Muscle Force Generation Class Demo

How do Arnold's muscles generate so much force (Figure 1)?

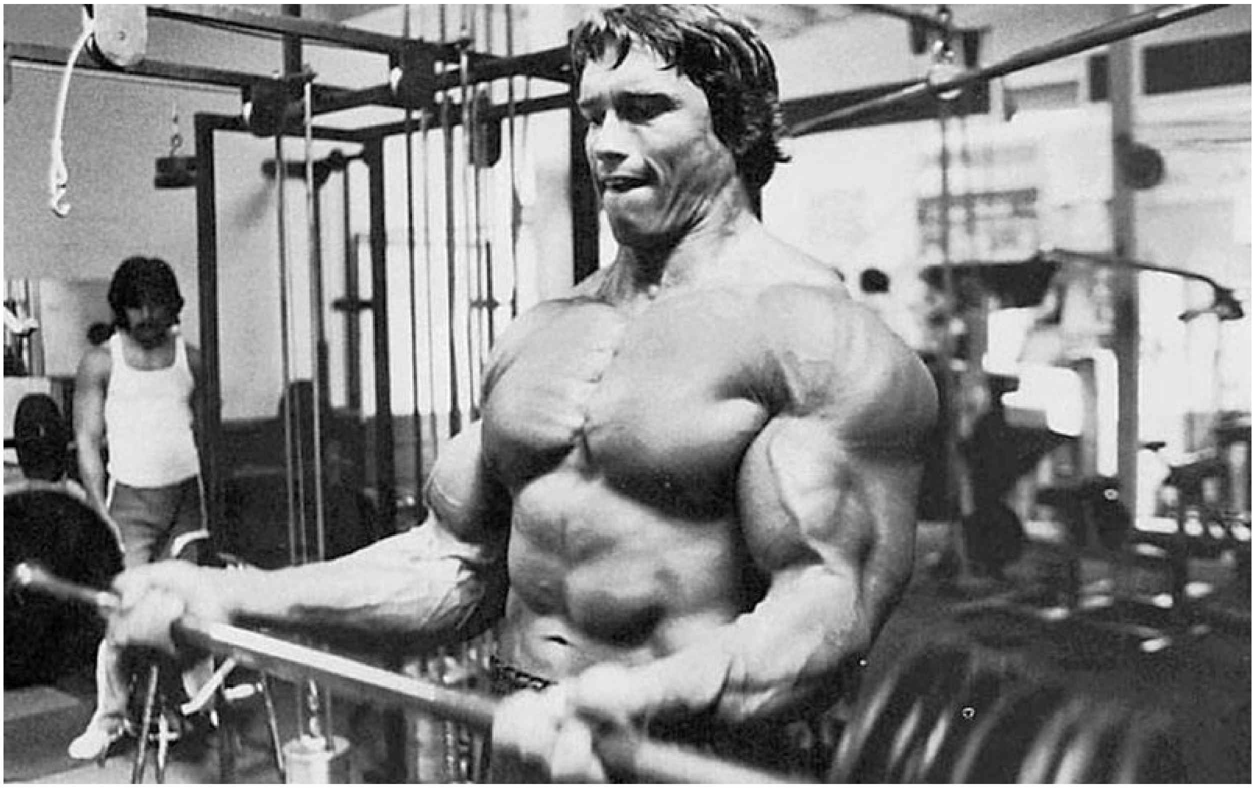

Figure 1. Arnold Schwarzenegger demonstrates legendary muscle force production during his body building days as a bystander watches in amazement.

Well, when you break it down (Figure 2), the same way as you, me, or the guy in the background of Figure 1, mesmerized by watching Arnold doing bicep curls. If only he knew the underlying science behind how muscles generate force... The building block of muscle force generation is the sarcomere (Figure 2). A widely adopted theory of how the sarcomere generates force is the sliding filament theory where protein filaments create crossbridges that are capable of shortening the sarcomere during muscle contraction by 'climbing up' respective filaments. There are several fundamental mechanical relationships that characterize the ability of a muscle to generate force including the dependence on length (Figure 3) and how the total force produced by a muscle is influenced by passive stretching of sarcomeres (Figure 4). Additionally, the effects of multiple sarcomeres in parallel (think Arnold) or in series have important implications for force production and human movement (Figure 5).

These mechanical relationships are fundamental topics that will be covered in Biomechanics of Human Movement (EMEC 440/540). I would like to students to be able to experience how a sarcomere works and better understand these principals through inquiry-based learning with a functional model of a sarcomere. A strong secondary purpose will be for biomechanics outreach with elementary through high school students. Capstone students should not feel that they are required to be familiar with these relationships in order to work on this project. Requirements for the model/demonstration are:

- A physical model that can be easily transported across campus
- In general, I'd liked students to be able to generate curves like those in Figures 3-5. The basic force-length relationship (Figure 3) is a requirement.
- A modular model would be preferred so that multiple 'sarcomeres' could be placed in parallel or series to demonstrate relationships in Figure 5.
- Basic instrumentation that allows net force production (tension generated by the 'muscle') to be measured.
- Actuation to demonstrate concentric/eccentric contractions that maintain physiologically-consistent force producing behavior.

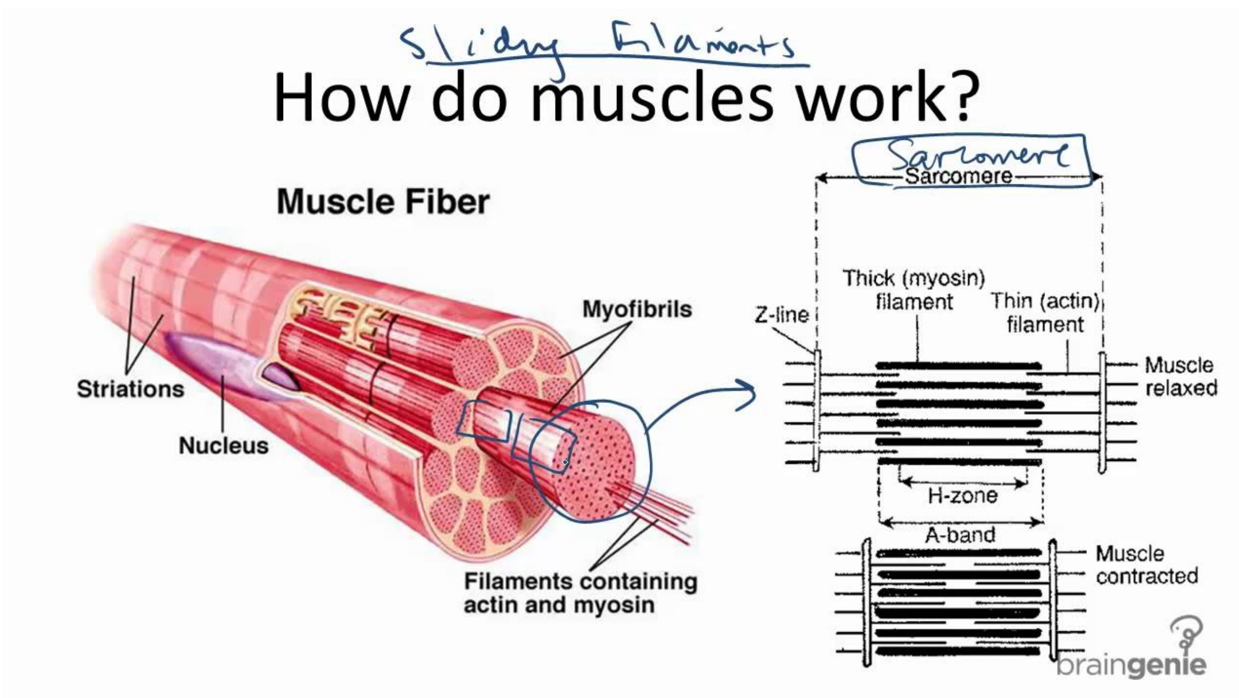

Figure 2. Hierarchy of components that make up a muscle fiber (left) with schematic of the sarcomere and it's mechanism (right). The sliding filament theory (right) is the fundamental mechanism behind muscle contractions that facilitate force production.

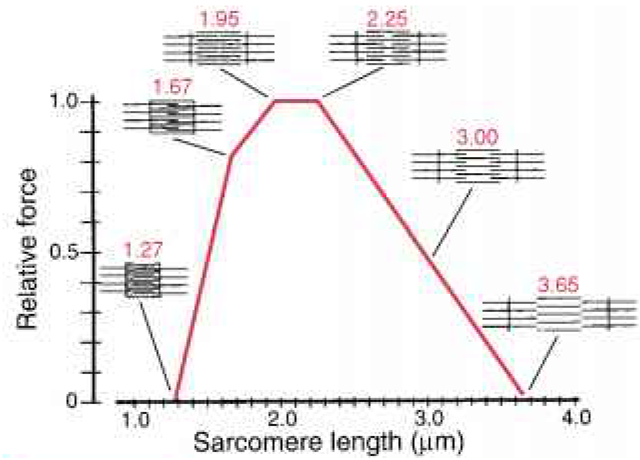

Figure 3. A schematic representation of a sarcomere's force-length relationship. The force production capacity of a sarcomere is dependent on the number of crossbridges between protein filaments (actin and myosin), which depend on sarcomere length.

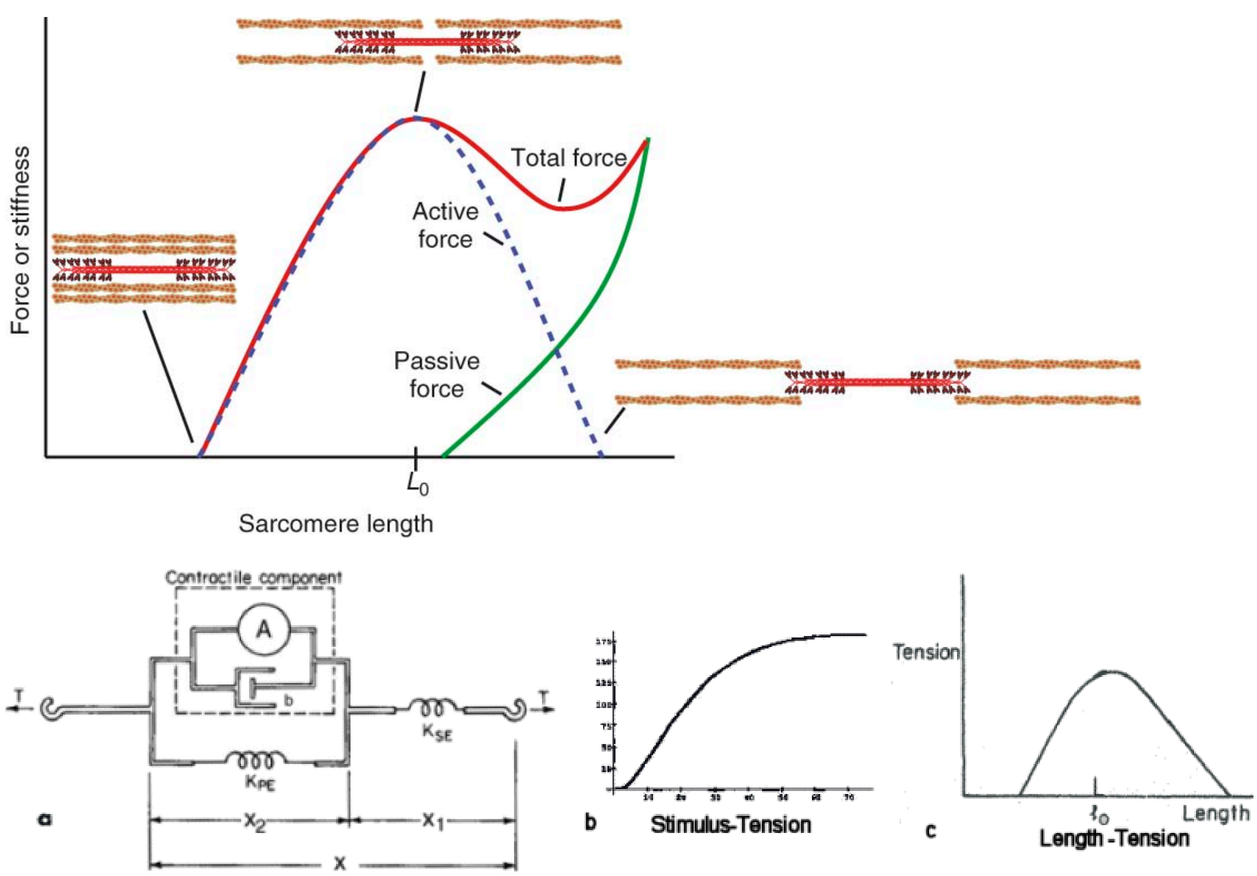

Figure 4. The actual force production from a sarcomere incorporates active (as seen in dashed line and Figure 3) along with passive elastic force production when stretched beyond the resting length. The bottom shows how muscles are often modelled using a 'Hill Type Muscle Model'.

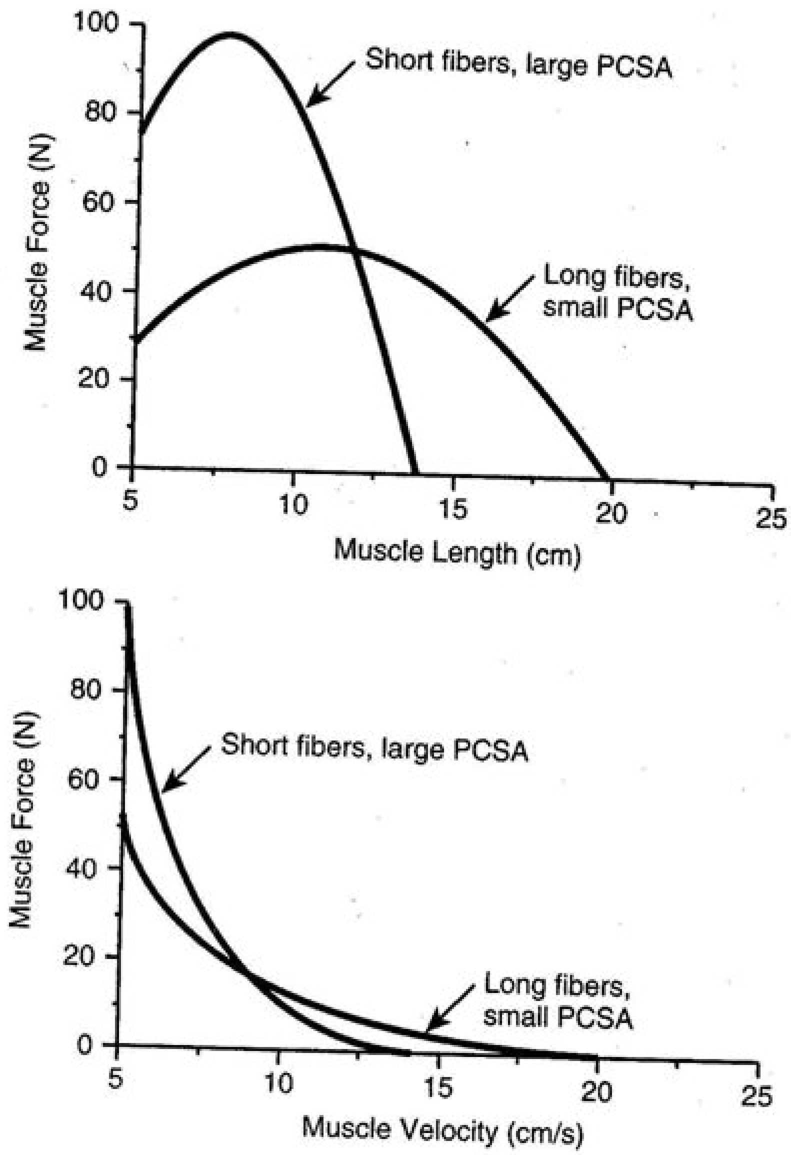

Figure 5. Muscle fibers that are short and have a large physiological cross-sectional area (PCSA) product higher forces, but do not reach as high of contraction velocities. Muscle fibers that are thinner (smaller PCSA) and longer produce less peak force, but are capable of contracting at faster speeds. PCSA and fiber length are dependent on sarcomeres being in series and in parallel.