

Motivation

- Numerous motor control studies have predominantly explored unconstrained tasks.
- Insights about control of unconstrained movements may not apply to interactions with objects or tools.
- We study manipulation of a complex tool; hitting a target with a bull whip.
- Control based on internal model of the infinitely-dimensional whip plus arm is not realistic.
- We explore dimensionality of participants' arms and the whip using principal component analysis (PCA).

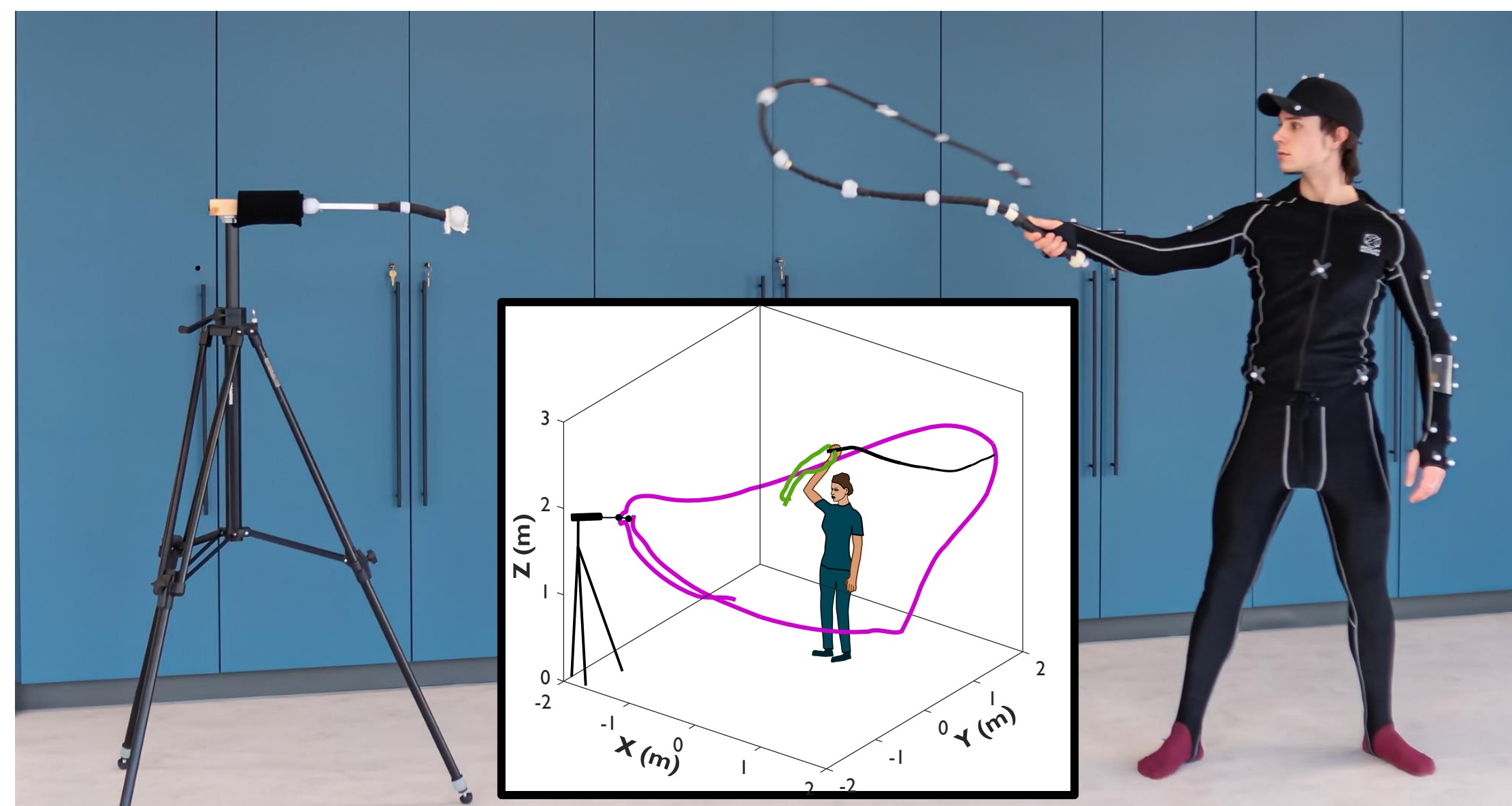
- What is the dimensionality of the Arm+Whip system?
- Does dimensionality differ between individuals with different skill levels?
- Does dimensionality of the whip and arm relate to the performance error?

Methods

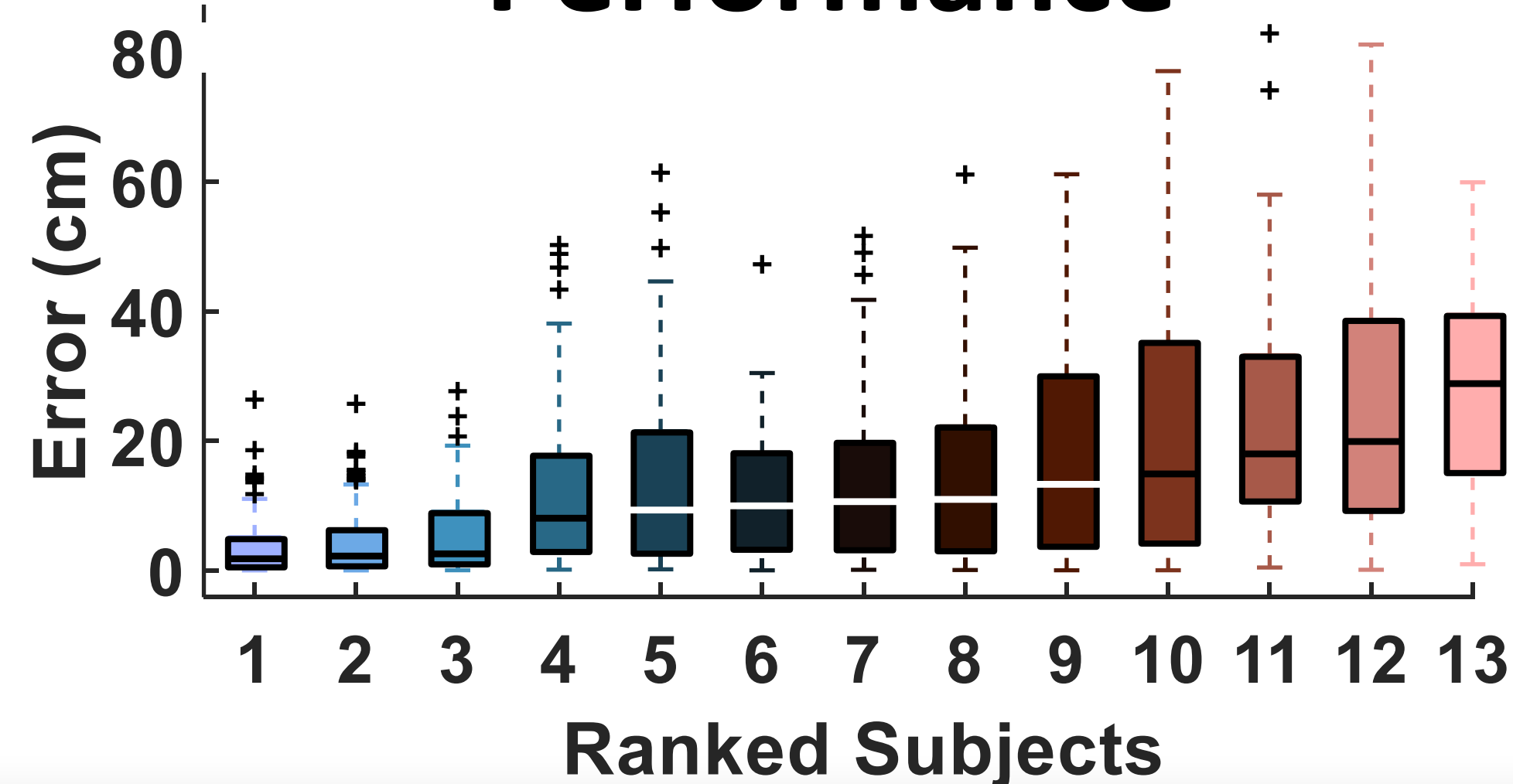
13 subjects manipulated a 1.6m-long bullwhip, trying to hit a target at a 2.2m distance. They performed ~150 trials in continuous rhythmic fashion.

Motion capture (Qualisys) tracked 23 markers on landmarks of the right arm (8), the whip (10), and the target (5).

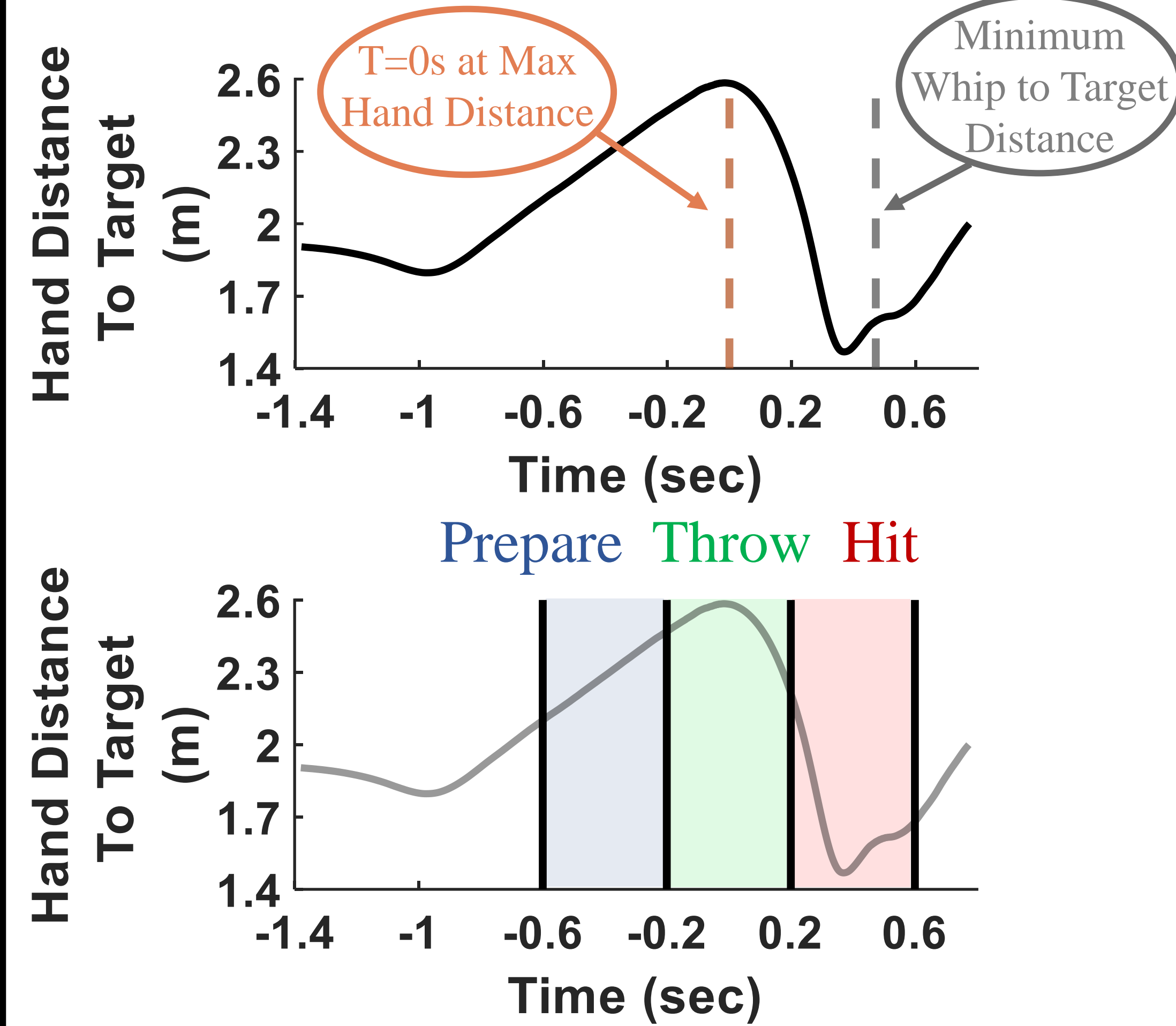
Spatial Trajectory



Performance

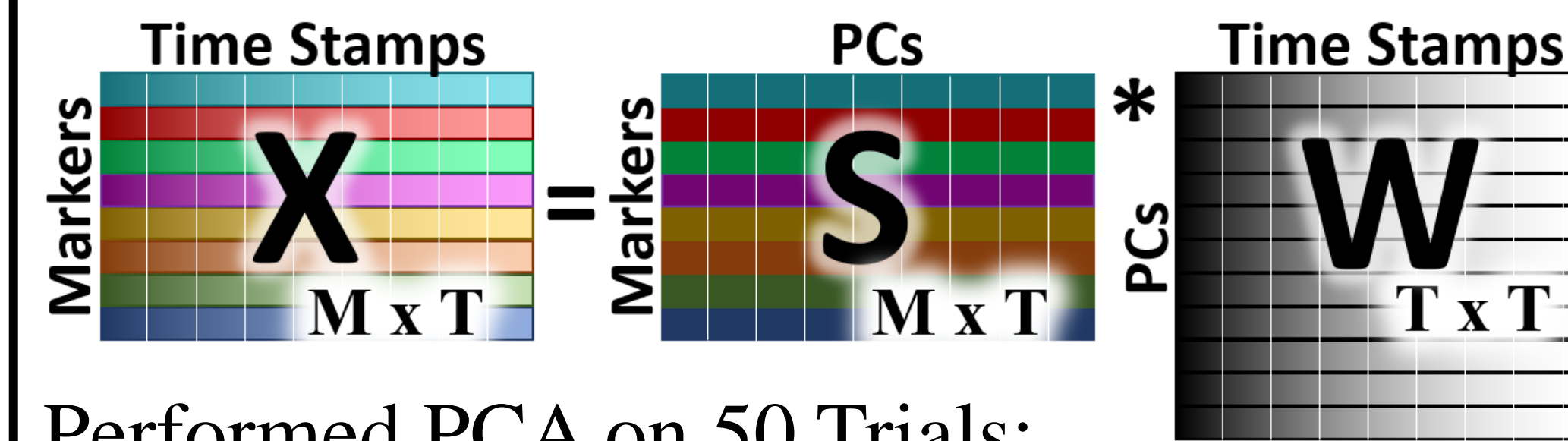


Temporal Landmarks



3 stages of the trial were analyzed: Preparatory, Throwing, and Hitting stages. Minimum distance to target reached at ~0.5s.

PCA

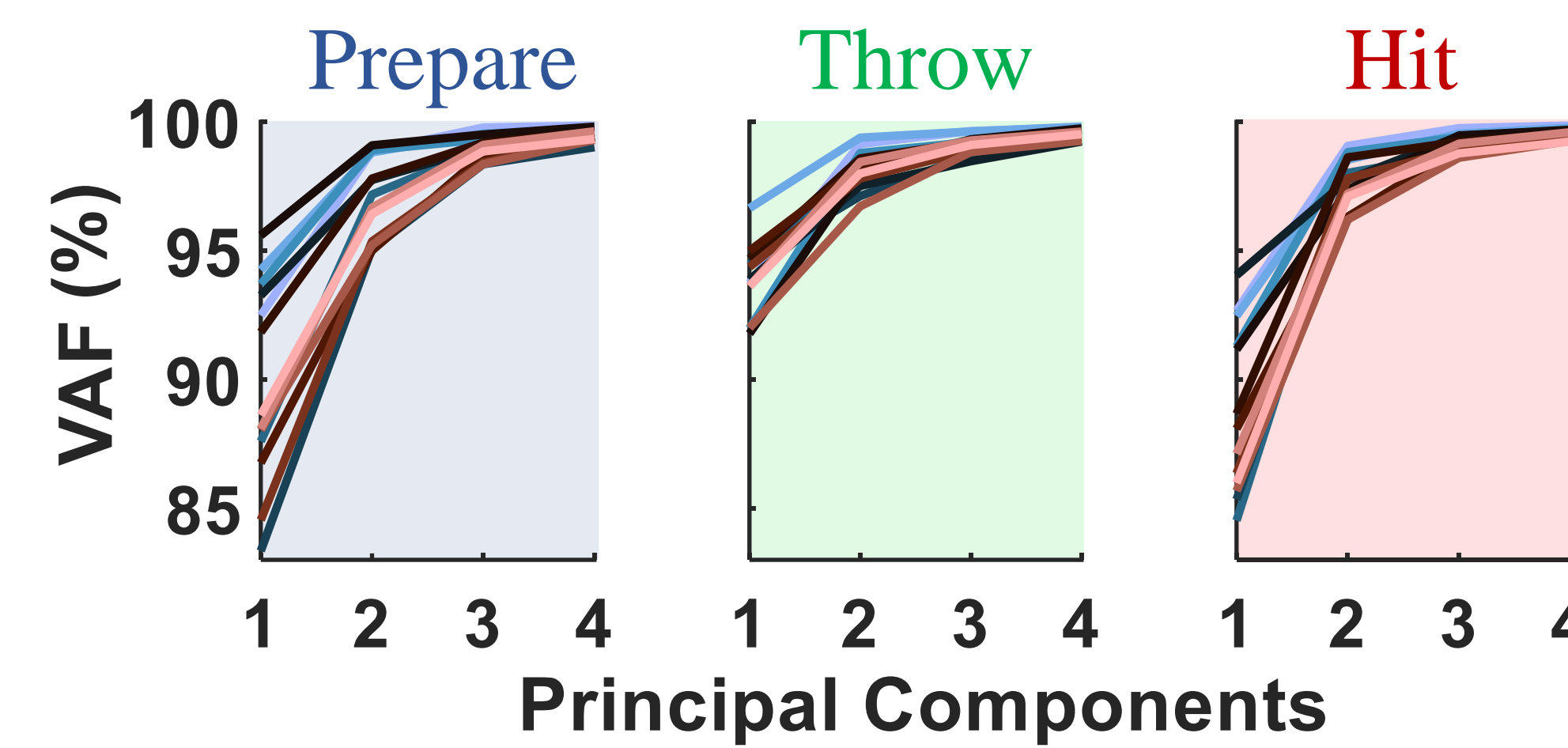


Performed PCA on 50 Trials:

3*4 Arm Marker Positions (X, Y, and Z)

3*10 Whip Marker Positions (X, Y, and Z)

Variance Accounted For (VAF)



Arm and whip are low dimensional.

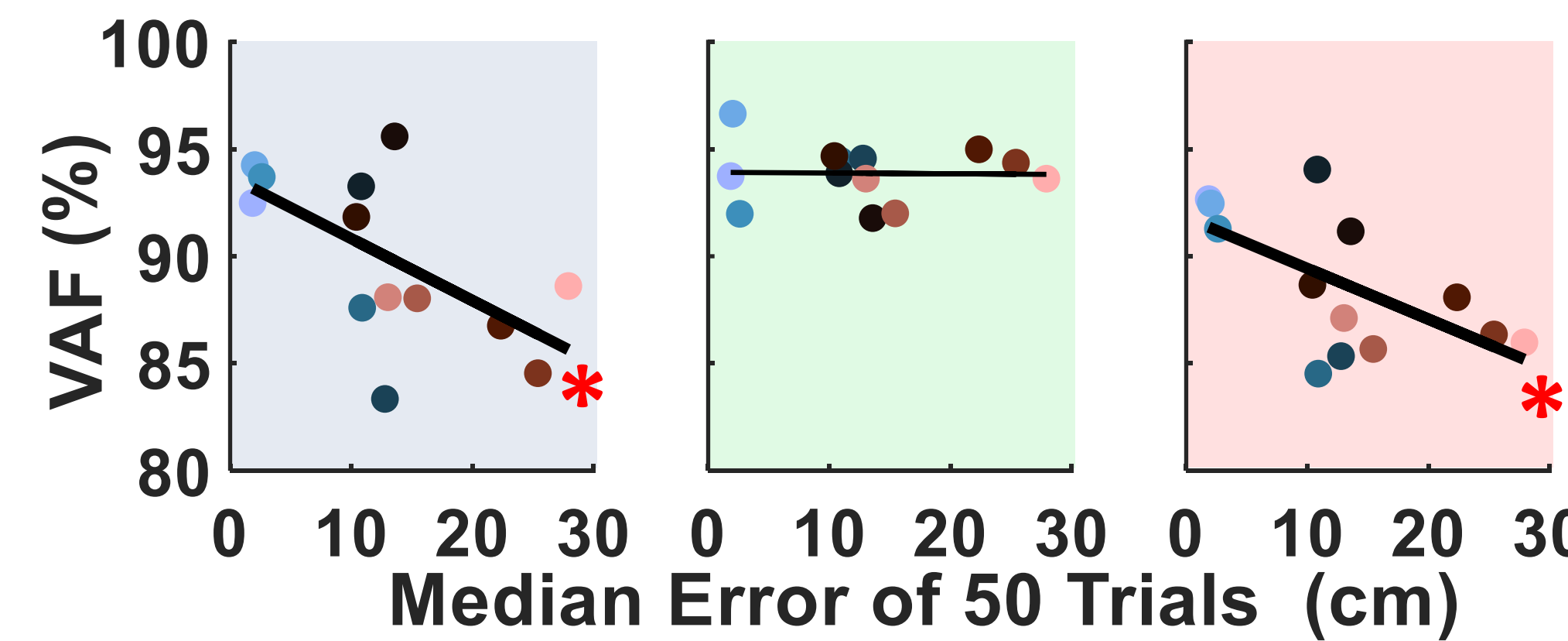
Conclusions

- The Arm + Whip system is low-dimensional. The 1st and 2nd PCs account for over 95% of the variance in the data.
- VAF by the 1st PC of the whip in the preparatory and hitting stages correlates with performance both between and within subjects.
- The variance of the whip is the main driver of the variance in the overall system.

High-level Interpretation:

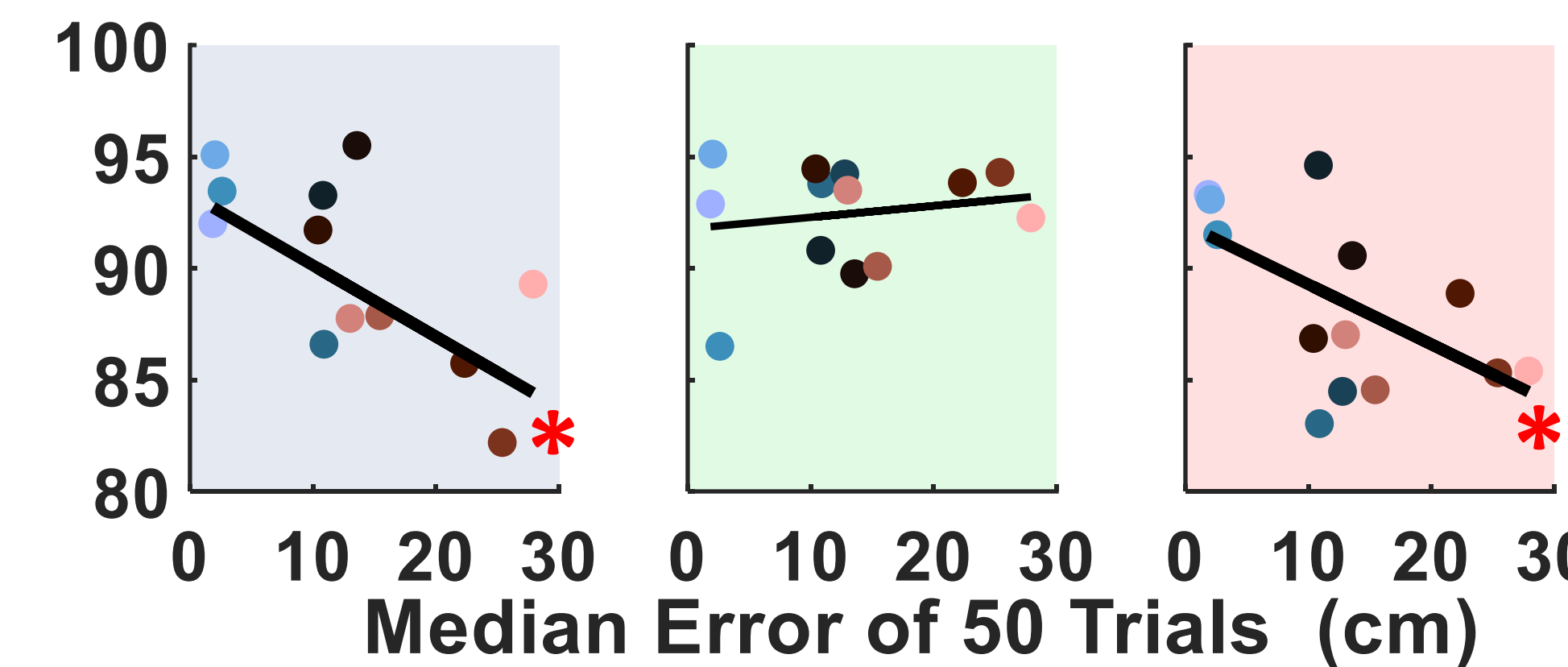
The complex system of the whip is reduced to few dimensions. This could enable humans to create "knowledge" about the complex object and how to interact with it.

Arm + Whip PCA

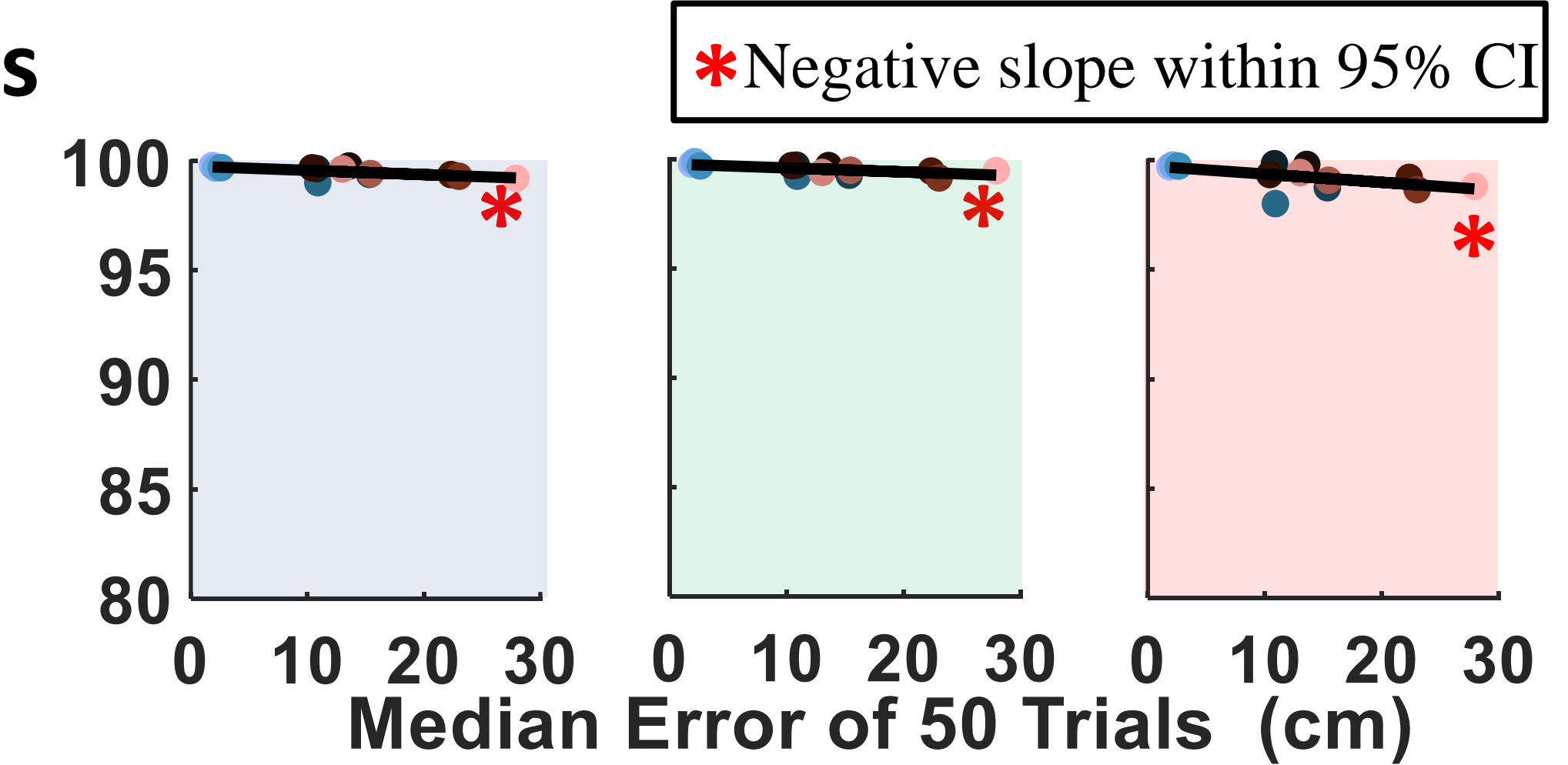


Whip PCA

VAF by PC-1 versus Error – Between Subjects

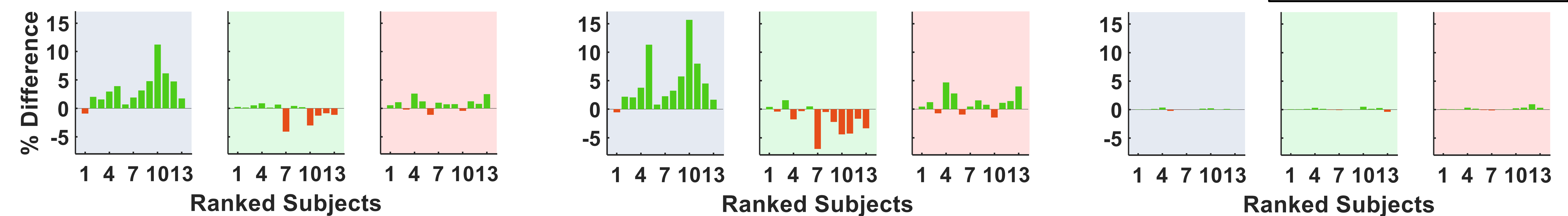


Arm PCA



VAF (%) in preparatory and hitting stages negatively correlate with median error. Whip dominates the VAF (%) of the Arm + Whip system.

Difference in VAF by PC-1 for 10 Best & Worst Trials – Within Subjects



The 1st PC of the whip position accounts for most of the variance in the Arm + Whip system in all 3 trial stages.

VAF by 1st PC of the whip position correlates with performance in preparatory and hitting stages, both between and within subjects.