Similar Movements Induce Drastically Different Muscle Contraction Velocities

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Question

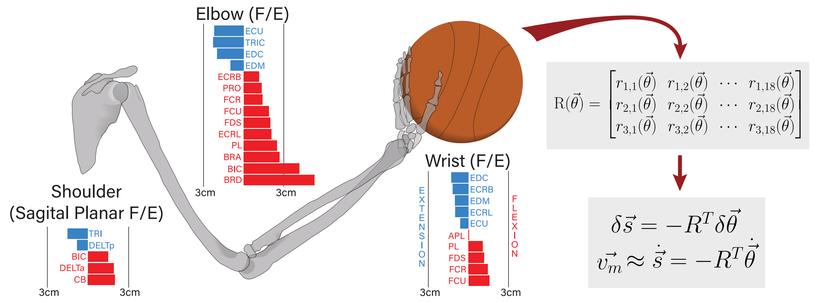
Is there a difference between a good shot and a good looking shot in basketball?

- 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.

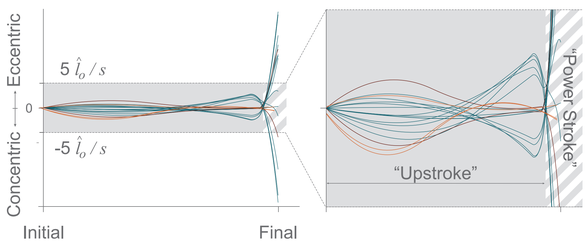
Each shot underwent a different hand trajectory but all had identical initial and final hand positions and velocities.



$$R(\vec{\theta}) = \begin{bmatrix} r_{1,1}(\vec{\theta}) & r_{1,2}(\vec{\theta}) & \cdots & r_{1,18}(\vec{\theta}) \\ r_{2,1}(\vec{\theta}) & r_{2,2}(\vec{\theta}) & \cdots & r_{2,18}(\vec{\theta}) \\ r_{3,1}(\vec{\theta}) & r_{3,2}(\vec{\theta}) & \cdots & r_{3,18}(\vec{\theta}) \end{bmatrix}$$

$$\delta\vec{s} = -R^T\delta\vec{\theta}$$
$$\vec{v_m} \approx \dot{\vec{s}} = -R^T\dot{\vec{\theta}}$$

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.



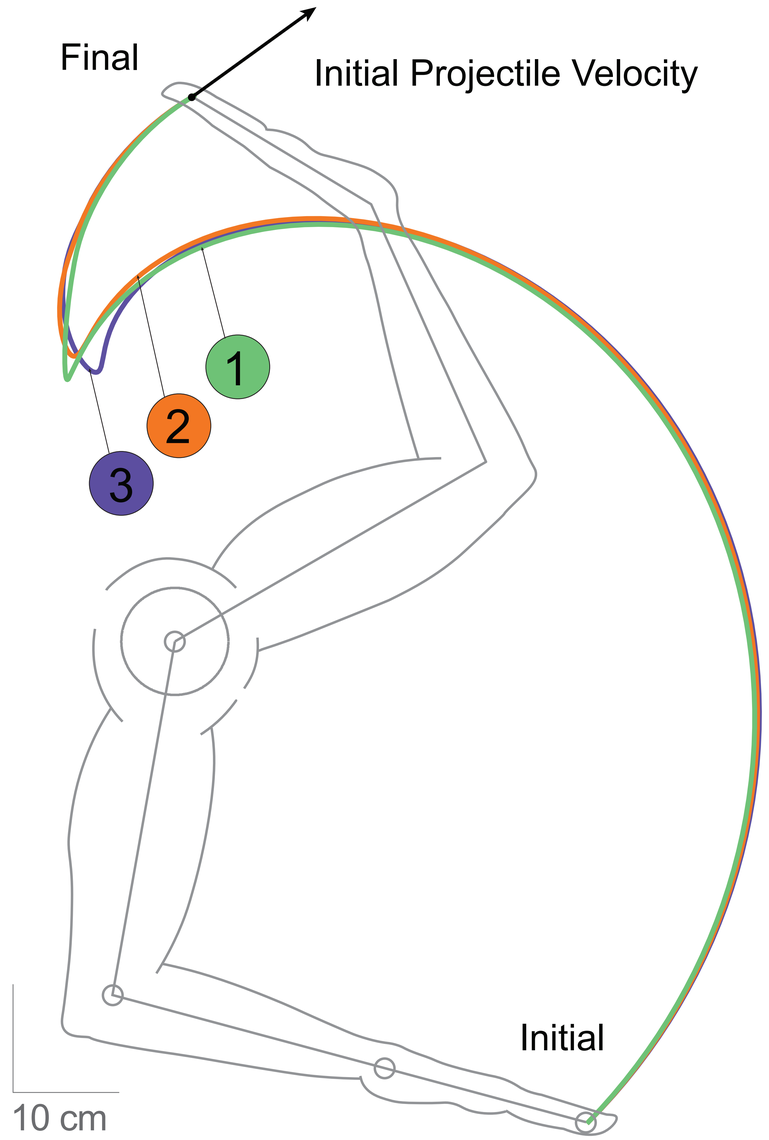
Note: These colors denote mono-articulating shoulder muscles, biceps/triceps, and all other muscles of the elbow and wrist. Zero velocity occurs when a muscle changes the direction of its contraction.

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.

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

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

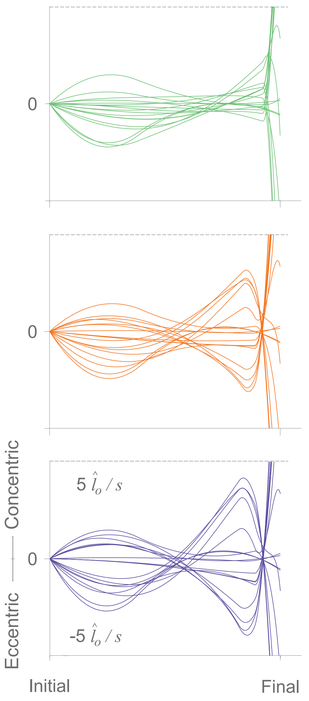
Results

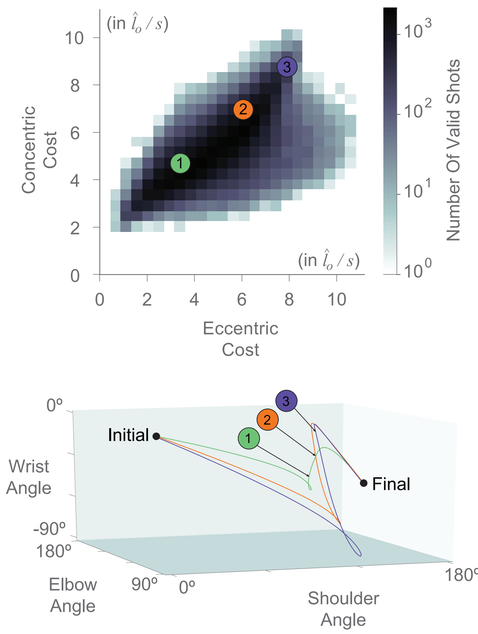


Results (cont.)

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, Yngvason, 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] Holzbaur, KR, Murray, WM, & Delp, SL, *Annals of Biomedical Engineering*, **33**(6), 829-840, 2005.

(Additional references available upon request.)

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