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Including Wrist Flexion in the Human Arm Model Changes Everything!

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ABSTRACT

Does your introductory physics laboratory experiment that analyzes the human arm as a lever assume an inflexible wrist? If so, the analysis of the biceps force required to perform a biceps curl will lead to results that contradict experience: one does not expect the required biceps force to decrease as the mass is raised. We will show that allowing for wrist flexion leads to agreement with empirical data: that the required force does increase as the mass is raised if the wrist angle is allowed to be optimal.

HUMAN ARM AS A CLASS-3 LEVER

- Fixed wrist, fixed shoulder [1]
- Good for understanding…
  - Rotational equilibrium
  - why large biceps forces are necessary for equilibrium.
  - the arm as a class-3 lever

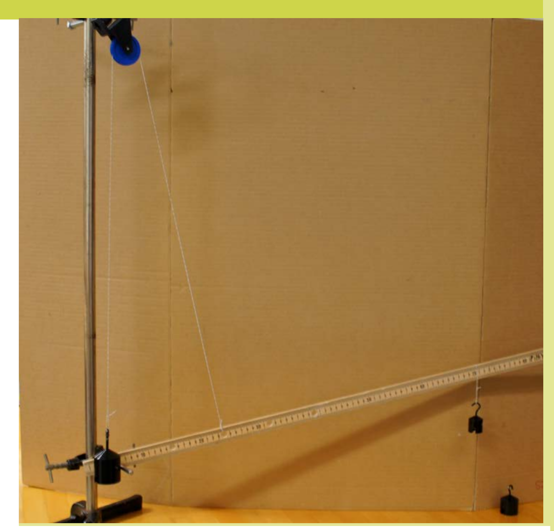


Fig 1. Human arm model

MODELING IS A PROCESS

- Predicts that mechanical advantage *increases* throughout biceps curl: the curl gets "easier".
- During natural curling motion, mechanical advantage is actually a minimum for horizontal forearm.
- Physics certainly does "apply to the real world"!
- Add flexion/extension of shoulder and wrist: problem solved!

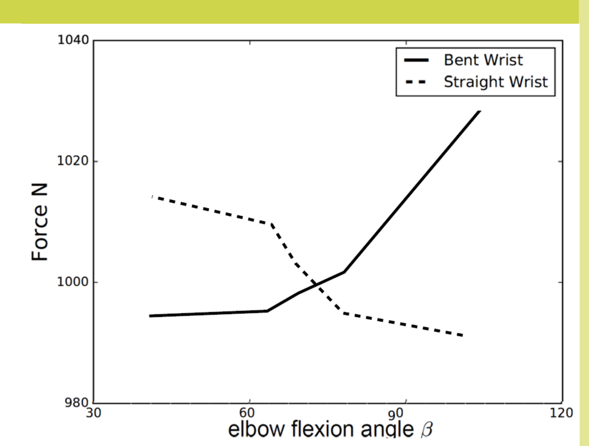


Fig 2. The maximum force that a student was able to apply as a function of elbow flexion angle β depends on wrist flexion/extension.

ISN'T THIS TOO COMPLICATED?

- Yes! We don't drag our students through the trig.
- Students interpret the result in Fig 4 (at right) to see that a simple extension to the lever model recovers the expected behavior.
- This is an end-of-lab conceptual application, demonstrating that physics does apply to "real life", and that models can be refined as needed

A REALISTIC EXTENSION TO LAB

"REALITY CHECK" FOR SIMPLE MODEL

1. What does this model suggest about the required force as the forearm is raised? Interpret Fig. 3, a plot of mechanical advantage ($MA = F_{hand}/F_{biceps}$) for the simple lever mode

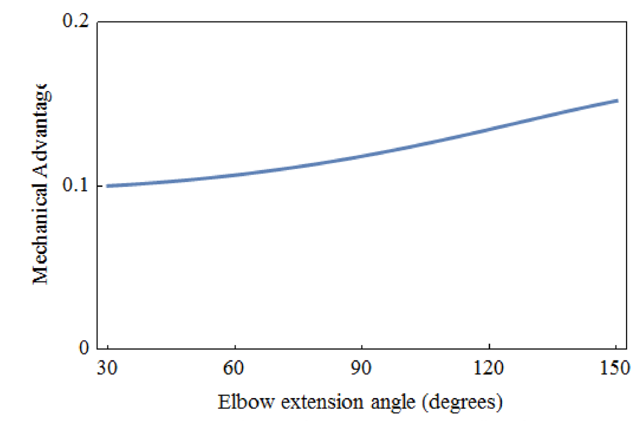
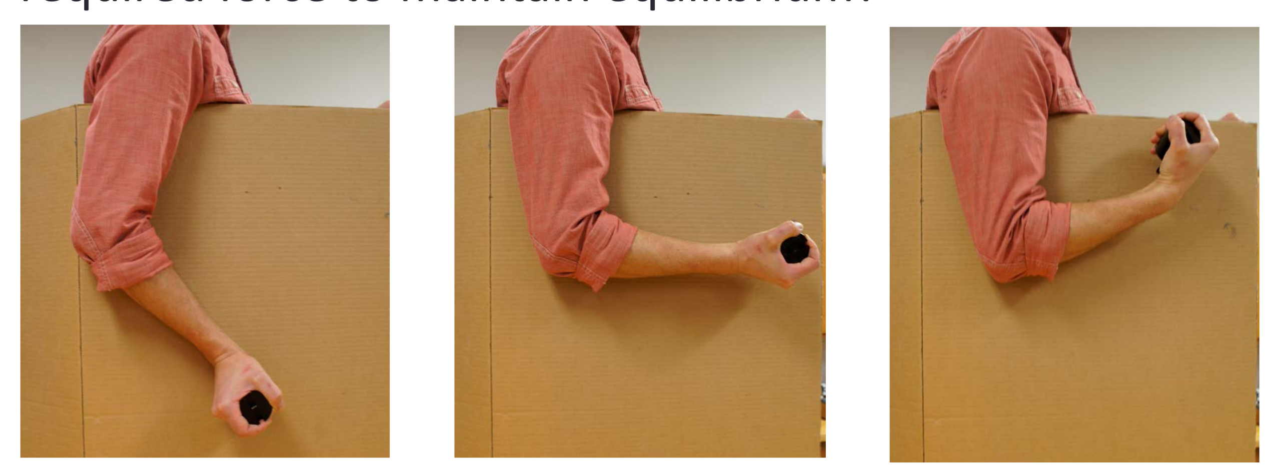


Fig 3 The simple lever model predicts that mechanical advantage increases during curl.

2. During which part of the natural curling motion below does it seem "hardest"? "Easiest"? What does this suggest about the required force to maintain equilibrium?



3. On Fig 3, use the value at 90° as a reference and sketch the relationship you expect for mechanical advantage above or below 90° for a natural curling motion

ADD SHOULDER, WRIST MOTION

During a natural curling motion, the shoulder and wrist also bend. In Figure 4, the mechanical advantage is plotted for three sets of fixed shoulder and wrist angles. To compare "apples to apples", the x-axis is the orientation of the forearm $\theta = 90° - (\alpha + \beta)$.

5. Use this result to explain the natural motion of the shoulder and wrist during a biceps curl.

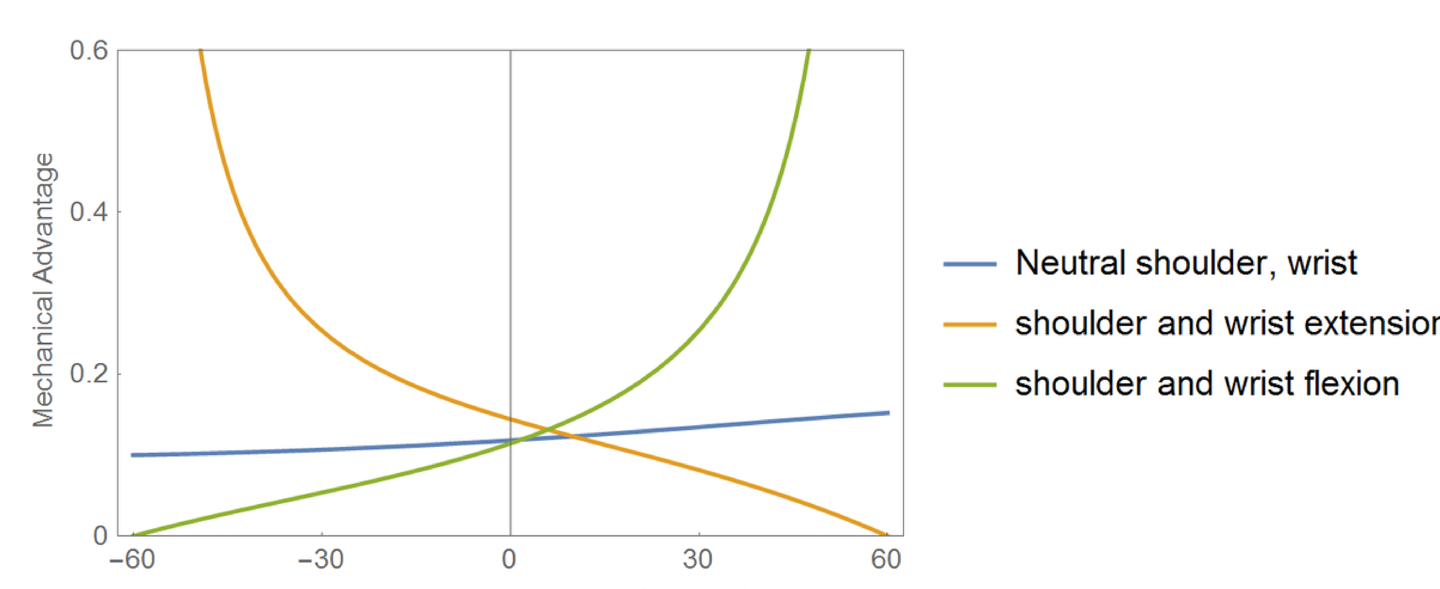


Fig 4. Mechanical advantage as a function of forearm angle for three fixed shoulder and wrist positions.

APPENDIX: SHOULDER AND WRIST

As is often the case when improving a model, the only real challenge is in the computational details (trigonometry).

Shoulder and wrist extension	Shoulder and wrist flexion

Let negative α, γ correspond to extension.

Condition for rotational equilibrium

$$\sum\tau = 0$$
$$= F_{bic} L_{ins} \sin\beta' - F_{han}\left(L_{for} + L_{han}\cos\gamma\right)\sin(\alpha+\beta+\gamma)$$

Mechanical advantage for forearm lever

$$MA = \frac{F_{han}}{F_{bic}} = \frac{L_{ins}\sin\beta'}{\left(L_{for} + L_{han}\cos\gamma\right)\sin(\alpha+\beta+\gamma)}$$

Substitute these trigonometric details into the above equation.

Length of biceps $L_{bic}(\beta)$ from law of cosines

$$L_{bic}^2(\beta) = L_{hum}^2 + L_{ins}^2 + 2\,L_{hum}L_{ins}\cos\beta$$

Biceps angle β' from law of sines

$$\sin\beta' = \frac{L_{hum}}{L_{bic}(\beta)}\sin\beta$$

$$MA = \frac{L_{ins}L_{hum}}{\left(L_{for} + L_{han}\cos\gamma\right)L_{bic}(\beta)}\frac{\sin\beta}{\sin(\alpha+\beta+\gamma)}$$

Simple lever is a special case ($\alpha = \gamma = 0$)

$$MA = \frac{L_{hum}L_{ins}}{\left(L_{for} + L_{han}\right)} \times \frac{1}{L_{bic}(\beta)}$$

REFERENCES

[1] M. Kutzner and A. Kutzner, A progression of static equilibrium laboratory exercises. The Physics Teacher, 51 (7) 2013.

IDEAL LAB PROJECT

I Didn't **E**xpect **A**pplications to **L**ife! (IDEAL)

- Life-science and personal fitness applications
- Use of simple statistics to form quantitative conclusions
- www.southern.edu/physicslab