Dynamic Primitives in Human Manipulation of Dynamically Complex Objects

Salah Bazzi[1], Stephan Stansfield[2], Neville Hogan[2], Dagmar Sternad[1]

[1]Northeastern University, Biology, Electrical and Computer Engineering and Physics

[2]Massachusetts Institute of Technology, Mechanical Engineering, Brain and Cognitive Sciences

The Action Lab

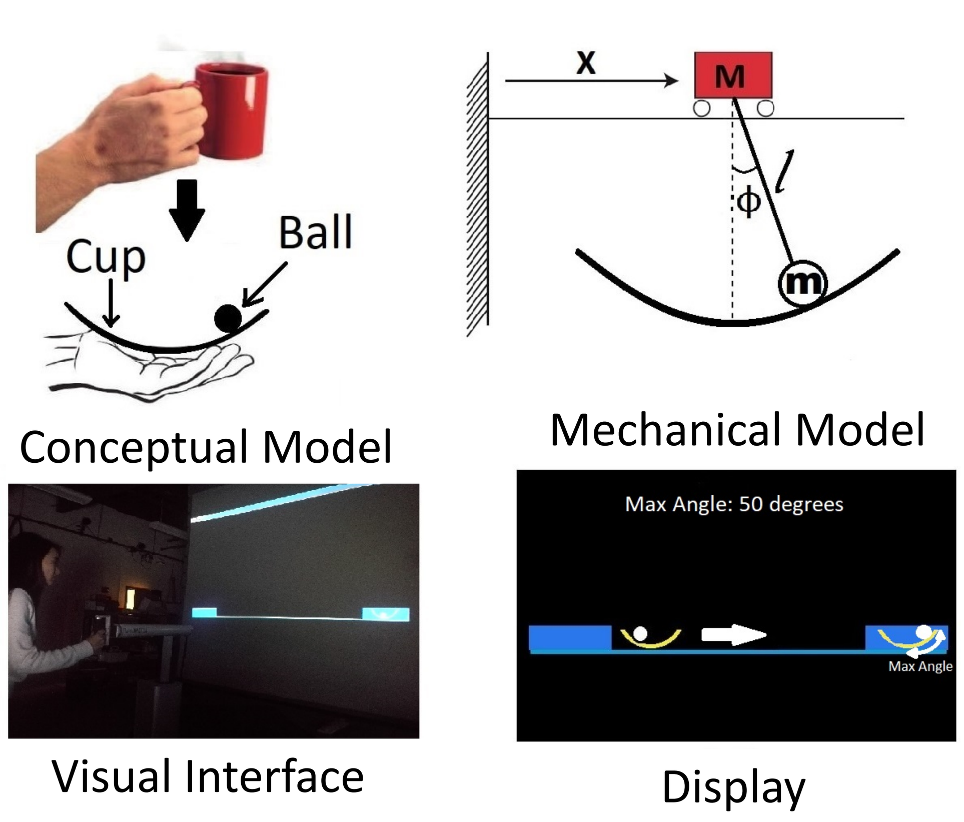
Newman Laboratory for Biomechanics and Human Rehabilitation

How Do Humans Manipulate Complex Objects?

- Dynamically complex objects: non-rigid, underactuated, nonlinear, chaotic dynamics
- Long delays imply heavy reliance on predictive (feedforward) control based on an internal model
- But complex internal models seem unlikely

Overall Hypothesis:
Humans simplify control of physical interactions by using dynamic primitives: submovements, oscillations, mechanical impedance [1].

Experiment 1



Instructions: Move the cup from the start box to the target box with no residual oscillations of the ball. Do not lose the ball. Avoid moving very slowly.

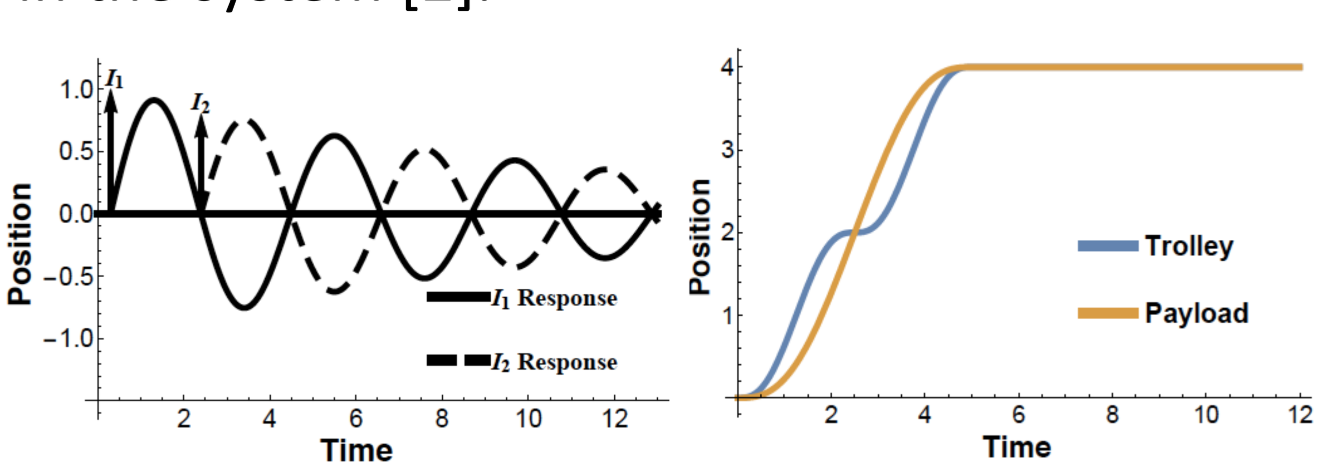
Protocol: 4 blocks with 50 trials each.

Feedback: Ball angle upon entering the target.

$$(m+M)\ddot{x}_C = ml\left(\dot{\phi}^2\sin(\phi) - \ddot{\phi}\cos(\phi)\right) + u$$
$$l\ddot{\phi} = -g\sin(\phi) - \ddot{x}_C\cos(\phi)$$

Control via Input Shaping

An impulse-based control strategy that eliminates residual vibrations in the system [2].



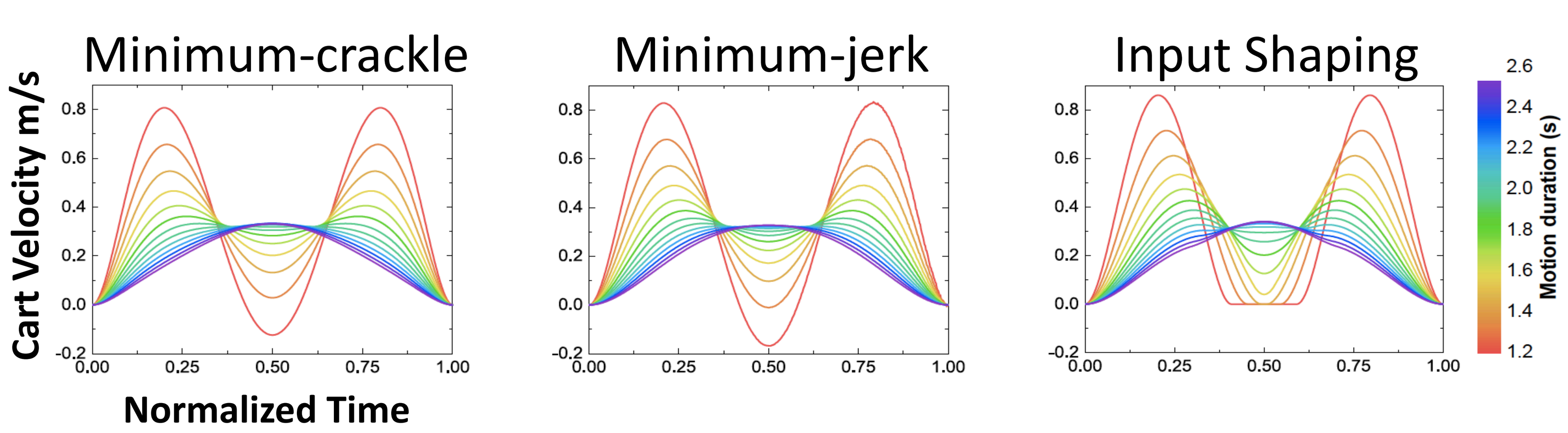
Hypothesis:
Humans use submovements using Input Shaping strategy to complete the task.

Alternative Models

Optimization-based models:

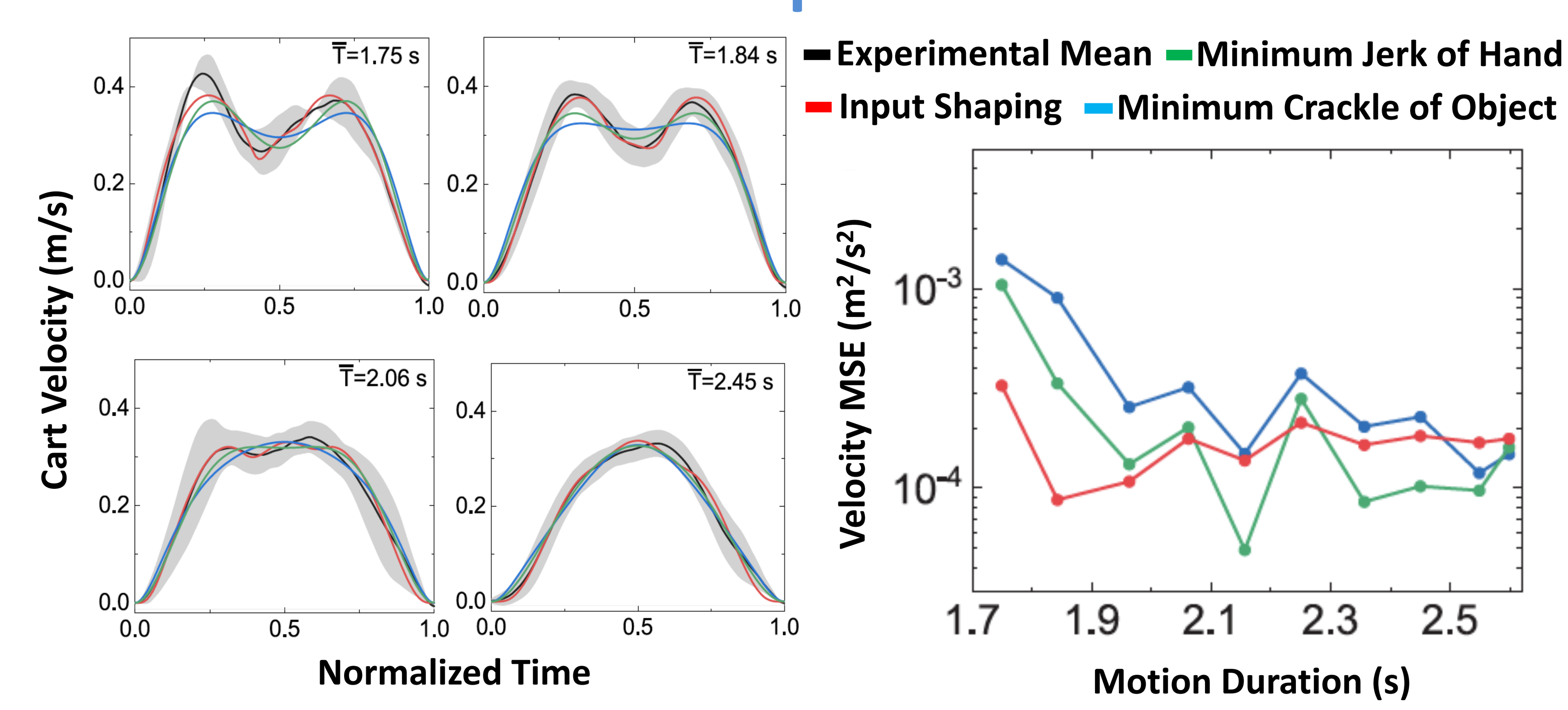
- Minimum crackle of the object [3]
- Dynamically-constrained minimum jerk of the hand [4]

Predictions:

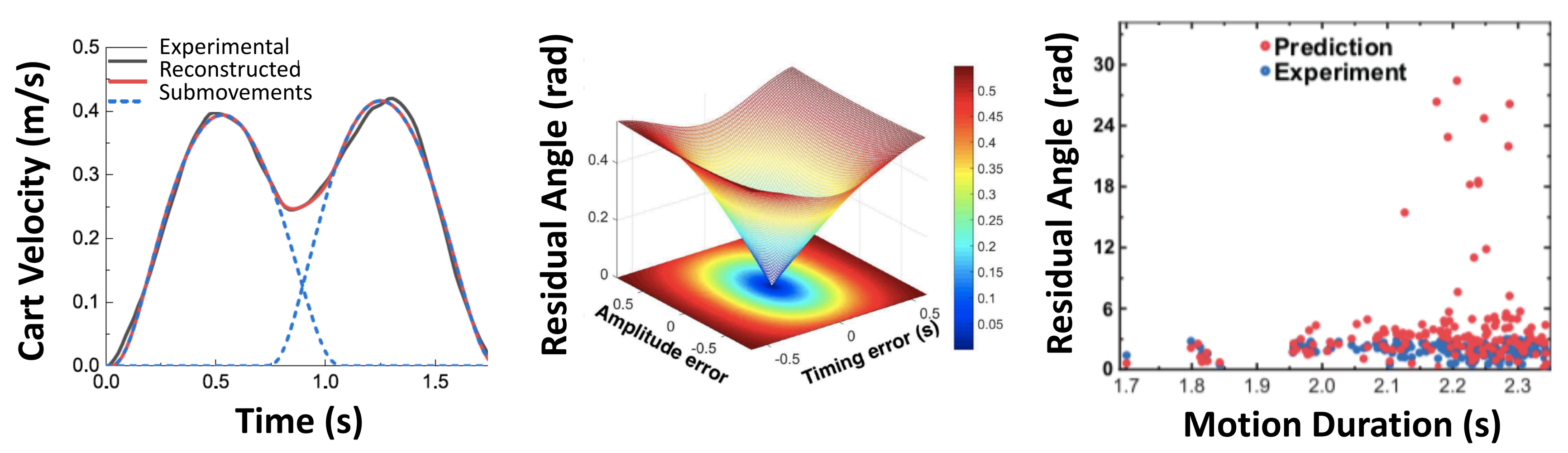


Models provide different predictions for fast movements

Model Predictions and Experimental Results



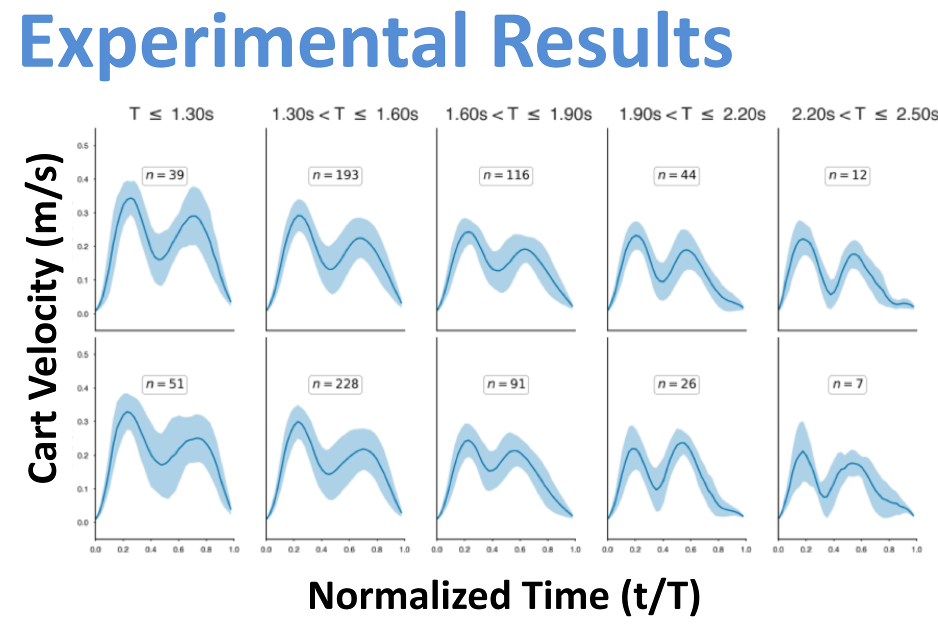
Submovements



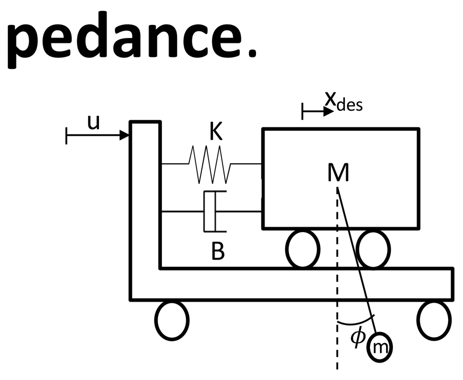
Experiment 2

Instructions: As Experiment 1 but additional time constraint provided by a metronome.
Protocol: 4 blocks, 50 trials each. In the first 2 blocks subjects trained the time constraint and residual angles separately.
Feedback: Maximum ball angle after reaching target and success/failure in meeting the time constraint.

Experimental Results



Asymmetric velocity peaks ⇒ human control model may include **coupled hand impedance**.



Summary and Conclusions

- Input Shaping with submovements is as good as optimization strategies, with less computational cost.
- Humans exploit hand impedance to negotiate interactive dynamics.

References

1. N. Hogan and D. Sternad, “Dynamic primitives of motor behavior,” Biological Cybernetics, vol. 106, no. 11-12, pp. 727–739, 2012.
2. T. Singh and W. Singhose, “Input shaping/time delay control of maneuvering flexible structures,” in American Control Conference (ACC), vol. 3, 2002, pp. 1717–1731.
3. J. B. Dingwell, C. D. Mah, and F. A. Mussa-Ivaldi, “Experimentally confirmed mathematical model for human control of a non-rigid object,” Journal of Neurophysiology, vol. 91, no. 3, pp. 1158–1170, 2004.
4. M. Svinin, Y. Masui, Z.-W. Luo, and S. Hosoe, “On the dynamic version of the minimum hand jerk criterion,” Journal of Robotic Systems, vol. 22, no. 11, pp. 661–676, 2005.
5. H. Guang, S. Bazzi , D. Sternad, and N. Hogan. Dynamic Primitives for Manipulating Non-Rigid Objects. IEEE International Conference on Robotics and Automation (ICRA) , 2019, pp. 3783-3789.

2020 NSF NRI Principal Investigators' Meeting
February 27-29, 2020 | Arlington, Virginia

Award ID#: NSF-NRI 1637854 (DS)
NSF-NRI 1637814 (NH)