16.423J/HST515J Space Biomedical Engineering and Life Support
Muscle Homework Assignment

1. (1 point) Briefly describe muscle coactivation.

2. (2 points) From the readings and lecture, what did you learn about the sliding filament mechanism? (A few sentences please).

3. (1 point) Physiologists have long known that muscle speed decreases with increasing load (Refs. Fenn and Marsh, 1935; Hill 1938; Jewell and Wilke, 1960; Wilke 1950). Briefly explain what this has to do with optimal bicycle design (i.e., gear design).

4. (6 points) Simulink exercise on muscle atrophy of long-duration space flight: models, results and consequences.

   A. Copy into your directory the 3 Matlab files provided by Joe Saleh. They are available on the web site in the Assignment section. Be sure to copy the files in a directory included in the path. Save them with the correct extension (joe_env.mat, joe_var.m, joe_model.mdl). You could create a "work" directory to put your files and add it to the path (File → Set Path) so that the software will be able to recognize your files).

   B. From a Matlab window, type the command "load joe_env.mat"

   C. Enter the following parameters in the Matlab command window, or use the file "joe_var.m" to assign the parameters:
      - w1=8
      - w2=30
      - d=0.9

- df=d
- dff=d
- w1f=12
- w2f=50
- w1ff=16
- w2ff=70

D. Type “joe_model” to load the simulink model.

A little Background on the muscle model you're using: Muscle fiber transfer function

The muscle fiber twitch model you have previously seen in the course notes was analyzed in terms of a linear system response to a pseudo-impulse, and the transient analysis yields a transfer function H(s) with a response to the same input that best fits experimental data. The muscle fiber has a time delay between the stimulus and the force generation. Let τ_r be this latent period. Secondly, the force output rises smoothly from zero. According to the initial value theorem, and the derivation using the Laplace variable,

$$F(t=0) = \lim_{s\to\infty} s * \mathrm{F}(s)$$
$$F'(t=0) = \lim_{s\to\infty} s^2 * \mathrm{F}(s)$$

the simplest model that satisfies the above observations is a third order with a time delay:

$$H(s) = G * \frac{e^{-\tau_r \cdot s}}{\left(\frac{s}{\omega_1}+1\right) * \left[\left(\frac{s}{\omega_2}\right)^2 + 2\delta * \frac{s}{\omega_2} + 1\right]}$$

Typically, we use numerical values for the above parameters that are evaluated to match frog sartorius twitch characteristics: the latent period, the time to peak, the twitch duration and the ratio of the maximum amplitudes of twitch over tetanus tension. G is a scaling parameter and can be taken equal to one without loss of generality.

E. Run the simulation and note the differences between twitch response and each type of fiber.

4.1 The innervation ratio is the number of muscle fibers activated by a single alpha (α) motoneuron. Consider a simplified muscle model that consists of 1000 fibers with the following distribution:

- 500 slow fibers
- 300 fast fatigue resistant fibers
- 200 fast fatigable fibers

driven by 3 α motoneurons. How can you implement this in the Simulink model?

4.2 Consider all fibers activated and in a fused tetanus state. To do so with the Simulink model, simply replace the "pulse generators" by a step (found in 'Sources'). In order to respect the Henneman size (recruitment) principle and keep the model simple, choose the following amplitudes: 1 for the step activating the slow type fibers, 2 for the fast-fatigue resistant, and 3 for the fast fibers.

$$[\alpha_{slow}; \beta_{fast\ fatigue\ resistant}; \gamma_{fast}] = [1;2;3]$$

Now the output is the sum of the tensions produced by the 3 types of fibers. Run the simulation and discuss the force output.

4.3 Consider this result to be the overall maximum force generated by the lower limbs of a person in a 1G environment during an intense physical effort (i.e., all fibers activated). Hence, let the maximum activation levels of the three types of fibers be

$$[\alpha_{max}=1; \beta_{max}=2; \gamma_{max}=3].$$

During a normal stance, with only the slow fibers activated, what is the maximum force generated by the lower limbs? Run the simulation and derive your result. What is the activation pattern [α=?; β=?; γ =?]? Lets call this the nominal activation pattern, i.e., how a person usually activates her lower limb muscles while standing up. If the above person were Daffy the astronaut - who weighs 450 N - she wouldn't have a problem maintaining an upright position!

4.4 After spending several days onboard the space shuttle, Daffy returns with noticeable atrophy of her lower limbs: the fast fiber types are the most damaged, followed by the fast fatigue-resistant, then the slow fibers. To keep things simple, assume that 150 fast fibers were "damaged", 120 fast fatigue-resistant fibers and 100 slow fibers damaged. How can you implement these changes into the Simulink model? Upon return to Earth, can Daffy stand up under her nominal activation pattern? What is the force output in this case? What is the minimum activation pattern for her to stand up assuming that her slow fibers are fully activated and her fast fibers are not activated?

4.5 What is the maximum force she can generate? Compare it to your result in 4.2.

4.6 In fact, the atrophy of muscle fibers is a function of the time spent in a microgravity environment. For her second mission, Daffy spends 6 months onboard the space station (not exercising!). She returns to Earth with severe atrophy of her lower limbs: all fast fibers were damaged, 240 fast fatigue-resistant fibers, and 200 slow fibers damaged. What is the force output under the nominal activation pattern? Can Daffy stand up at all? (assume no weight loss)