

## **Manipulating a Whip: Complex Tasks Require Complex Methods**

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Daily life is full of interactions with objects that contain internal dynamics: examples include carrying a cup of coffee, spreading a tablecloth or making a bed. However, kinematic and dynamic analyses of such objects have been reported only for simplified tasks reduced to mass-spring or cart-pendulum systems. To advance understanding of how complex objects are controlled, this study examined human manipulation of an object with complex internal dynamics, a bullwhip.

16 participants used a 1.60m-long whip to hit a target in discrete style, with pauses between successive throws, and in rhythmic style, where the whip never came to rest between throws. Data recording of the fast and complex whip motions required customized markers and faithful reconstruction of the continuous whip necessitated physics-based gap filling and cubic-spline interpolation.

Participants' performance was evaluated by the minimum distance between the whip and the target. As the whip could reach the target with any point between its markers, the whip was interpolated applying cubic splines between each pair of adjacent markers. Spline arc lengths were constrained to stay constant as the markers were fixed on the whip.

Given the importance of whip motion for understanding human control, speed profiles of the whip were compared with a model of an unfolding 1D-thread with momentum conserved. Preliminary results showed similar sequence of speed profiles along the modeled thread as in the real whip. According to this metric, whip motion showed smoother unfolding in the rhythmic style.

Investigating complex tasks not only poses a challenge to human motor dexterity, but also to the researcher's computational methods, requiring innovative techniques for collecting and analyzing the data. The present study improved recording methods to set the stage for further investigation of how humans control flexible, underactuated objects.