HNCL Tutorial 1: Physiology

Please provide a solution with full calculations and brief explanations.

Question 1: Neural signal transmission

The most direct signal from motor cortex to muscle involves two fast (myelinated) neurones: one from cortex to the spinal cord and one from the spinal cord to the muscle. In these fast neurones, action potentials travel at about $100\,m/s$. Once the action potential reaches the muscles, it spreads throughout the muscle at about $4\,m/s$. In addition, the time to diffuse across a synapse (between neurones and at the neuromuscular junction) takes about $1\,ms$.

(a) Calculate the time it takes for a neural signal from motor cortex to contract a foot muscle, assuming rough dimensions of $1\,m$ from the cortex to spinal cord, $1\,m$ from spinal cord to muscle, and a muscle fiber that is $4\,cm$ long.

[20 marks]

(b) Calculate the percentage of travel time spent in each phase.

[20 marks]

(c) How does the total travel time of the neural signal compare to the delay in an electrical signal flowing through an electrical wire of the same total length (in copper wire, electrical signals travel at approximately 68% of the speed of light)?

[20 marks]

Question 2: Tendon-muscle system

(a) Considering the system of a muscle attached to a tendon, explain why a stiff tendon is necessary to ensure that the muscle is able to produce a large range of stiffness.

Hint: Model the muscle and tendon as springs, then derive the total muscle-tendon stiffness as a function of muscle stiffness and tendon stiffness.

[20 marks]

(b) In vivo measurement of the Achilles tendon stiffness yields $\kappa_h = 188\,N/mm$ in a typical human and about $\kappa_{kt} = 25\,N/mm$ in a Thylogale wallaby kangaroo.
Assuming similar muscles with stiffness κ in these two species, compare the stiffness of their muscle-tendon system? What is the consequence on their gait?

[20 marks]

a) $V_n = 100\,m/s$ $\quad L_1 = 1m$

$V_m = 4\,m/s$ $\quad L_2 = 1m$

$T_s = 1ms$ $\quad L_3 = 0.04m$

$$T = \frac{d}{s}$$

$$= \frac{1}{100} + \frac{1}{100} + \frac{0.04}{4} + 2 \times 0.001$$

$$= 0.01 + 0.01 + 0.01 + 0.002$$

$$= 0.032s$$

$$= 32ms$$

b) Phase 1 = 0.01s

Phase 2 = 0.01s

Phase 3 = 0.01s

$$\%\ \text{time}_{1,2,3} = \frac{0.010}{0.032} \times 100$$

$$= 31.25\%$$

% time for synapse = 3.125%

c) $L_{Total} = 2.04m$

$$V_c = 0.68 \times 300 \times 10^6$$

$$= 2.04 \times 10^6$$

$$T = \frac{2.04}{2.04} \times 10^{-8}$$

$$= 1 \times 10^{-8}s$$

Much faster.

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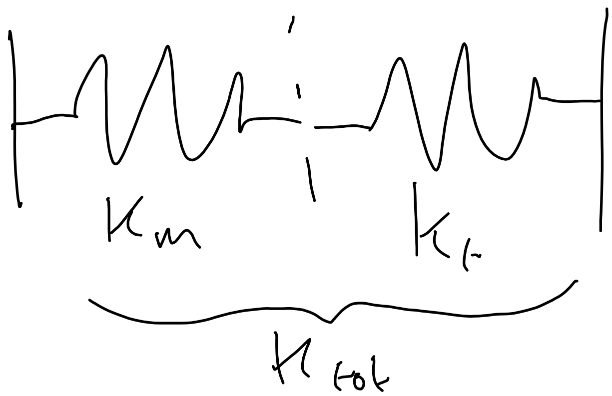
[20 marks]

a)



$$K_{tot} = \frac{K_m K_t}{(K_m + K_{tot})} \; ; \; K_t \to 0 \Rightarrow K_{tot} \to 1 .$$

b)

$$\frac{1}{K_h} = \frac{1}{K_{ht}} + \frac{1}{K} = \frac{(K_{ht} + K)}{K_{ht} K}$$

$$\therefore K_h = \frac{K_{ht} K}{(K_{ht} + K)} = \frac{188\,K}{(188 + K)}$$

$$\therefore K_K = \frac{K_{kt} K}{(K_{kt} + K)} = \frac{25\,K}{(25 + K)}$$

$$K_h > K_k$$

$$\frac{188K}{(188+K)} > \frac{25K}{(25+K)}$$

$$188K(25+K) > 25K(188+K)$$

$$188K^2 + \cancel{4700K} > 25K^2 + \cancel{4700K}$$

$$163K > 0$$

$$K > 0$$

$\therefore$ for all values of K, $K_h > K_k$.