How well do neuromechanically-based effort proxies represent the metabolic cost of reaching?

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1. Objectives

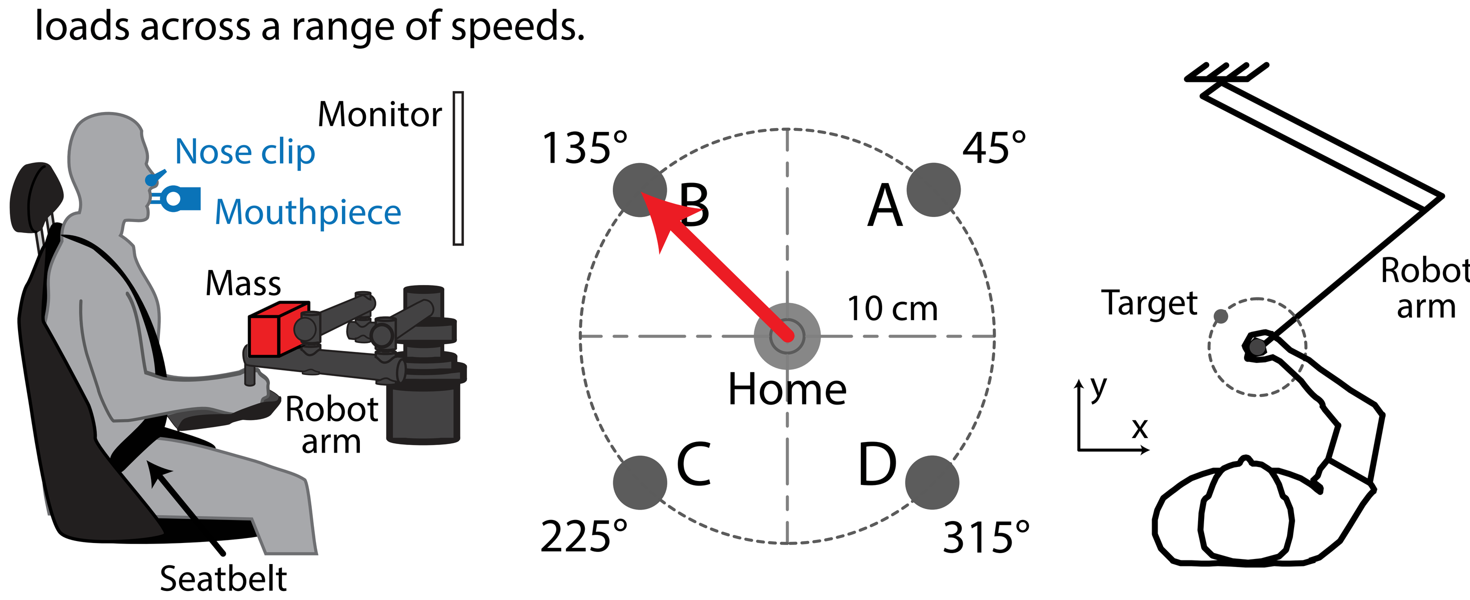
It has been suggested that there is an effort cost to arm reaching movements which is conserved across individuals[1]. Effort is often times represented by metabolic cost, which is represented by neuromechanical proxies[2].

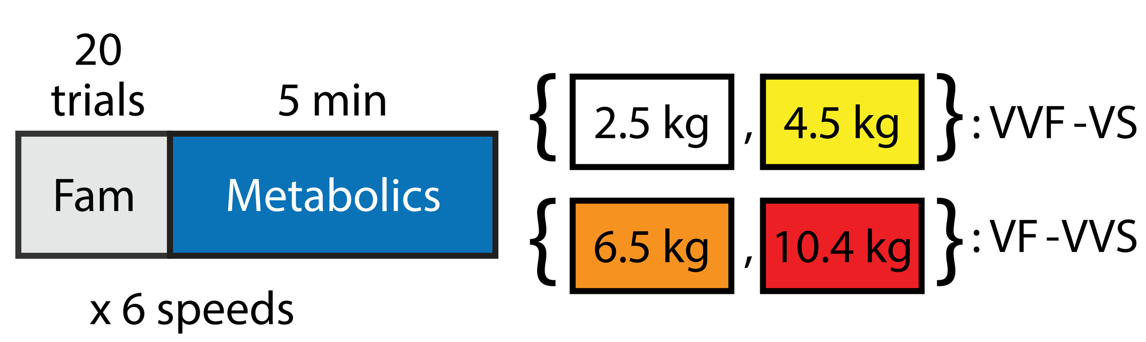
Question:

How do different neuromechanical proxies represent the metabolic power of reaching?

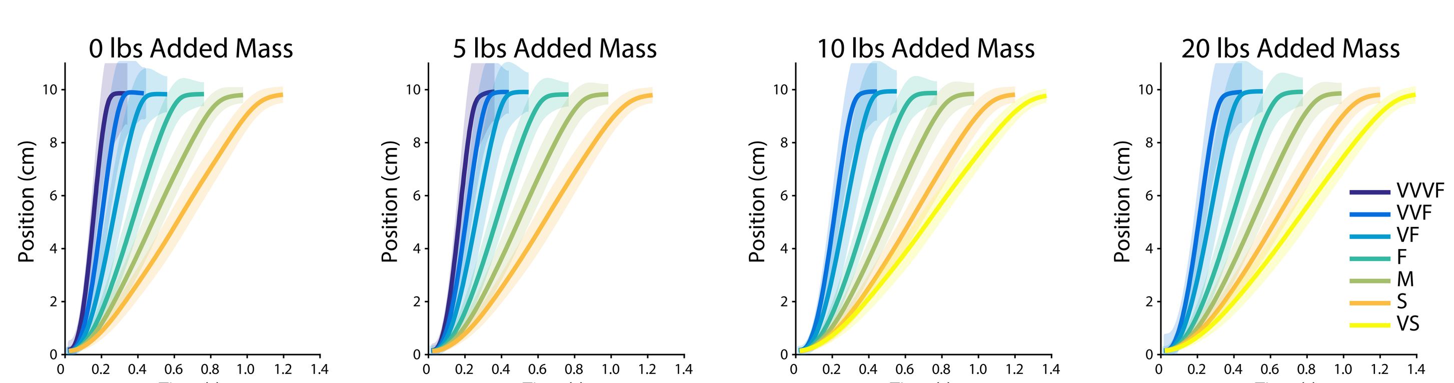
2. Measuring the Metabolics of Reaching

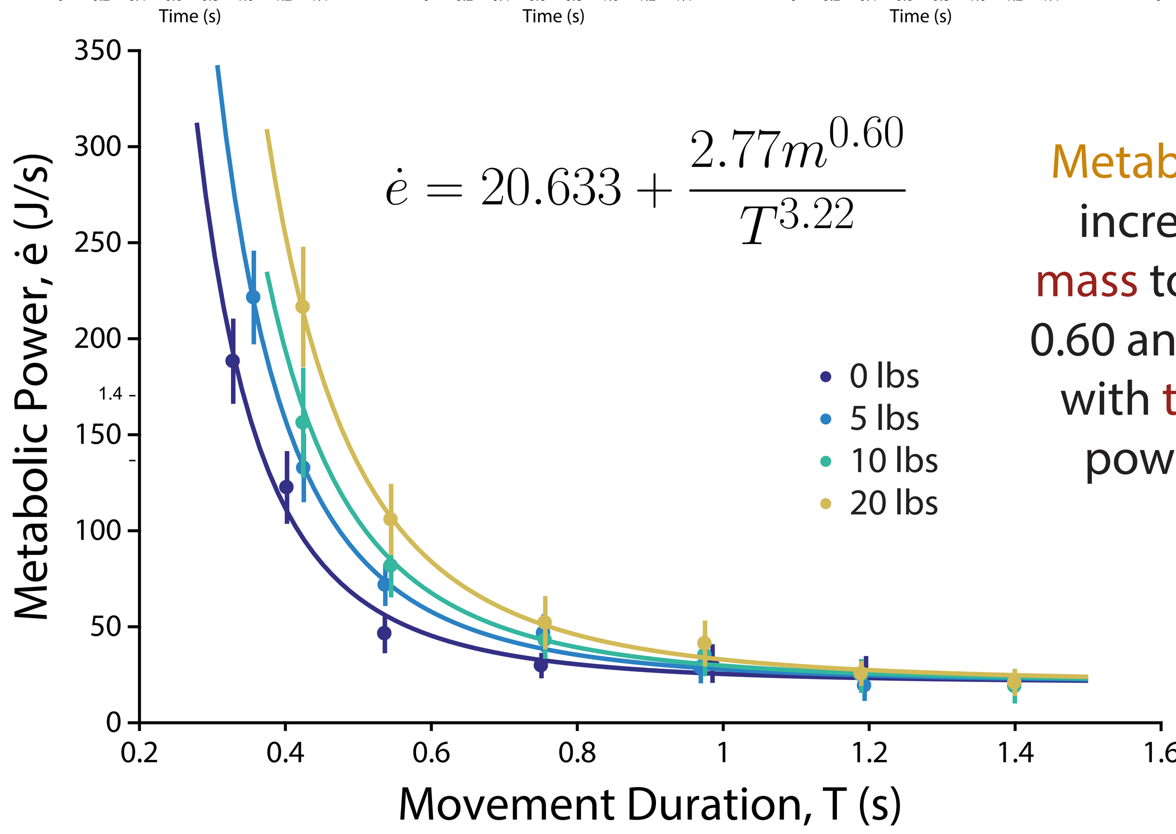
Subjects (N=8) perform10 cm reaching movements with various loads across a range of speeds.





3. Effect of Mass on Metabolic Power

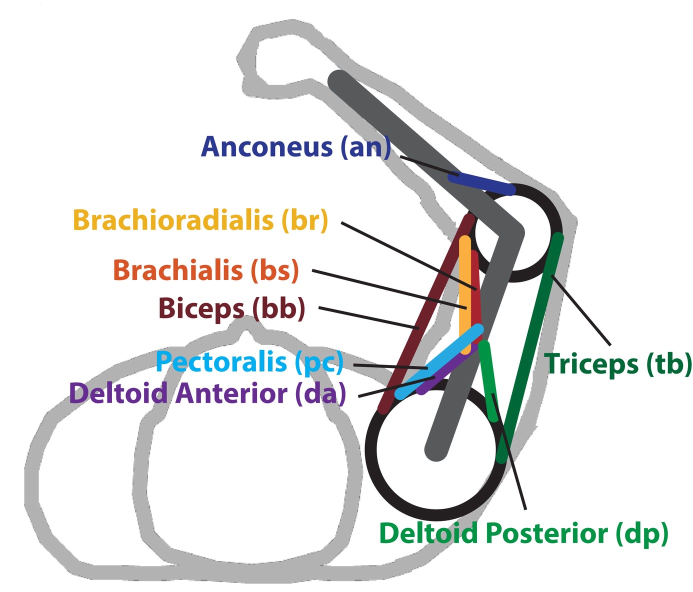


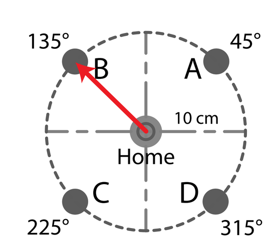


$$\dot{e} = 20.633 + \frac{2.77m^{0.60}}{T^{3.22}}$$

Metabolic power increases with mass to the power 0.60 and decreases with time to the power of 3.22

4. Arm Model





Neuromechanical Proxies:

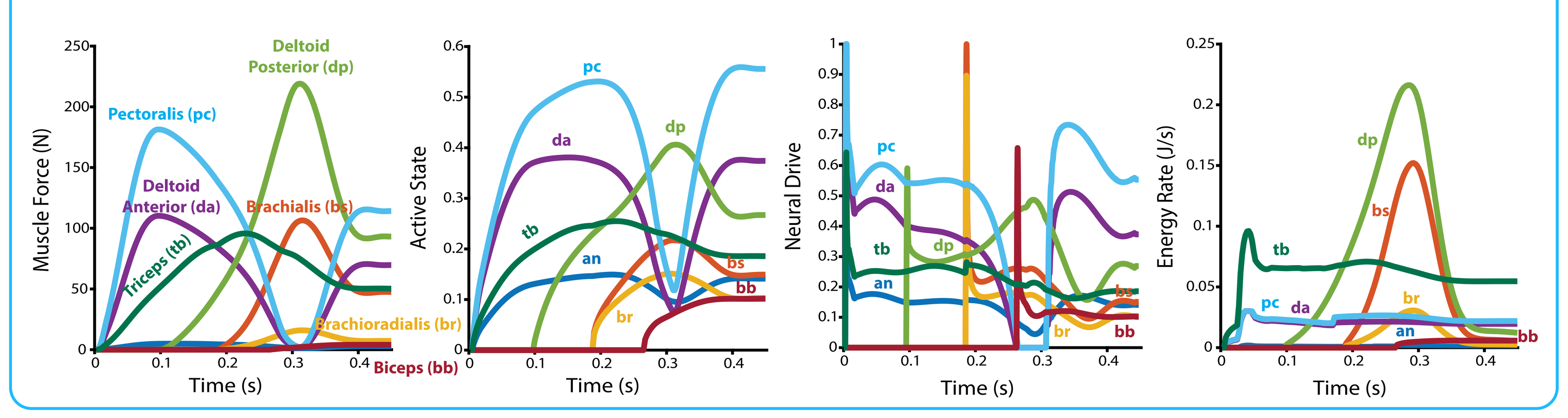
1) Joint Torque
Integration of elbow and shoulder joint torques.

2) Muscle Force
Integration and sum of the eight muscles forces.

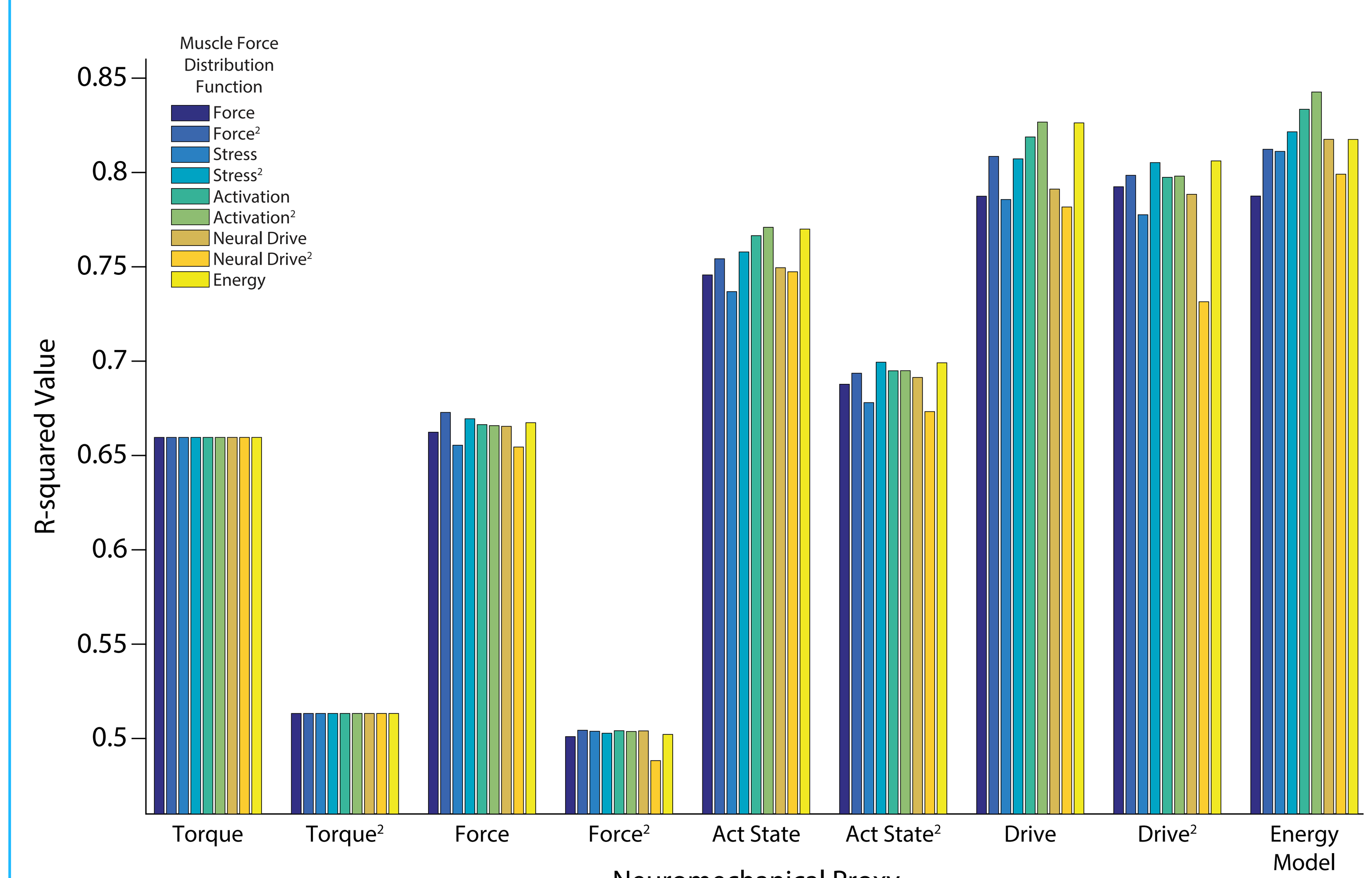
3) Muscle Active State
Integration and sum of muscles active states calculated from force-length and force-velocity properties.

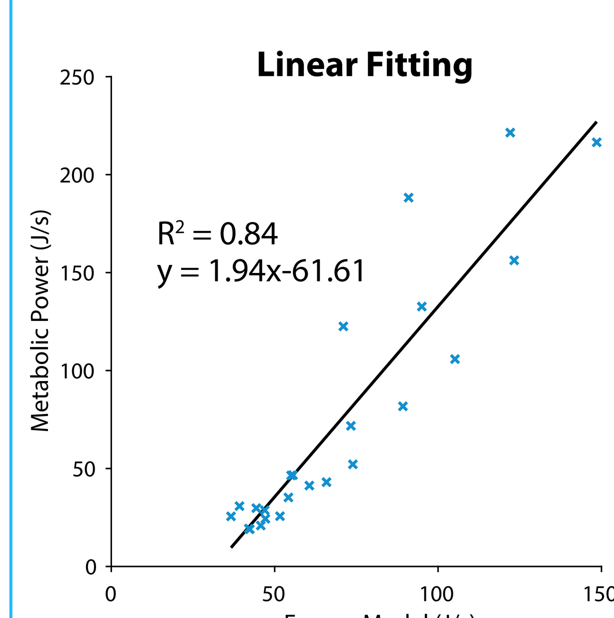
4) Neural Drive
Integration and sum of approximate control signal sent to muscles.

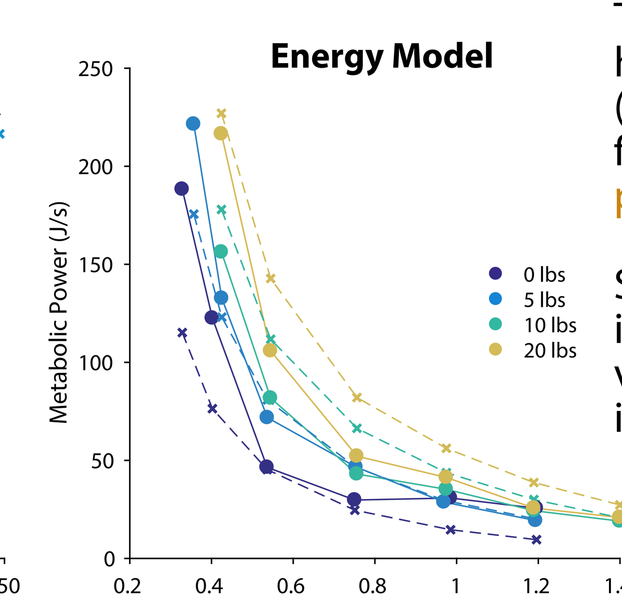
5) Energy Model[3]
Sum of the shortening/lengthening, activation and maintenence, and work energy rates.
$\dot{e} = h_{SL} + h_{AM} + w$



5. The Energy Model Fits Metabolic Cost Best





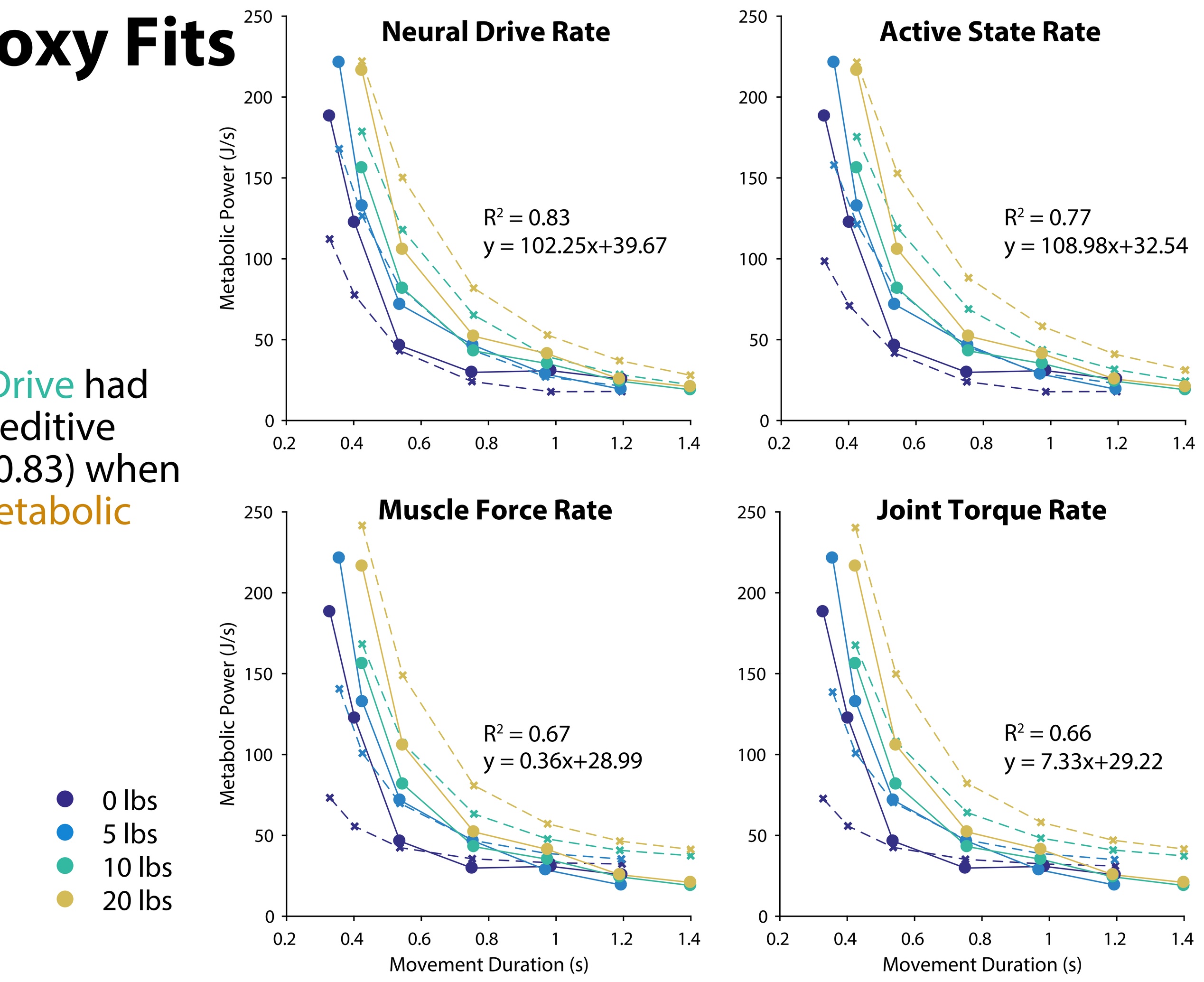


The energy model had the highest R^2 (0.84) value when fit to metabolic power.

Squaring the proxies reduced R^2 values for all proxies.

6. Proxy Fits

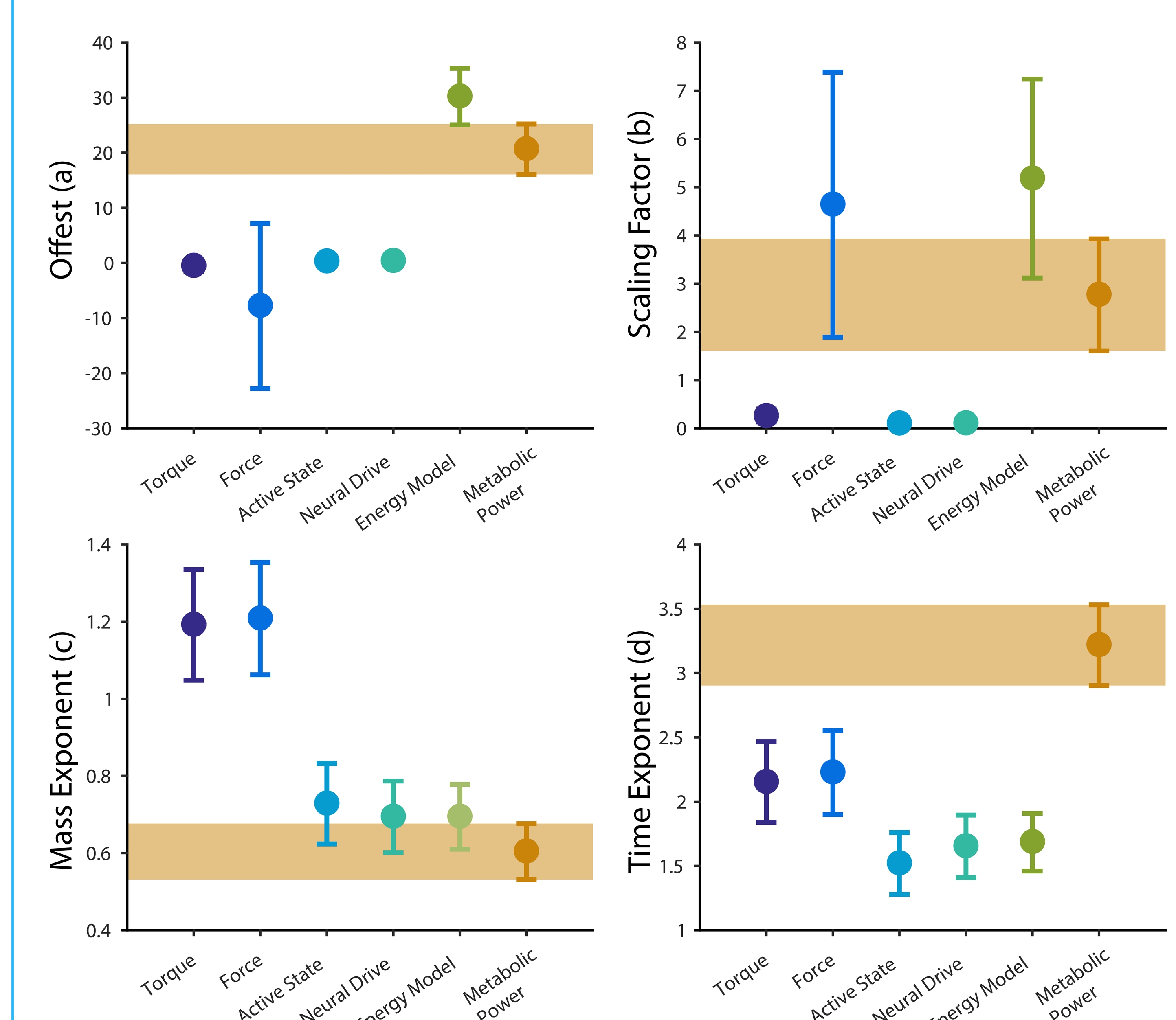
Neural Drive had good preditive power (0.83) when fit to metabolic power



7. Effect of Mass and Duration

The energy model was affected similarly to metabolic power by added mass and power offset.

$$\text{Proxy} = a + \frac{bm^c}{T^d}$$



8. Conclusions

We examined how multiple neuromechanical proxies are able to represent metabolic power in arm reaching and how these proxies are affected by mass and speed. We find that:

1) When fit to metabolic power, the energy model had the closest fit ($R^2 = 0.84$) and neural drive was a close second ($R^2 = 0.83$).

2) **Squaring** neuromechanical proxies lowered the predictive ability when fit to metabolic power.

3) The energy model could account for the effects of mass and the offset similar to metabolic power. However, it was limited in its ability to account for the effect of movement duration.

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References

1. Shadmehr, Huang and Ahmed (2016). Current Biology.
2. Berret, Chiovetto, Nori (2011). PLoS Computational Biology.
3. Umberger, Gerritsen, Martin (2003). Computer Methods in Biomechanics and Biomedical Engineering