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What would be the effect of having ‘nerves of steel’ on the ability to bend your elbow?

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Abstract
This article makes assumptions of the consequences of having coaxial steel cables for nerves. Where regular nerves are very flexible, for coaxial cables this is not necessarily the case since it is steel that has to be bent. It is found through calculations on the required momentum, taking the yield stress of steel into account, that having coaxial steel cables for nerves adds about 45 nN per axon through the elbow to the force required to lift the lower arm. Through calculations in two ways on the number of nerves that go through the lower arm, it is found that this number is around 2.4×10^7 so that the total additional force required to lift the lower arm is about 1.1 N.

Introduction

‘Having nerves of steel’ refers to someone having ‘an impressive ability to remain calm in dangerous or difficult situations’, according to Webster [1]. Since this expression being widely spread, even throughout multiple languages, it is interesting to examine the hypothetical consequences of it. This article explores some of the effects that steel nerves, or rather having steel wires instead of nerves, might have on the motoric operation of the human body. This article is related to the article *“Could ‘nerves of steel’ guide sensory signals?”* by the same author, and is based around the same assumptions [2].

Material properties

Steel nerves, or rather coaxial steel wires instead of nerves, would most likely be heavier than ordinary nerves are. To answer the question what the effect would be in terms of weight if the nerves would be replaced by coaxial steel wires, the densities of nerve-matter and steel are compared. The density of the normal neuron is assumed to be 1.1 kgL^{-1} [3] and the density of steel to be 7.8 kgL^{-1} [4]. In the most desirable case, the total mass of a steel nervous system would be the same as that of a normal nervous system. This means that the volume of the steel nerves needs to be roughly seven times smaller than that of the normal nerves. This will increase the total resistance of the steel nerves, but in terms of the difference in signal guiding capabilities between normal and steel nerves, this has little impact (since the steel will still outperform ordinary nerves by a significant amount; see [2]). However, this means that the diameter of the steel nerves would need to be decreased by a factor of roughly $\sqrt{7}$ since the volume of the nerve is proportional to the square of the radius. The steel nerves (the inner conductors of the coaxial cables) then have a radius of only about 2 μm [5].

Where an axon is very flexible, a steel nerve might not be. Therefore, the force required to bend a steel nerve is calculated. Here, the bending of the nerves at the elbow is taken. The moment required to bend a steel rod is given by:

$$M = \frac{S \times I}{y}, \tag{1}$$

where M is the moment required to bend, I is the so called second moment of inertia of the wire, y in this case the radius of the wire and S the yield stress of steel with a value of 350 MPa [6, 7]. I can be calculated through:

$$I = \frac{\pi r^4}{4}, \tag{2}$$

in which r is the radius of the wire [8].

Filling everything in, this gives for one steel nerve a moment of approximately 2.2 nNm. If the bicep is connected to the bones of the lower arm 5 cm away from the elbow joint and we assume that the nerves follow the bone, this gives a required force of roughly 45 nN per nerve that goes through the elbow. Considering the lower arm, hand included, has a mass of about 1.7 kg [9] and its centre of mass about 15 cm from the elbow, ones bicep already has to exert a force of approximately 50 N to pull up the lower arm.

A rough estimate on the total extra required force can be made: The average number of neurons in the brain is 86 billion [10]. 99% of all neurons are located in the brain or the spinal cord [11]. Of the remaining 0.5% per body half, 10% of the neurons have an axon trough the arm of which 50% passes the elbow. That means that 0.025% of the neurons have axons through the elbow, which would be about 2.4×10^7 axons. Multiply this by the 45 nN per axon found earlier and one could conclude that steel nerves add roughly 1.1 N to the force required to lift ones lower arm.

To validate above approximation, one could also make an approximation via the weight fraction that the lower arm is of the total body mass without the head. If the mass of the body (head excluded) is assumed to be 70 kg, the lower arm is about 2.4% of this. If it is assumed that the nerves outside of the brain and spinal cord are distributed evenly per unit of body mass, that would mean that 2.4% of the 1% non-head-or-spinal-cord neurons would be in the lower arm, which gives 0.024% of the total amount of neurons to pass through the elbow which is close to the previously calculated estimate of 0.025%.

Conclusion

In conclusion, having nerves of steel would make it more difficult to bend joints, as steel wires have a certain yield stress and are not as flexible as ordinary cells. Through calculations on the required moment to bend steel rods, it is found that due to the nerves in this hypothetical situation now being coaxial steel cables, the bicep would need to exert an additional 1.1 N in order to bend the elbow.

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