

Similar Movements Induce Drastically Different Muscle Contraction Velocities

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Question

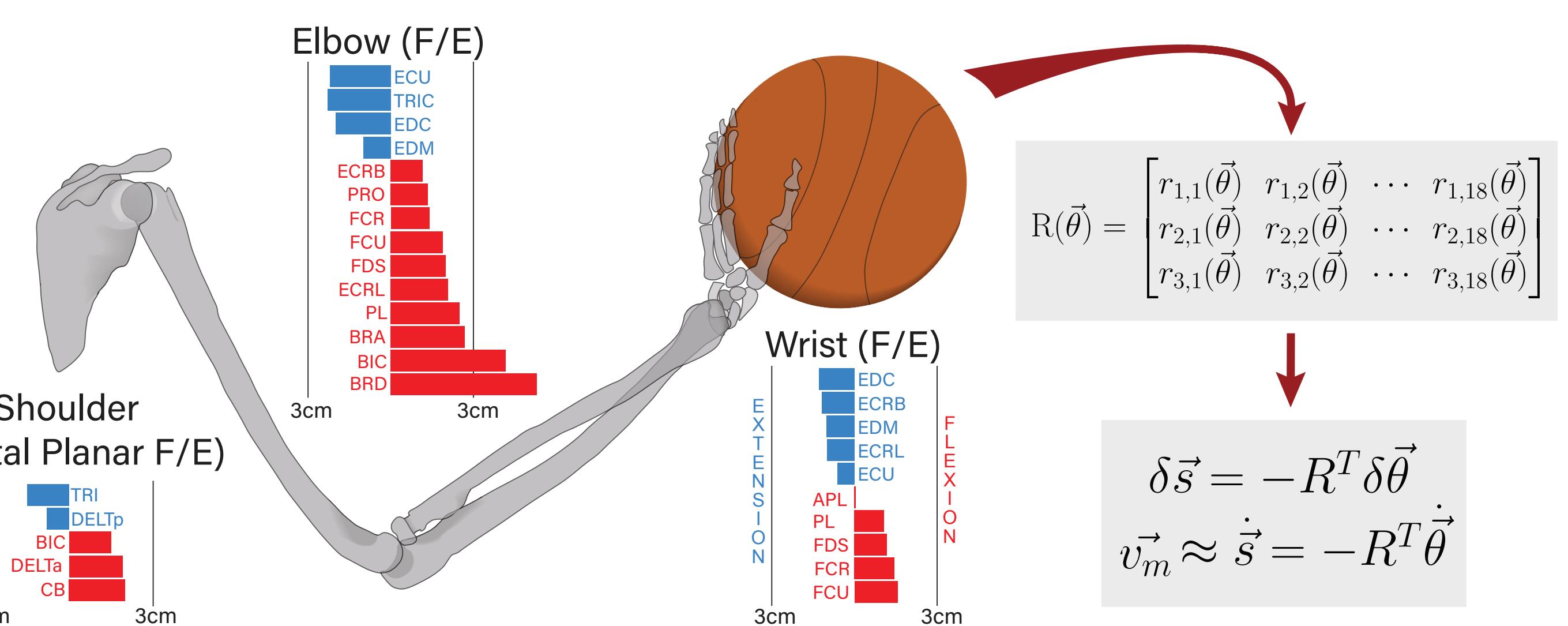
Is there a difference between a **good shot** and a **good looking shot** in basketball?

- Recent work re-emphasizes that neural control of limb movements is in fact **overdetermined**, with the rotation of a **few joints** determining the length changes in **many muscles** [1, 2].
- As per Sherrington, if even one eccentrically contracting muscle fails to silence its stretch reflex appropriately, movement will be disrupted [3].
- Throws requiring **faster eccentric contractions** will naturally require **more precise neural modulation**, and are likely more prone to variability.
- We investigated whether kinematically similar throws could exhibit large differences in eccentric and concentric muscle contraction velocities.

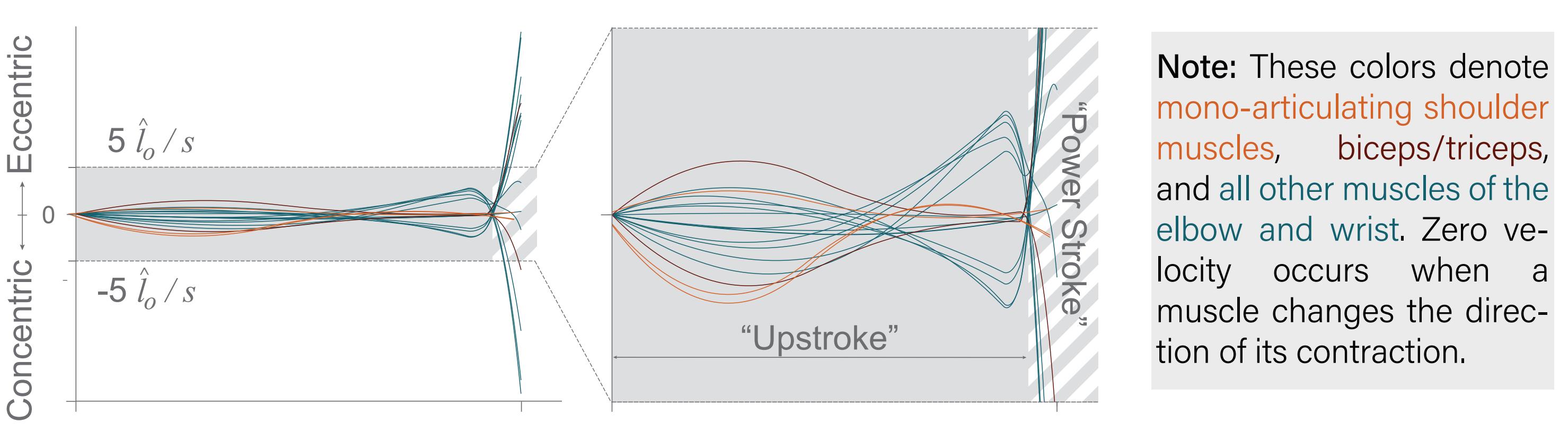
Methods

We utilized an **18-muscle planar arm model** to calculate a family of 100,000 random, feasible shoulder, elbow and wrist joint rotations that produced stereotyped basketball shots.

Each shot underwent a different hand trajectory but all had identical initial and final hand positions and velocities.



Using a **posture-dependent moment arm matrix** we estimated **muscle velocities** from angular velocities [1, 4, 5, 6]. Each shot exhibits a unique **muscle velocity profile**.

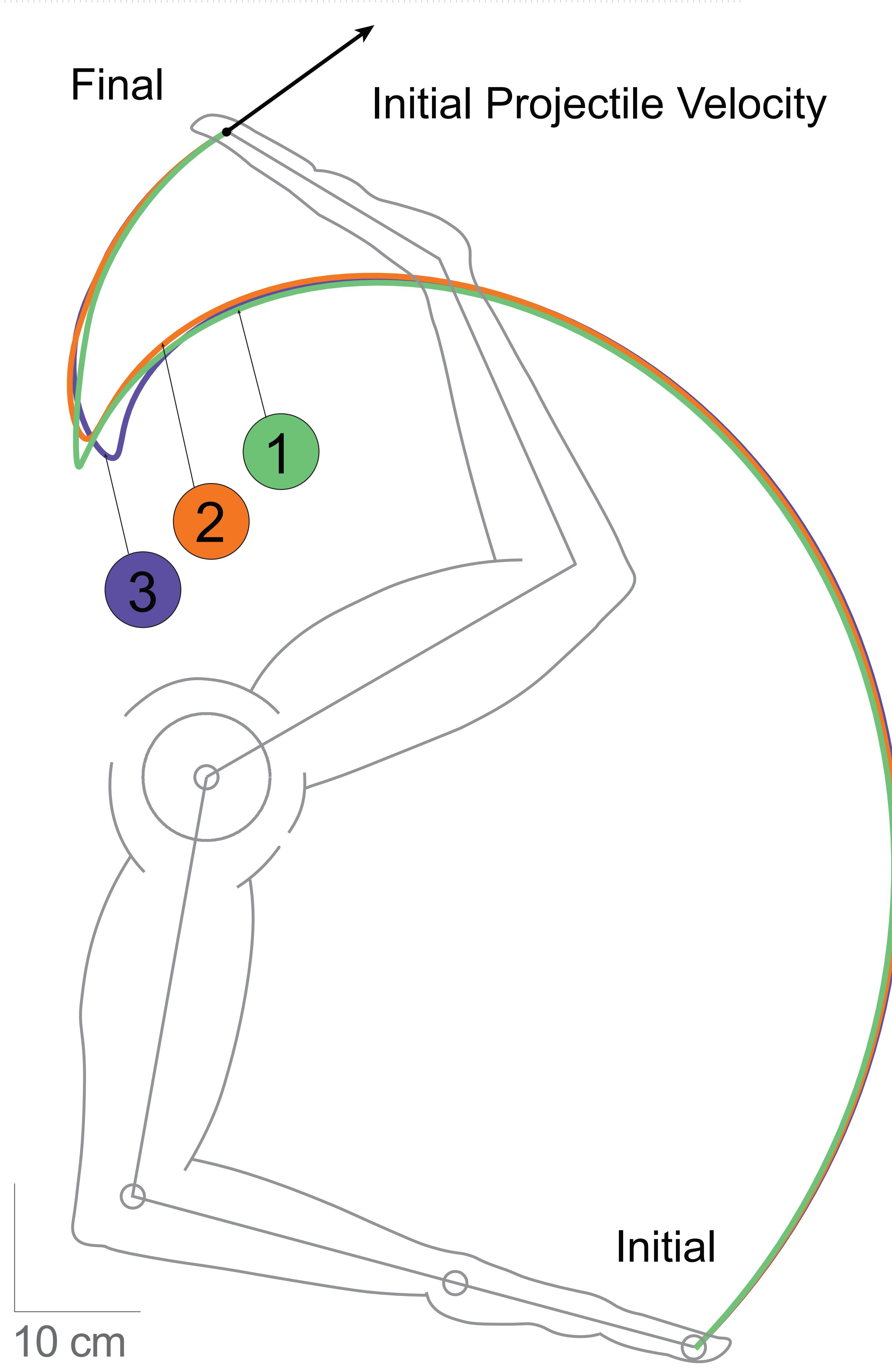


We calculated the **Euclidean norms** of the maximal eccentric and concentric velocities during the "upstroke." These metrics are indicative of the **eccentric and concentric contraction levels**, respectively.

$$\text{Eccentric Cost} = \sqrt{\sum_{i=1}^{18} \max(v_{ecc,i}(t))^2} \quad \text{s.t. } v_{ecc,i}(t) = \begin{cases} v_{m,i}(t); & v_{m,i}(t) \geq 0 \\ 0; & v_{m,i}(t) < 0 \end{cases}$$

$$\text{Concentric Cost} = \sqrt{\sum_{i=1}^{18} \min(v_{conc,i}(t))^2} \quad \text{s.t. } v_{conc,i}(t) = \begin{cases} 0; & v_{m,i}(t) \geq 0 \\ v_{m,i}(t); & v_{m,i}(t) < 0 \end{cases}$$

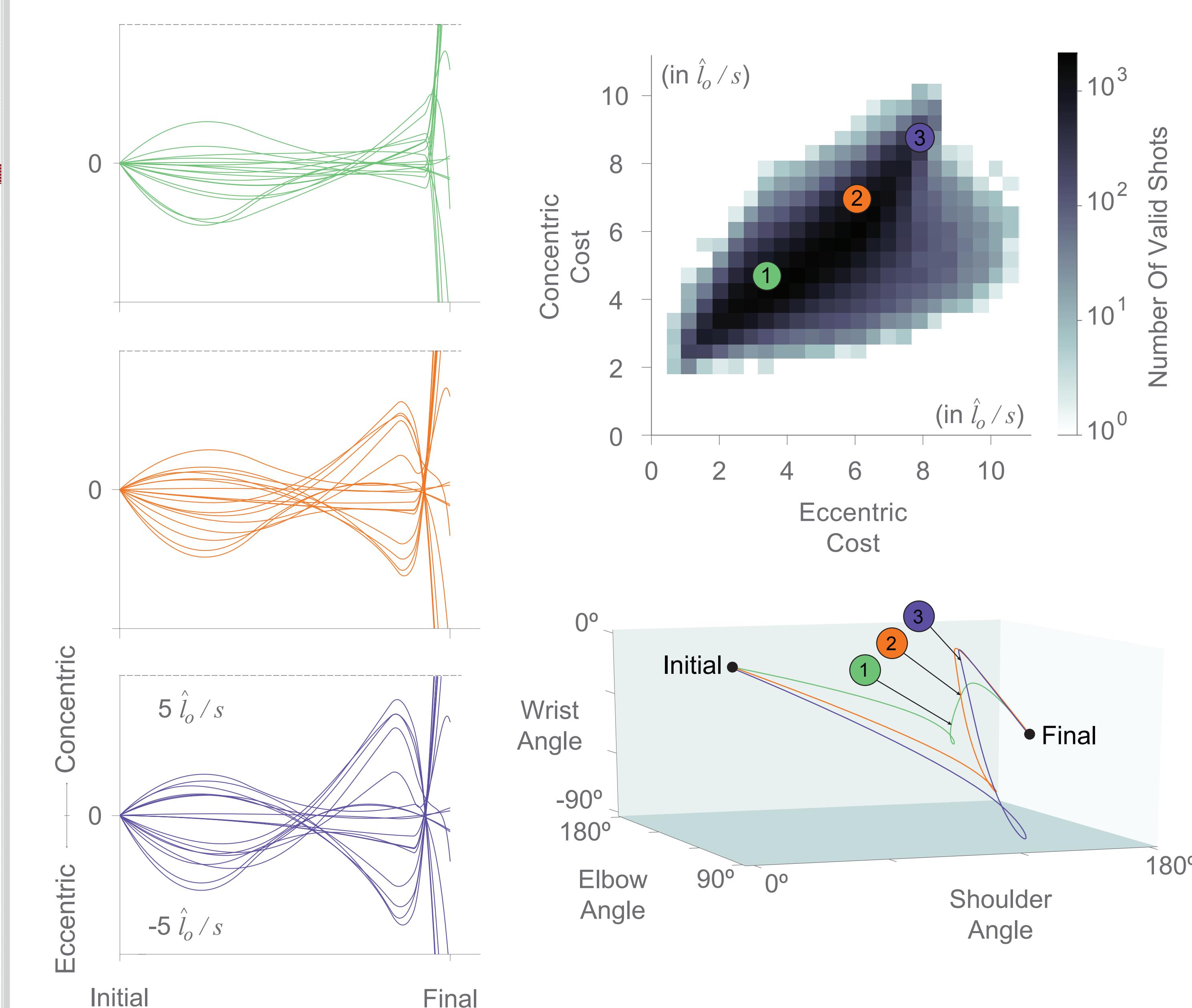
Results



Results (cont)

Three kinematically similar hand trajectories with:

- Different eccentric/concentric contraction levels (top right)
- Different angle trajectories (bottom right)
- Different muscle contraction velocity profiles (left).



Discussion

- To produce a given movement trajectory, all muscle activations must be appropriately coordinated, and afferent feedback from lengthening muscles must be appropriately tuned.
- Valid trajectories are not intrinsically equivalent, but rather distinct in their muscle velocity profiles.**
- The time-sensitive coordination of reflexes is overdetermined, challenging the notion of muscle redundancy for the control of movement.
- These results begin to explain why learning to move well is so difficult, and why smooth and accurate movements are so easily disrupted in neurological conditions.

References:

- [1] Valero-Cuevas, FJ. *Fundamentals of Neuromechanics*. Springer-Verlag London, 2016. [2] Valero-Cuevas, F, Cohn, B, Yingyao, H, & Lawrence, E. *J Biomech*, **48**(11), 2887-2896, 2015. [3] Sherrington, C.S. *Exp. Physiol.*, **6**(3), 252-310, 1913. [4] Winter, DA. *Biomechanics and motor control of human movement*. Fourth edition, Elsevier B.V., 2013. [5] Ramsay, JW, Hunter, BV, & Gonzalez, RV, *J Biomech*, **42**(4), 463-473, 2009. [6] Holzbauer, KR, Murray, WM, & Delp, SL. *Annals of Biomedical Engineering*, **33**(6), 829-840, 2005.

(Additional references available upon request.)

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