



Tactile Motion Coordinate Transforms in Somatosensory Cortex



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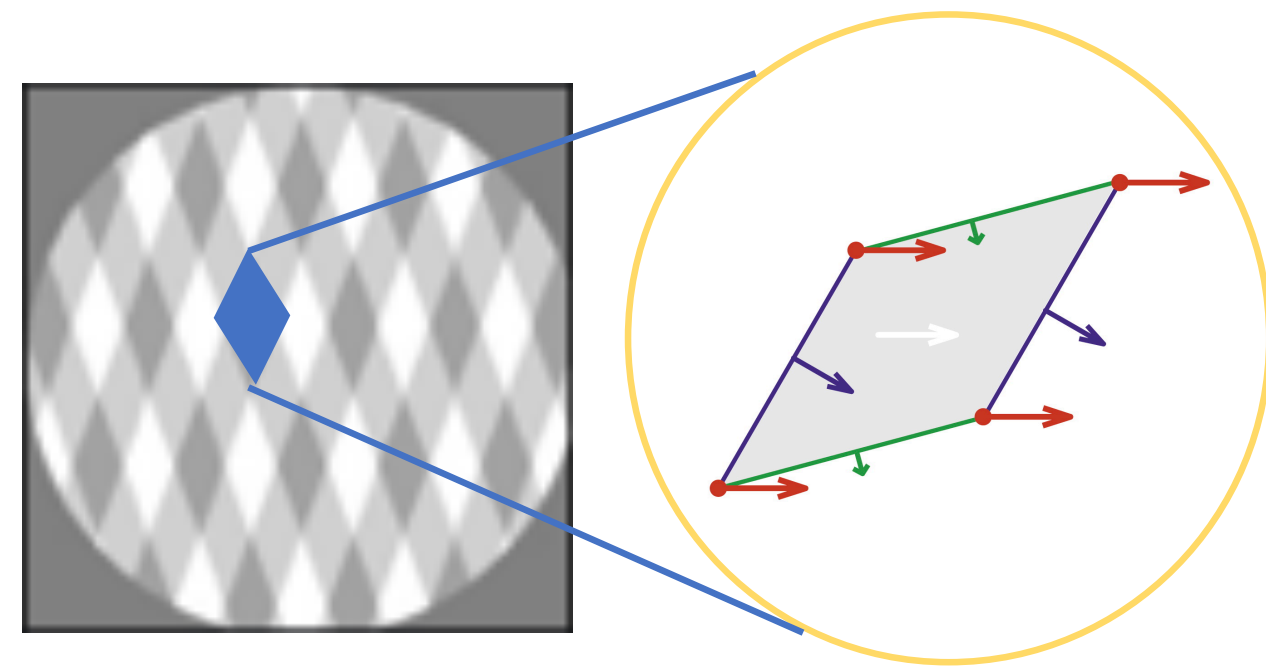
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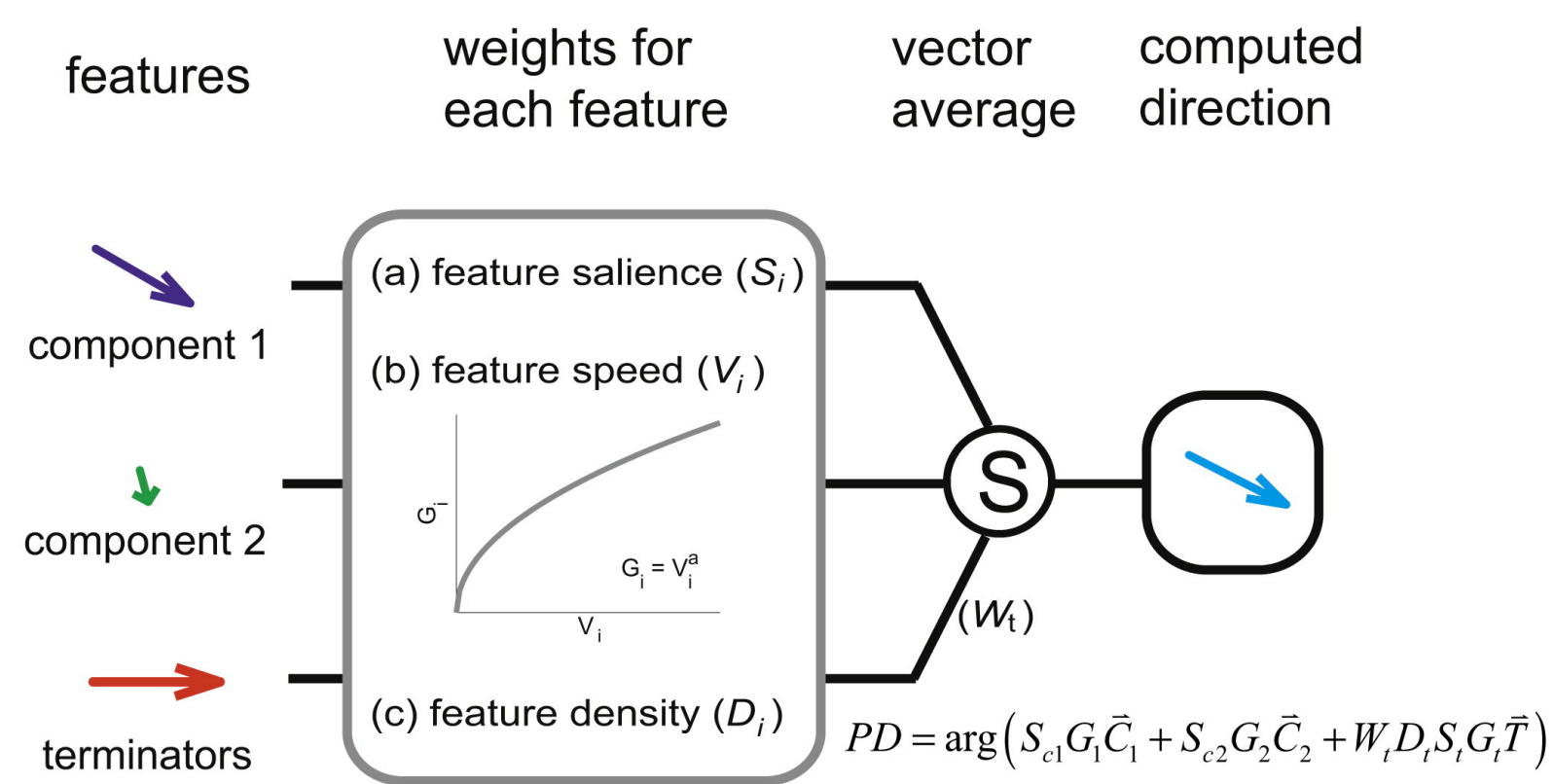
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Tactile Motion studies generally done with the hand in one posture



Different Components of a plaid

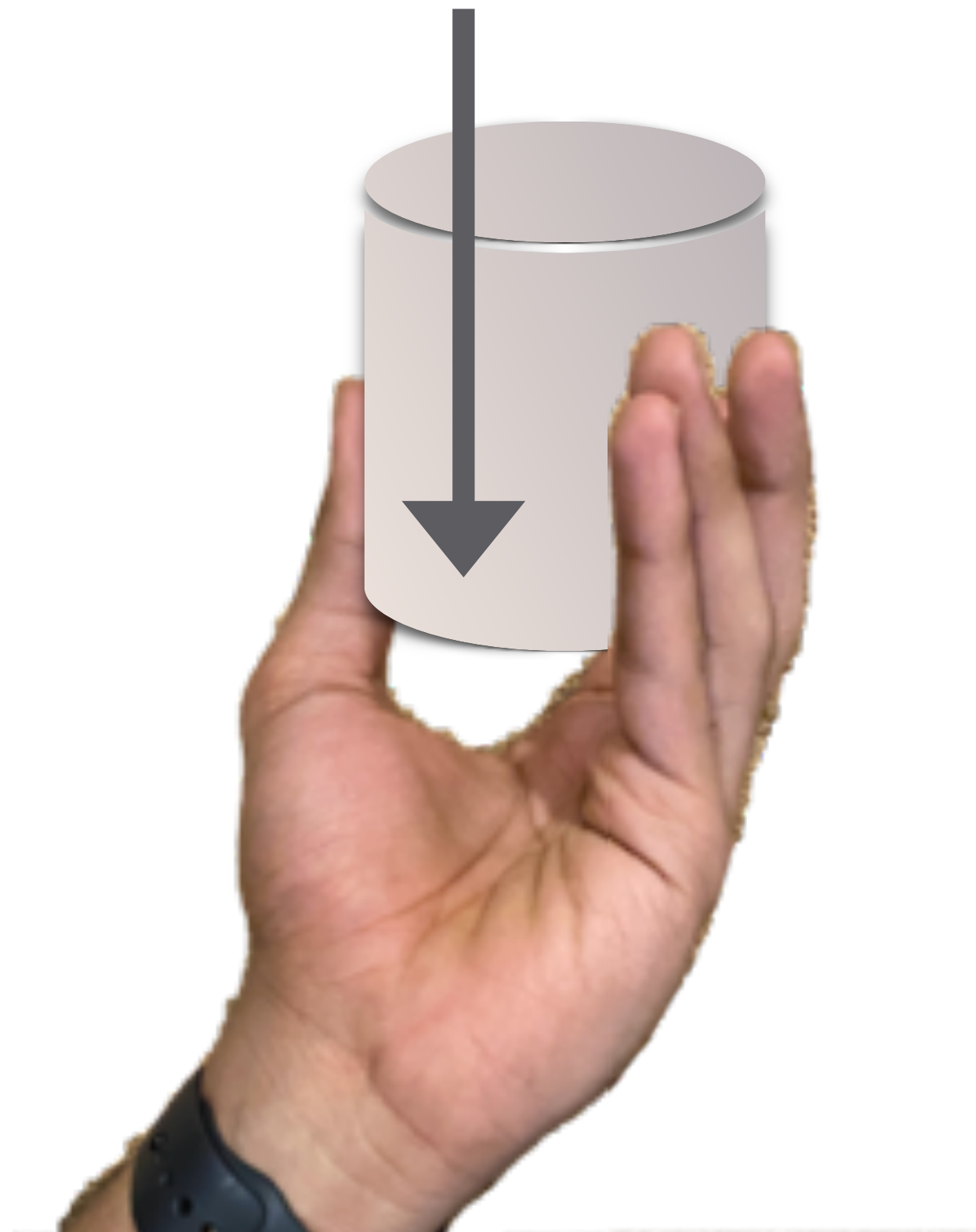


How components of a plaid are integrated to generate a global motion percept

- Pei et. al^[1] studied neural mechanisms underlying local tactile cue integration generating a global motion percept.
- Provided the **Vector Average Model** for tactile cue combination.
- Does not take into consideration reference frame and proprioceptive state of the arm

[1] Pei, Y. C., Hsiao, S. S., Craig, J. C., & Bensmaia, S. J. (2011). "Neural mechanisms of tactile motion integration in somatosensory cortex." *Neuron*, 69(3), 536-547.

Is the object moving down or towards the palm?



Downwards

Towards the palm

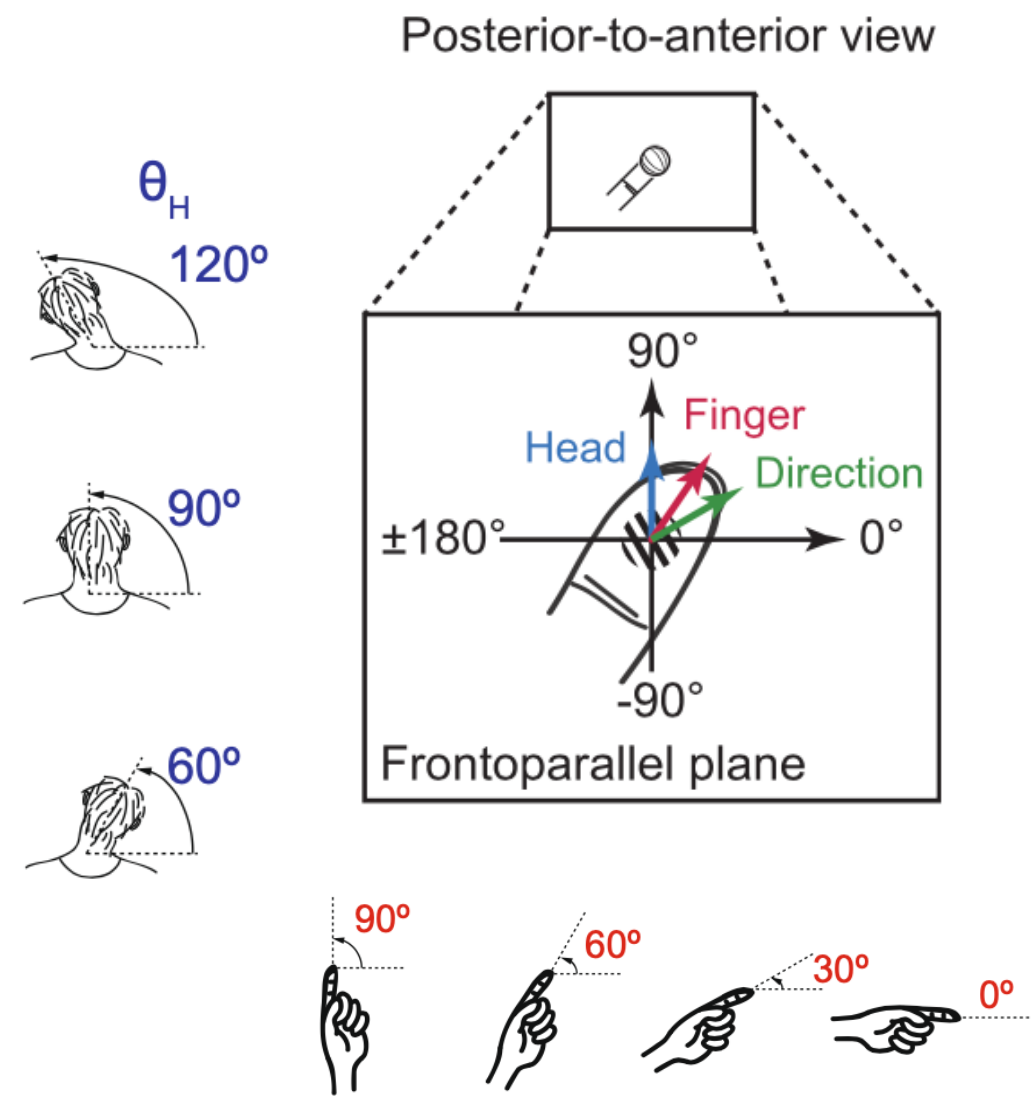


Downwards

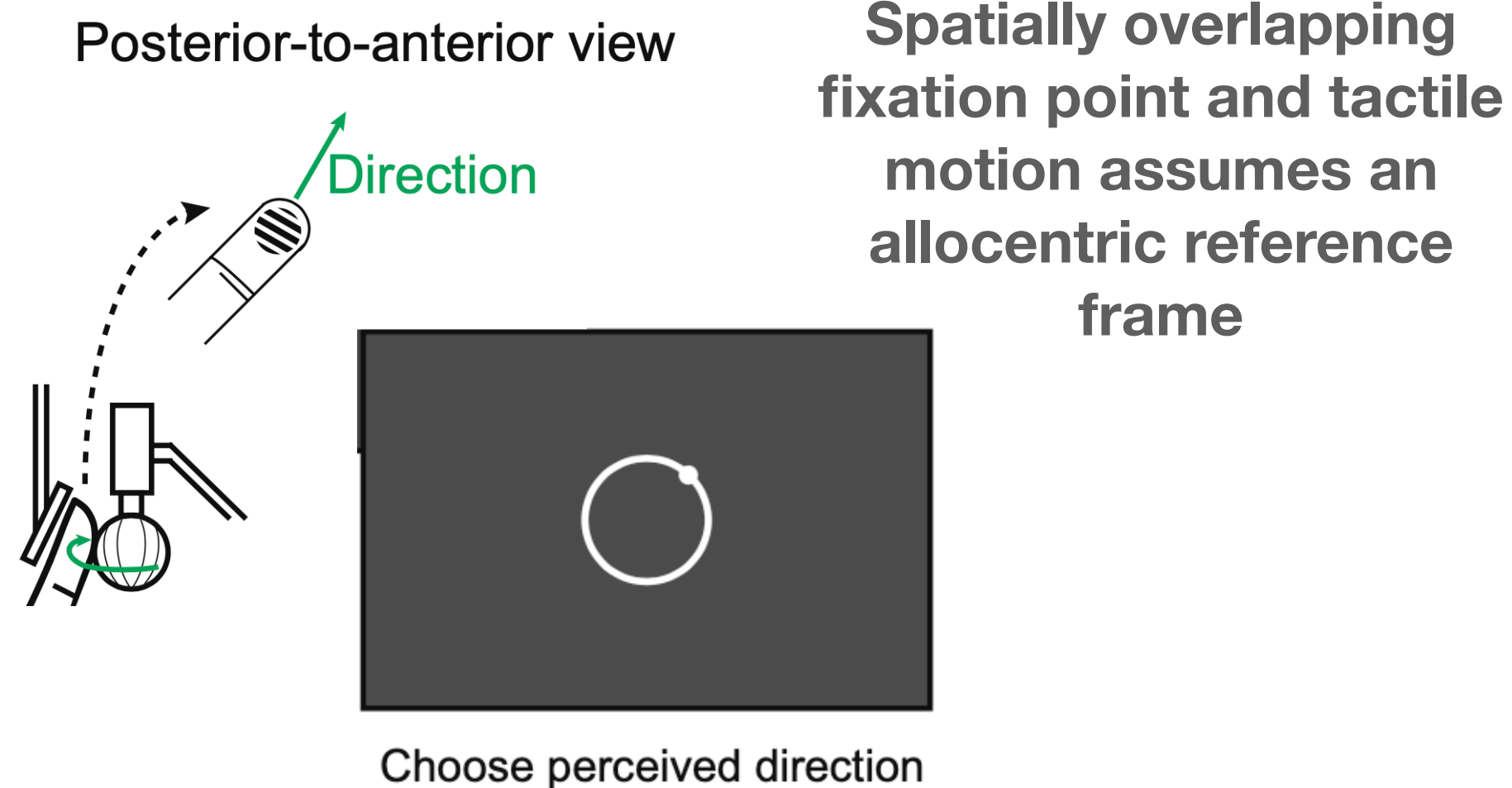
Away from the palm

No computational framework for tactile motion perception under different reference frames and proprioceptive state exists

Both head and finger posture were modulated.

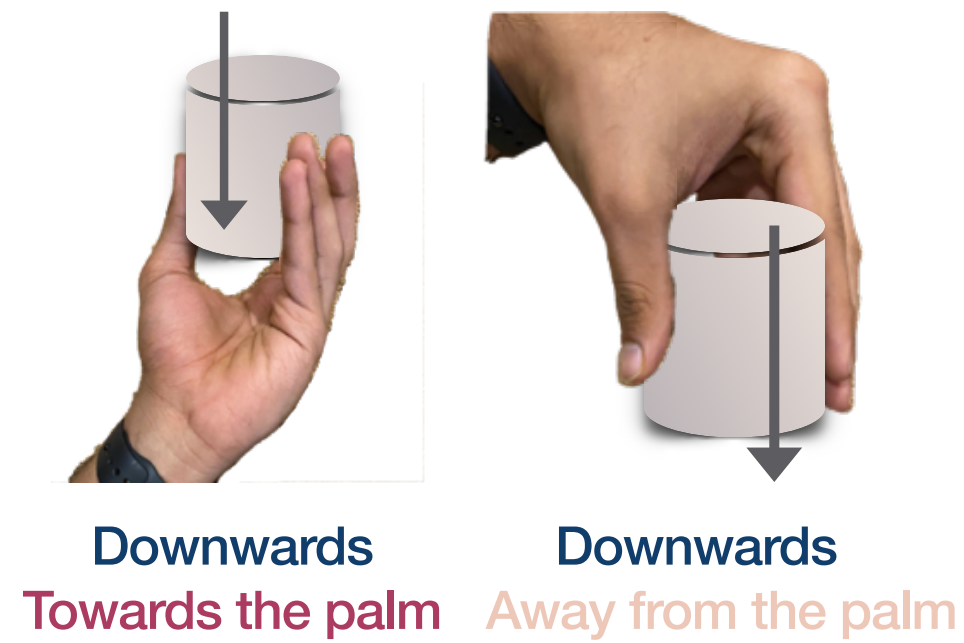


- Chen et. al^[1] explore systematic biases in tactile motion perception under different proprioceptive state within an assumed reference frame.
- Lacks an explicit reference frame which leaves ambiguity on the selected reference frame.
- No computational account for the coordinate transformations under motion perception.



[1] Chen, Yueh-Peng, et al. "Relative posture between head and finger determines perceived tactile direction of motion." *Scientific reports* 10.1 (2020): 1-13.

Is the object moving down or towards the palm?



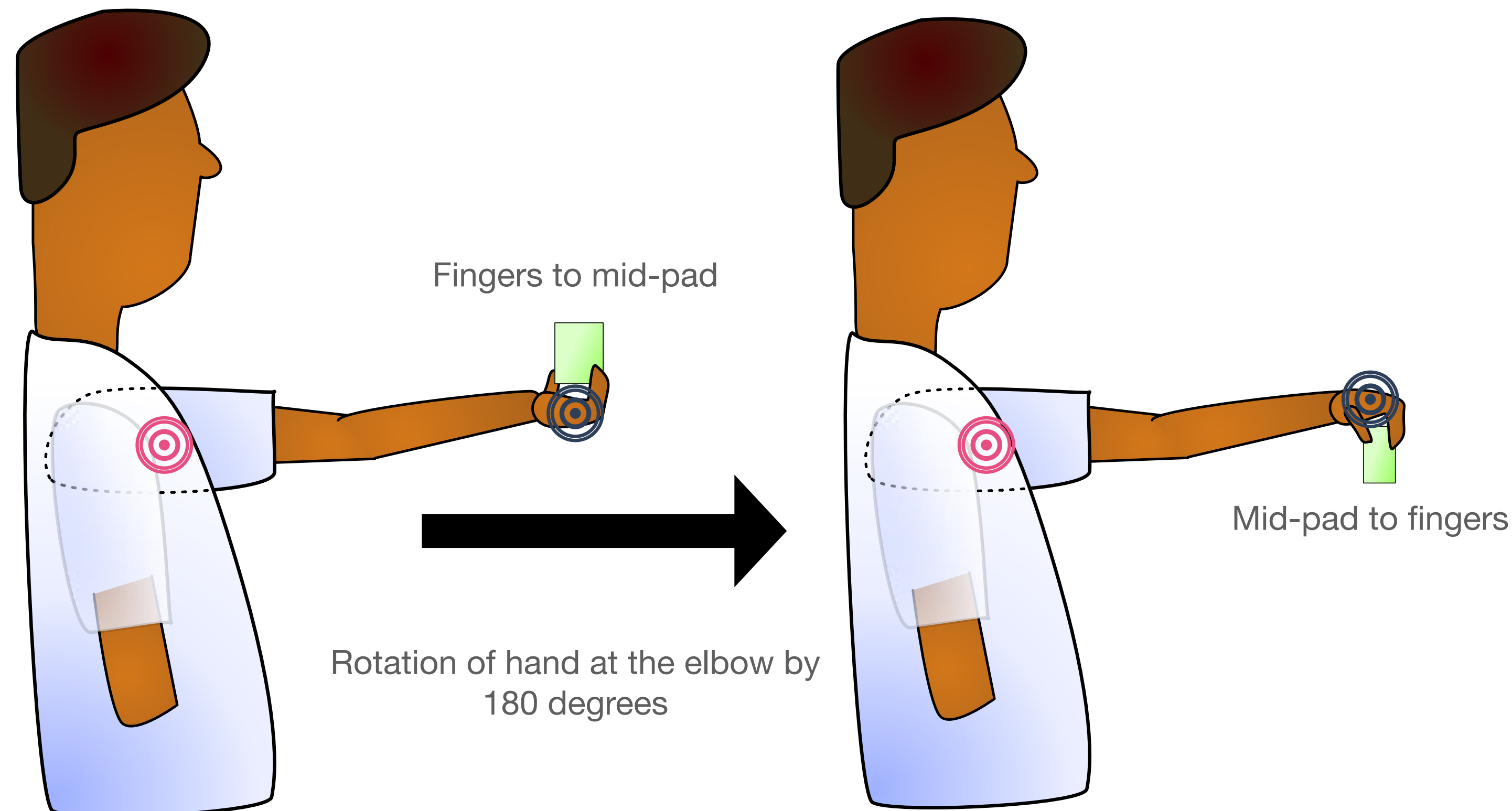
What changes between the two cases?

The posture of the hand

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

= Proprioceptive state of the arm

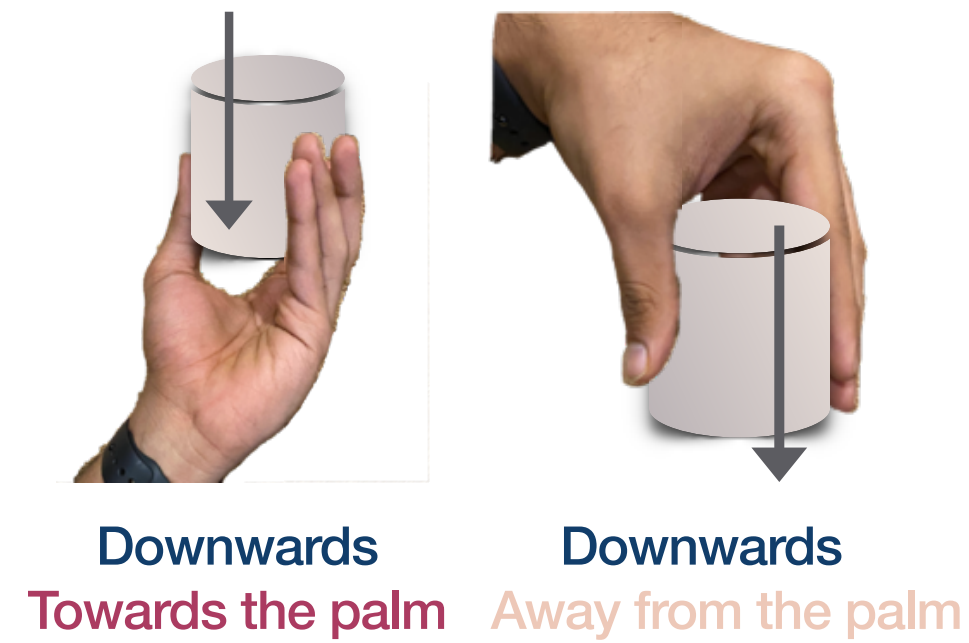
= Cutaneous motion information



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

Motion in hand reference frame changes

How do proprioceptive signals interact with the cutaneous motion information?

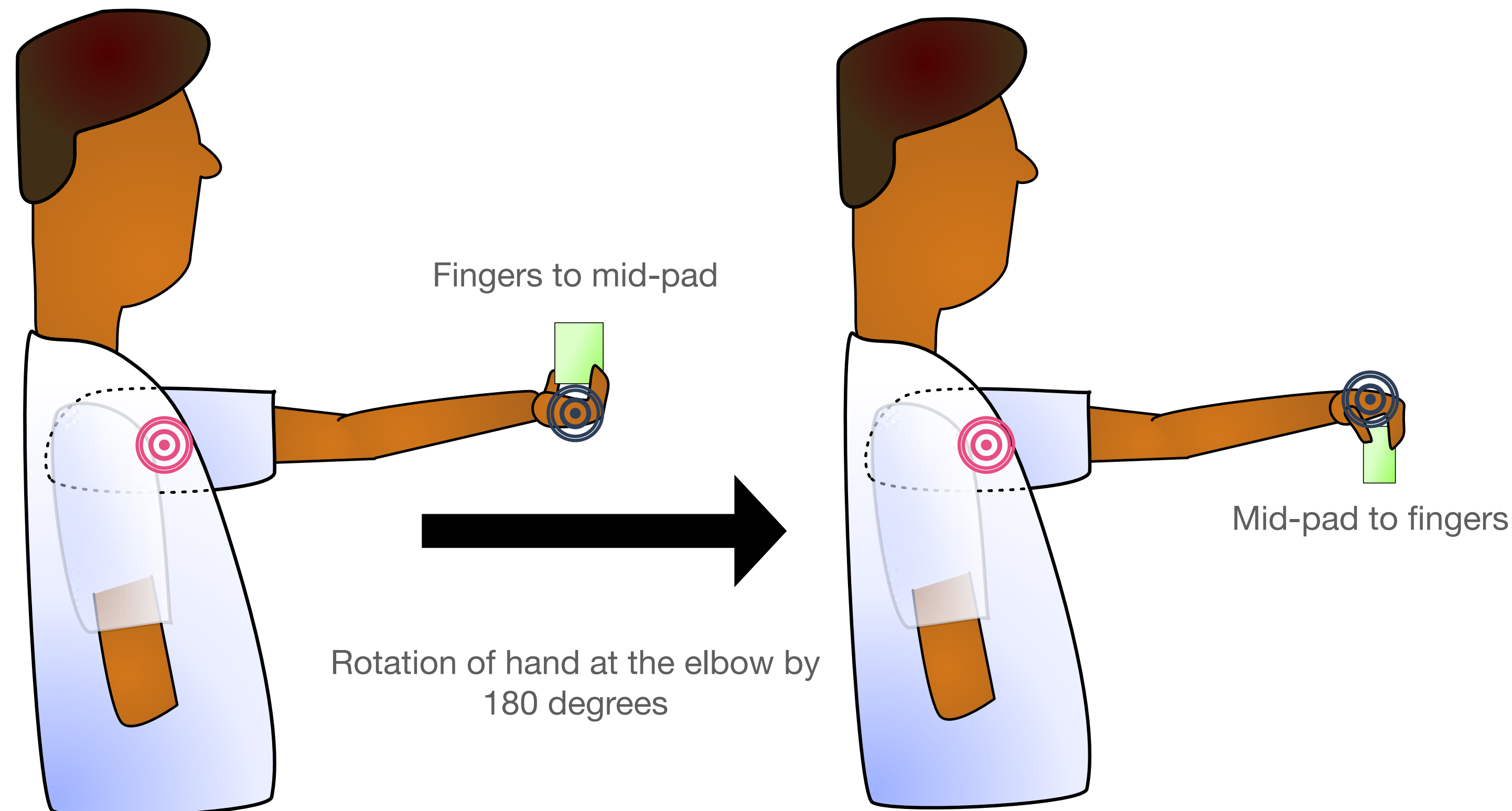


What changes between the two cases?

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

How do proprioceptive signals interact with the cutaneous motion information?

Experiment Design: 2-AFC Motion Direction Discrimination

Two reference frames: Head-Centric and Hand-Centric

2-alternate Force Choice Motion
Direction discrimination task

Two Task Instructions:

LEFT vs RIGHT

w.r.t the center of the body

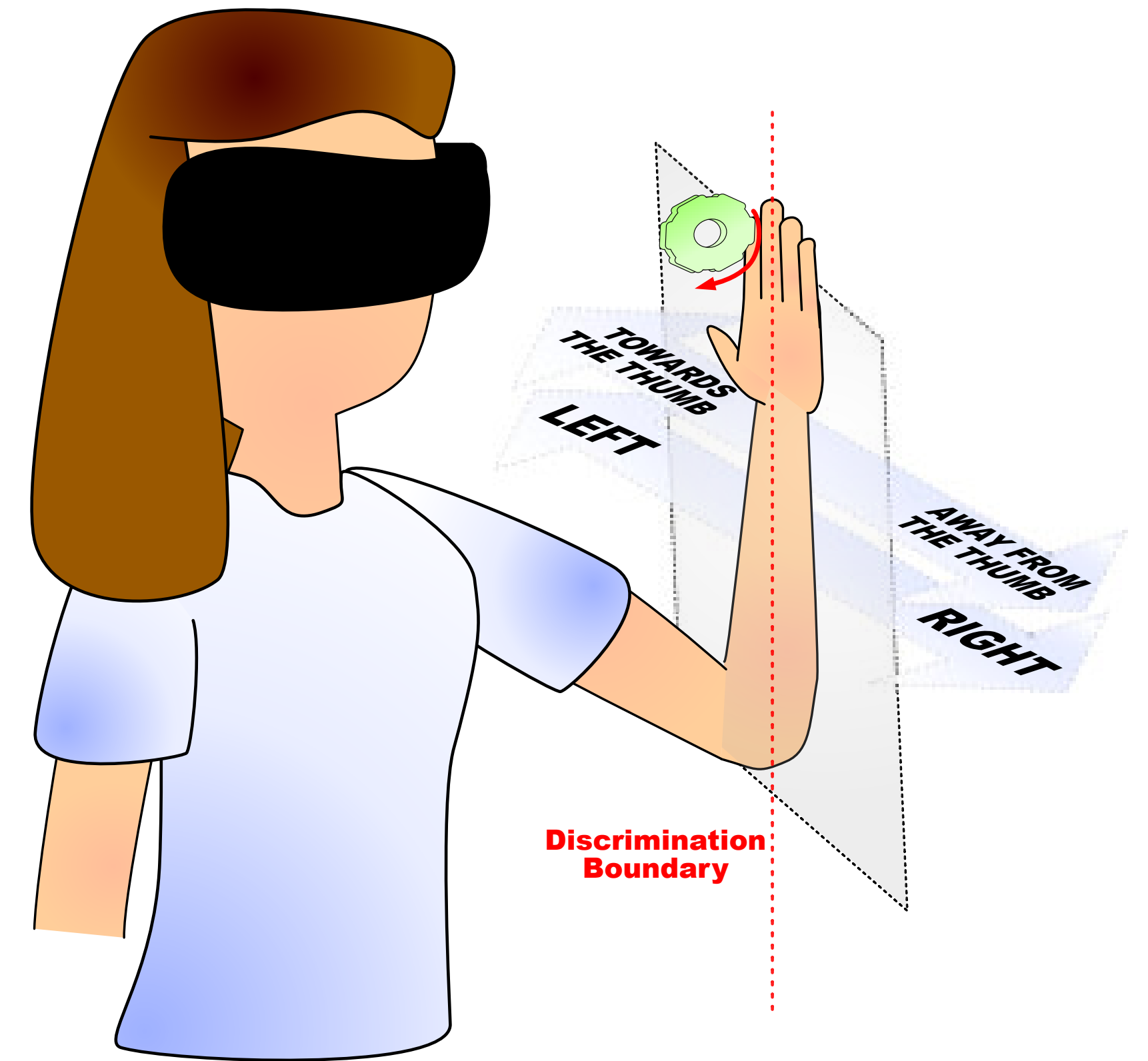
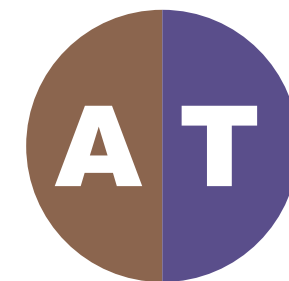
Sternum-Centric Reference Frame



AWAY vs TOWARDS

the thumb-edge of the palm

Finger-Centric Reference Frame



Experiment Design: Task Timeline

2-AFC Motion Direction discrimination task

Vertical (V)

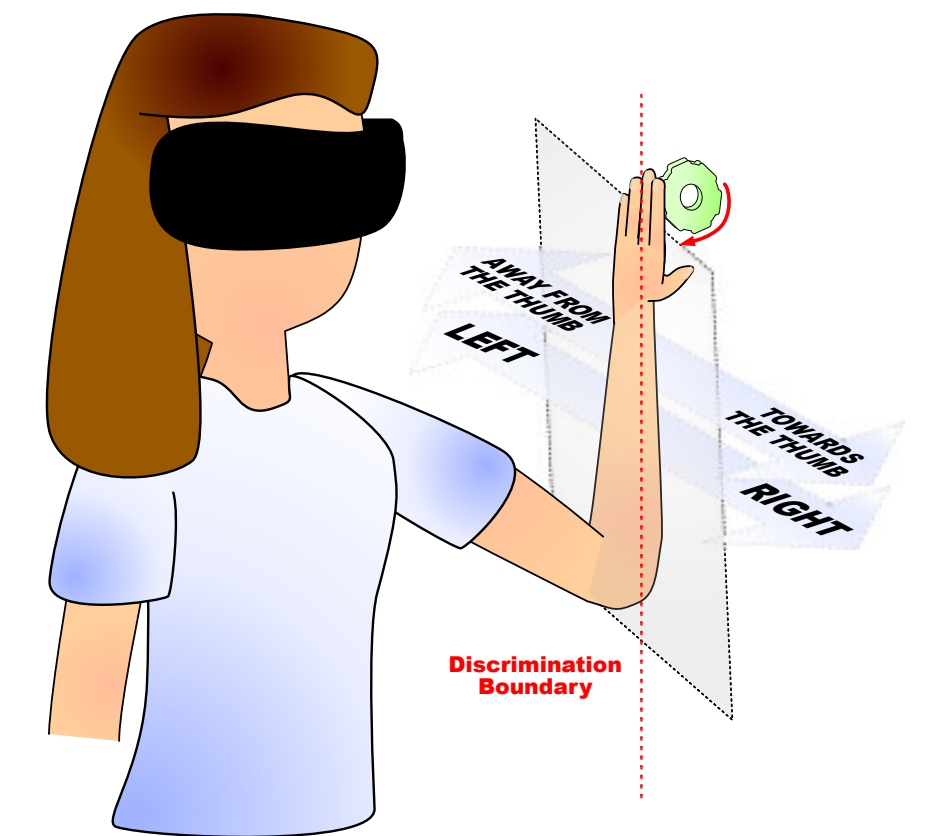
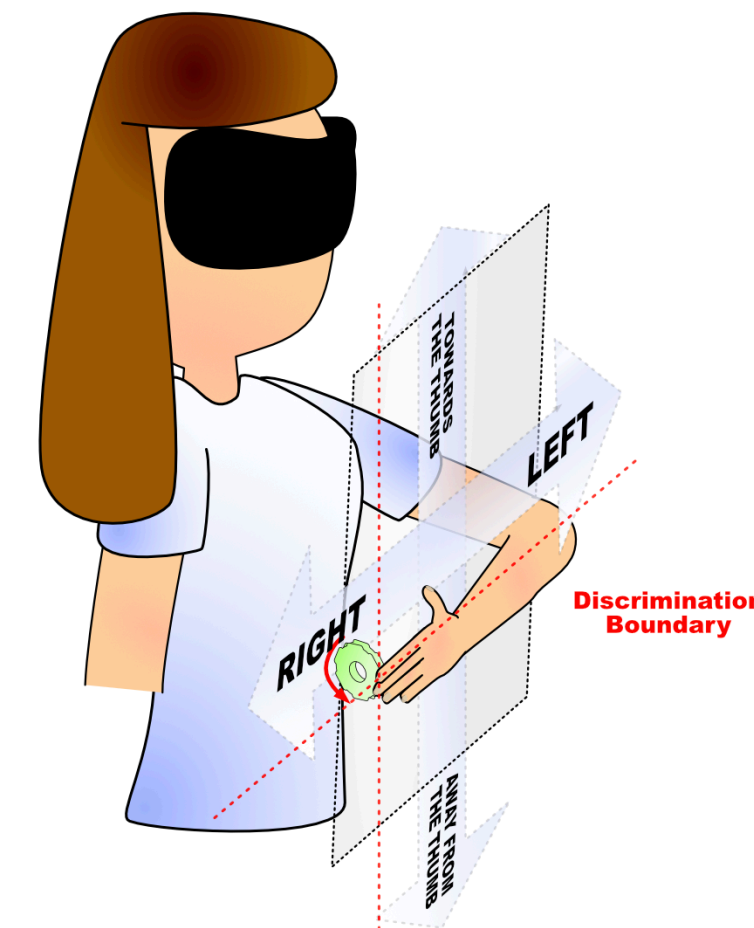
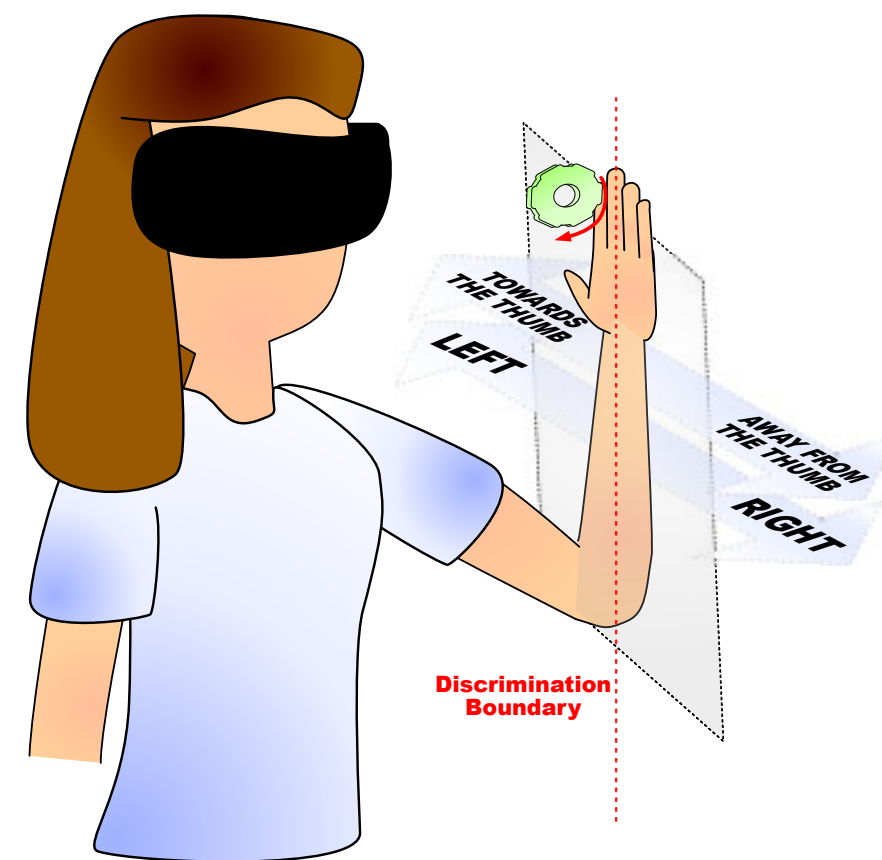
Horizontal (H)

Inverted Vertical (I)

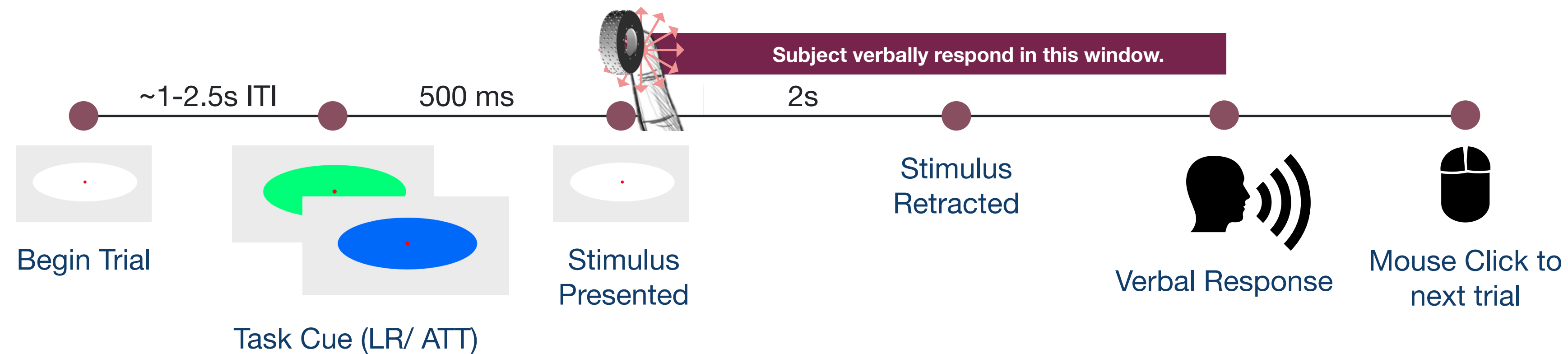
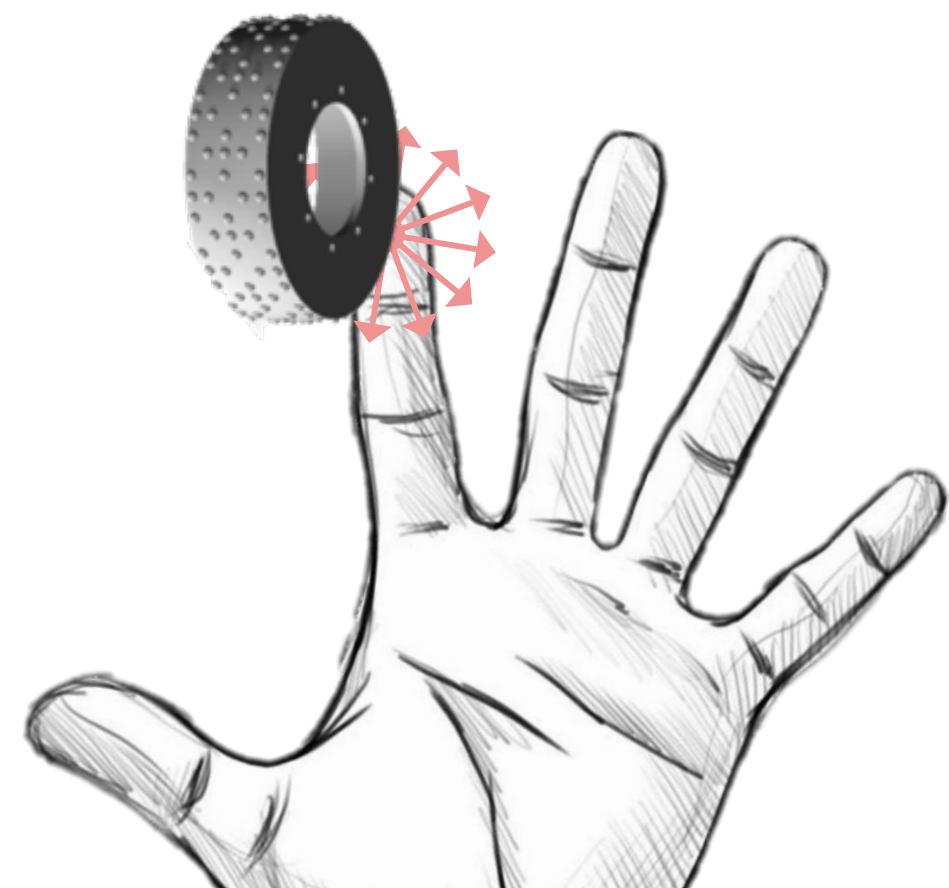
Sternum-Centric Reference Frame



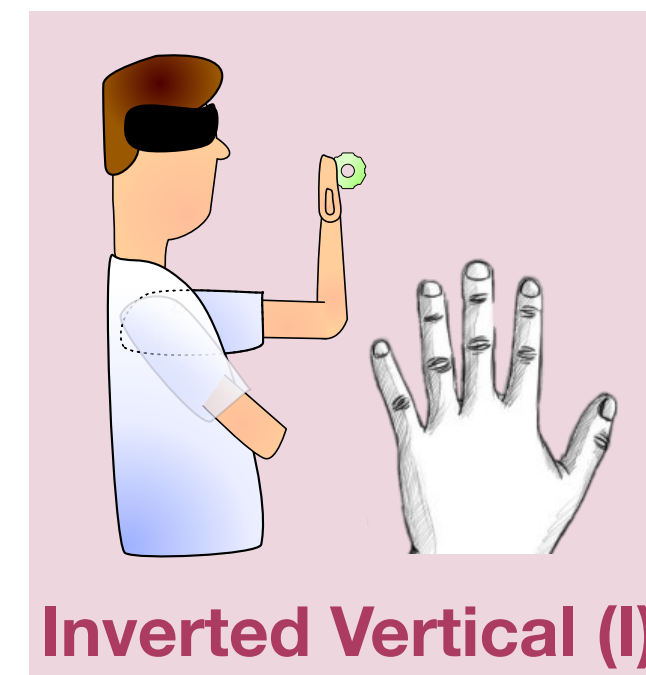
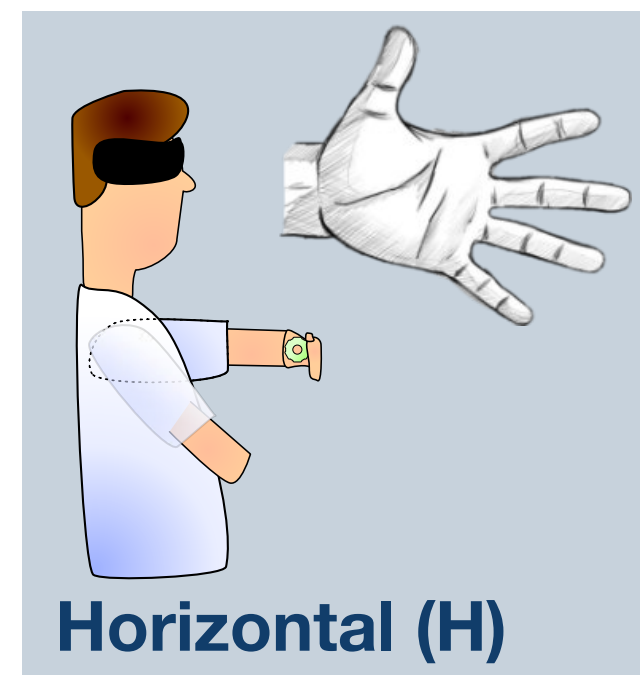
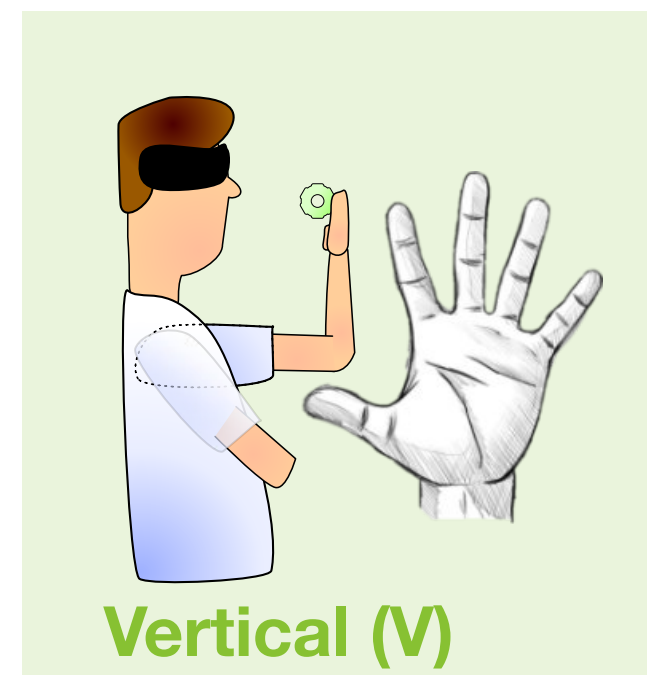
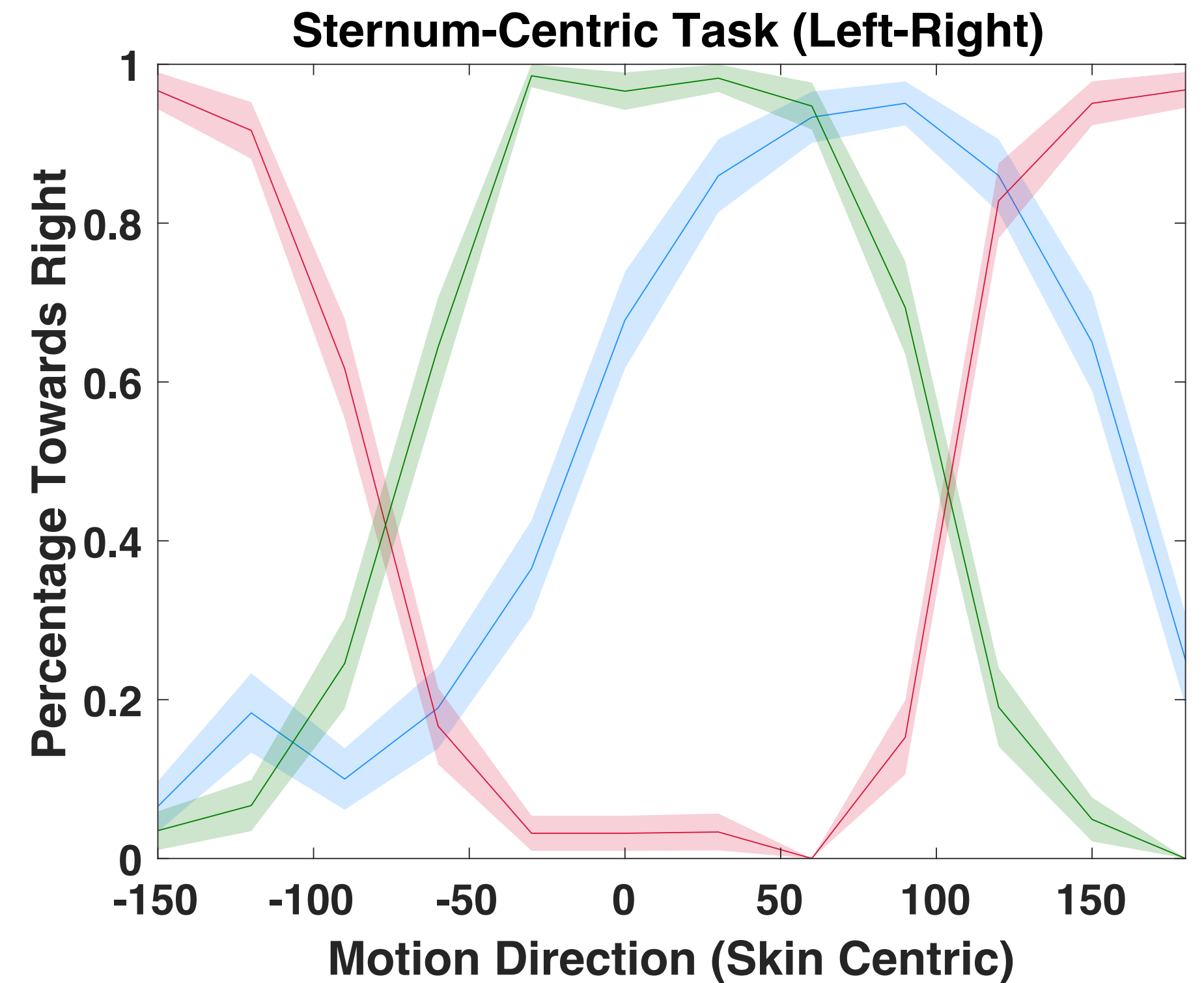
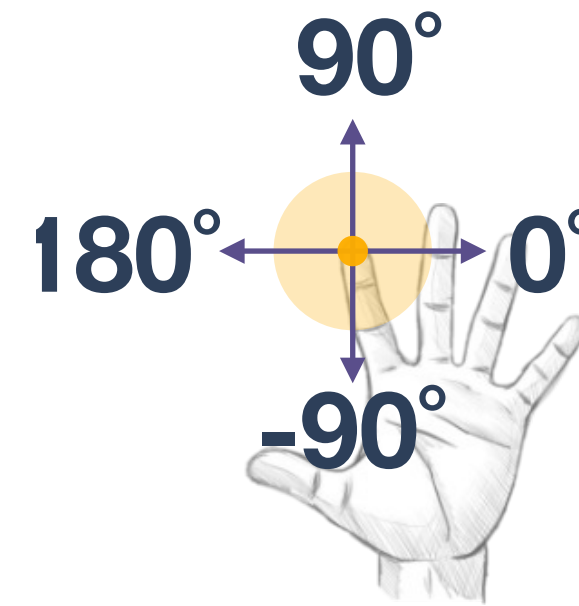
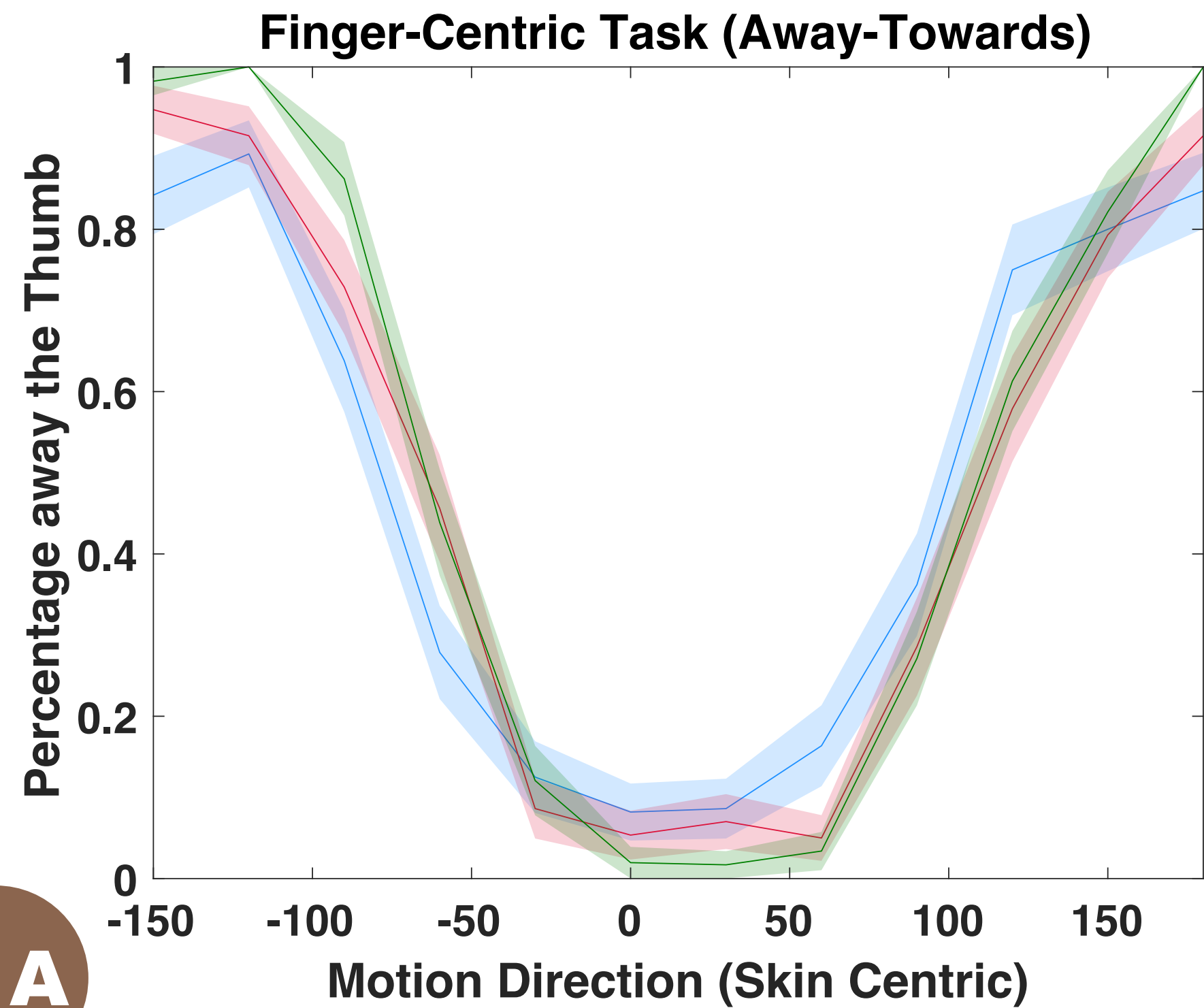
Finger-Centric Reference Frame



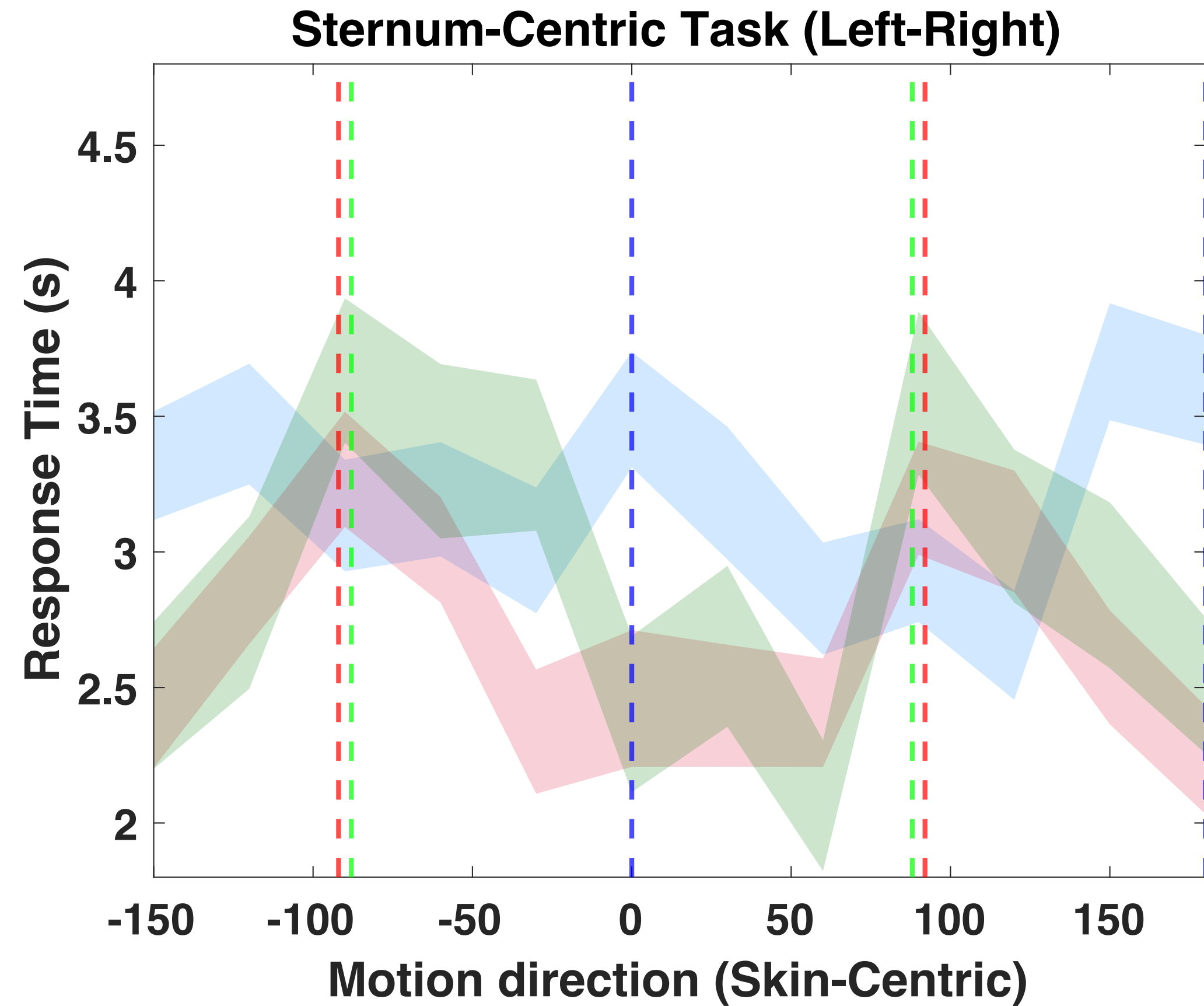
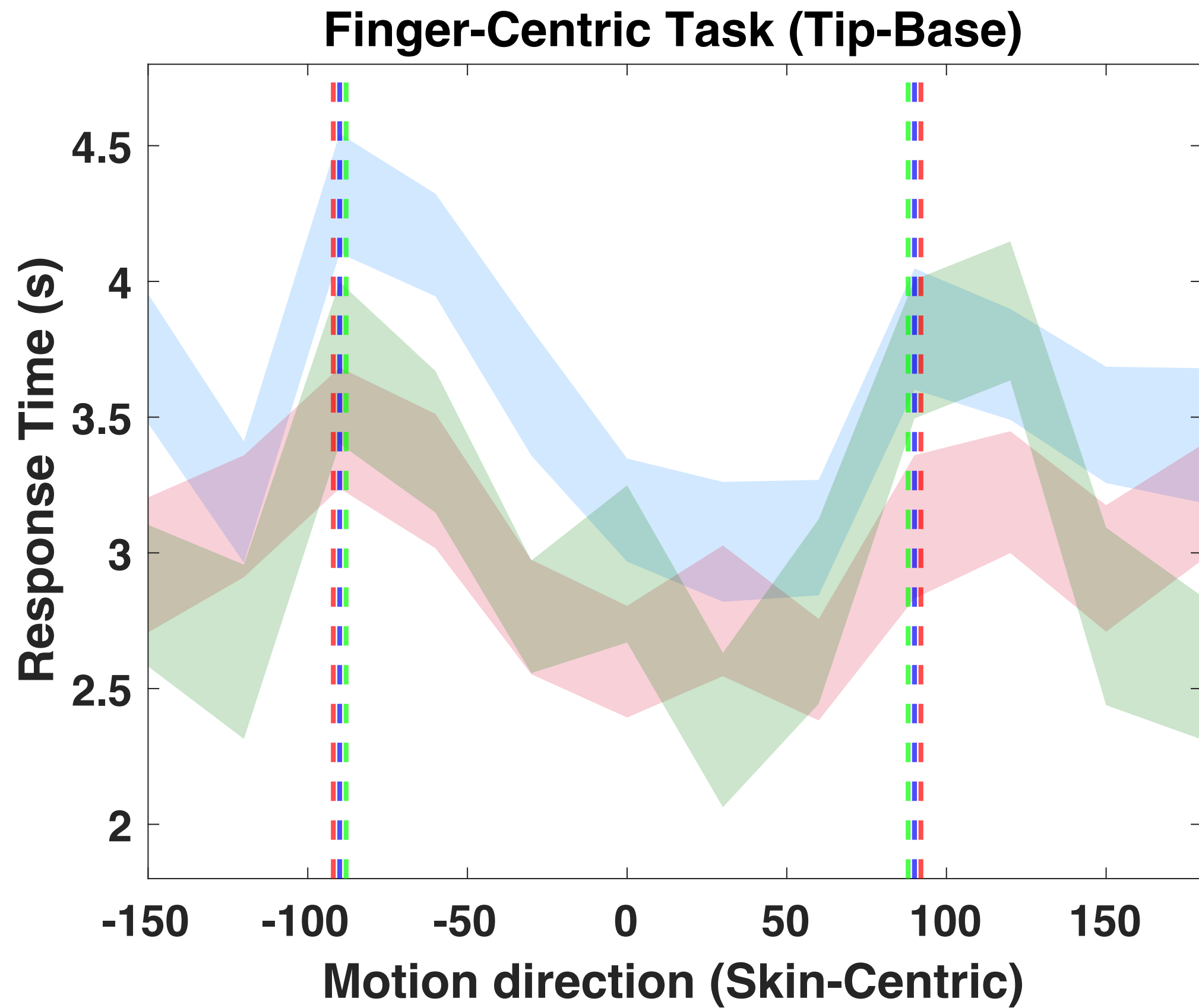
Dot Motion Stimulus at D2 for 2 seconds, steps of 30 degrees.



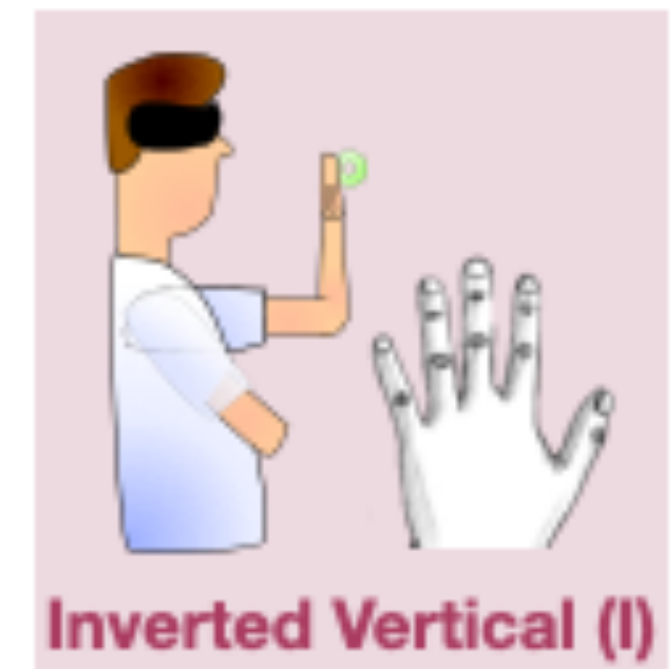
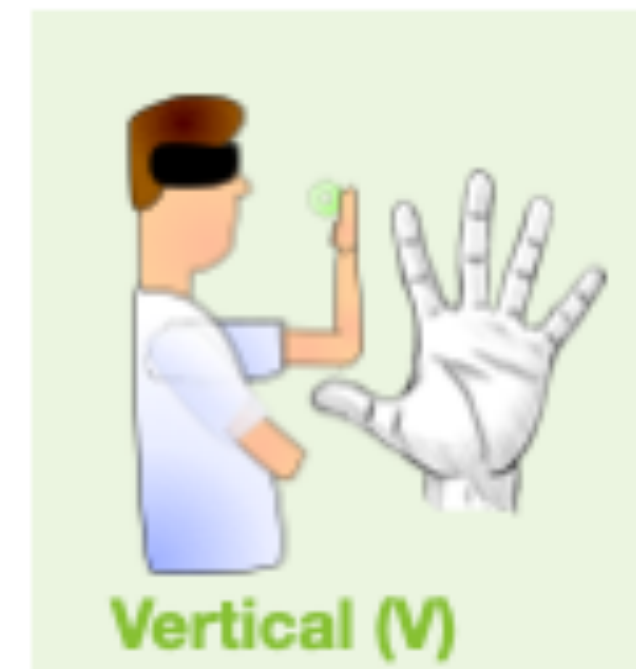
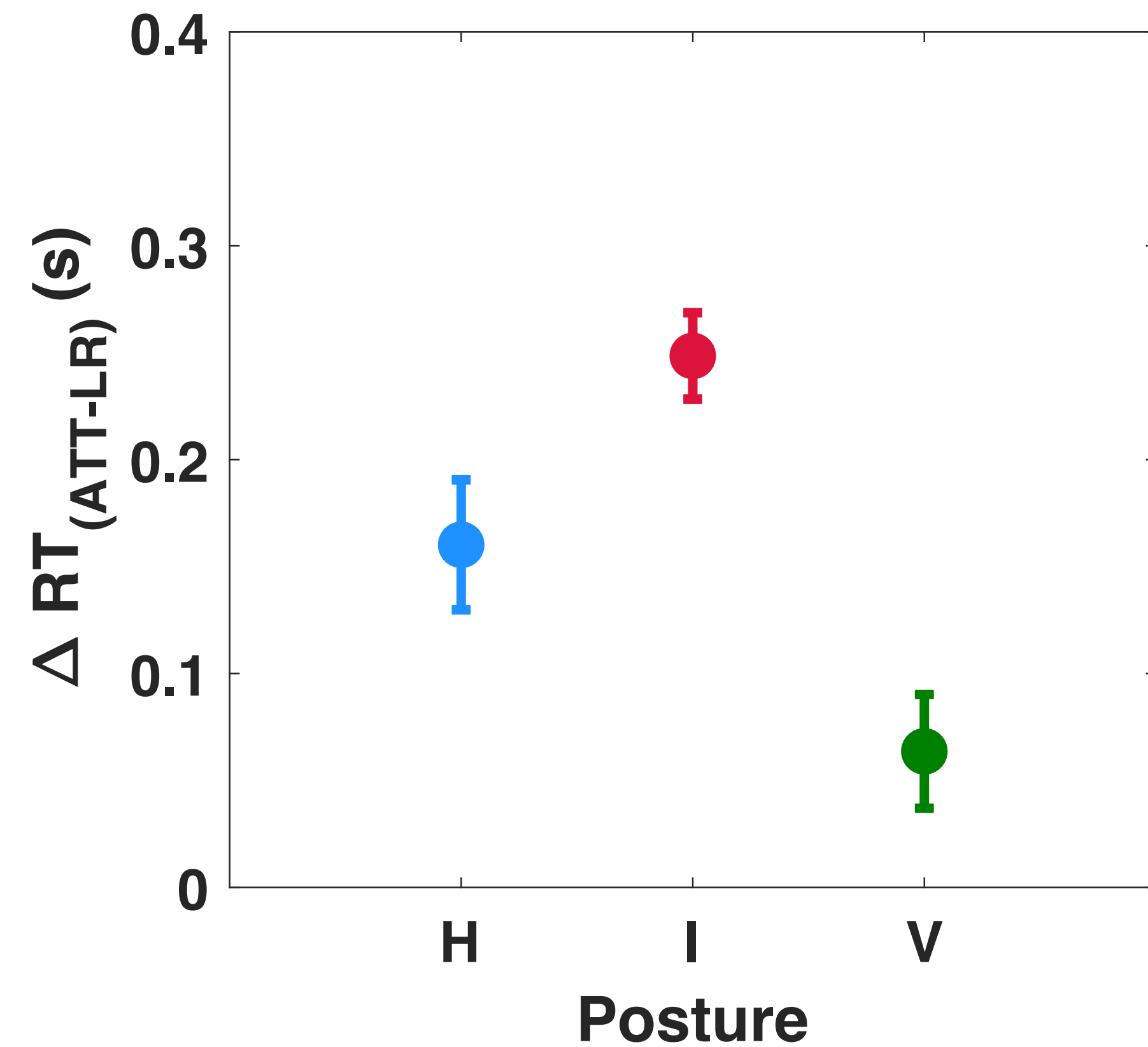
Subjects flexibly perceive motion in multiple reference frames



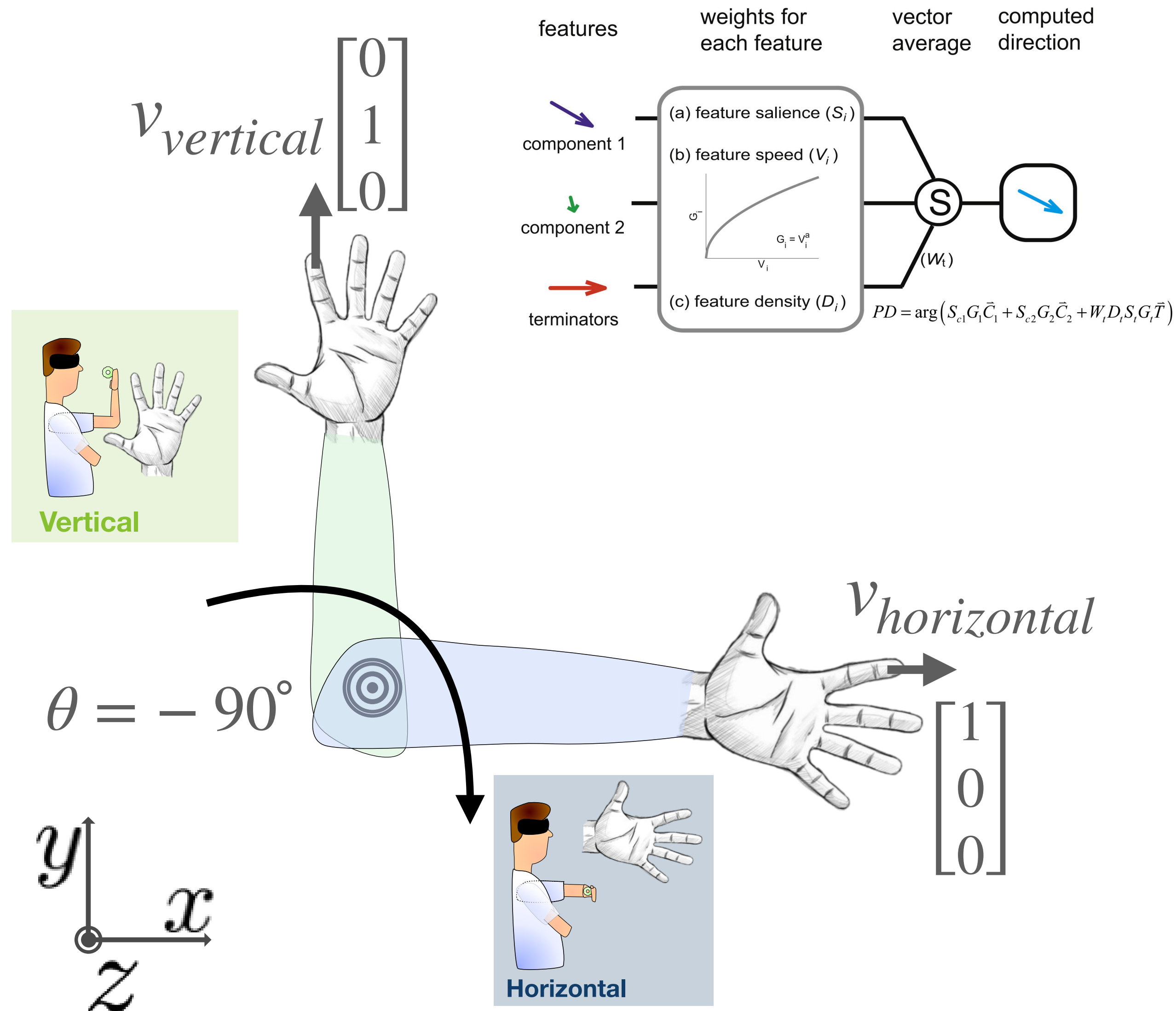
Subjects take longer to respond around the discrimination boundary



Finger-centric task takes longer than the sternum-centric task



Tactile motion representations are derived from Euler Matrix Transformations of the motion information on the skin by the joint proprioceptors.



$$R_{elbow}(z) = \begin{bmatrix} \cos(\theta) & -\sin(\theta) & 0 \\ \sin(\theta) & \cos(\theta) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$R_{elbow}(z) = \begin{bmatrix} 0 & -1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

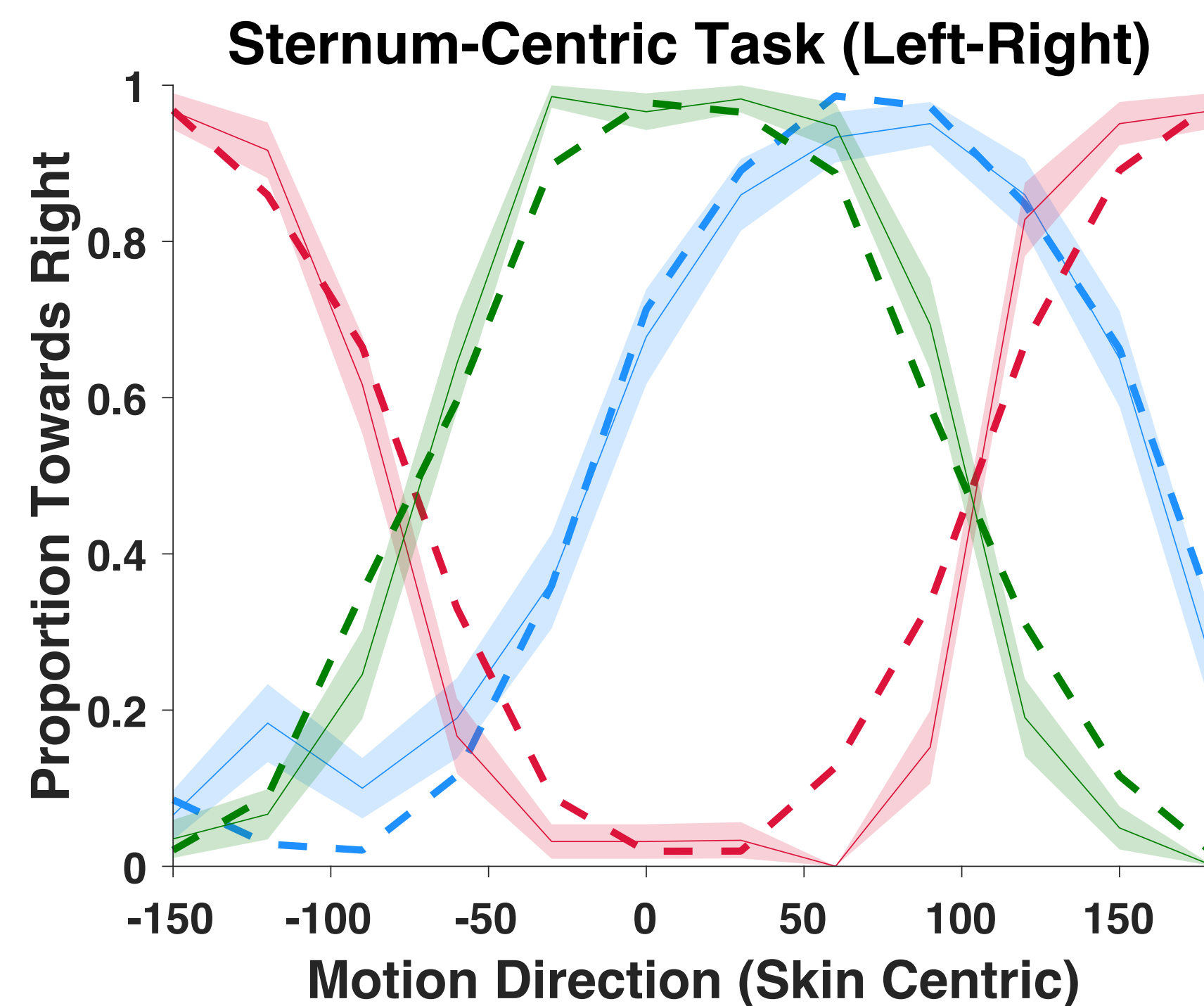
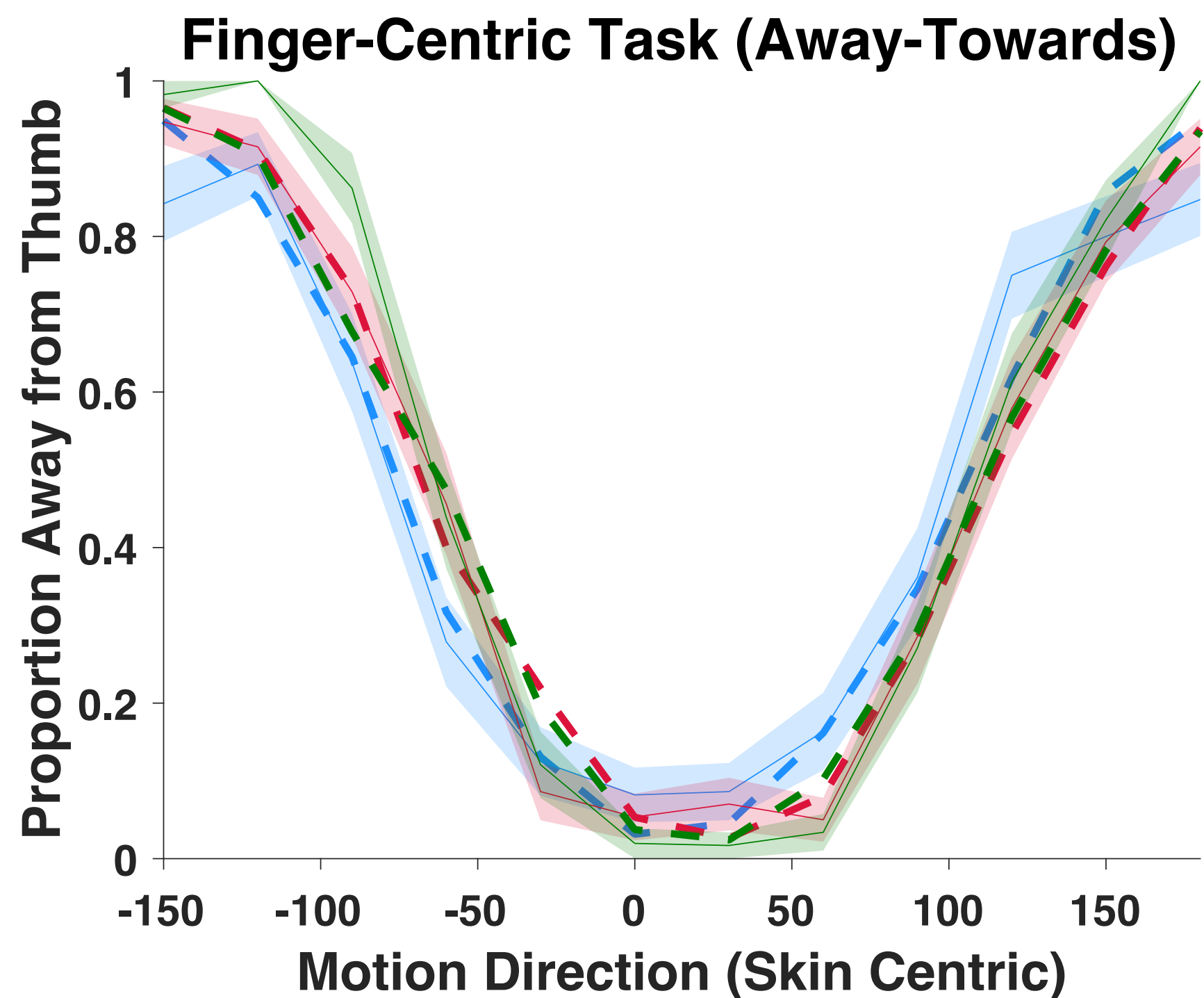
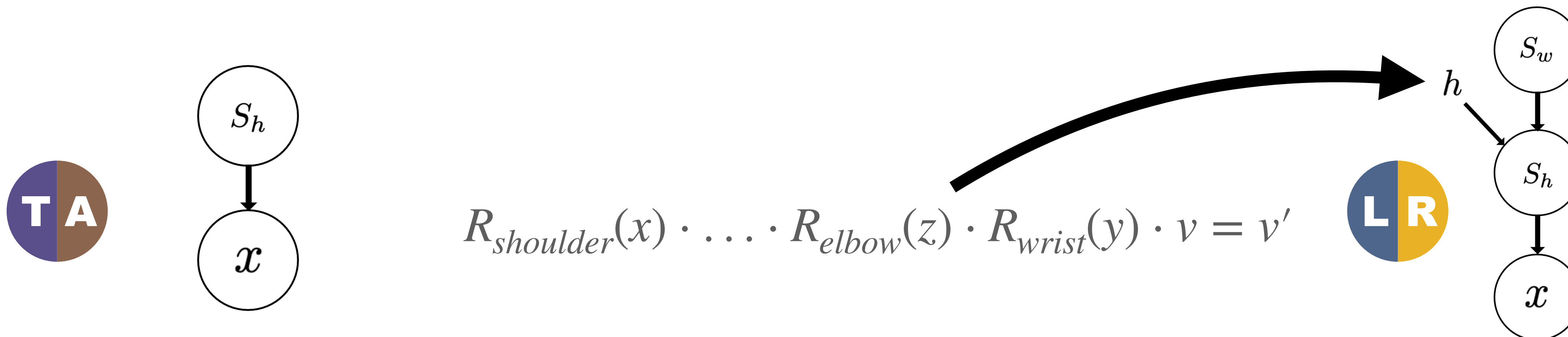
$$R_{elbow}(z) \cdot v_{vertical} = v_{horizontal}$$

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

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

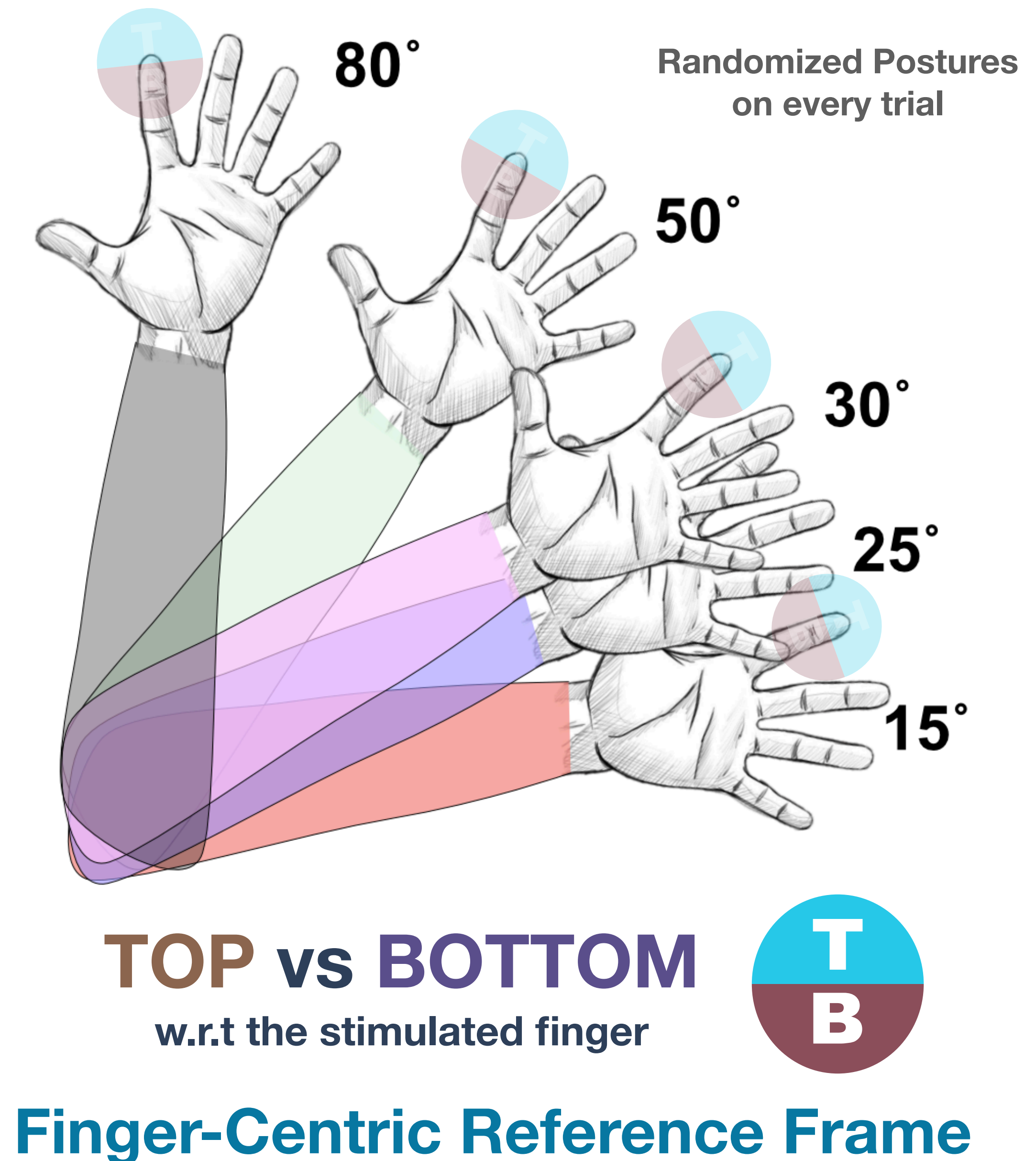
$$R_{shoulder}(x) \cdot \dots \cdot R_{elbow}(z) \cdot R_{wrist}(y) \cdot v = v'$$

Bayesian Generative model predicts human behavioral results



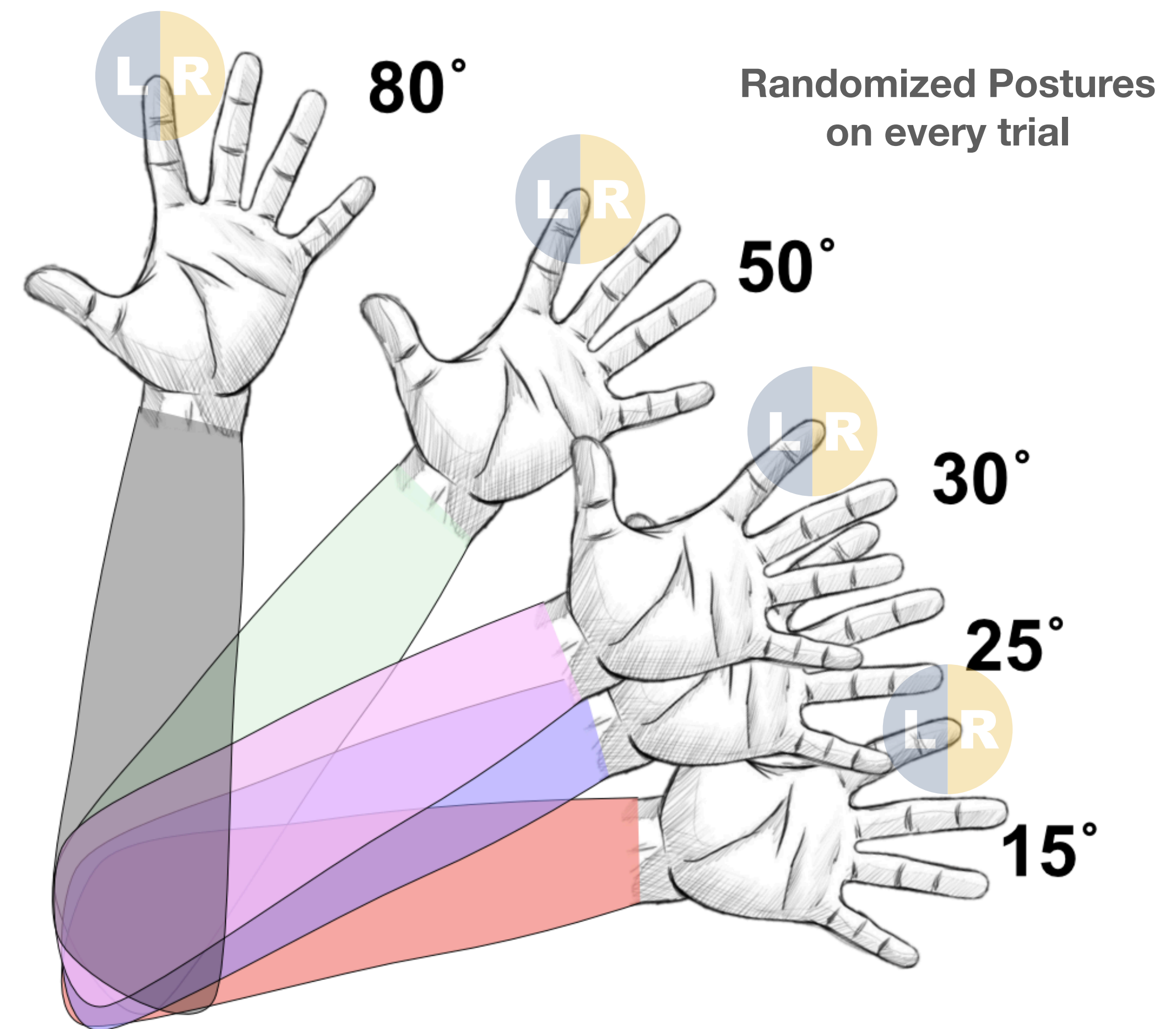
Unresolved questions from of the current experiment

- Does the Blocked-posture design seep cognitive effects with perceptual changes of proprioceptive state/ reference frames?
- How does the sensitivity and bias of motion discrimination changes across difference postures and reference frames
- Can the Bayesian Generative model be generalized to other reference frames?
- What is the threshold at which subjects observed a proprioception difference?



Unresolved questions from of the current experiment

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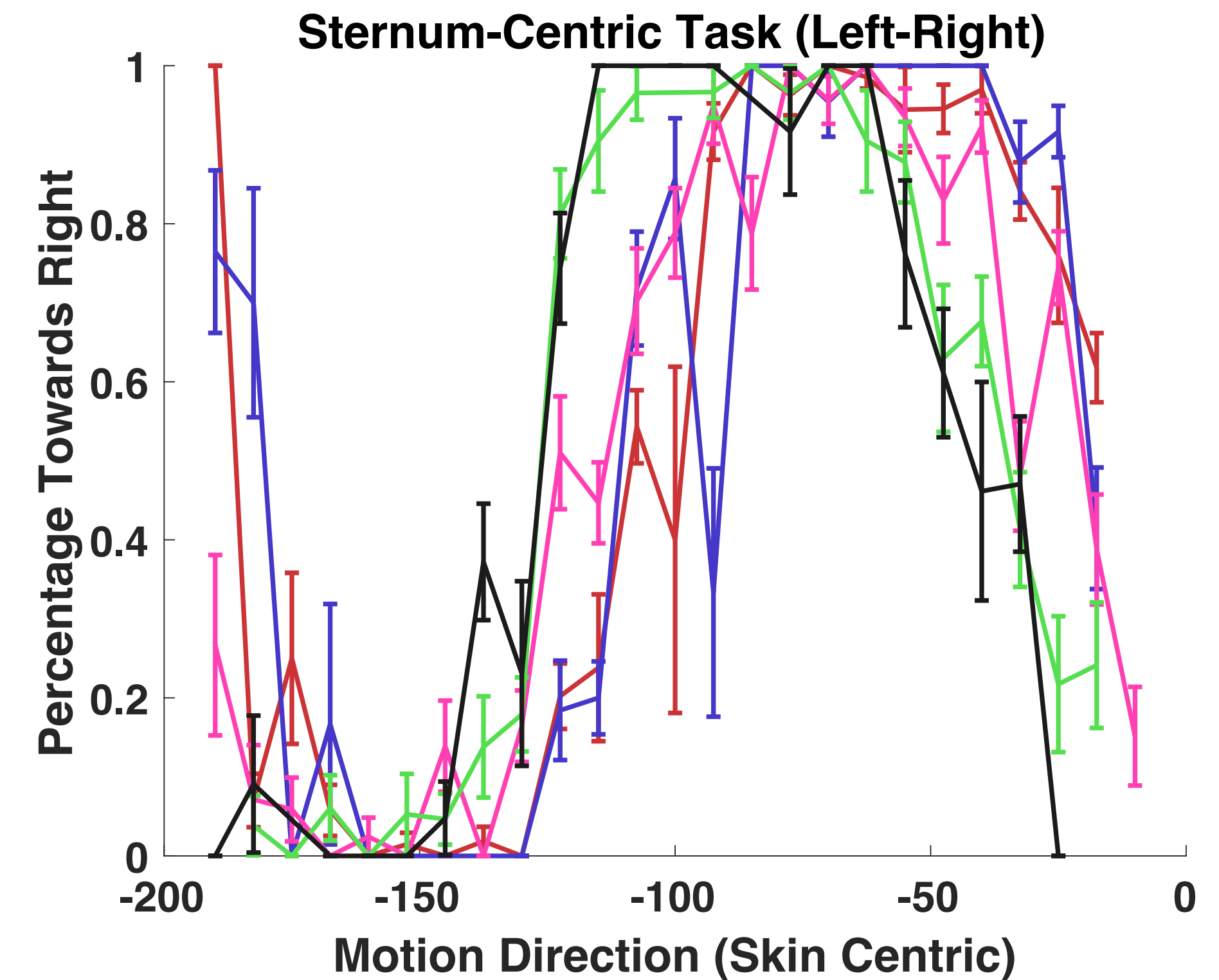
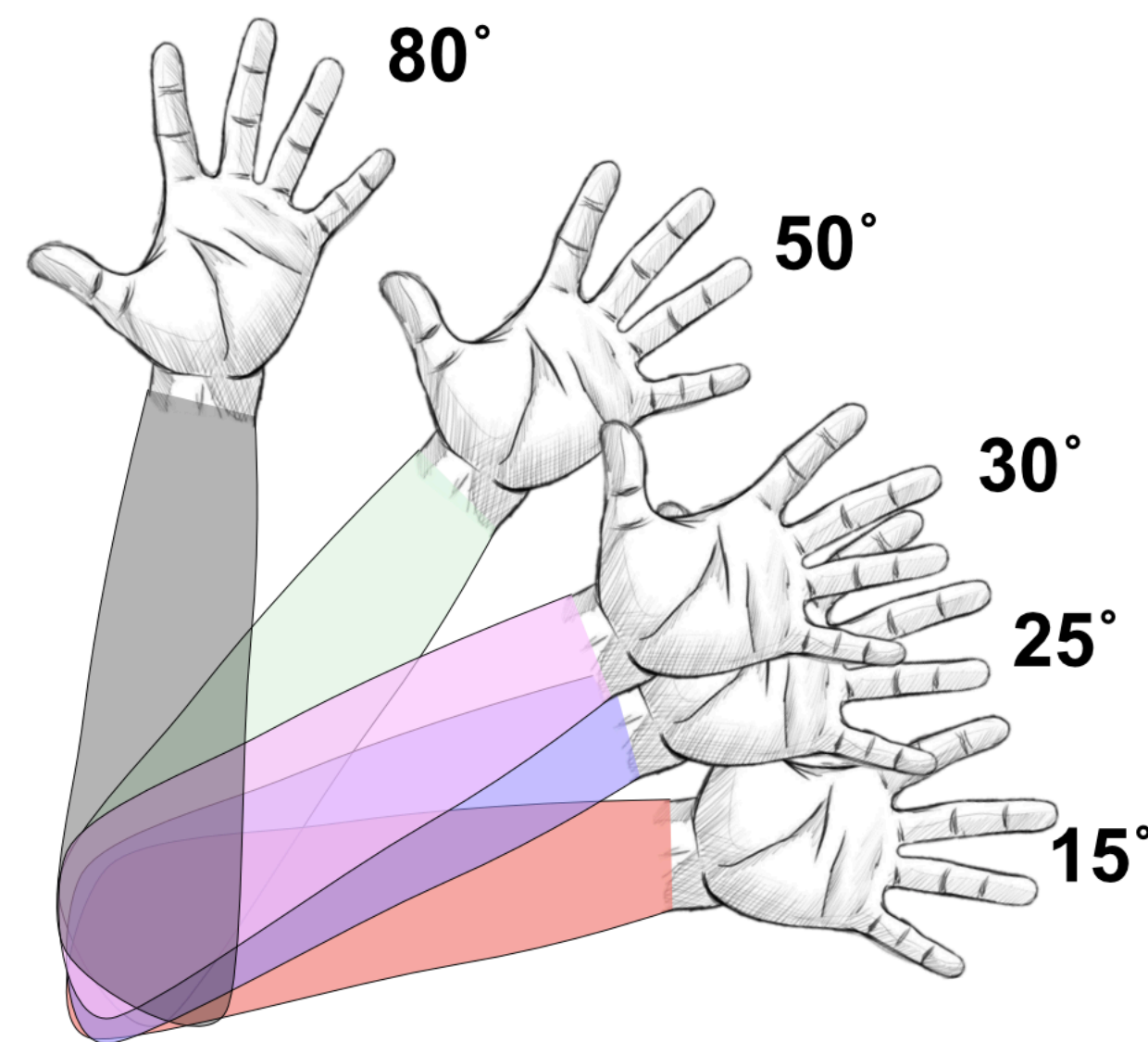
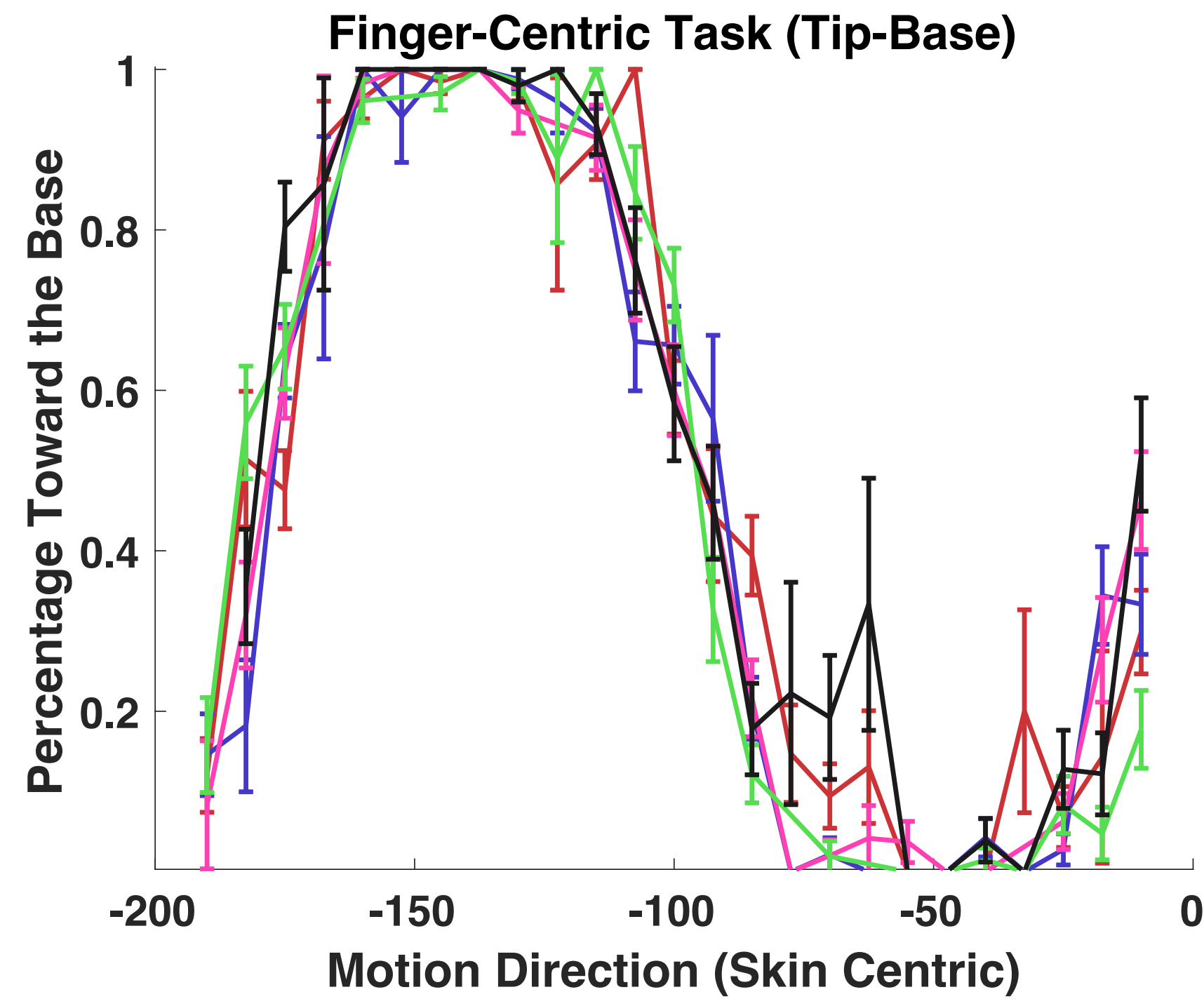


LEFT vs RIGHT
w.r.t the center of the body

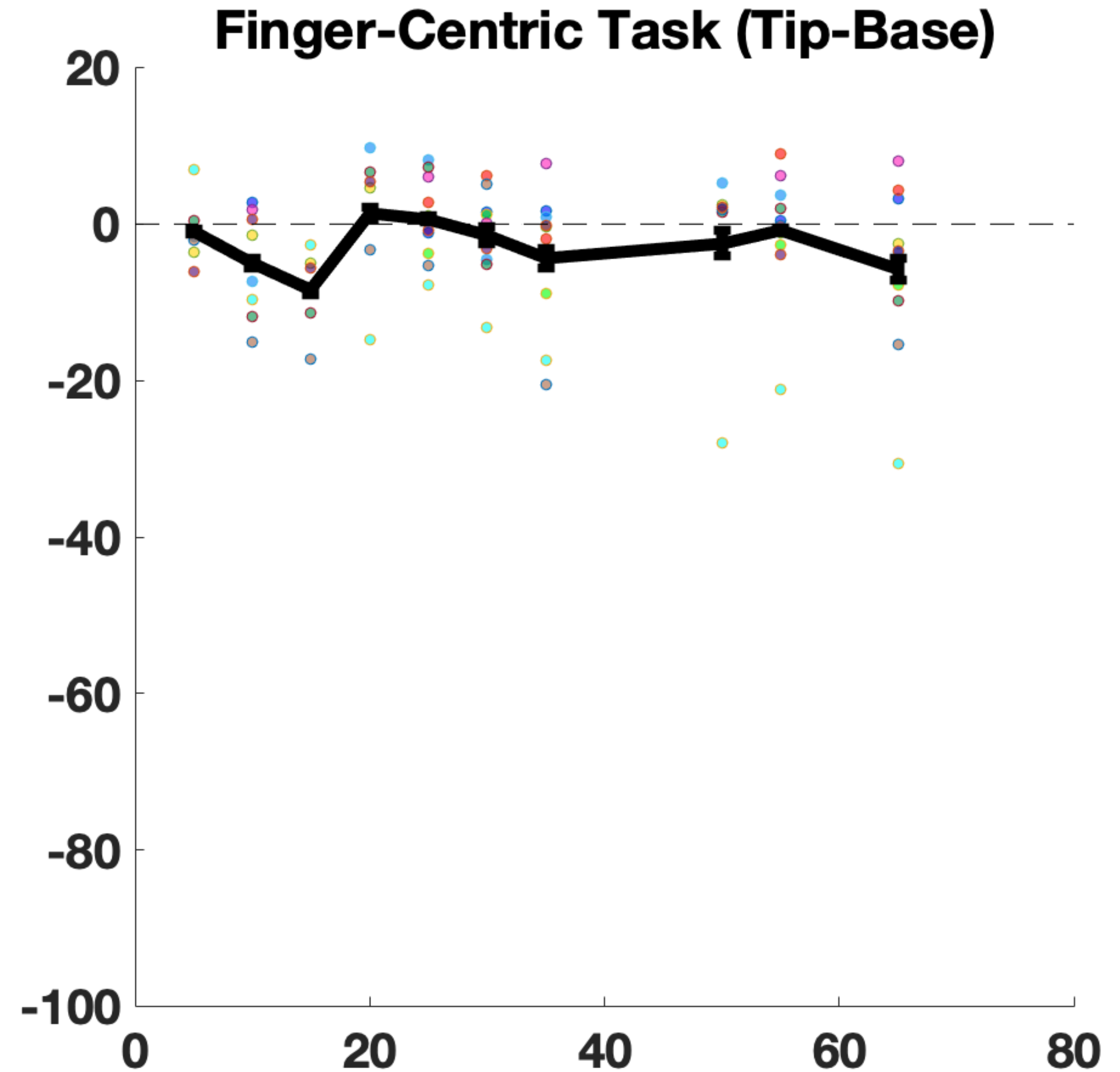
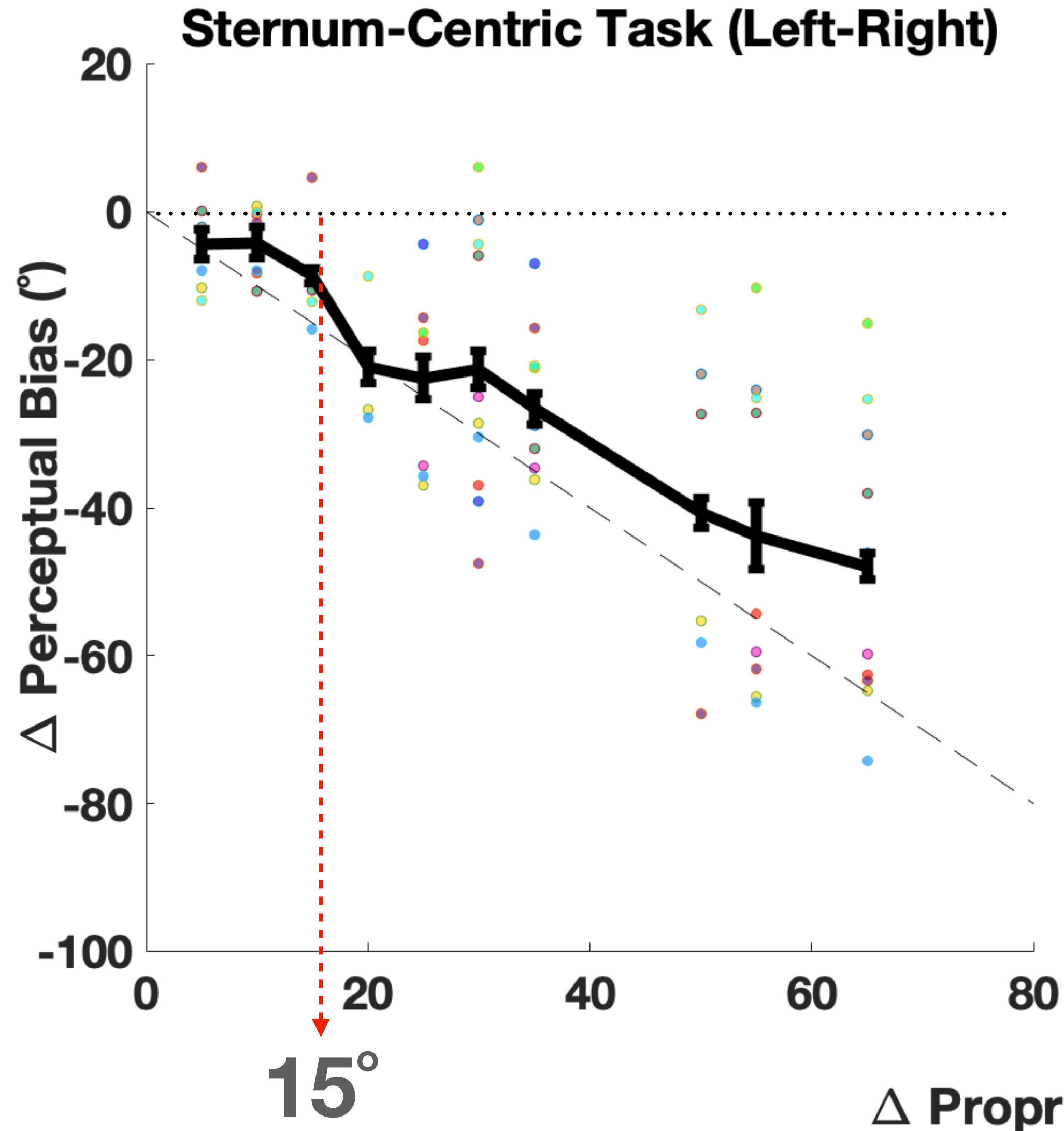


Sternum-Centric Reference Frame

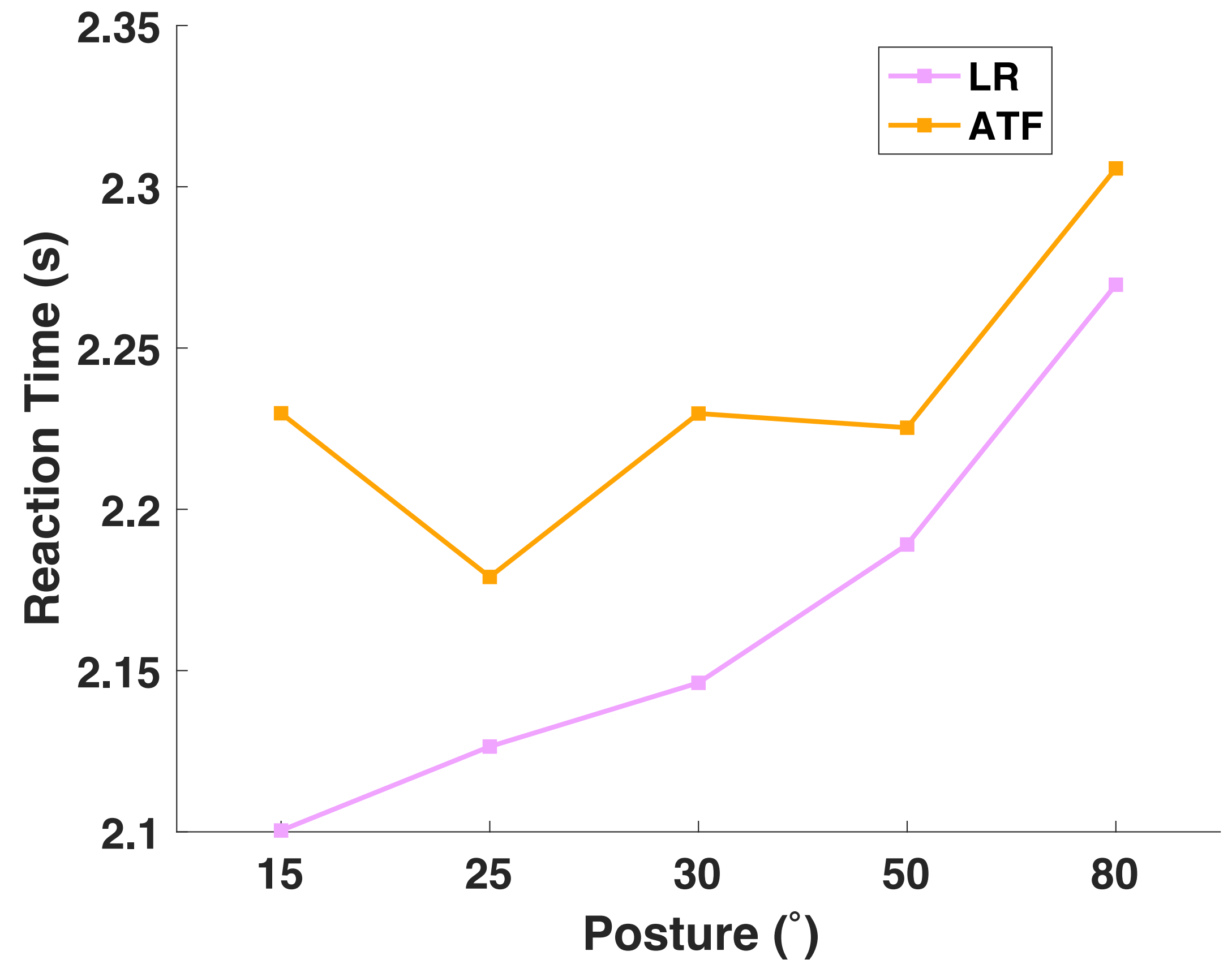
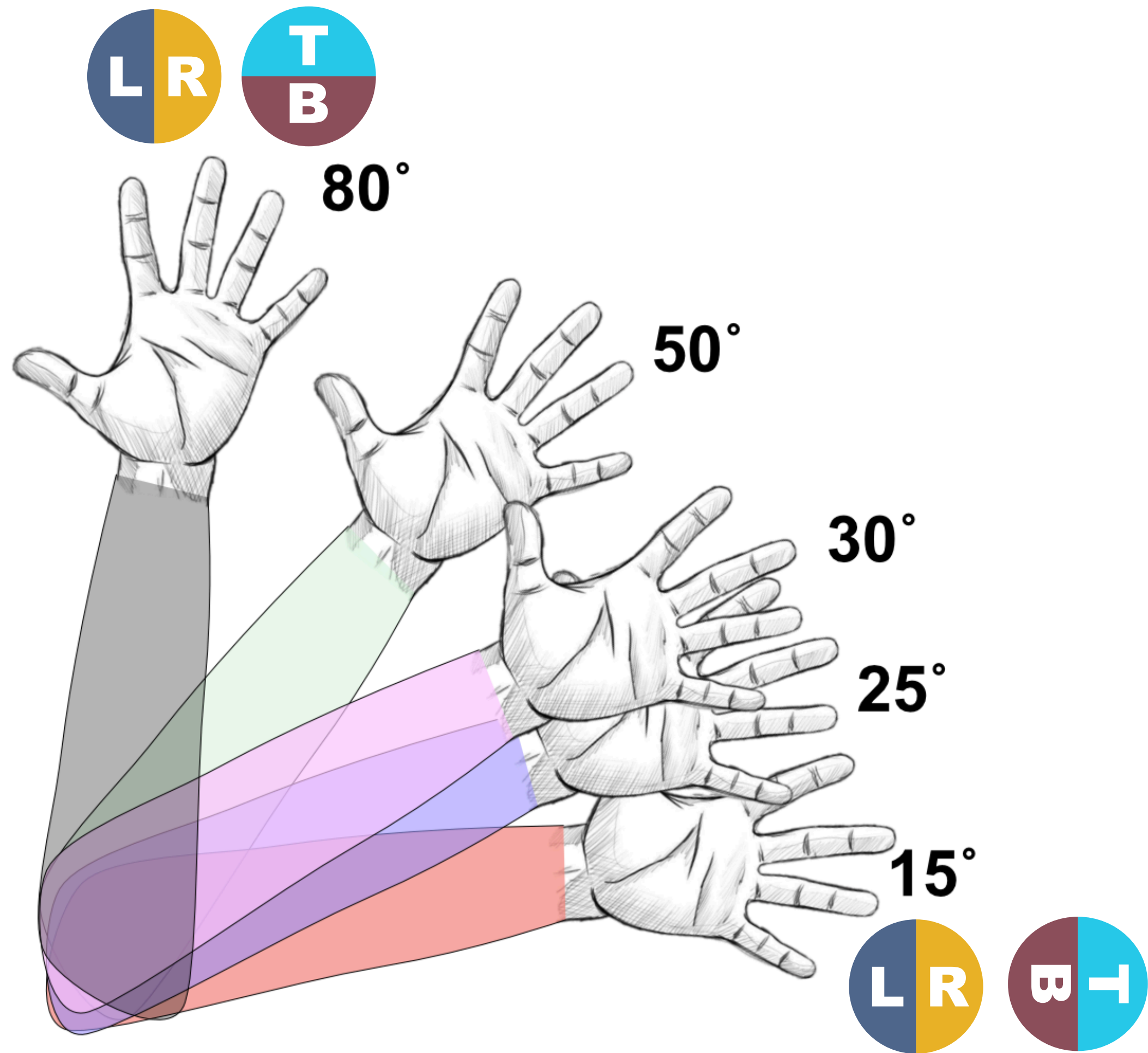
Proprioception modulates tactile motion perception in a reference frame-dependent manner



Difference in Proprioceptive State is observed only in the Sternum Centric Reference Frame

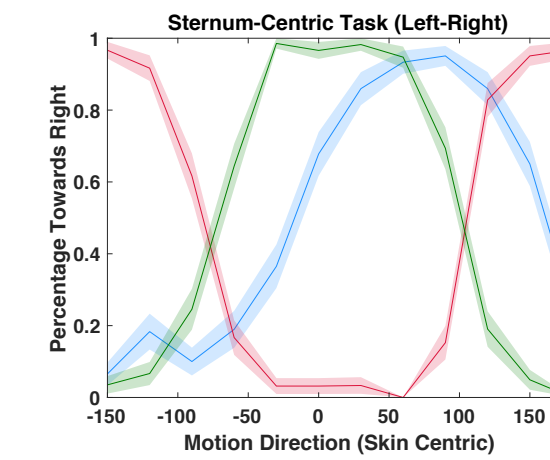
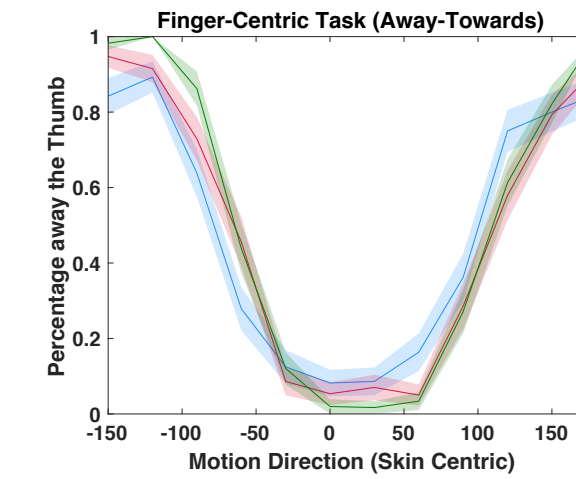


Overlapping of discrimination spaces across reference frames reduces reaction time



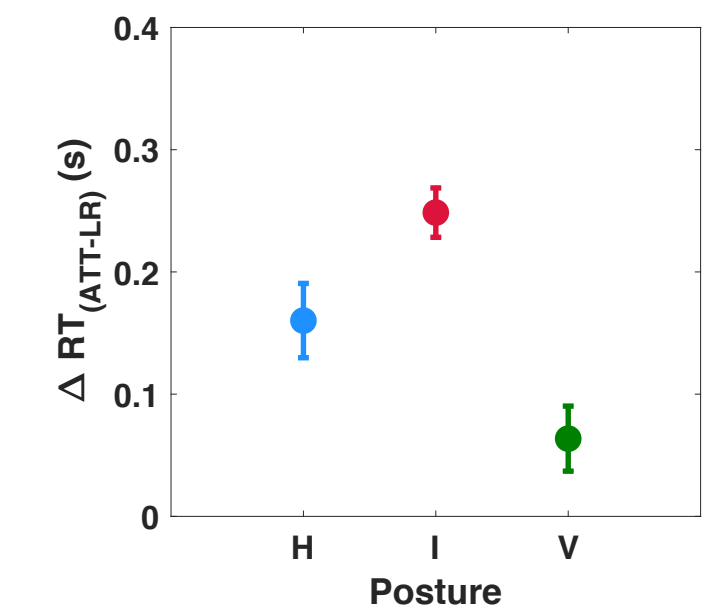
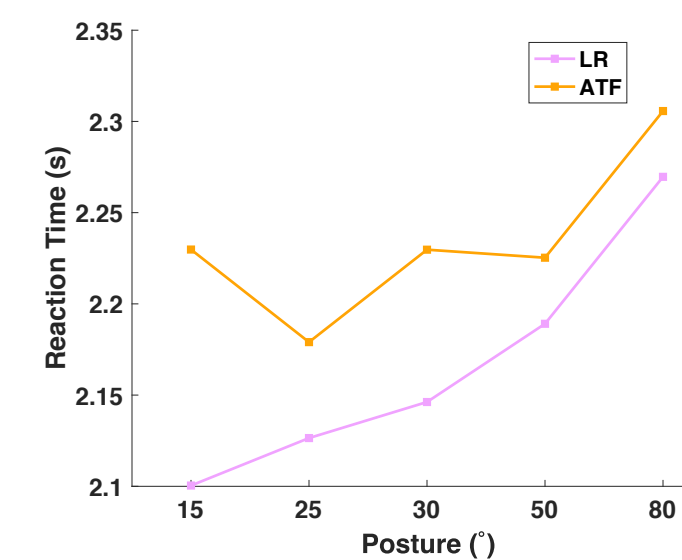
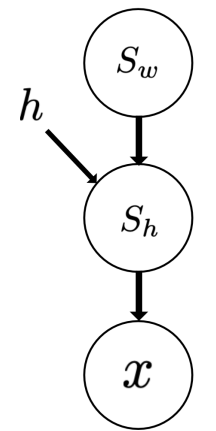
Key Takeaways

- Humans show flexible encoding of tactile motion across reference frames
- An Euler Matrix Transformation-based Bayesian Generative Model explains responses across reference frames and proprioceptive states
- Reaction time across reference frames decreases as the discrimination space overlaps



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

$$R_{elbow}(z) = \begin{bmatrix} \cos(\theta) & -\sin(\theta) & 0 \\ \sin(\theta) & \cos(\theta) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$



Acknowledgements

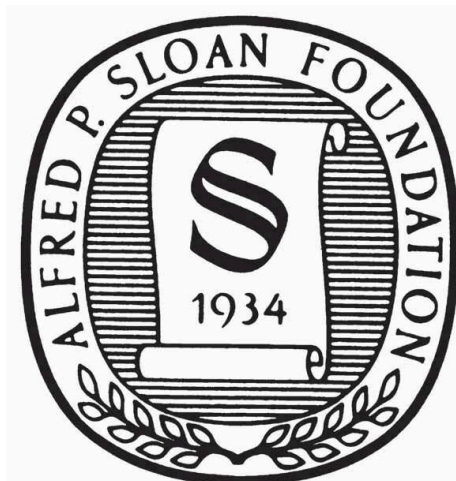


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