Manipulating a Whip: Motor Control beyond Reach?

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Over the past decades much of motor neuroscience research has focused on unconstrained reach-like movements under highly controlled conditions. While this may yield insights into the role of internal models and optimal feedback control strategies, it is challenging to extrapolate this understanding to more advanced tasks such as interacting with objects that have internal dynamics. Using the extreme example of manipulating a bullwhip, this study asked how humans can achieve dexterity in manipulating the wave dynamics of the whip's infinite number of degrees of freedom.

16 participants attempted to hit a target with the 1.60m-long whip either in discrete style, with pauses between throws of the whip, or in rhythmic style, where the whip never came to rest between throws. Performance was quantified by success rate, error and variability of error. All measures showed better performance in the discrete style, but performance showed improvement only in the rhythmic style. Hand trajectories in state space and speed profiles indicated similar patterns for both styles. In particular, the tangential speed of the hand revealed two principal submovements in both styles, identifying two movement phases: preparatory phase and throwing phase. The preparatory phase was significantly longer in the discrete style. Comparison of the whip motion showed smoother unfolding in the rhythmic style, indicating smoother energy propagation along the whip.

Taken together these findings indicate that having more time in the discrete style to set proper initial conditions allows for a better performance. However, the features found in the rhythmic style suggest other mechanisms might be engaged. Based on observations of a two-peaked hand speed profile, we suggest that humans may represent control of this prodigiously complex dynamic object in terms of the parameters of primitive actions – submovements – that are used for interactive control.