HOMEWORK #03

Course: **MCEN 5228 – Modeling of Human Movement**

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Problem 1) :-

Muscle fiber force, $F(m) = F_0^M \left[a \times f^l(\tilde{l}) \times f^v(\tilde{v}) + f^{pe}(\tilde{l}) \right]$

where, a = activation
l = fiber length
v = fiber velocity
$f^l(\tilde{l})$ = normalized active force-length function
$f^v(\tilde{v})$ = normalized force-velocity function
$f^{pe}(\tilde{l})$ = normalized passive force-length function
F_0^M = Maximum isometric muscle force

We are required to find how the equation simplifies for the following cases,
a) isometric b) at optimal fiber length
c) maximally activated d) passive

a) isometric

For isometric case, we have $v=0$, as lengths do not change

$$\therefore \quad \tilde{v} = \frac{v}{v_{max}} = 0$$

$$\Rightarrow \quad f^v(\tilde{v}) = f^v(0) = 1$$

($\because$ from force-velocity curve, we have $f^v = 1$ when $v = 0$)

$$\therefore F(m) = F_0^M \left[a \times f^l(\tilde{l}) \times 1 + f^{pe}(\tilde{l}) \right]$$

$$\Rightarrow \quad \boxed{F(m) = F_0^M \left[a \times f^l(\tilde{l}) + f^{pe}(\tilde{l}) \right]}$$

b) at optimal fiber length, we have,

$$\lambda = \lambda_0$$

$$\therefore \tilde{\lambda} = \frac{\lambda}{\lambda_0} = \frac{\lambda_0}{\lambda_0} = 1$$

$$\therefore f^{l}(\tilde{\lambda}) = f^{l}(1) = 1 \quad \text{and,}$$

$$f^{pe}(\tilde{\lambda}) = f^{pe}(1) = 0$$

(from active force-length and passive force-length curve)

$$\Rightarrow F(m) = F_0^M \left[a \times 1 \times f^{v}(\tilde{v}) + 0\right]$$

$$\Rightarrow \boxed{F(m) = F_0^M \left[a \times f^{v}(\tilde{v})\right]}$$

c) maximally activated

for this case, $a = 1$

$$\Rightarrow F(m) = F_0^M \left[1 \times f^{l}(\tilde{\lambda}) \times f^{v}(\tilde{v}) + f^{pe}(\tilde{\lambda})\right]$$

$$\Rightarrow \boxed{F(m) = F_0^M \left[f^{l}(\tilde{\lambda}) \times f^{v}(\tilde{v}) + f^{pe}(\tilde{\lambda})\right]}$$

d) passive

for this case, $a = 0$

$$\Rightarrow F(m) = F_0^M \left[0 \times f^{l}(\tilde{\lambda}) \times f^{v}(\tilde{v}) + f^{pe}(\tilde{\lambda})\right]$$

$$\Rightarrow \boxed{F(m) = F_0^M \left[f^{pe}(\tilde{\lambda})\right]}$$

Problem 2) :- We are required to design two muscles : one for force and the other for excursion.

~~Also~~, Design constraints:

1) Each muscle cannot exceed a volume of 600 cm^3.

2) "Strong"ialis muscle should generate 1800N of maximum force and should be able to generate at least 800N over a range of 5 cm.

3) "Stretch"ialis muscle should generate 900N of maximum force and should generate at least 400N over a range of 10 cm.

a) :- We can select PCSA and optimal fiber length (l_0^M) for designing our muscle or we can compute PCSA and l_0^M from the relations we know. But, we have to be careful not to exceed the volume constraint. I will go with both methods.

Method 1 : $PCSA = f_0^M / \sigma_0^M$

where σ_0^M is peak isometric stress and $\sigma_0^M = 0.3\,MPa$

$\therefore$ For Strongilias $\Rightarrow$ $PCSA = \frac{1800N}{0.3\times10^6\times10^{-4}} \frac{cm^2}{N}$

$PCSA_{strong} = 60\,cm^2$ //

For Stretchialis $\Rightarrow PCSA_{stretch} = \frac{900\,N}{30\,N/cm^2}$

$$PCSA_{stretch} = 30\,cm^2 \,//$$

Next, Optimal fiber length, $l_o^M = \frac{\text{Muscle Volume}}{PCSA}$

$$(l_o^M)_{strong} = \frac{600\,cm^3}{60\,cm^2} = 10\,cm \,//$$

$$(l_o^M)_{stretch} = \frac{600\,cm^3}{30\,cm^2} = 20\,cm \,//$$

Method 2: I will select, l_M^o and then compute PCSA maintaining the volume constraint.

Let, $(l_M^o)_{strong} = 5\,cm \,//$ and

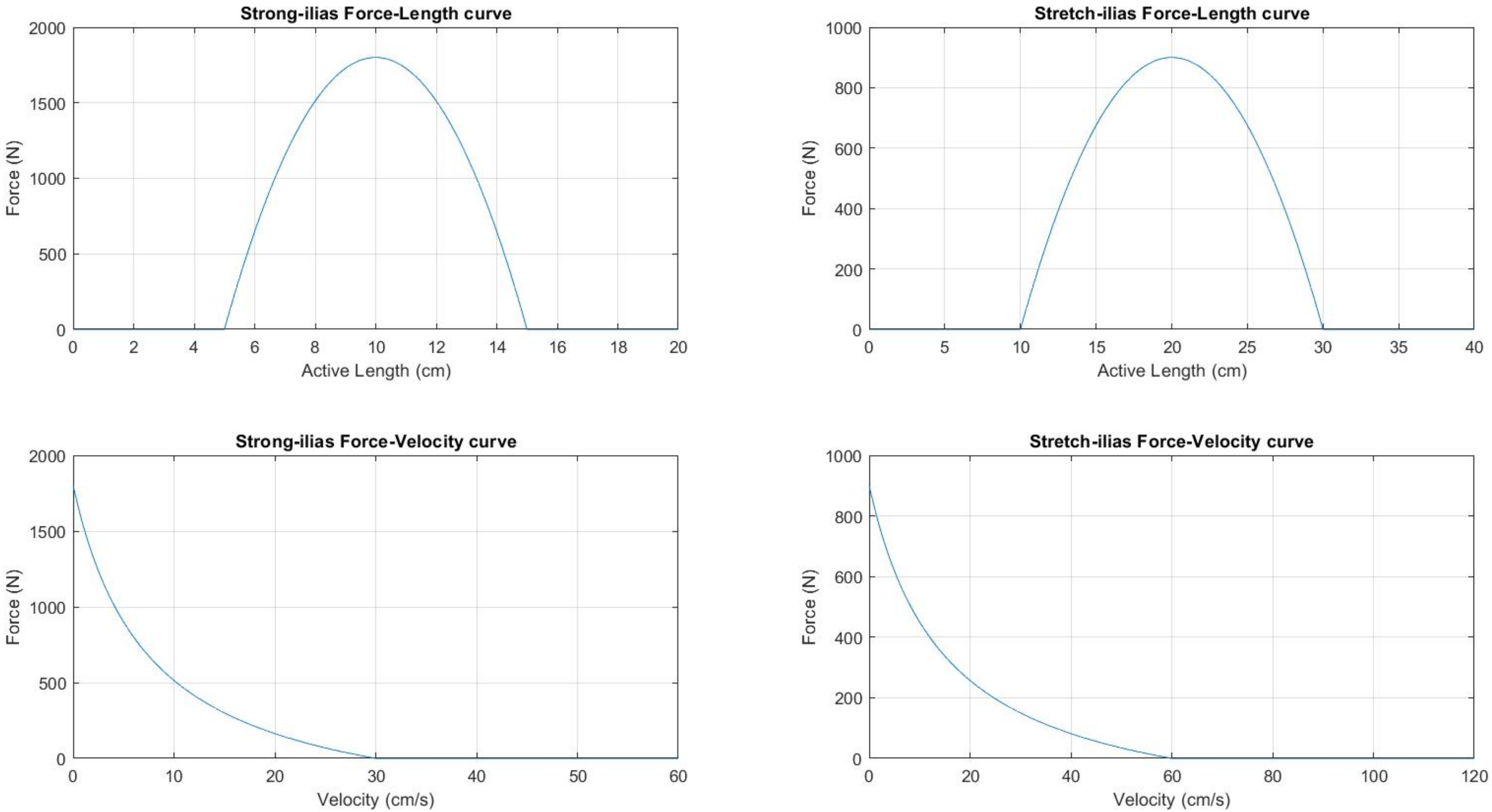
$$(l_M^o)_{stretch} = 10\,cm \,//$$

$$\therefore (PCSA)_{strong} = \frac{600\,cm^3}{5\,cm} = 120\,cm^2 \,//$$

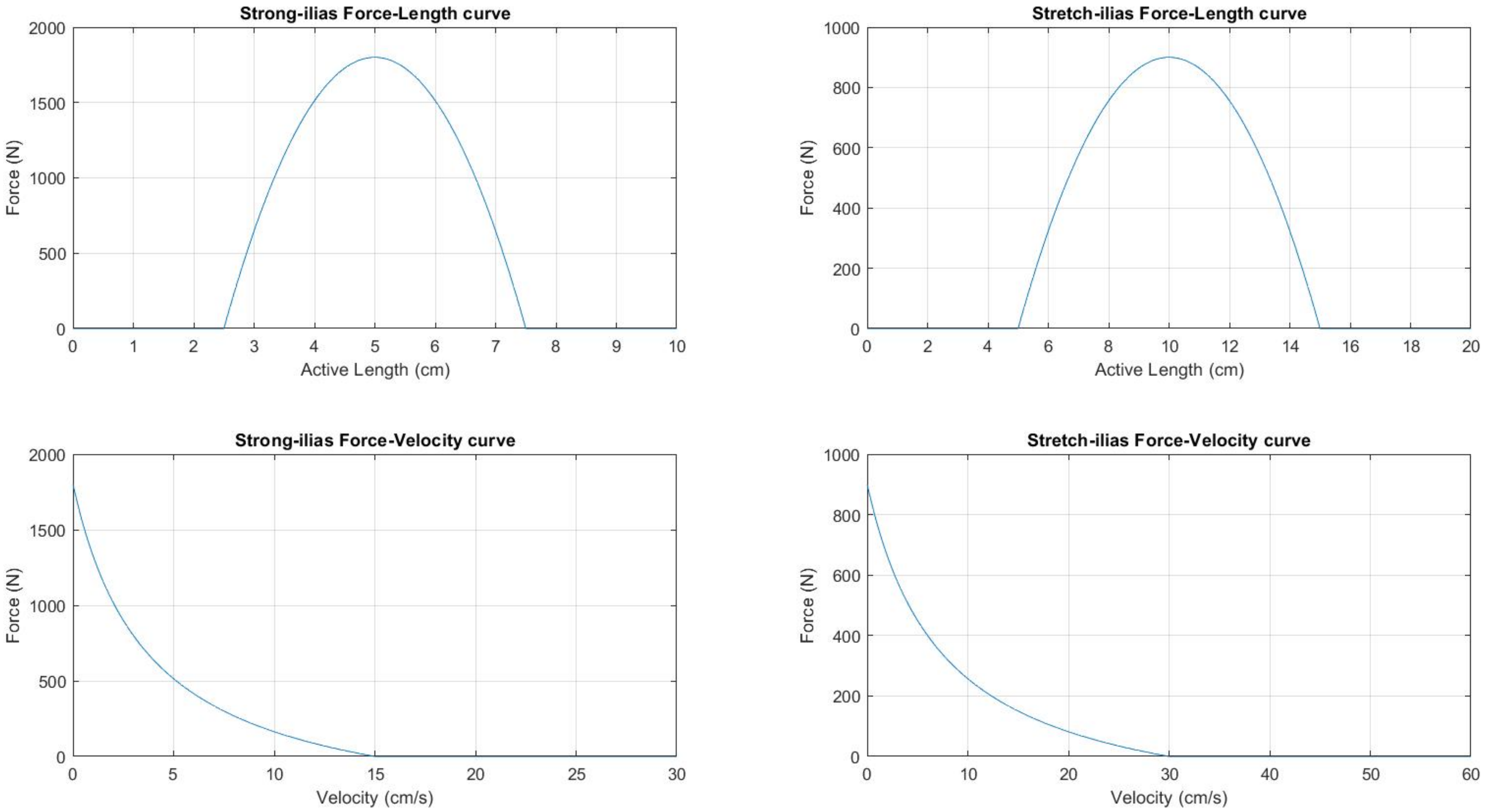
$$(PCSA)_{stretch} = \frac{600\,cm^3}{10\,cm} = 60\,cm^2 \,//$$

I will plots the curves with both methods.

Method-1 (Calculation)



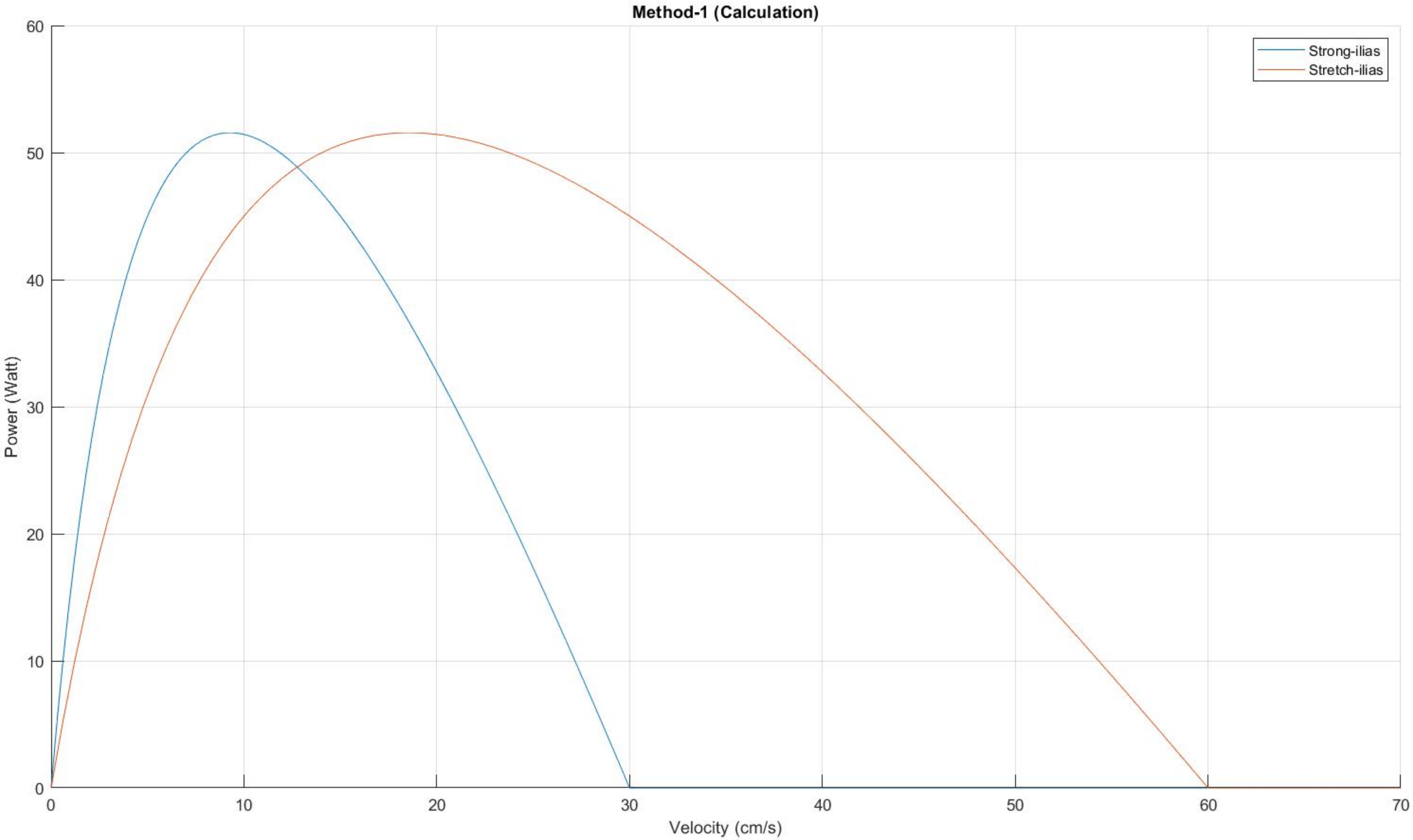
Method-2 (Selection)

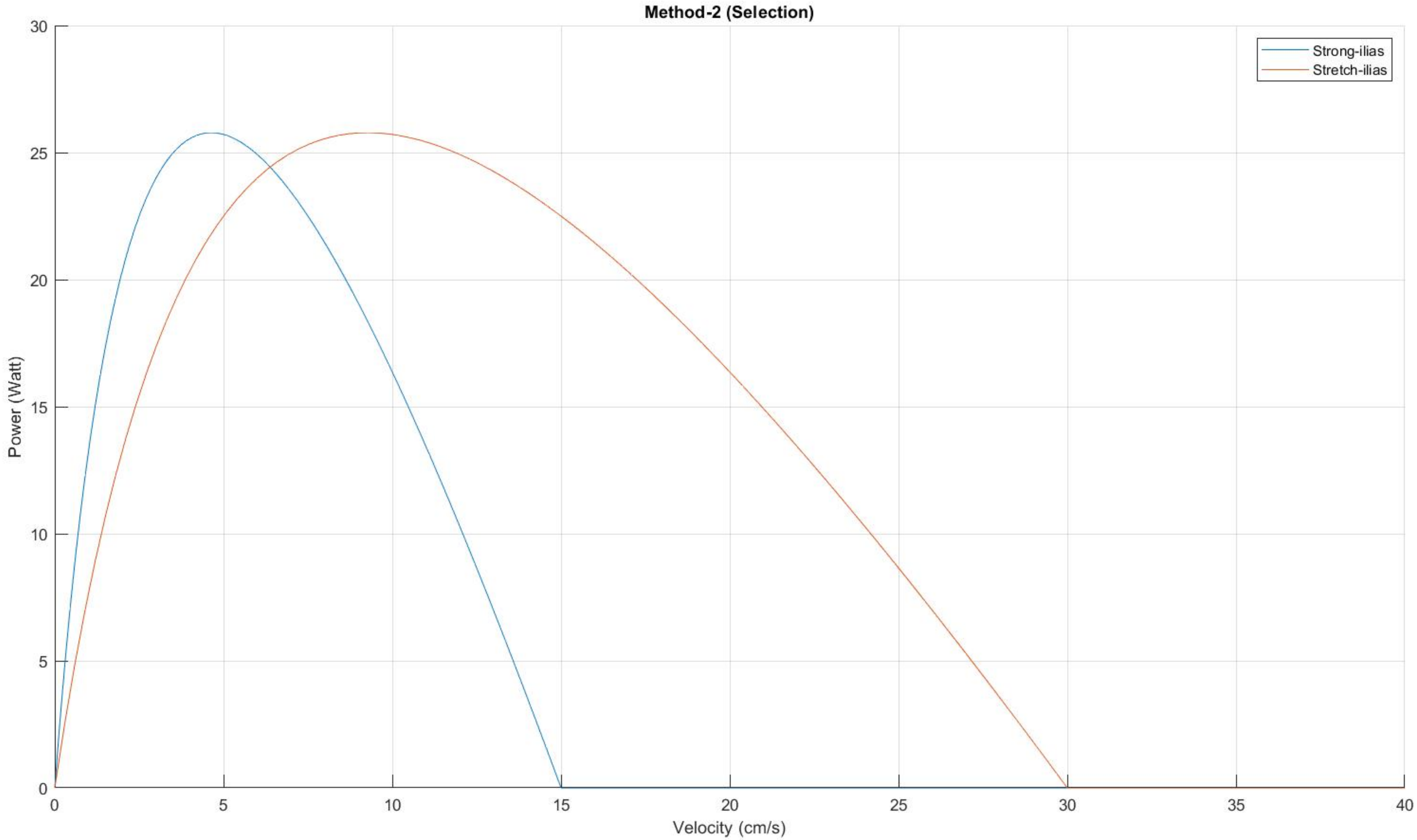


b) :- Every joint in our body is actuated by multiple muscles which have its own architecture and geometry. The muscles that actuate a joint come in pairs : agonist muscles that rotate the joint in one direction and antagonist muscles that rotate it in the opposite direction. Because muscles only exert pulling forces, our body has such arrangement.

From part a, we can say that Strongialis has large PCSA, short fibers and thereby small moment arm. However, Stretchialis has long fibers, small PCSA and large moment arm. Based on our plots, we can see that because of multiple muscles we have access over large force relationship as compared to a single muscle. As we know, total muscle moment for the joint is computed by summing the moment-vs-angle curves, therefore we get maximum voluntary isometric moment for the joint.

Moreover, Strongialis gives more muscle force at less optimal muscle length. Therefore, we get more force over smaller range of length. However, Stretchialis have long fibers and small PCSA which gives maximum shortening velocities ~~for lengthening as well as~~ as compared to Strongialis. Thus, the combination of muscles gives more access to larger forces, higher shortening velocities and contributes to total joint moment over the entire range of motion.


Method-1 (Calculation)
Strong-ilias
Stretch-ilias
Power (Watt)
Velocity (cm/s)
0
10
20
30
40
50
60
70



Method-2 (Selection)
Strong-ilias
Stretch-ilias
Power (Watt)
Velocity (cm/s)
0
5
10
15
20
25
30
35
40

c) :- Power generated by both Strongialis and Stretchialis is quite similar and the values are very close to each other. The difference lies in the power distribution around ~~according~~ ~~to~~ the shortening velocity. We can clearly see from the plots that the power curve of Strongialis is narrower and that of Stretchialis is broader. Strongialis has shorter fibers and large PCSA and therefore it achieves the maximum power over smaller range of velocity. However, Stretchialis has longer fibers and short PCSA, which explains the ~~p~~ broader power distribution. Thus, Stretchialis achieves maximum power over larger range of velocity as compared to Strongialis. Strongialis gives access to more values of power over smaller range of shortening velocity. Stretchialis gives the same values of power but over larger range of shortening velocity.

Problem 3) :-

In the article "Reducing the energy cost of human walking using an unpowered exoskeleton", the authors have made a claim that reduction in metabolic cost may take place because of reduced muscle forces. It is stated in the article that changes in whole-body metabolic rate is difficult to attribute, however with an unpowered exoskeleton they find an assosiation with reduced muscle forces at the assisted ankle joints. Further, muscles consume energy whenever they are active or even when producing force. When doing this activity, muscles do not perform any mechanical work. The authors support their claim stating that if they simply reduce muscle force it can lead to saving of metabolic energy. To further support their hypothesis, they performed measurement on all exoskeleton springs and found reductions in the biological component of ankle moment and the activity of major plantarflexor muscles. Both of these findings were indicative of reduced muscle force. Reductions occurred when muscle fascicles are isometric and therefore perform little mechanical work. Simulation models with 180 N m rad^{-1} spring, gave reduction in biological component of ankle moment of about 14% and 22% in mid-stance soleus electrical activity. The authors extrapolated these values, and expected about 4-6% reduction in overall metabolic rate as compared to observed 7% reduction.