Kinematically similar basketball free throws have surprisingly different muscle contraction velocity profiles

Daniel A. Hagen[1]
Steven Caja[1]
Suraj Chakravarthi Raja[2]
Francisco J. Valero-Cuevas[1,3]
[1]Department of Biomedical Engineering, USC
[2]Department of Electrical Engineering, USC
[3]Division of Biokinesiology & Physical Therapy, USC

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, the movement will be disrupted [3].
- Throws requiring faster eccentric contractions will naturally require more precise alpha-gamma coordination, and are likely more prone to variability.
- We investigated whether kinematically similar throws could exhibit large differences in eccentric and concentric muscle fiber 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 with a different hand trajectory but all with identical starting and ending 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 from the elbow and wrist. Zero velocity occurs when a muscle changes the direction of its contraction.

Methods (cont.)

We calculated the Euclidean norms of the maximal eccentric and concentric velocities during the "upstroke." This metric is indicative of the eccentric and concentric contraction levels, respectively.

$$\text{Eccentric Cost} = \sqrt{\sum_{i=1}^{18} \max(|v_{m,i}|)^2} \quad (\text{where } v_{m,i} \geq 0)$$

$$\text{Concentric Cost} = \sqrt{\sum_{i=1}^{18} \max(|v_{m,i}|)^2} \quad (\text{where } v_{m,i} \leq 0)$$

Results

Results (cont.)

Three kinematically similar hand trajectories with:

- Different levels of eccentric and concentric contractions (middle panel, bottom right)
- Different angle trajectories (middle panel, bottom left and right panel, bottom traces)
- Different muscle fiber velocity profiles (right panel, middle traces).

Discussion

- Muscle velocity profiles provide a way to distinguish between good shots and good looking shots.
- Athletes must search the solution space effectively as it has consequences to the needed precision for alpha-gamma coactivation.
- 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 (Kobe Bryant!), 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.)

Acknowledgements:

We thank the University of Southern California for facilities provided during the course BME/BKN 504, and Dr. Emily Lawrence who laid the foundation for this research and shared her prior work.

dhagen@usc.edu