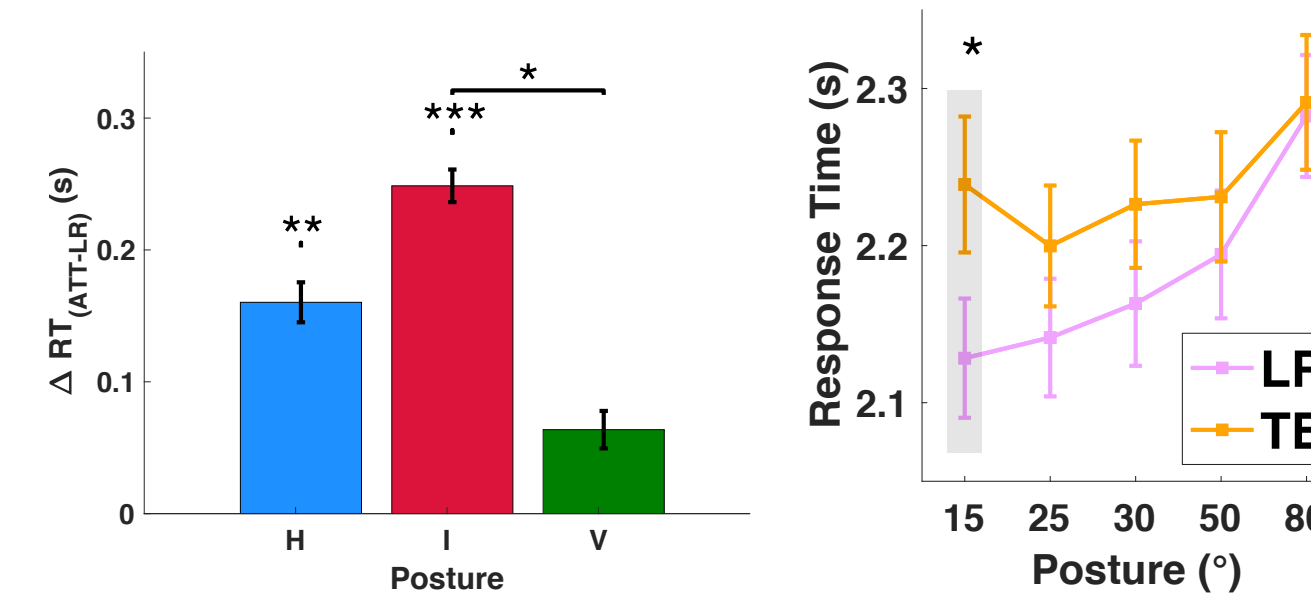
- We show that humans flexibly perceive tactile motion direction in different coordinate systems



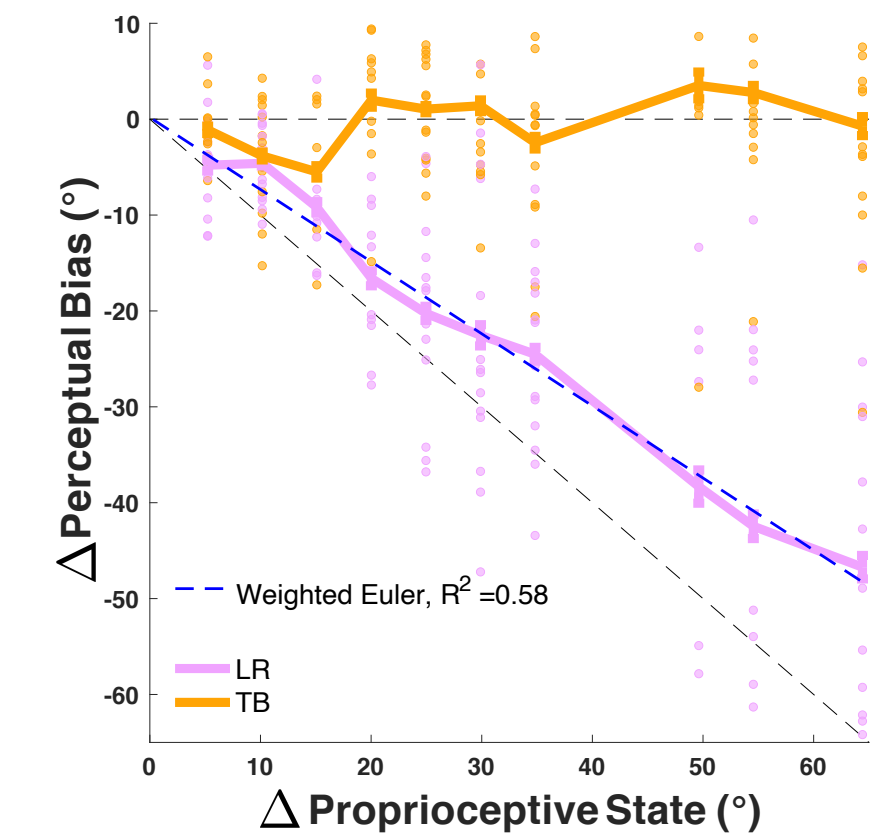
- A modified Euler-matrix based generative model explained behavioral report.



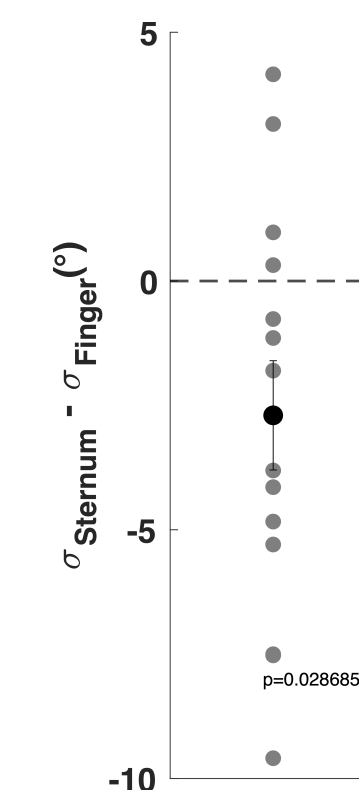
- Faster reaction times in the sternum-centric task.



- 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



# Acknowledgements

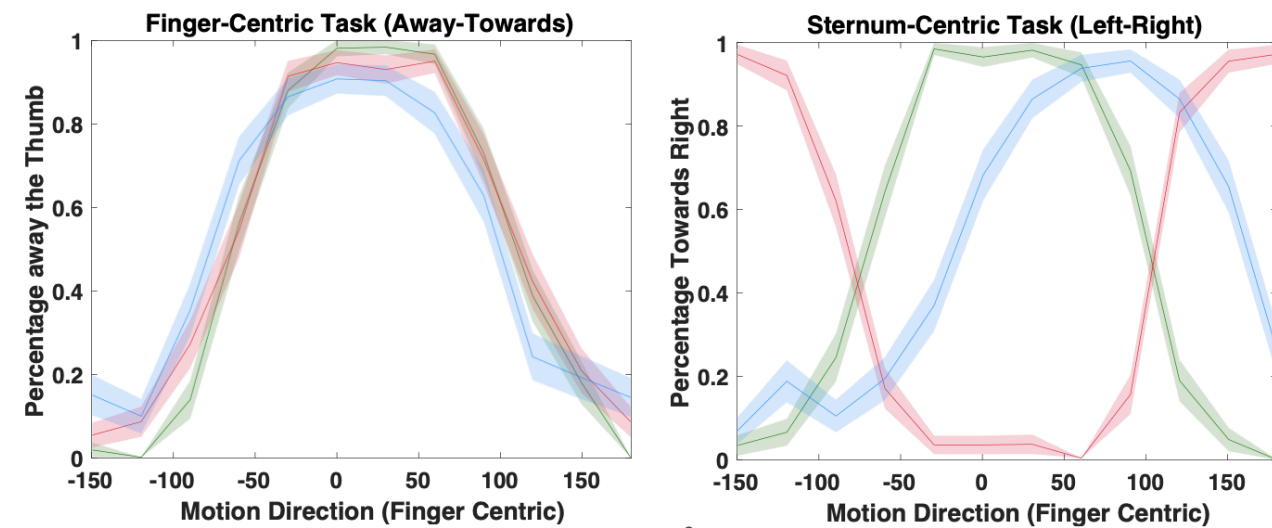


- ***Prof. Manuel Gomez-Ramirez, Prof. Ralf Haefner, Prof. Gregory DeAngelis*** for their continual guidance throughout the project.
- ***Sabyasachi Shivkumar***: For modeling and fitting the behavioral results
- ***Catalina Feistritzer, Amy Fuller, Yihan Xie***: Processing data and running human participants.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

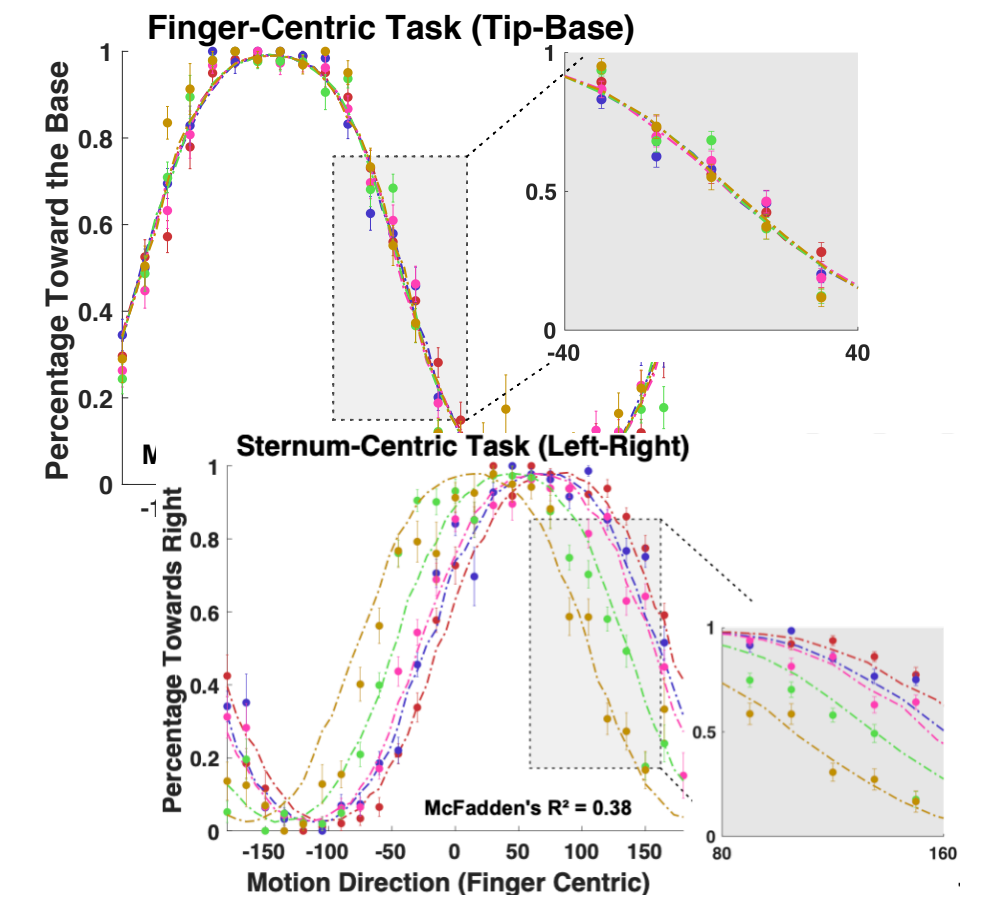
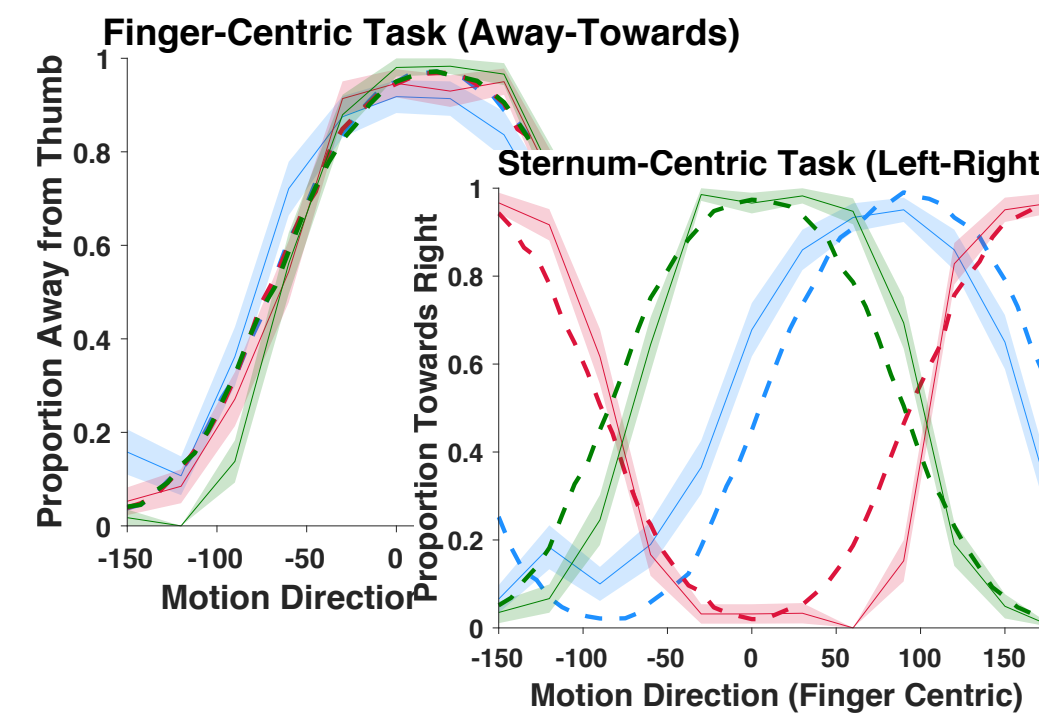


# Questions and Comments

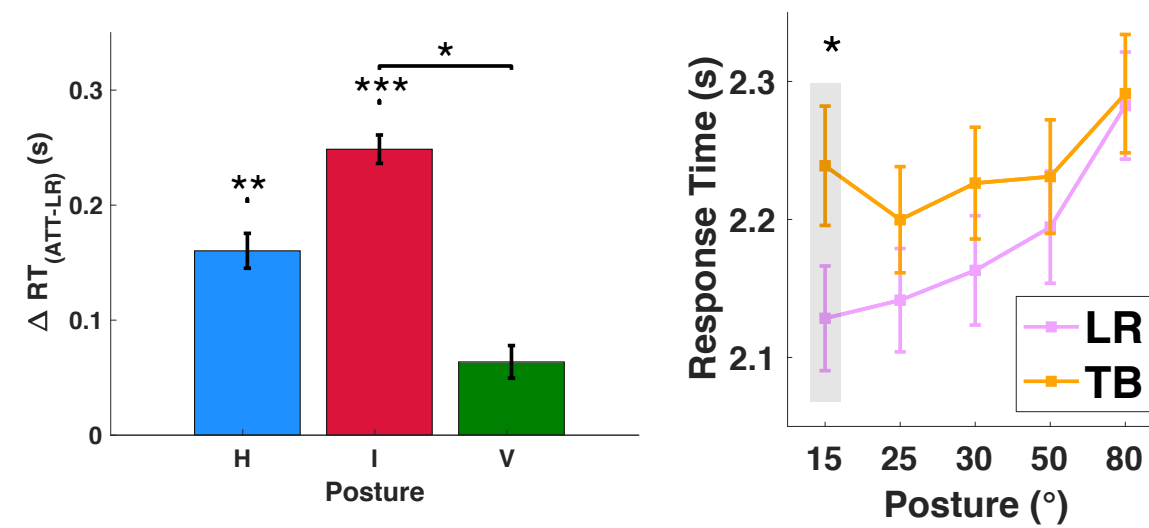
- We show that humans flexibly perceive tactile motion direction in different coordinate systems



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

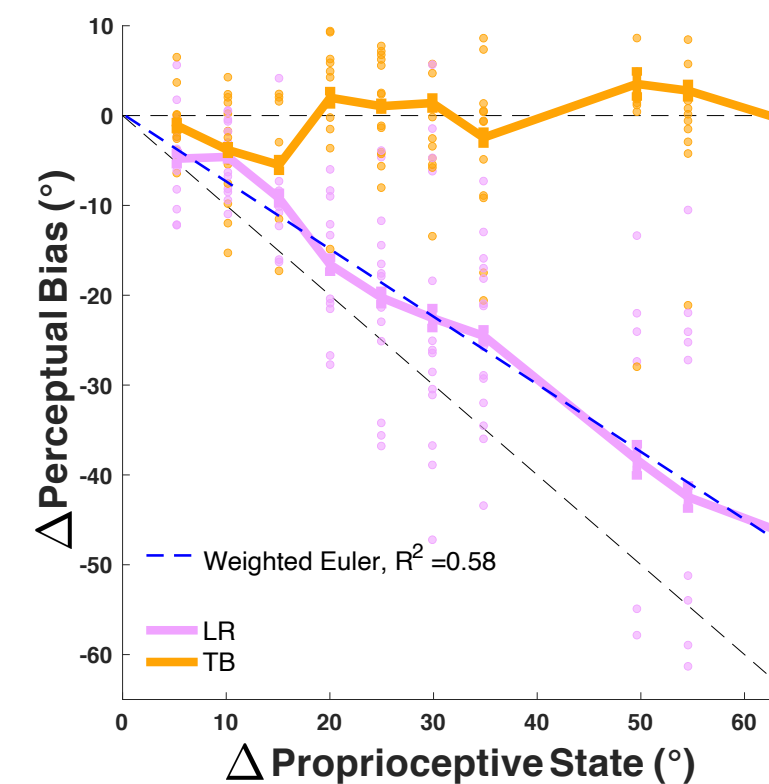


- Faster reaction times in the sternum-centric task.

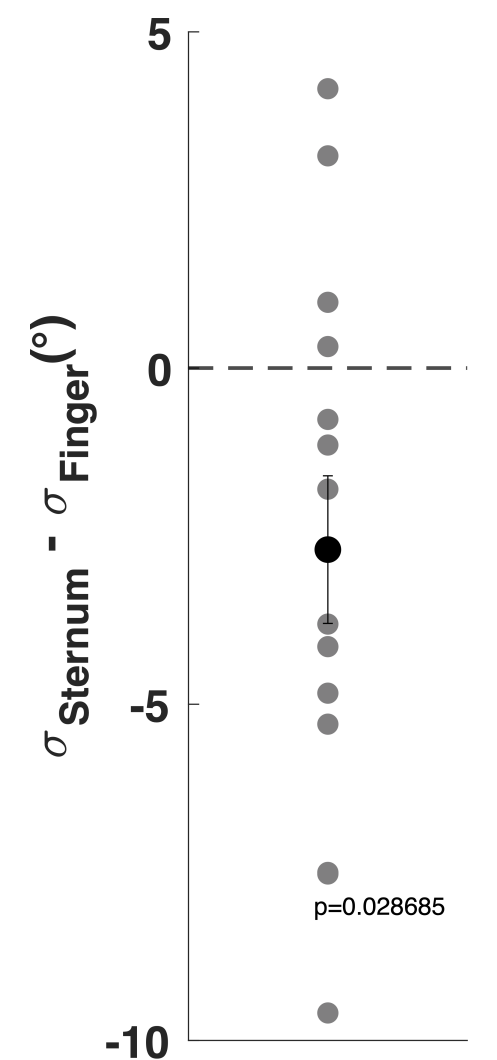


- The finger-centric task has a constant bias. The sternum-centric task has a posture dependent bias.

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 PI: Manuel Gomez-Ramirez  
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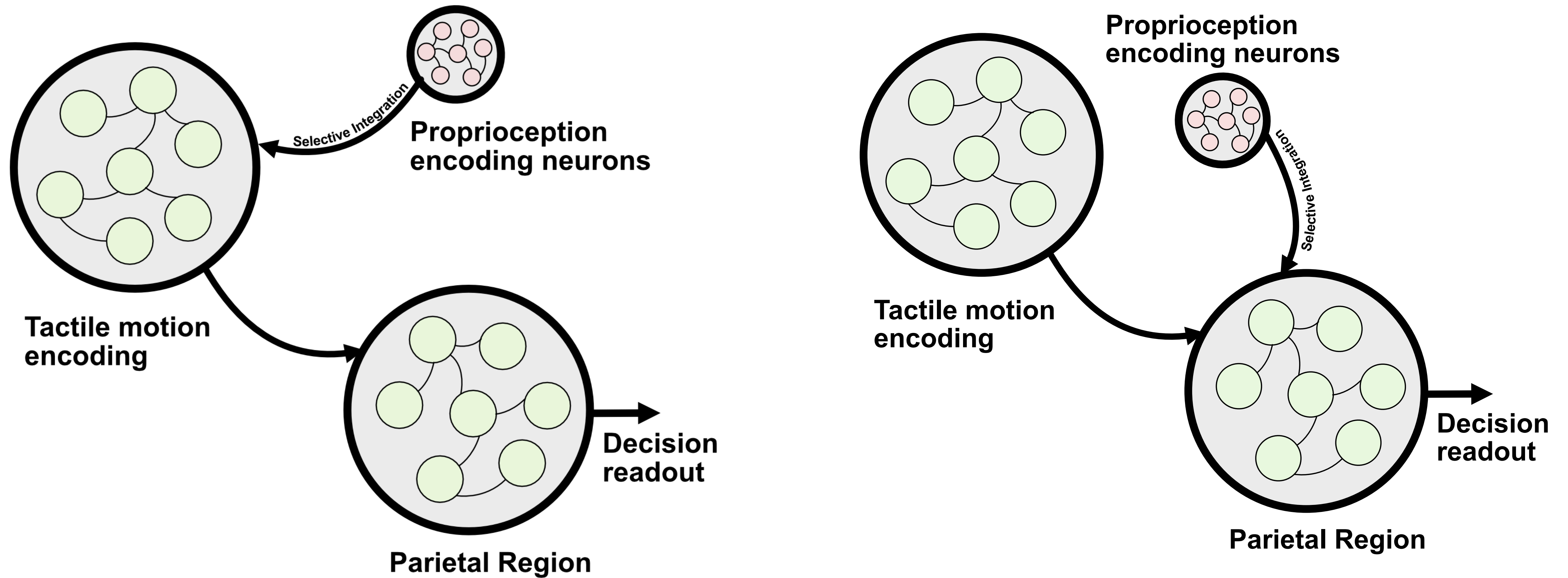


- Discrimination sensitivity higher in the finger-centric task

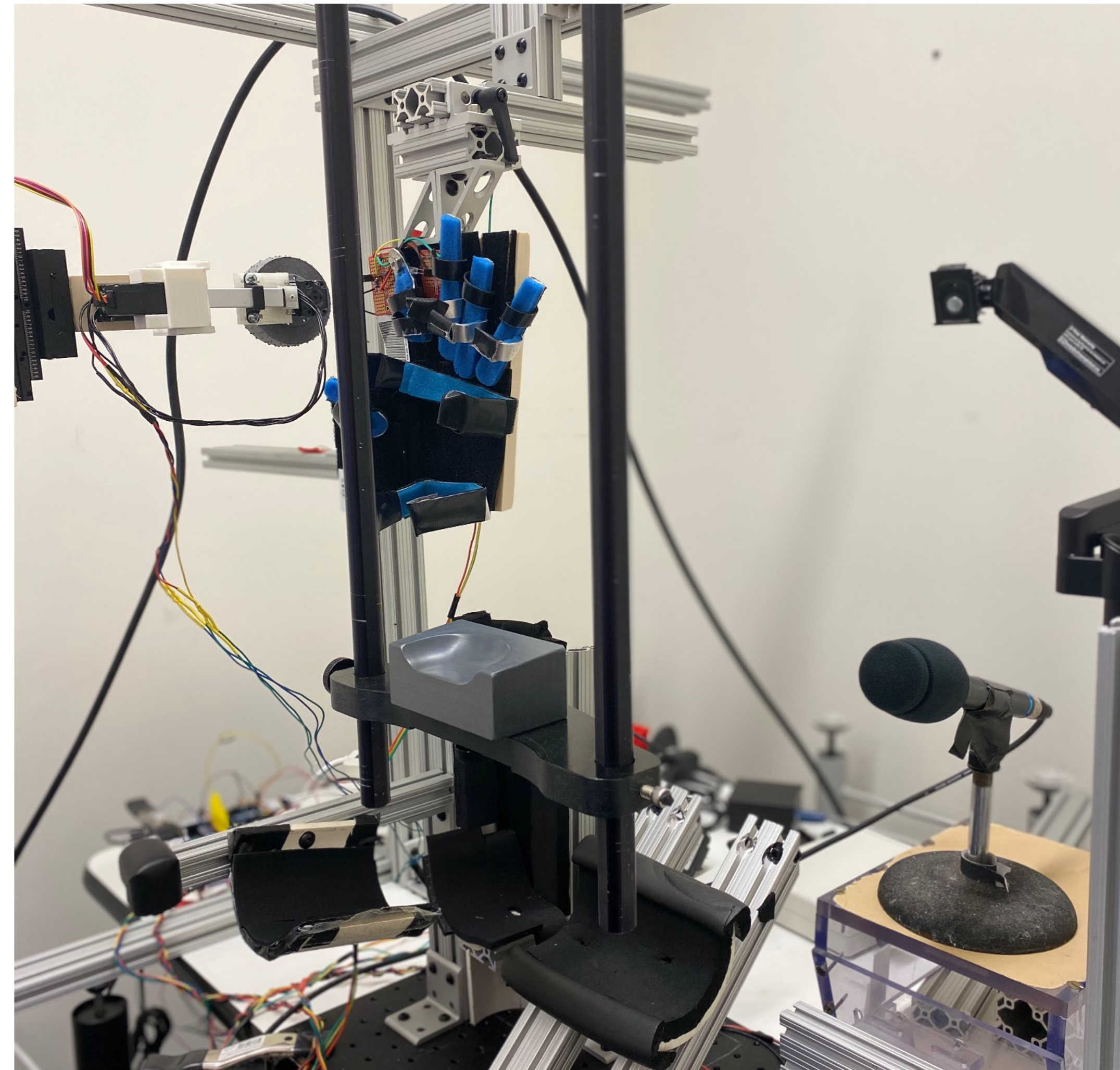
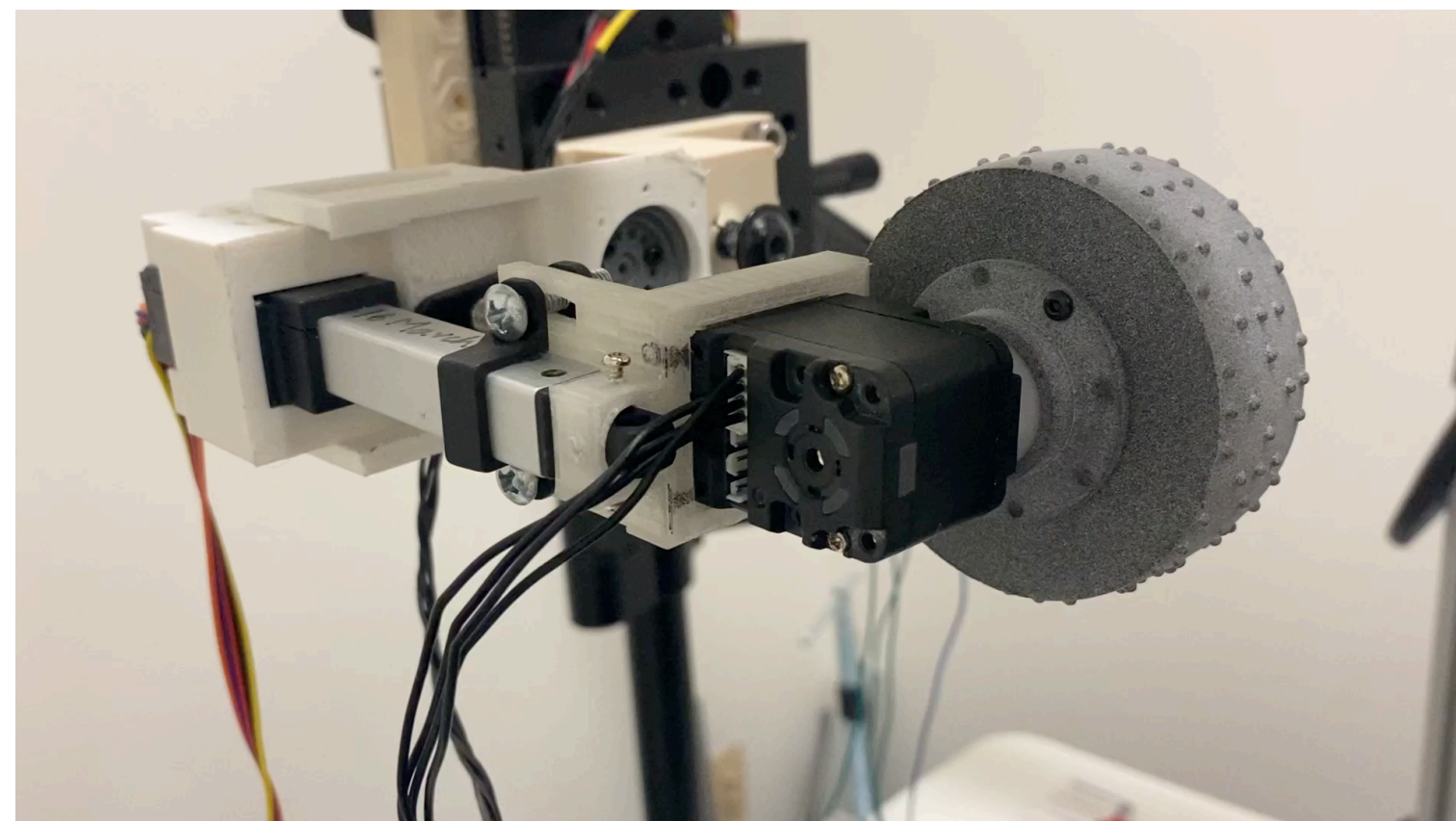
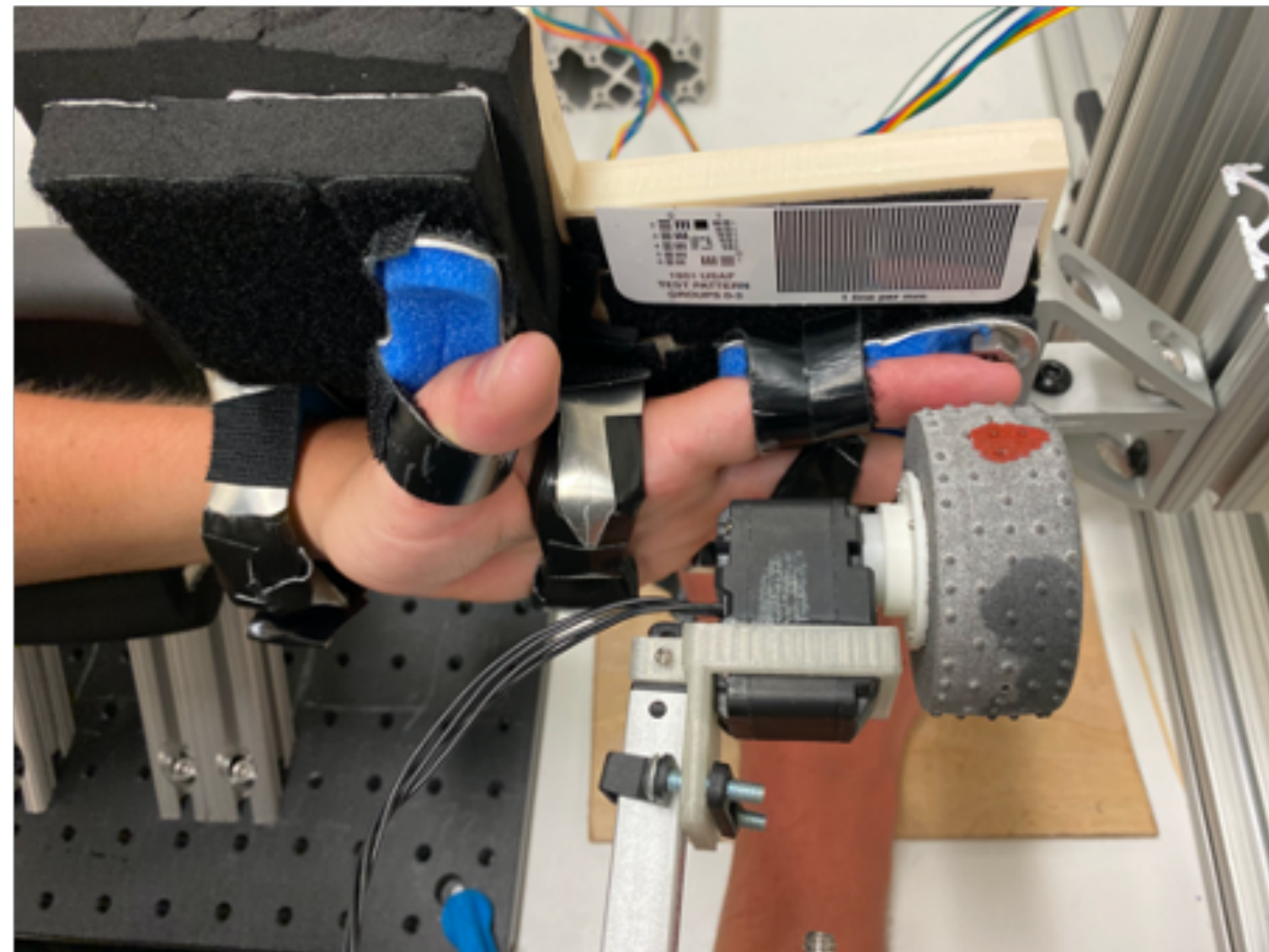


# **Supplementary Material**

# Neural implementation possibilities

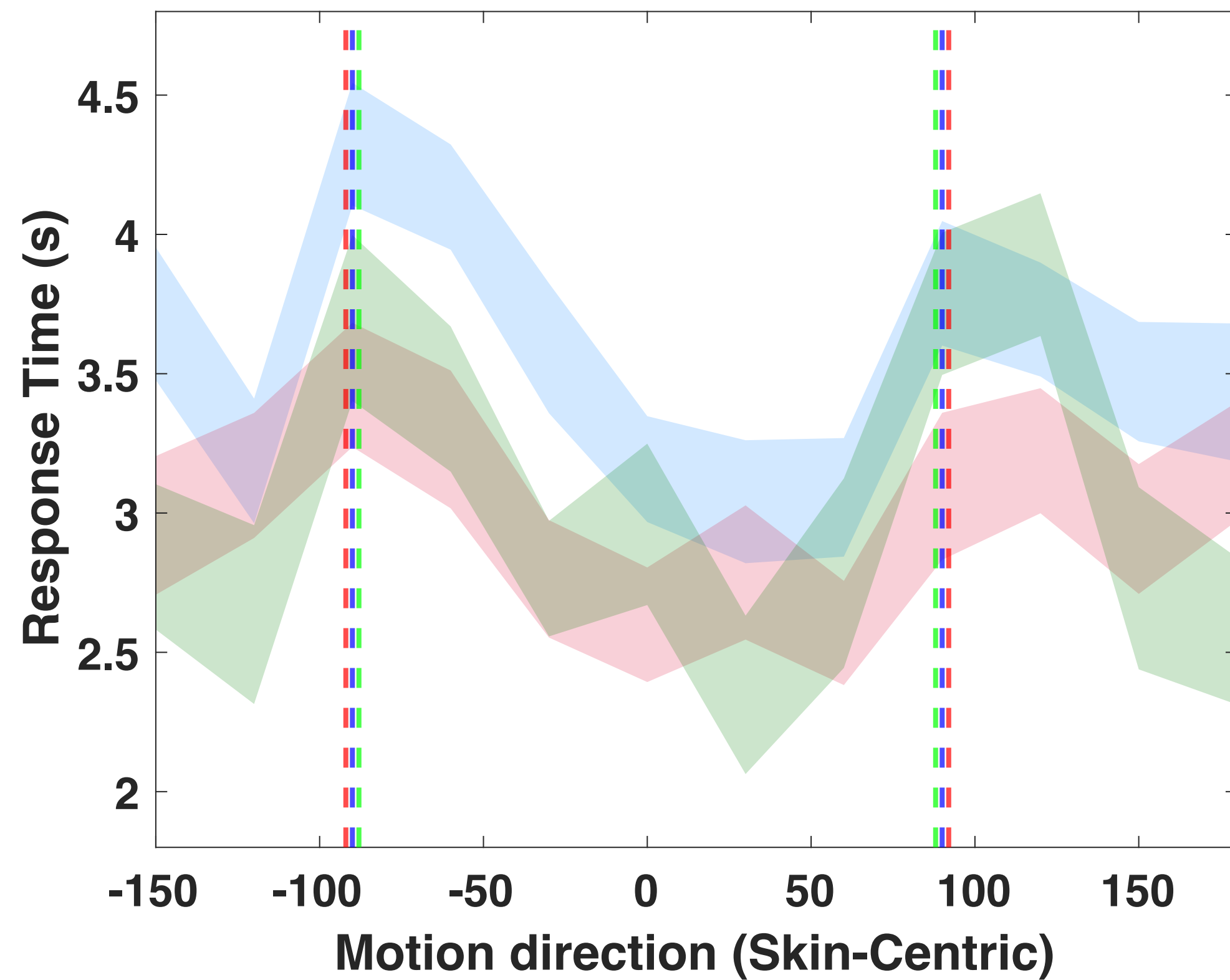


# Old Experiment Design

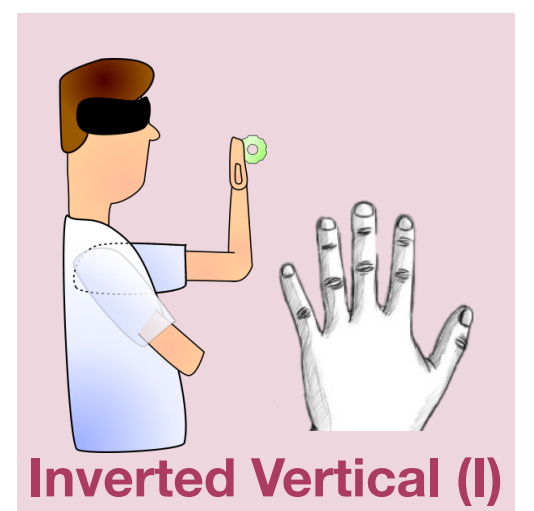
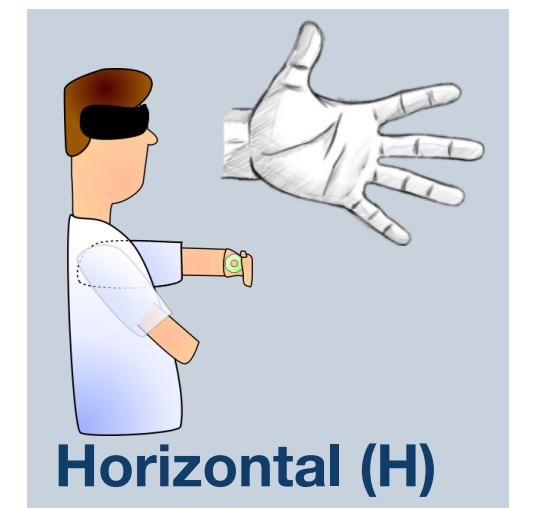
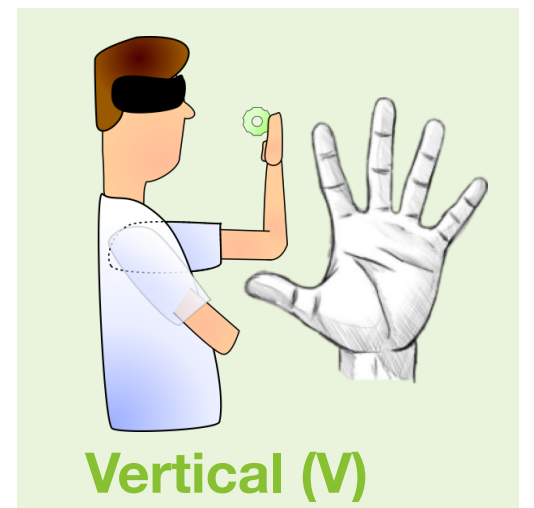
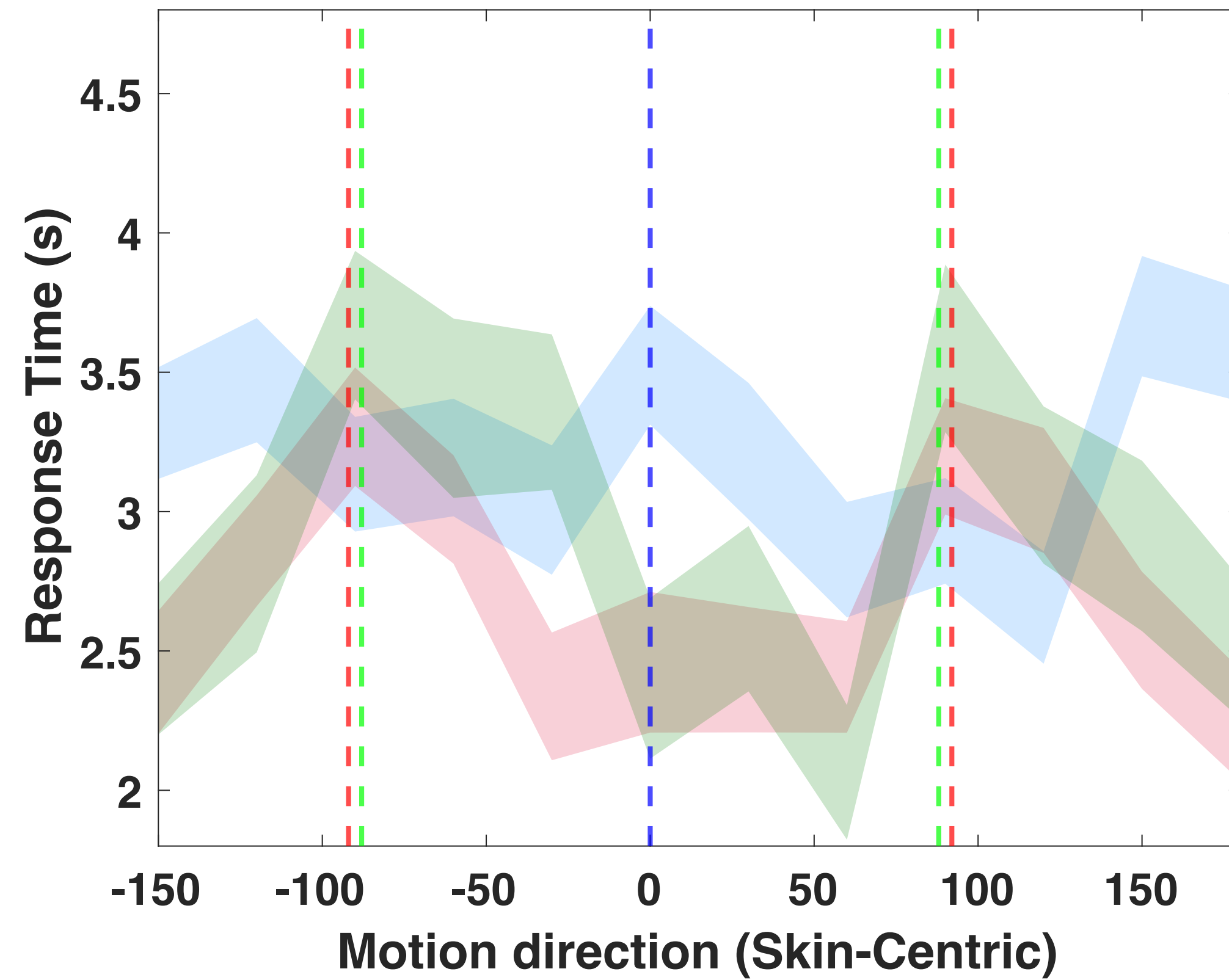


# How the reaction time changes with the angle measure.

## Away/ Towards the thumb

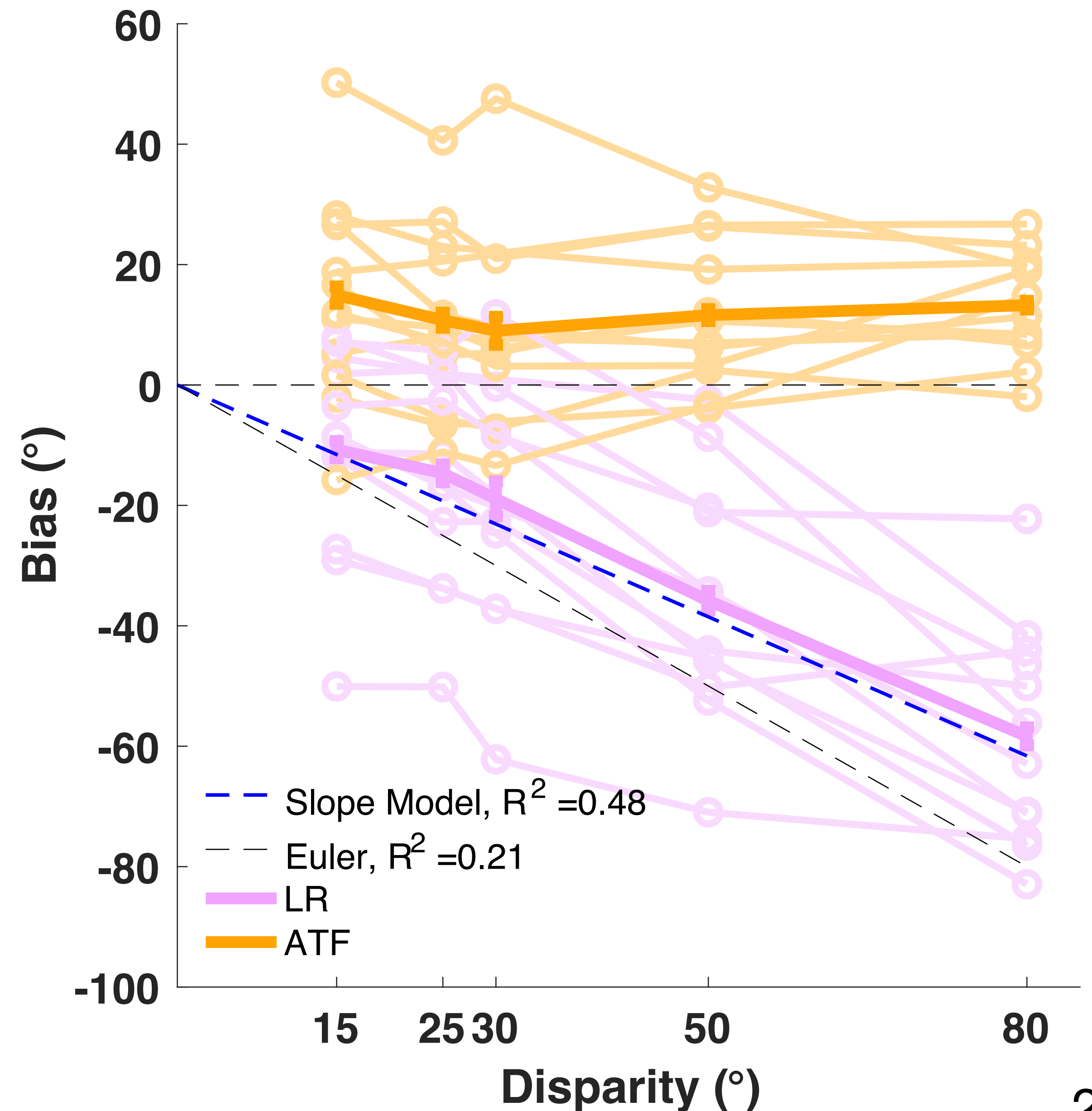


## Left/ Right

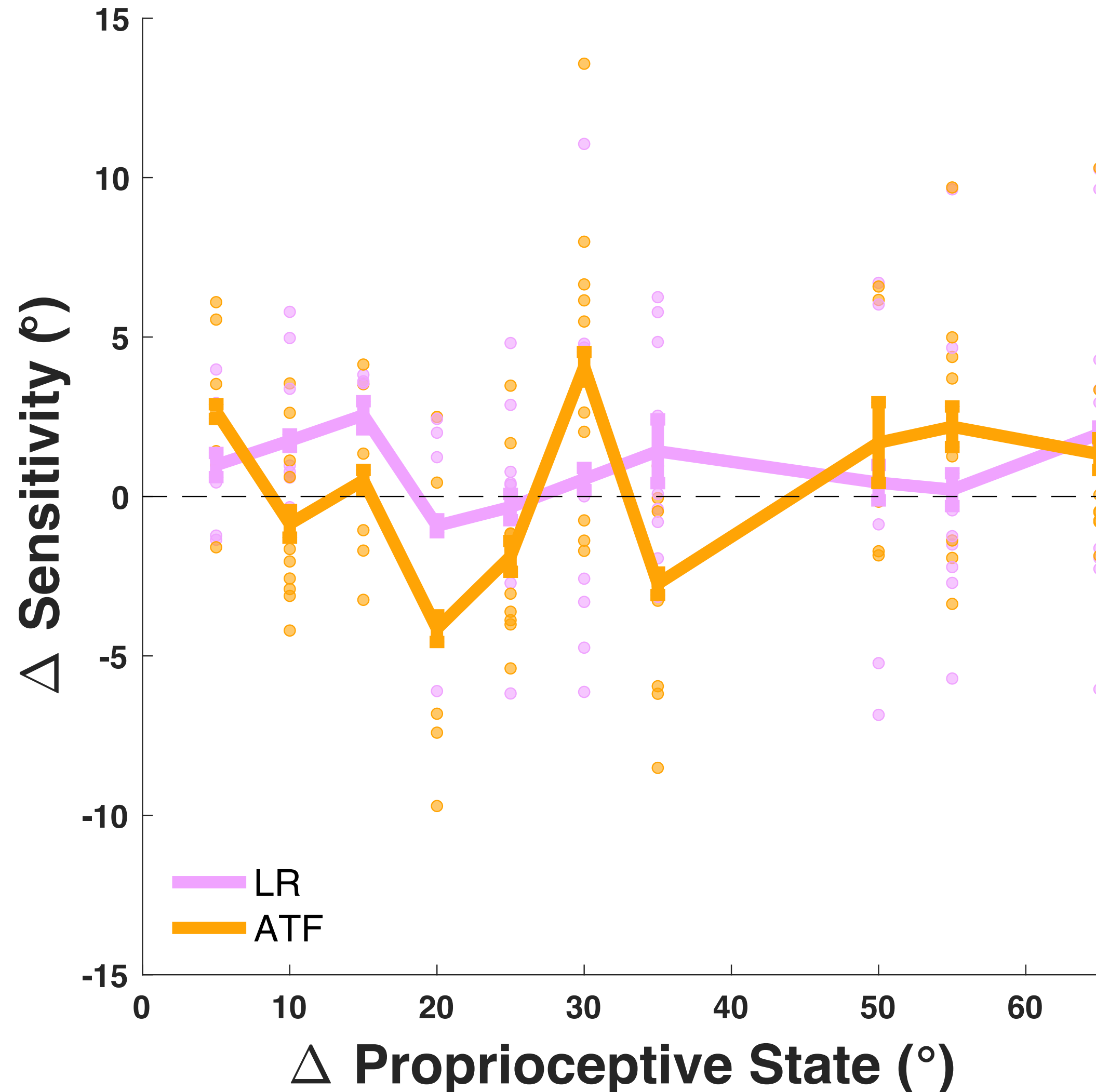


**Proprioceptive bias in tactile motion report in the sternum-centric coordinate system.**

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

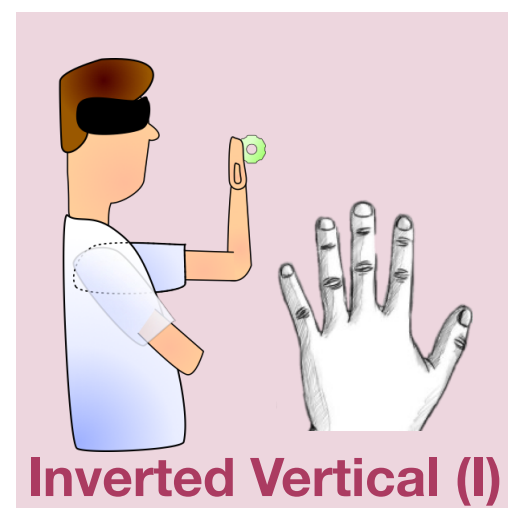
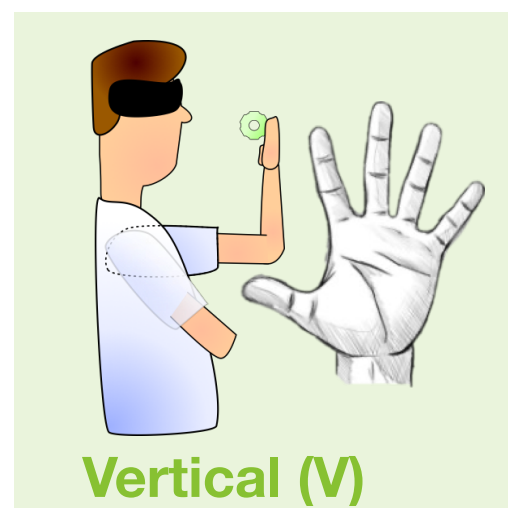


# Why do we choose only one sensitivity term to model our results?

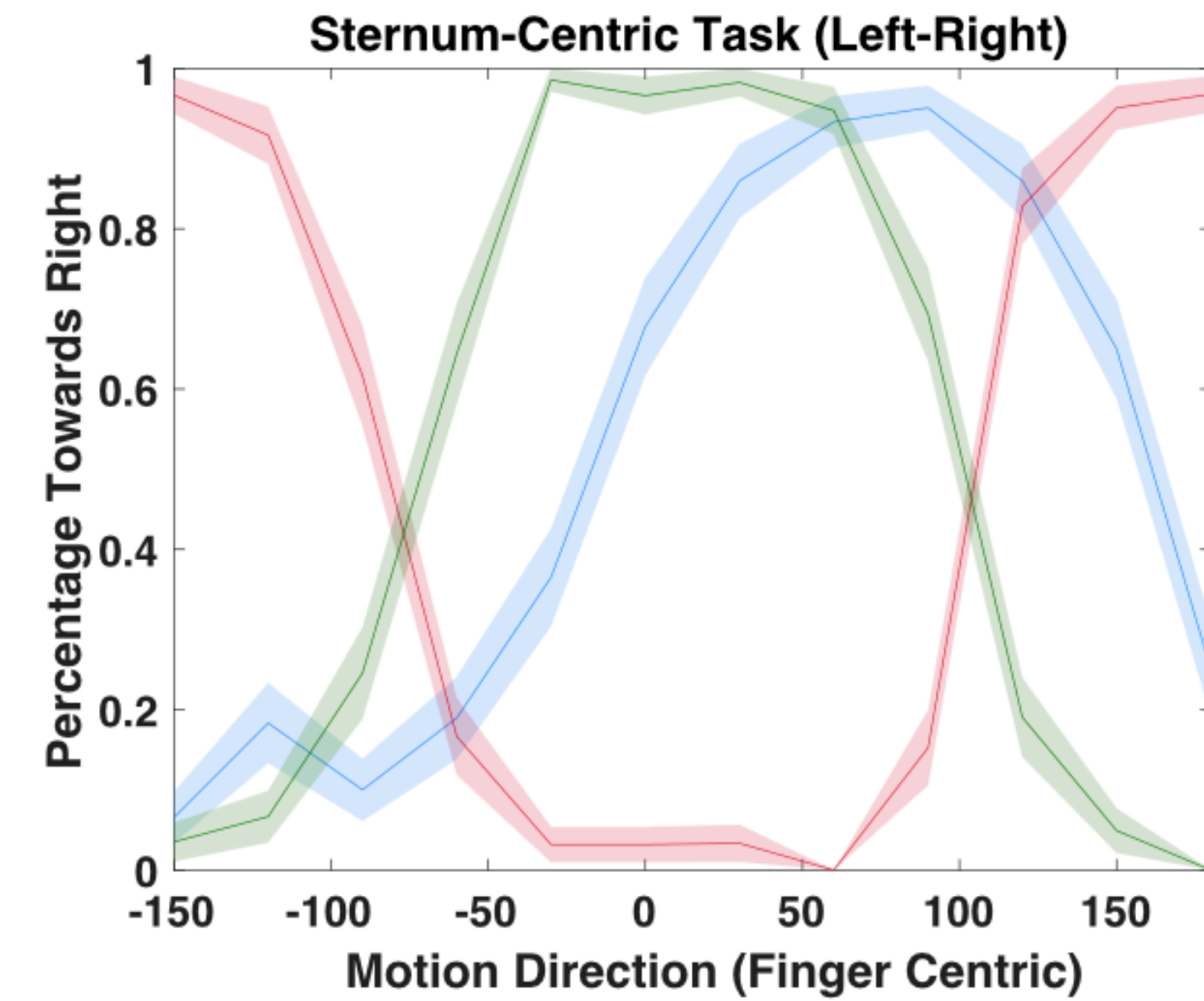
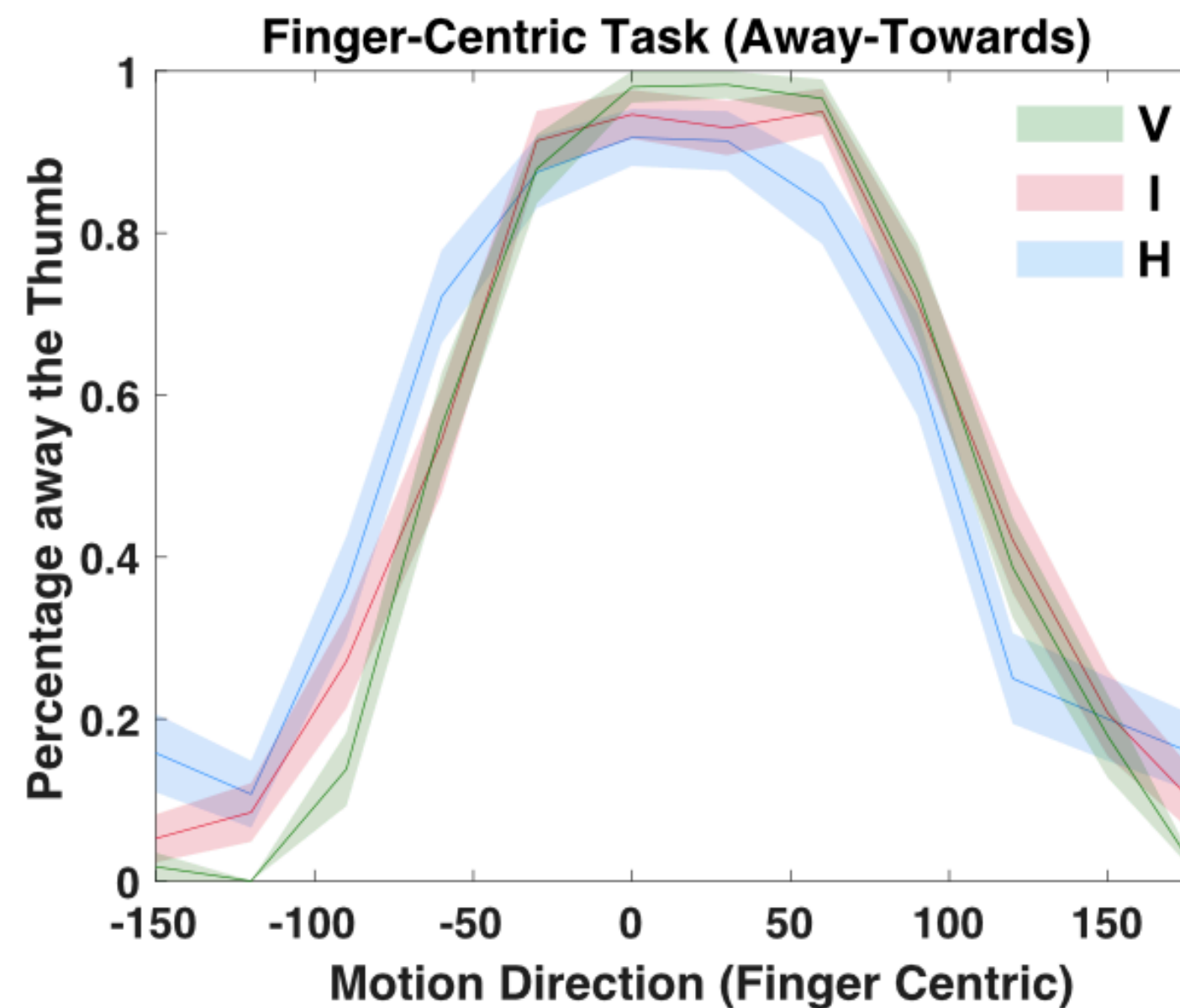


**Similar sensitivity difference across different proprioceptive states.**

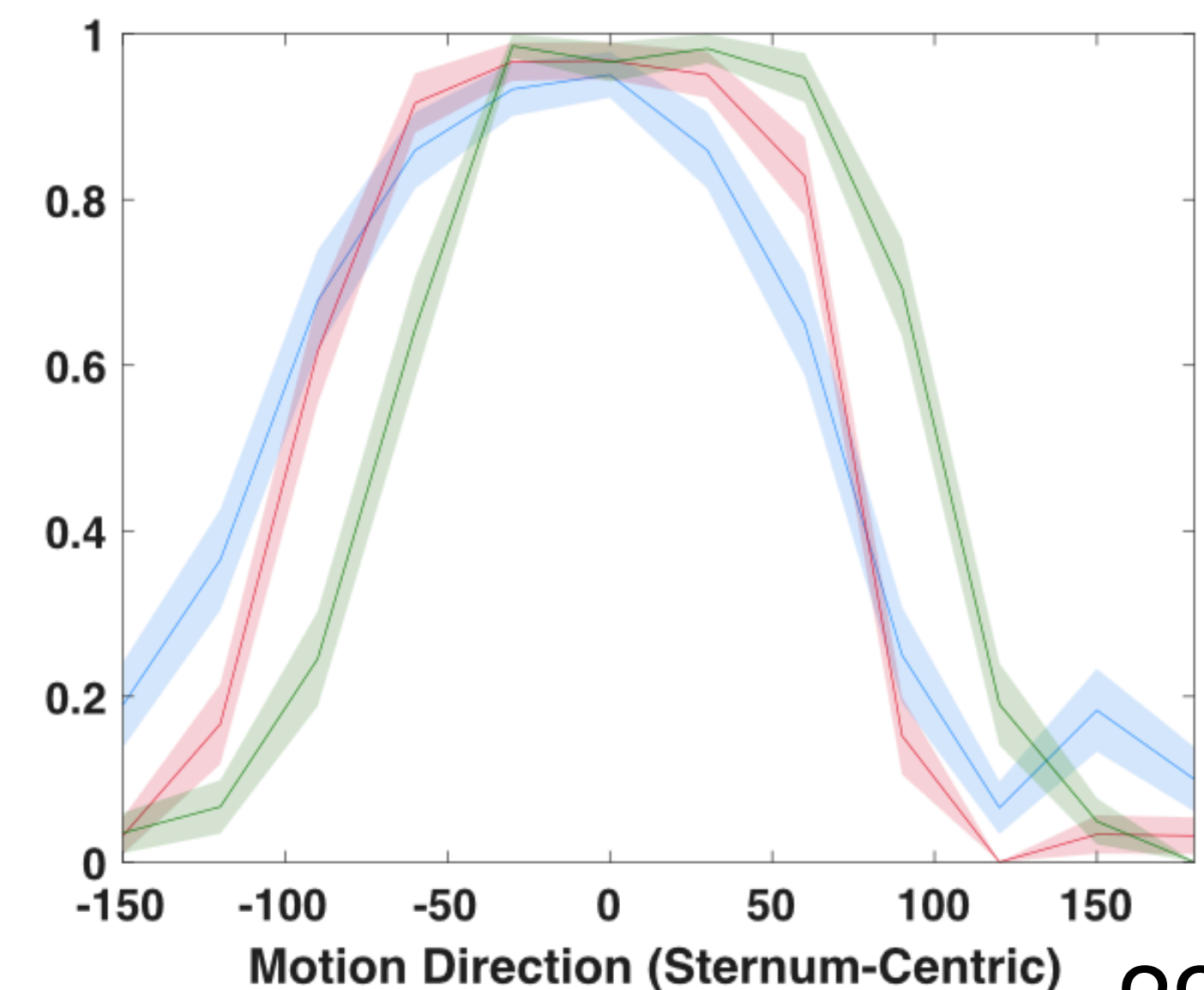
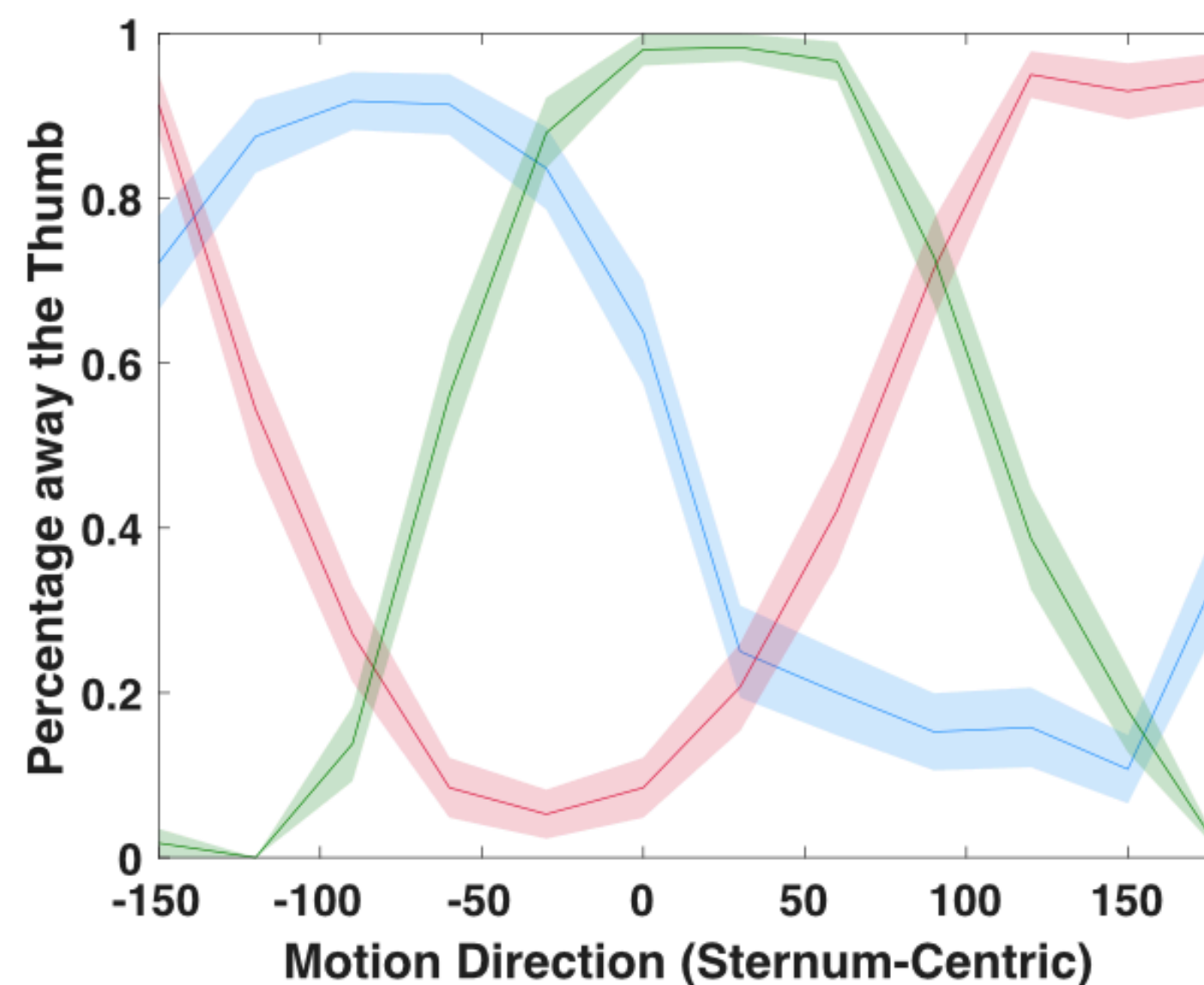
# Responses of the population in two coordinate systems



## Responses in finger-centric reference frame



## Responses in sternum-centric reference frame



# Sensitivity difference across two reference frames

