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# Robot Motion Affects Human Force Regulation in Physical Human-Robot Interaction

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## Motivation

- Regulation of interaction forces is critical in physical human-robot interactions (pHRI).
- Maurice et al.<sup>1</sup> showed that human force regulation is better when robot movements exhibit human-like features.
- In human movements, velocity  $v$  scales with radius of curvature  $r$  obeying the power law, with  $K$  as gain factor:

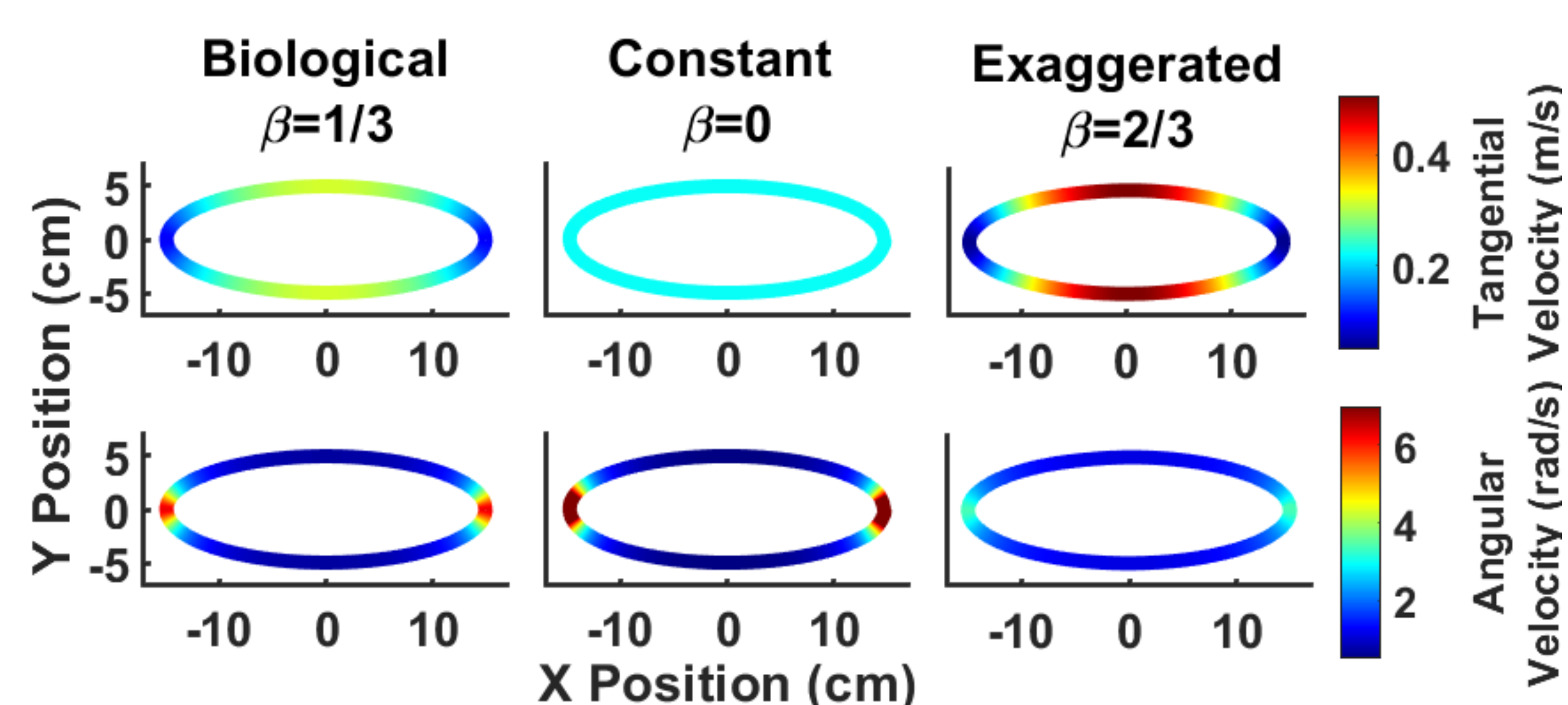
$$v(t) = Kr(t)^\beta, \beta = 1/3$$

- West et al.<sup>2</sup> showed that applied force of humans cannot be decoupled from the robot's motion.
- Understanding this coupling allows for developing robot controllers that accommodate their human partner.
- This study tests different profiles of robot motion to examine if the human applied forces depend on the:

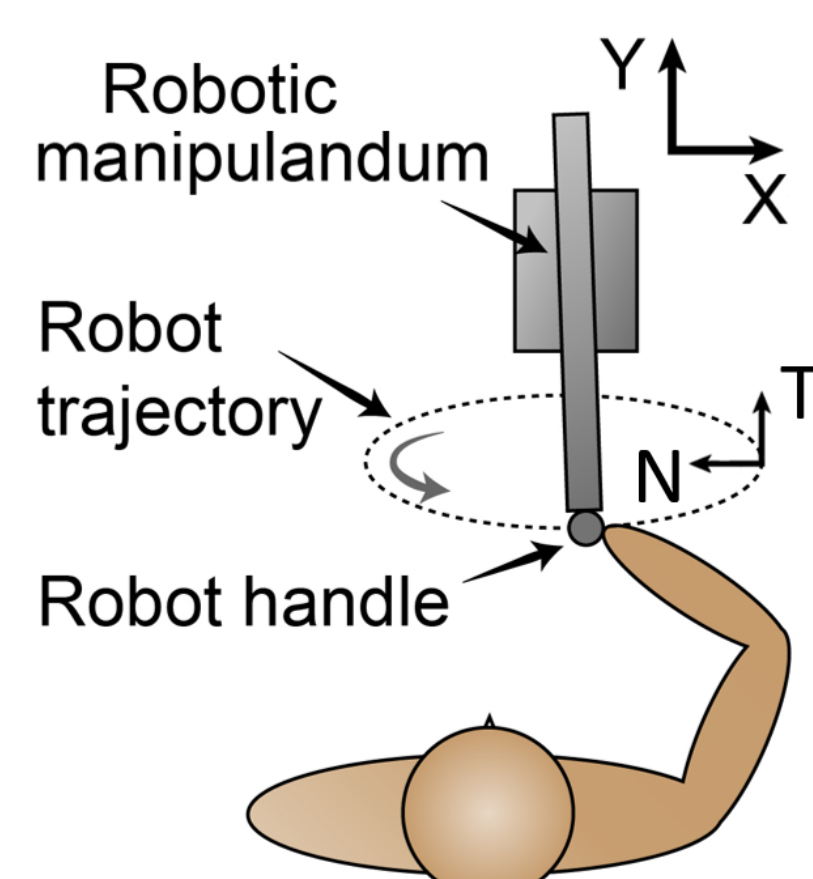
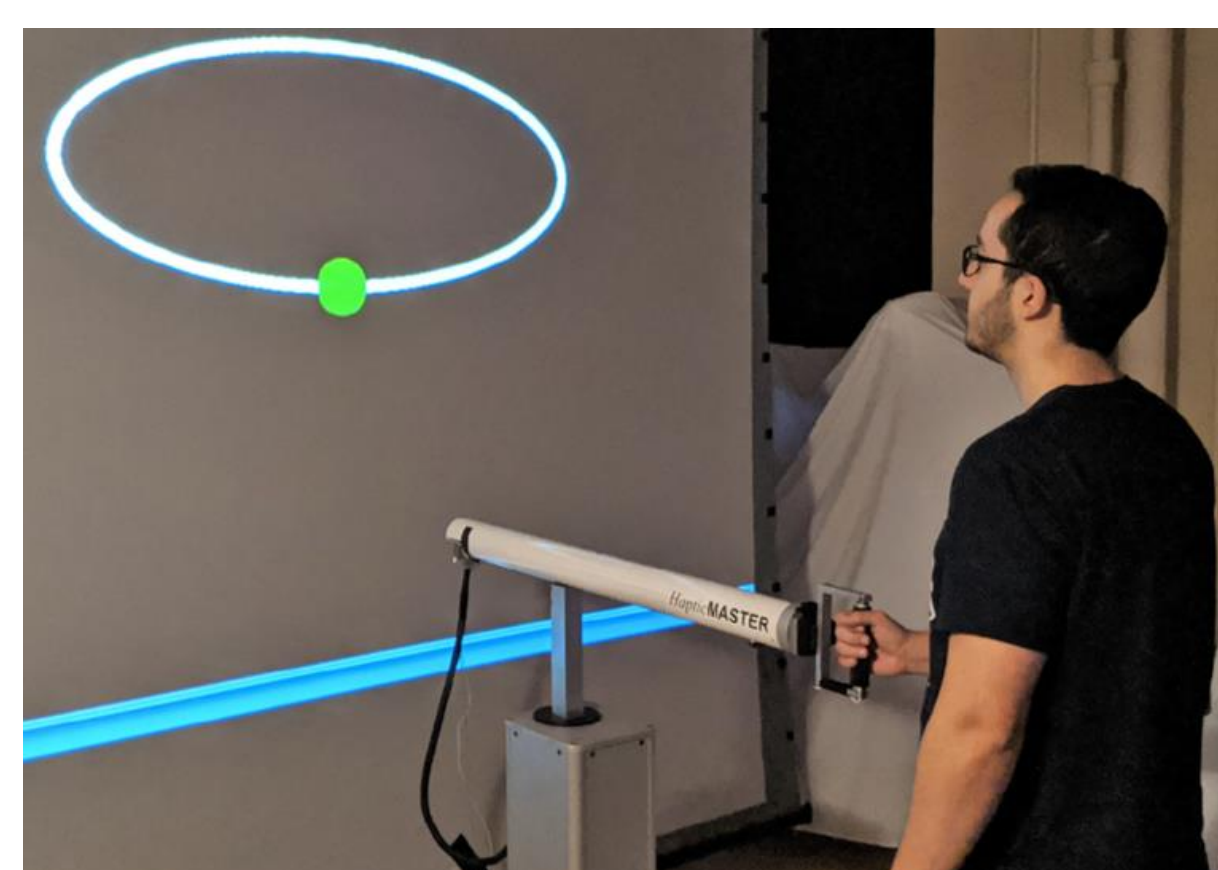
- trajectory's curvature (**H1**)
- tangential velocity (**H2**)
- angular velocity (**H3**).

## Methods

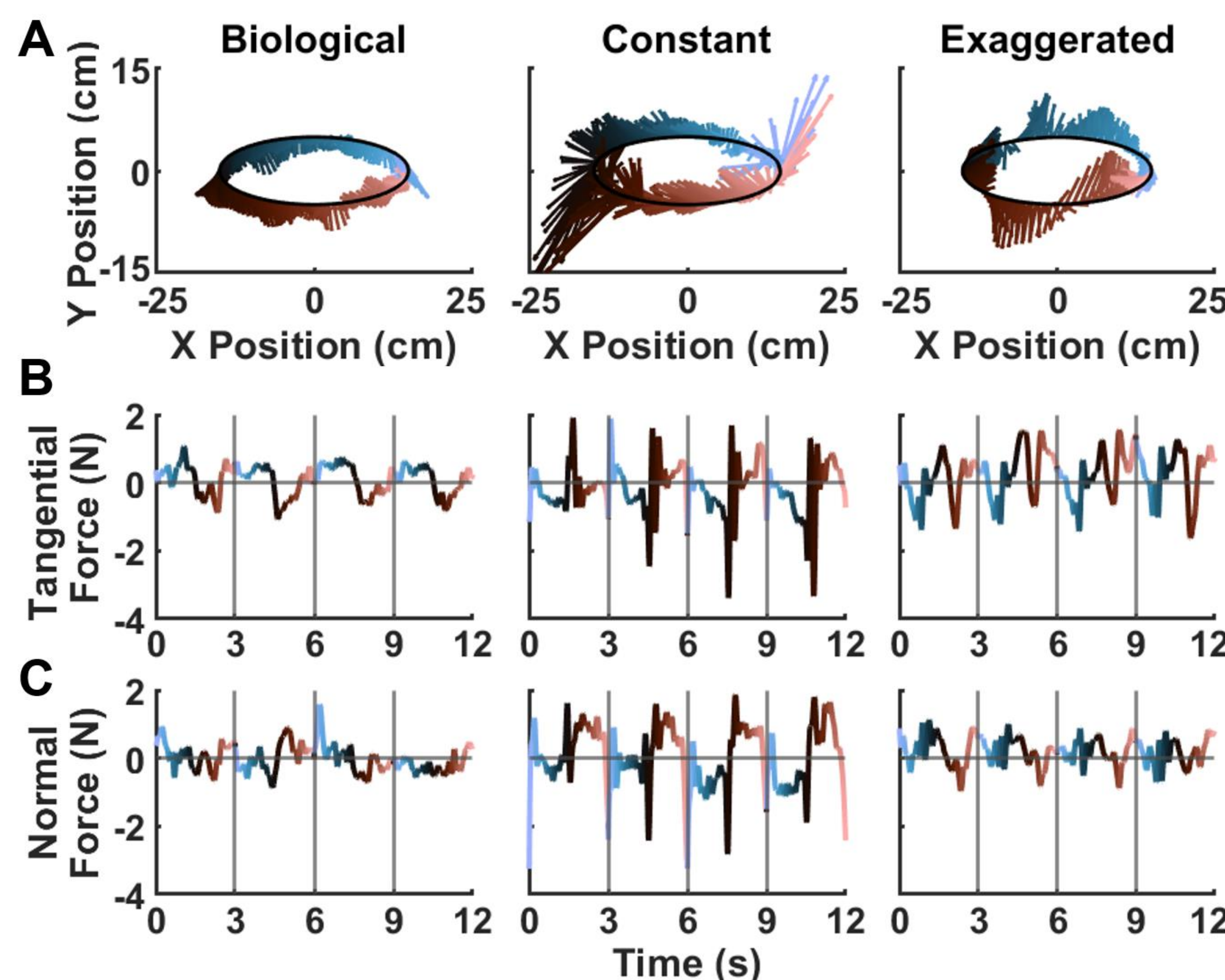
- Robot traced a planar ellipse (major axis = 15cm, minor axis = 5cm) with 3 different velocity profiles:



- 22 subjects were assigned to 1 of the 3 velocity profiles.
- 3 sessions - 80 trials each, analyzed last 10 trials.
- Dependent measures: Tangential and normal force applied by participants on the robot.

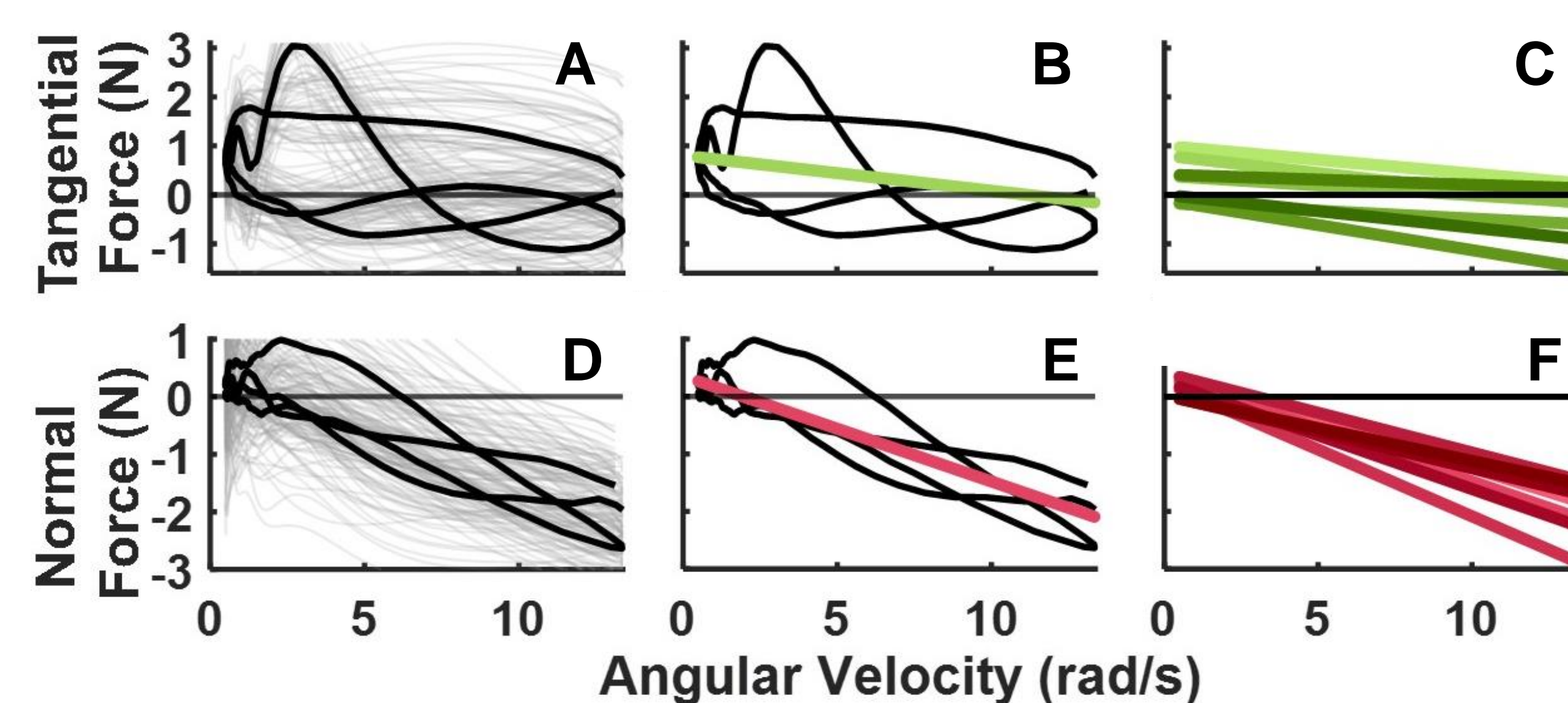


## Force Patterns



- Different velocity profiles elicited different force patterns despite having the same curvature profile (**H1 rejected**).
- Large variations of applied force in the *constant* profile with fixed tangential velocity (**H2 rejected**).

## Force vs Angular Velocity - Analysis

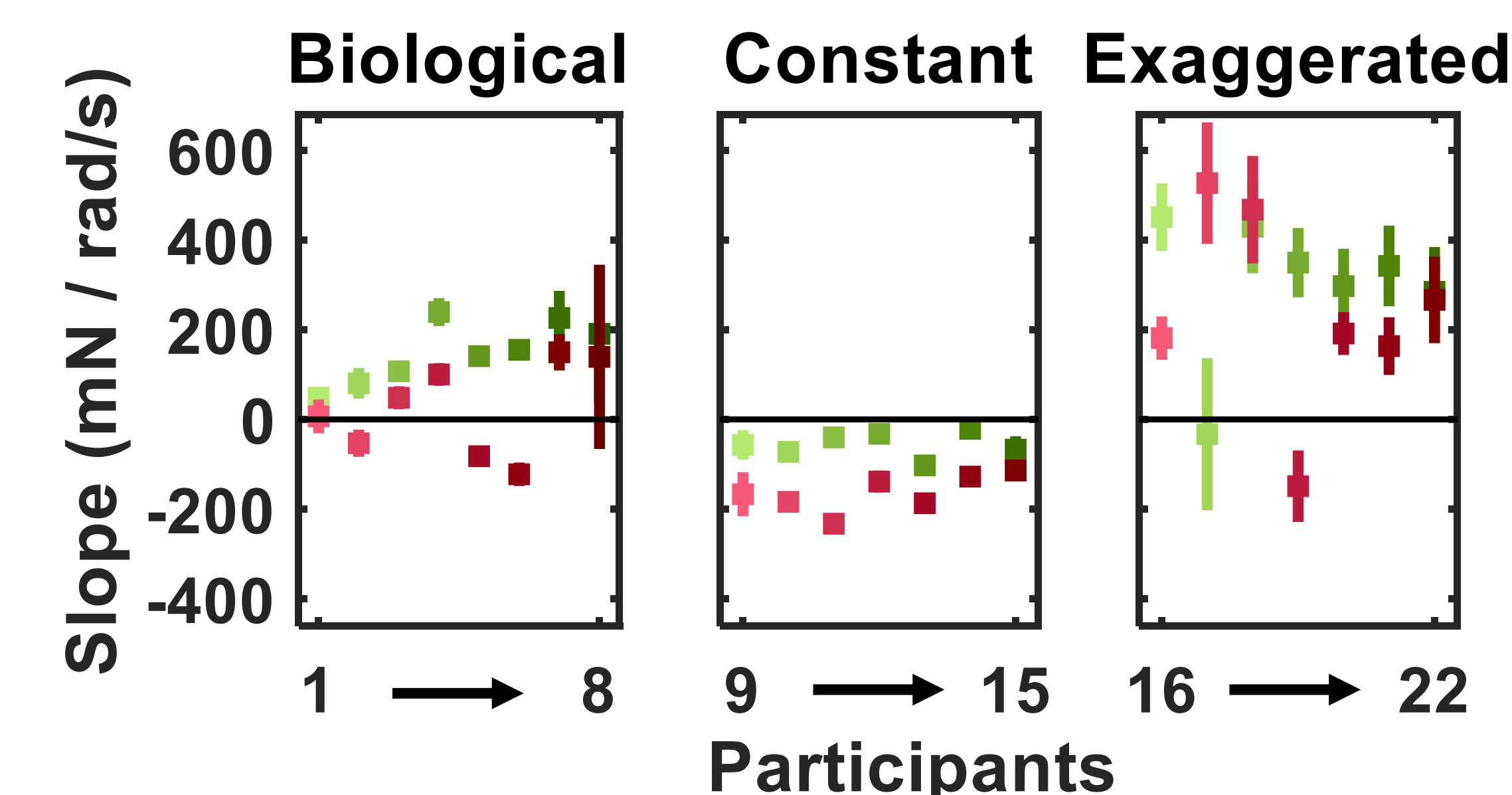


Slopes of linear regressions quantified how applied forces depended on the robot's angular velocity. Figures above show tangential and normal forces of the *constant* velocity profile.

## References

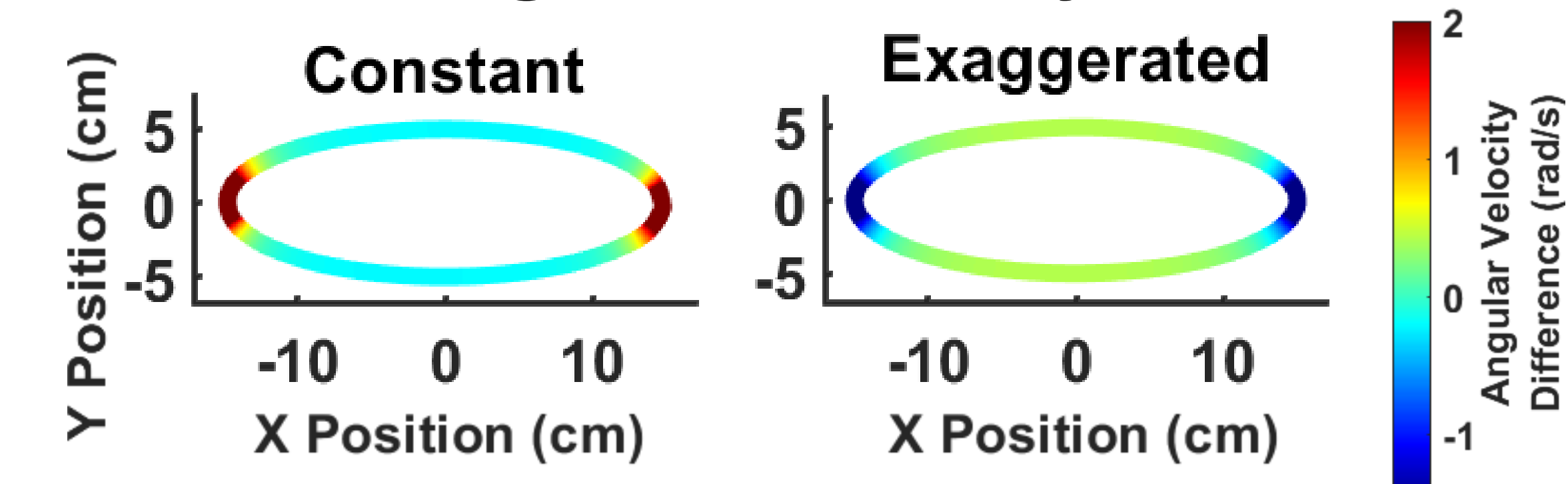
1. P. Maurice, M. Huber, N. Hogan, and D. Sternad. Velocity-curvature patterns limit human-robot physical interaction. IEEE RAL, 2018.
2. A. M. West, J. Hermus, M. Huber, P. Maurice, D. Sternad, and N. Hogan. Dynamic primitives limit human force regulation during motion. IEEE RAL, 2022.

## Force vs Angular Velocity - Results

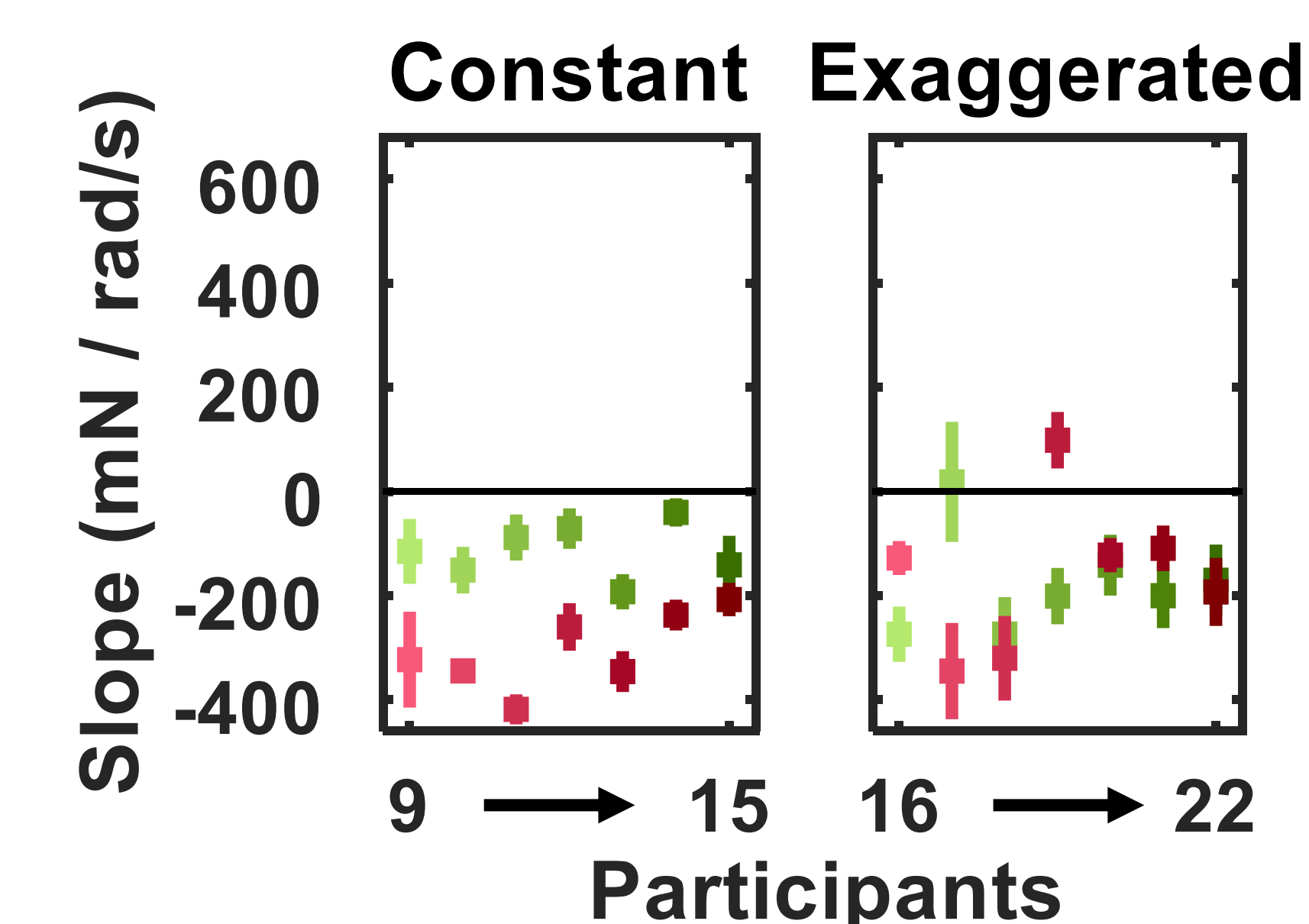


Magnitude of applied force correlated with the robot's angular velocity (**H3 supported**).

## Force vs Angular Velocity Difference



Additional question: Do deviations in angular velocity from the *biological* profile lead to higher applied forces?



All slopes show a negative relation with *angular velocity difference*. In both conditions, magnitude of force depended on deviations of angular velocity from the biological profile.

## Conclusions

- Human movement has certain limitations that need to be recognized for pHRI tasks.
- Robot movement profiles that deviated from the power law led to higher interaction forces applied by the human partner.
- Robot motion that incorporates the human preferred movement features enables more efficient and safer pHRI.