Coordinate Transforms Mediating Tactile Motion Representations

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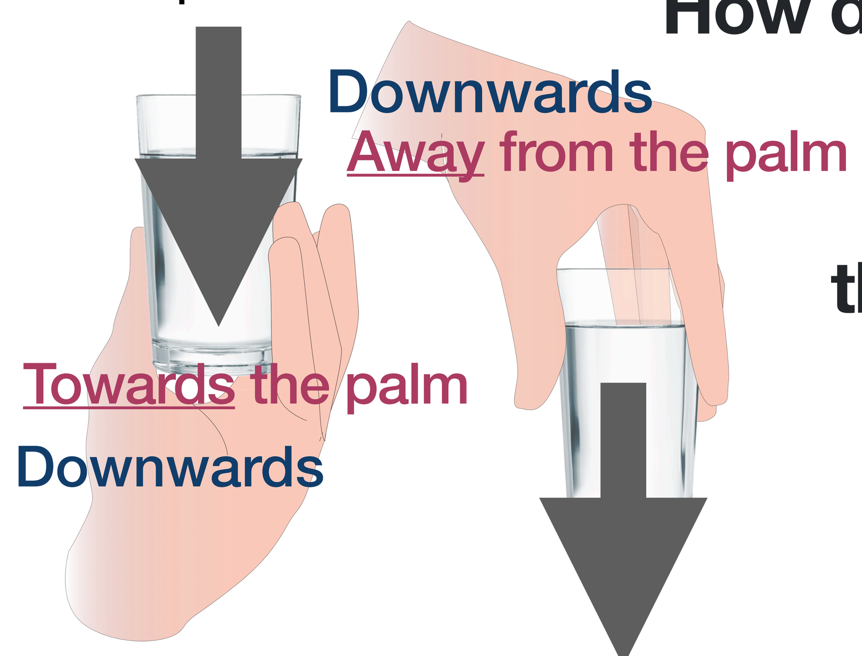
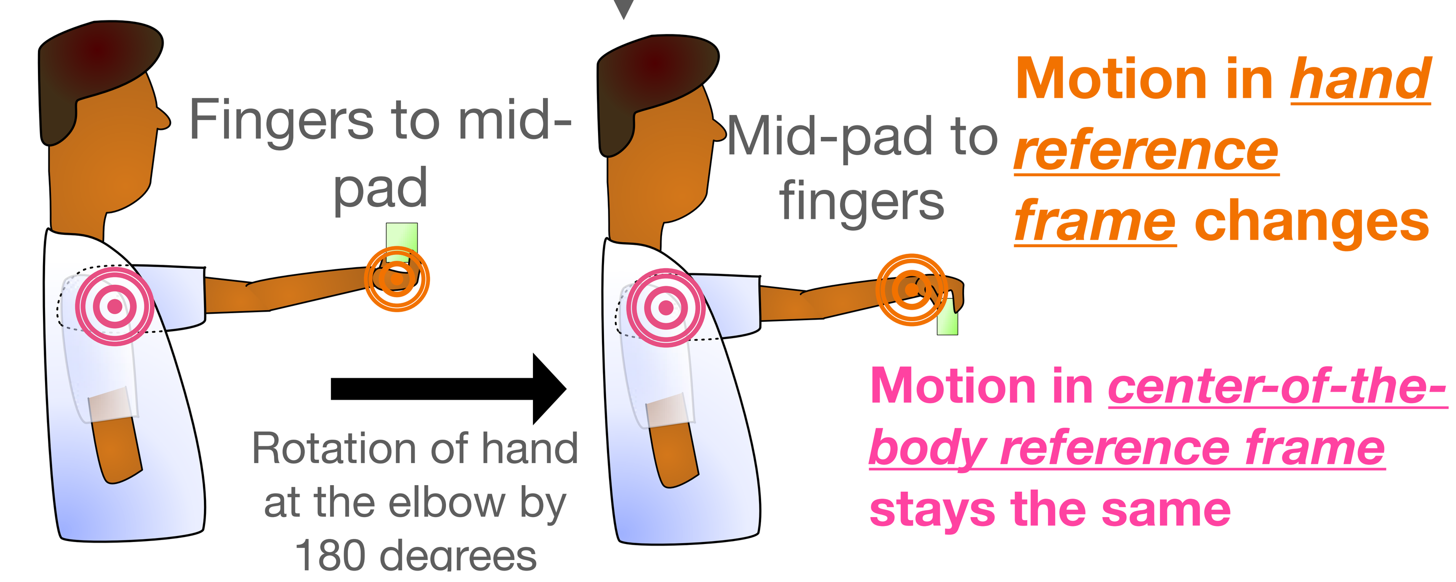
INTRODUCTION

- Tactile motion perception is key to manipulating dynamic objects in our environment
- Tactile motion has generally been studied in only one posture *(e.g. Pei et. al 2010, 2011)*, but different postures impact how motion is interpreted:

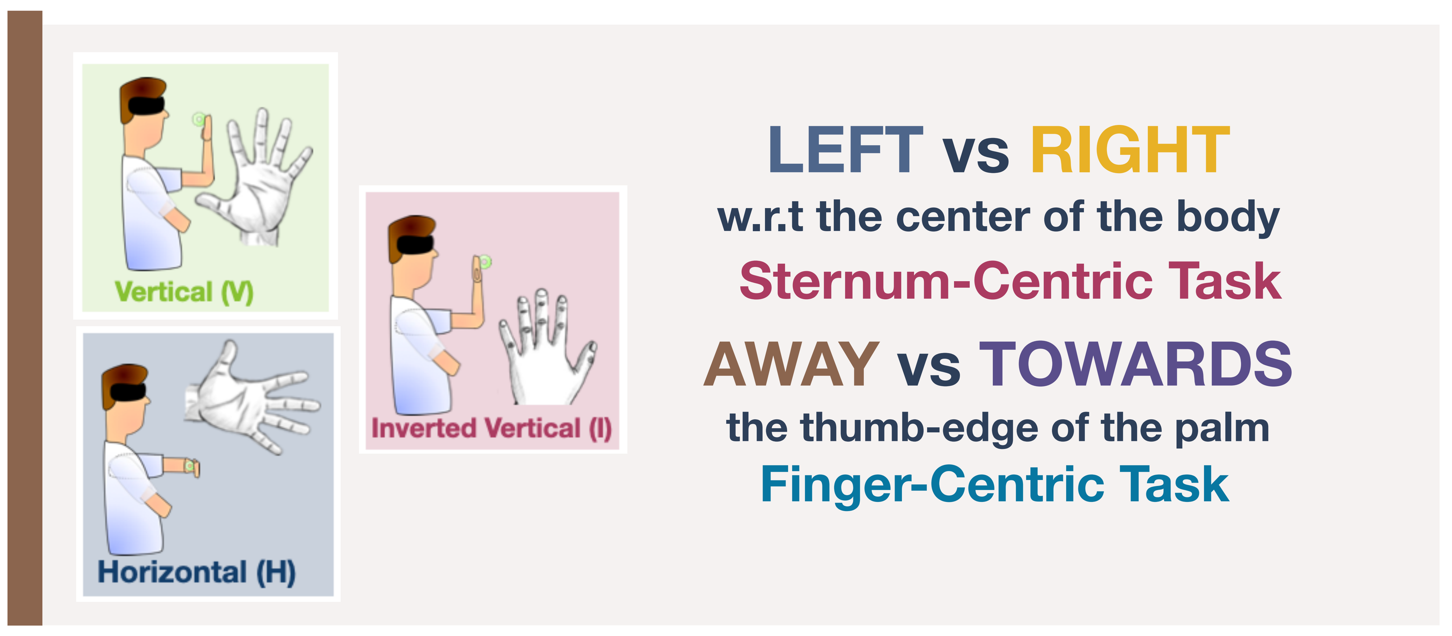


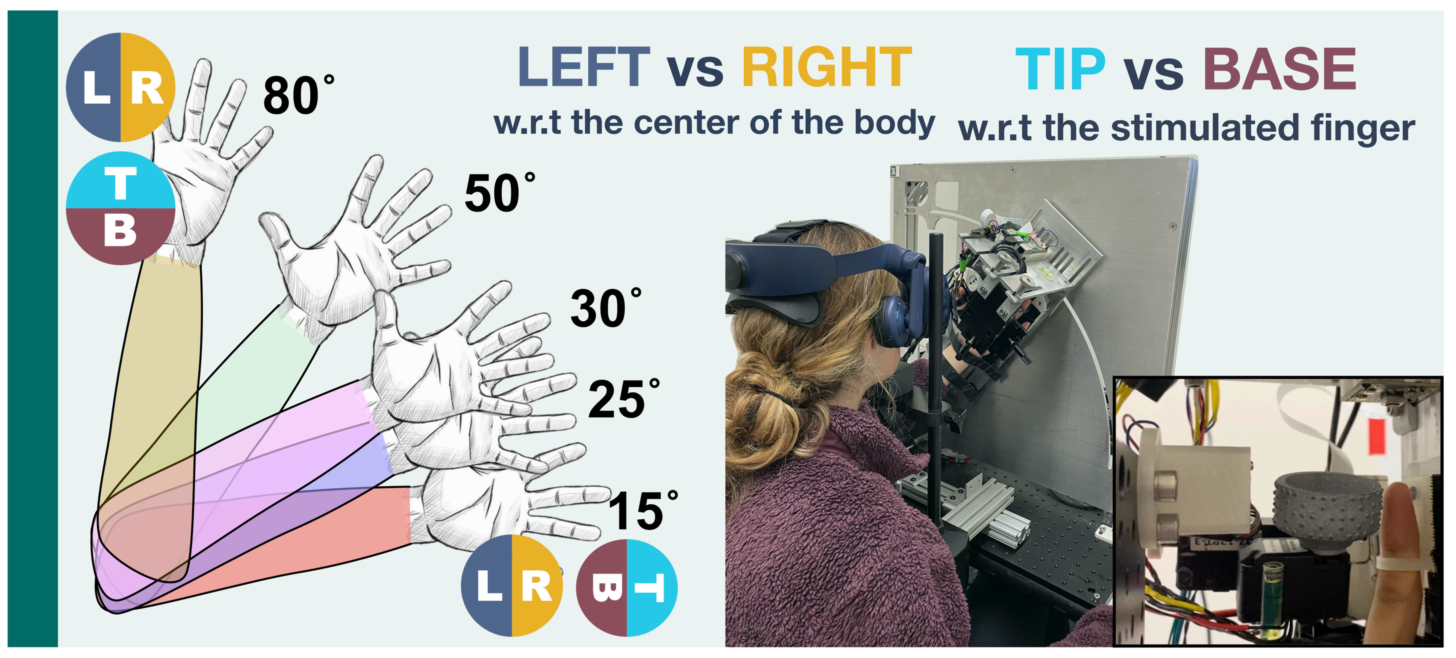
How do posture signals interact with motion information on the skin? How this integration controlled by the reference frame?

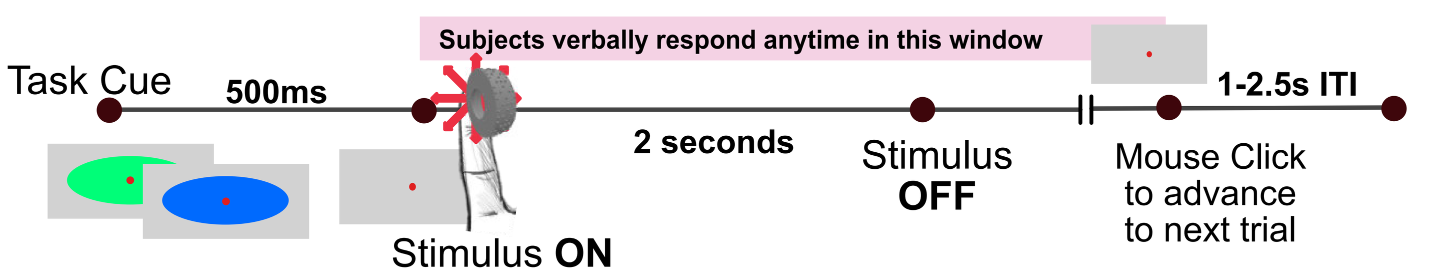


METHODS

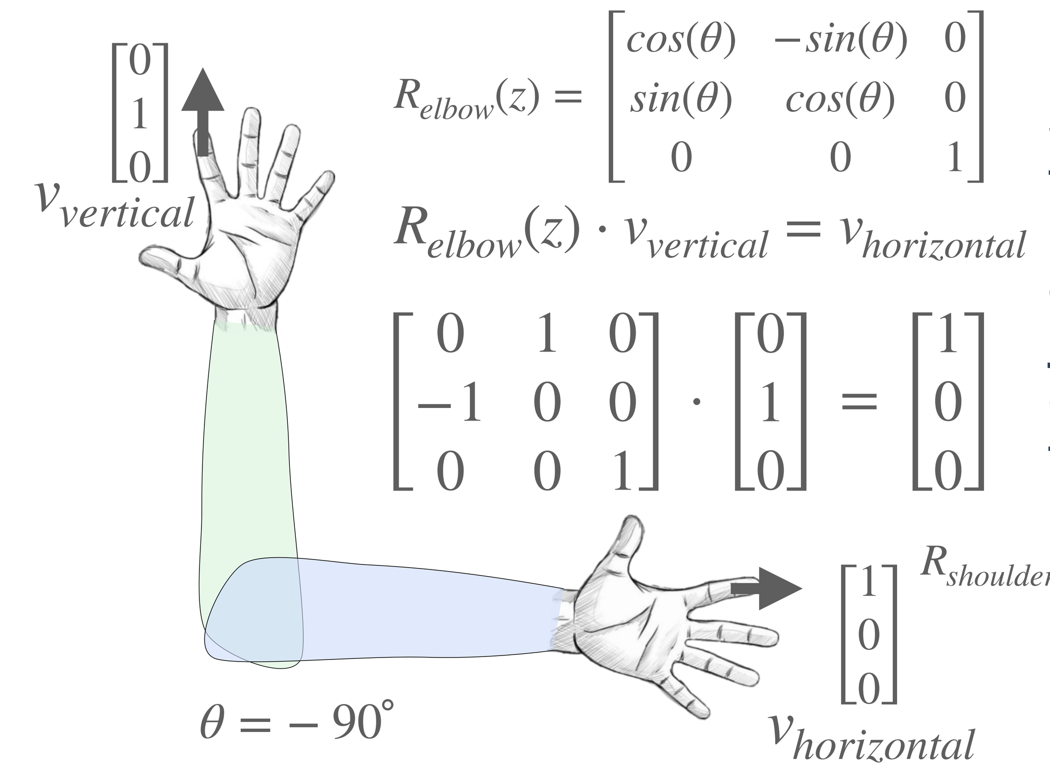
Two-Alternate Force Choice Motion Direction discrimination







Euler Matrix Transformations explain tactile motion report



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

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

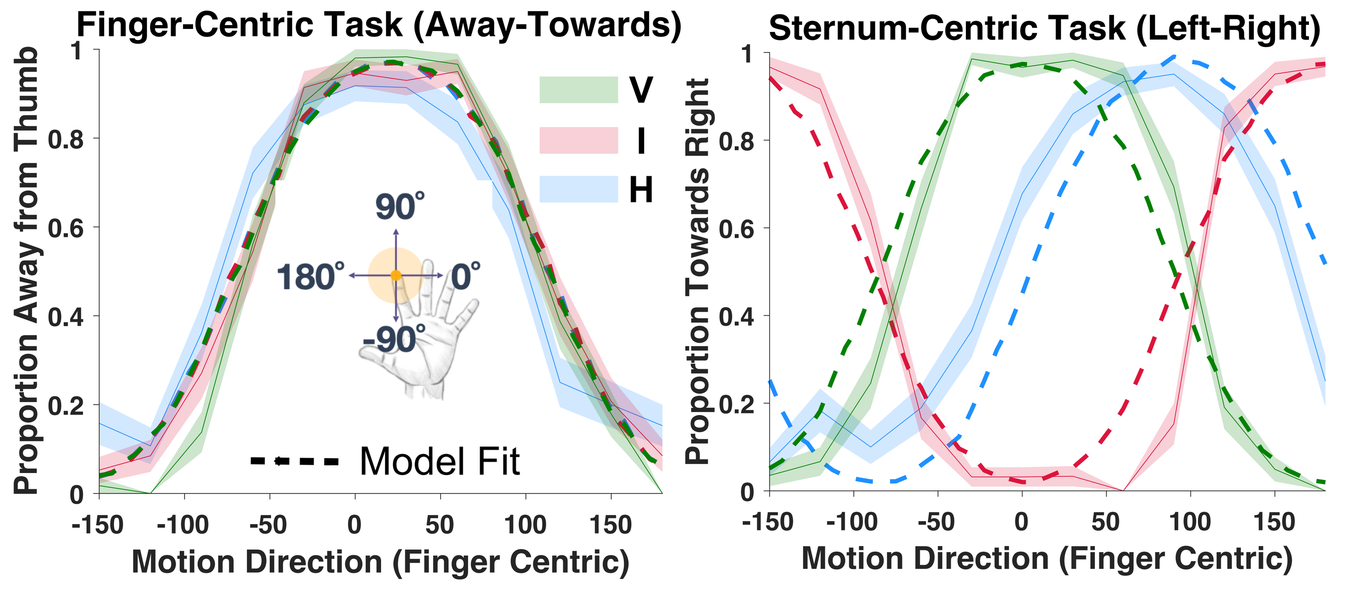
$$\begin{bmatrix} 0 & 1 & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$

$$v_{vertical} = \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}, \quad v_{horizontal} = \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}, \quad \theta = -90^\circ$$

$$R_{shoulder}(x) \cdot \ldots \cdot R_{wrist}(z) \cdot v = v'$$

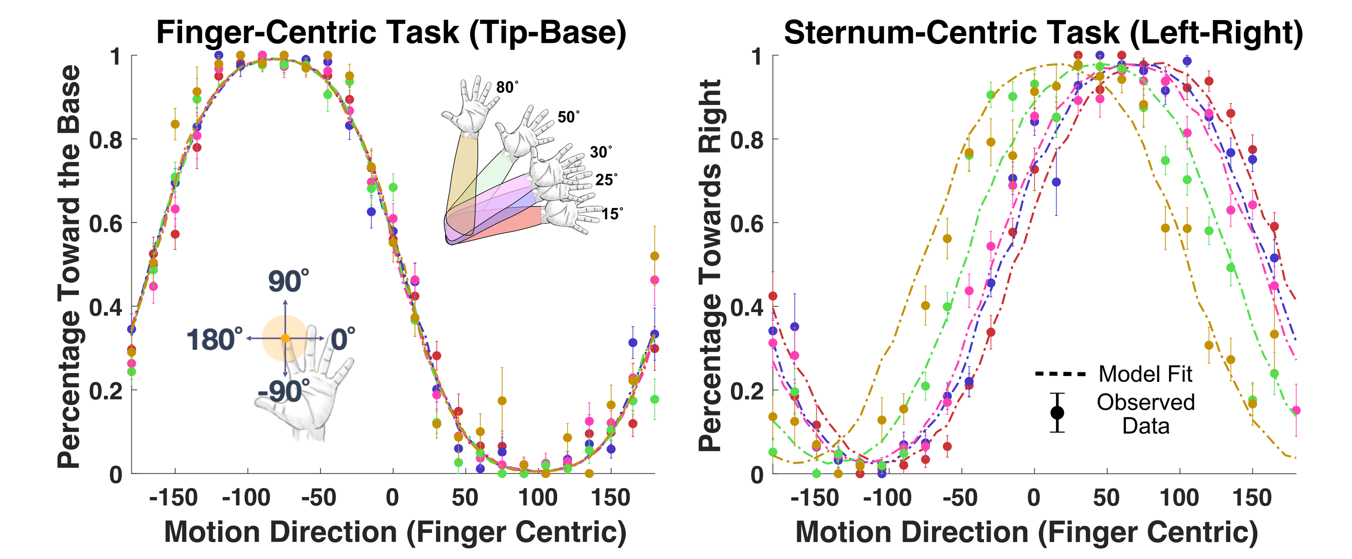
Similar matrix transformation can be performed at each proprioceptor joints in between different reference frames.

Subjects flexibly perceive motion in multiple coordinate systems



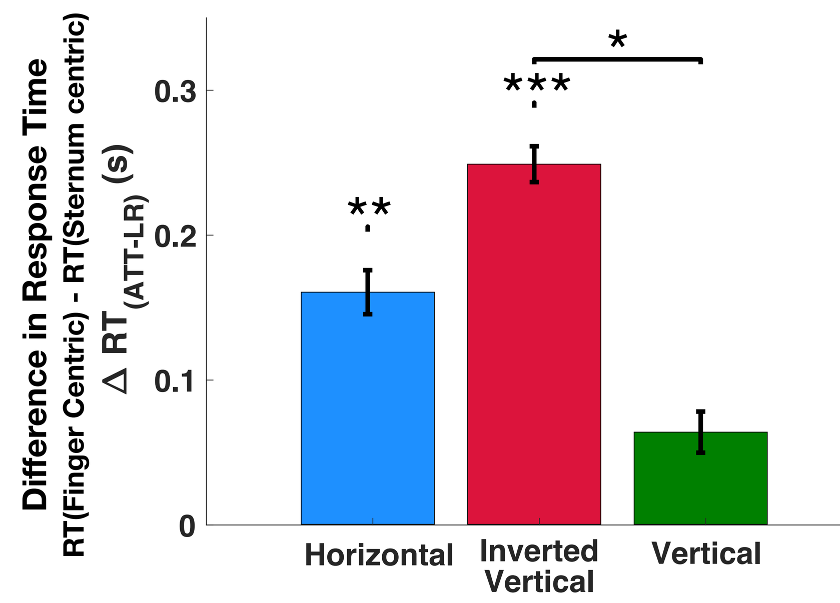
Population Level (N = 12) Psychometric curves for tactile motion report. The three postures are : vertical (V, green), horizontal (H, blue), and Inverted Vertical (I, red).

Proprioception modulates tactile motion in a reference frame-dependent manner

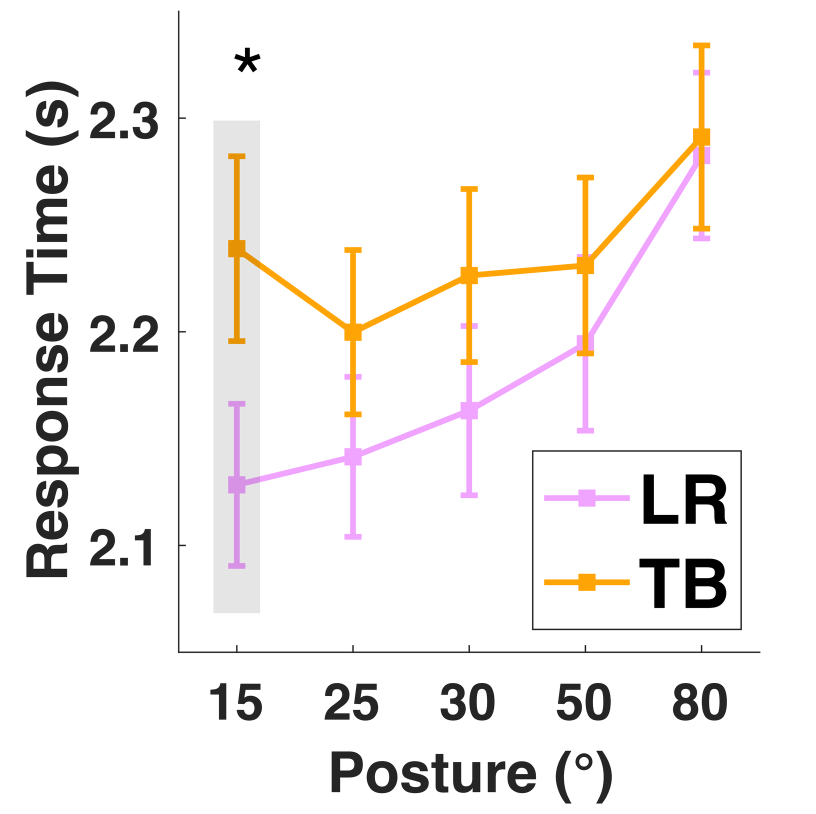


Population Level (N = 14) Psychometric curves for tactile motion report in the Tip-Base task (Left) and the Left-Right Task (Right) with motion direction (x-axis) in the finger-centric reference frame.

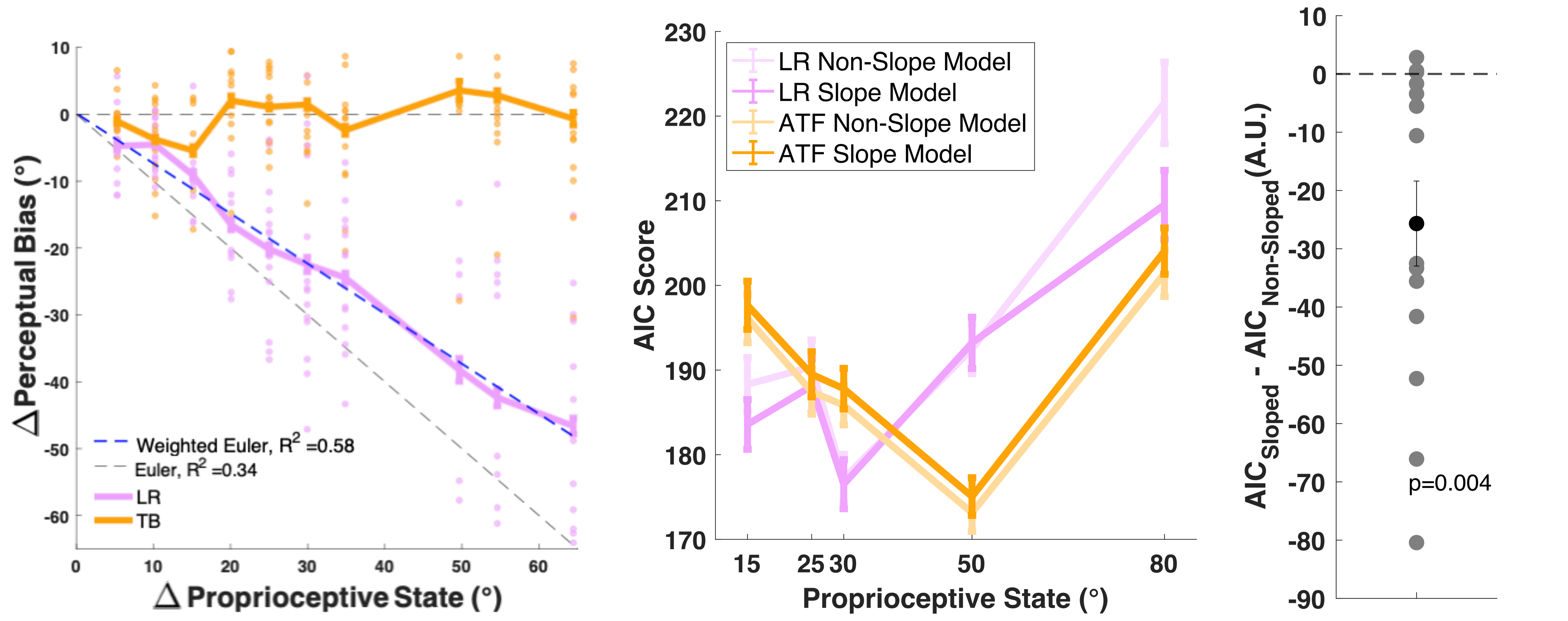
Faster response times in sternum-centric task



Response times in sternum-centric task are dependent on proprioceptive state

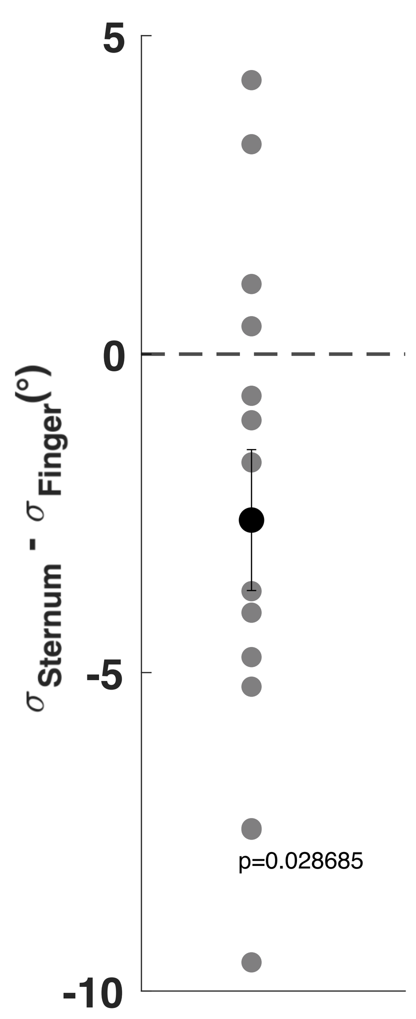


Proprioception biases tactile motion in sternum-centric task



Off diagonal shift of the LR curve remarks the proprioceptive dependent bias emerging only when proprioception is utilized in the decision i.e. the sternum-centric task (LR). We modeled this using a weighted Euler model (Slope model) with an additional slope term for the perceived posture (dotted-blue). Constant bias in the finger-centric task (TB).

Proprioceptive noise in the sternum-centric task



A negative difference implies a transformation noise emerging from proprioceptors from the finger-centric to the sternum-centric reference frame

CONCLUSION

Humans flexibly perceive tactile motion direction in different coordinate systems.

A proprioception-dependent slope term explained behavioral report better than a simple Euler-matrix based computation.

Faster and proprioceptive dependent response times in the sternum-centric task.

The sternum-centric reference frame has a posture dependent bias.

Extra transformation noise in Sternum-centric reference frame.