THE FORCE-VELOCITY RELATION STUDIED WITH A PNEUMATIC LEG-EXTENSION/CURL DEVICE

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INTRODUCTION

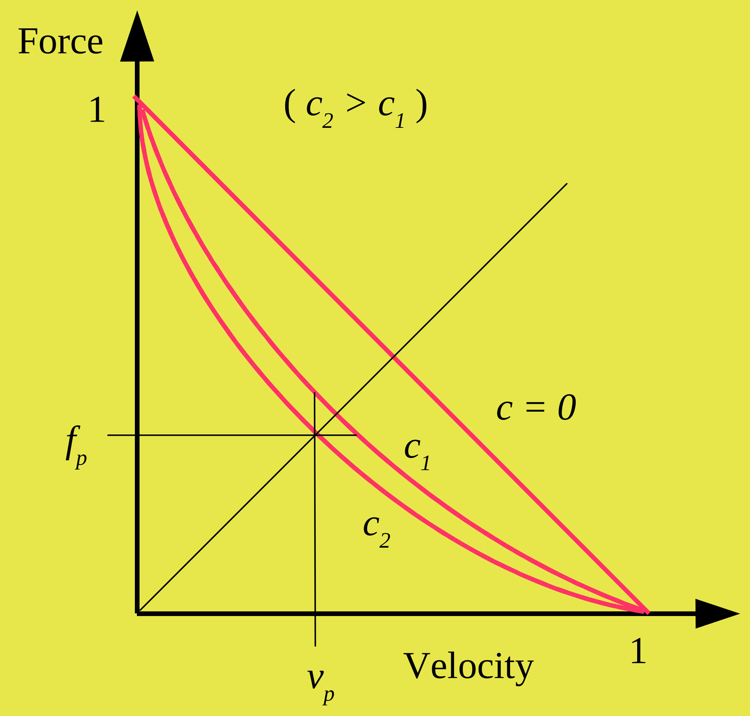
The purpose of the present study was to find out whether a simple Hill-model for the muscle could be useful for understanding the results obtained using an off-the-shelf pneumatic leg extension/curl exercise machine (non-isokinetic).

MATHEMATICAL MODEL

We use one of the simplest versions of the Hill model (A V Hill 1938) as described e.g. by W Herzog (1995). Accordingly, the force-velocity relation may be written as

(1) $$\frac{V}{V_0} = \frac{1-\frac{F}{F_0}}{1+c\frac{F}{F_0}} \qquad \frac{F}{F_0} = \frac{1-\frac{V}{V_0}}{1+c\frac{V}{V_0}}$$

where F_0 is the isometric maximum force, and V_0 is the maximum contraction velocity. Besides F_0 and V_0 we have only one adjustable parameter *c*, the so called *shape parameter*. The larger the value for *c* the more curved is the Hill curve ($c_2 > c_1$ in the figure below). Using the normalized variables $v = V/V_0$ and $f = F/F_0$ the force-velocity relation describes a symmetric curve. From this one sees that the power $P = FV$ attains its maximum at the midpoint of the curve, the coordinates given by



(2) $$v_p = f_p = \frac{1}{1+\sqrt{1+c}}$$

Nigg and v. d. Bogert (1995) quote a typical value around *c* = 2.5 for the shape parameter which corresponds to a maximum power output at velocity $V = 0.35\, V_0$ and force $F = 0.35\, F_0$.

METHODS

A pneumatic resistance machine (HUR Co, www.hur.fi) was used for recording MVC leg extensions employing varying resistance levels (2 to 8 bars). An inclinometer measures the angle of the lever (a measure of the joint angle) and a force transducer measures the torque exerted by the lower leg. Also isometric tests were performed in order to obtain the maximum isometric force.

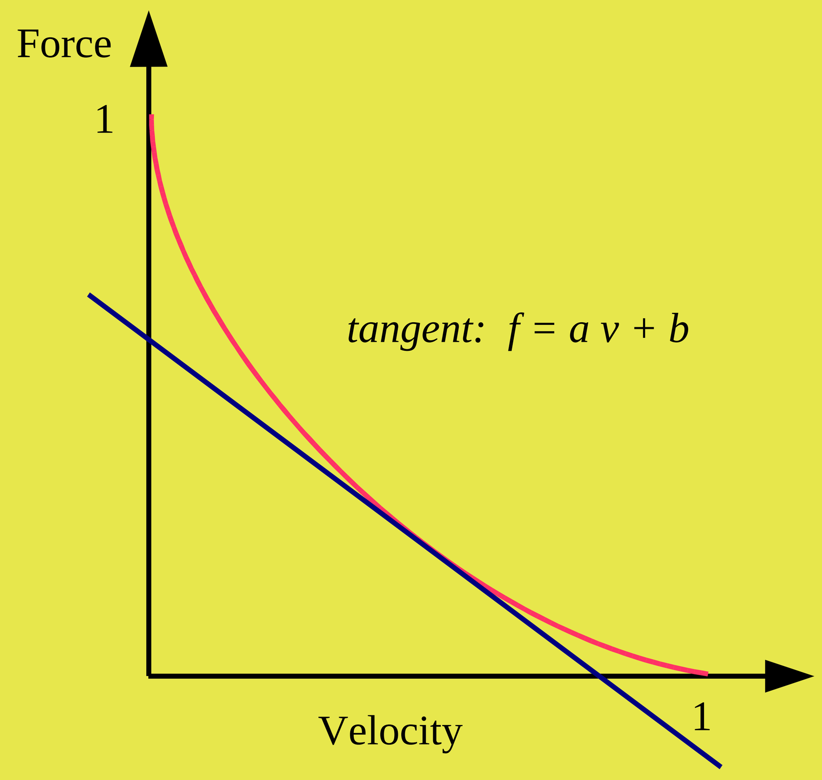
If we map e.g. the maximum torques versus the corresponding angular velocities for the tests we get points that generally lie quite close to a down sloping line as expected from the force-velocity relation. The shape parameter *c* for each subject was calculated by solving (2) for *c* by setting *f* = TQp/TQ0, where TQp is the torque measured at maximum power output and TQ0 is the isometric maximum. Since *c* is quite sensitive to the variations in the *f* we get a quite high variation in *c* between individuals. However, using a data set provided by Raimo Kuhanen (Kultu, Research Institute of Exercise Medicine) comprising 25 subjects, we were able to do some statistics.

RESULTS AND DISCUSSION

Measurements from 25 males (semipro hockey team: 21.3 ± 2.3 yr.; 179.4 ± 5.5 cm; 89.9 ± 6.5 kg) were analyzed (right leg). Computing the shape parameter as described above we obtained an average value of 3.04 ± 2.23. The average of the scaled torque (which is the same as scaled force) TQp/TQ0 was 0.35 ± 0.06 which may be compared to the quoted value of 0.35; i.e., *c* = 2.5. The maximum velocity VEL0 measured at the lowest load is naturally an underestimation of the true maximum velocity. From the average velocity at maximum power, VELp, which was found to be 410 deg/s (7.16 rad/s), we can estimate the average of the maximum velocity V_0 as VELp/0.35 = 1170 deg/s (20.4 rad/s), which is about 0.66 m/s for a quadriceps muscle assuming a moment radius of 3.3 cm. Above we have neglected the muscle length factor. More accurate results could likely be obtained taking this into account, but as a first approximation (1) will do as the joint angle region for maximum power were quite similar for all subjects. An interesting observation is that if we fit a straight line (which works quite well)

(3) $$TQ = A \cdot VEL + B$$

to the measured torques and velocities (a straight line approximation of the force-velocity curve) it is found that the A and *B* parameters are strongly correlated. This can be easily explained on the basis of (1) if we suppose that (3) is close to a tangent to the curve (1). Indeed, (1) would then predict a relationship



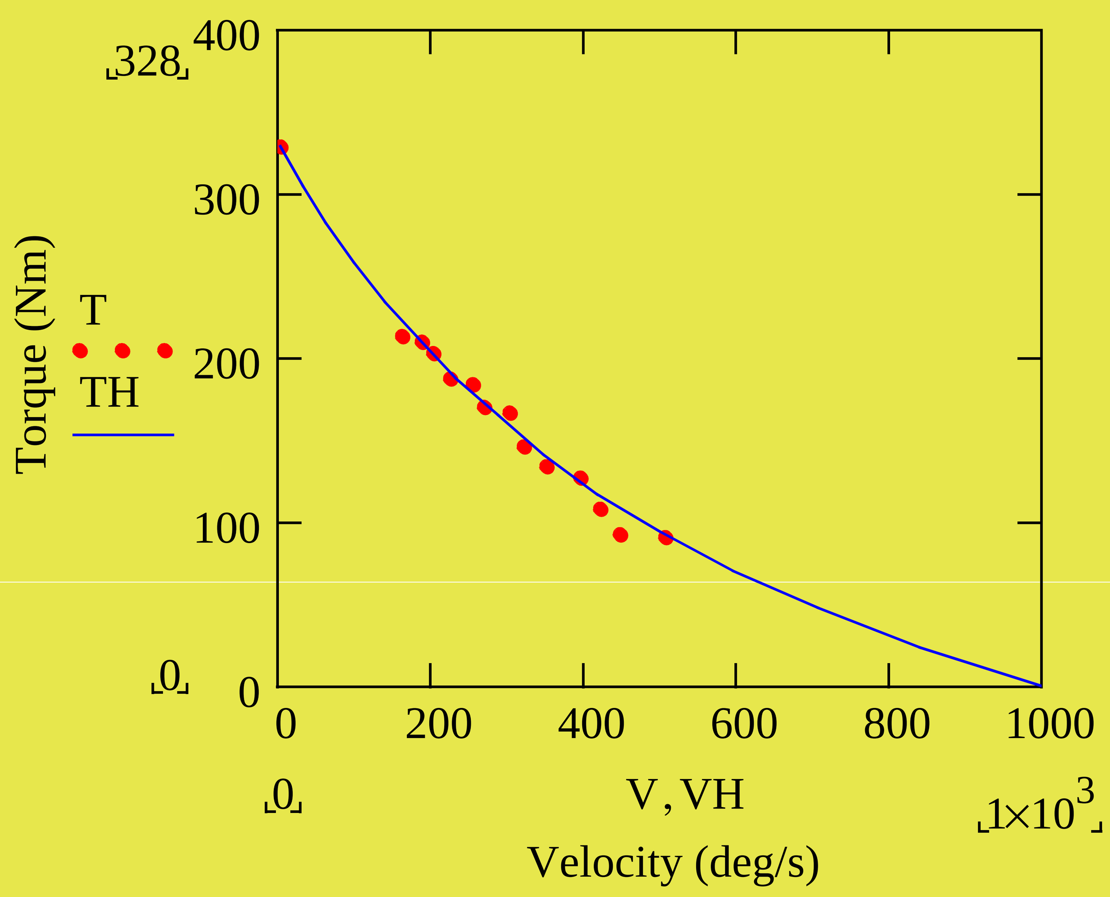
(4) $$A = -\frac{1}{V}B + \frac{F}{V}$$

where *V* is the velocity and *F* the force at the tangent point. Indeed, when we calculated the averages of 1/VEL and TQ/VEL for the 3 bar resistance level tests we got 0.0024 s/deg and 0.255 N m s/deg respectively, to be compared with the regression line

$$A = -0.00238\, B + 0.258$$

for the *A* and *B* parameters of the test group (correlation coefficient being -0.80).

The figure below shows a typical force-velocity diagram for one of the test subjects (here the torque is a measure of the force). Each point corresponds to one kick except for the isometric test at *V* = 0. The superimposed Hill-curve has the shape parameter *c* = 1.50 and for fitting we have used V_0 = 1000 deg/s.



SUMMARY

Our cursory study shows that the simple Hill-model (1) can help explain some important features of the data obtained with the pneumatic leg extension machine and thus suggests future comparisons with more detailed models. That the Hill-model is relevant for leg-extension has been suggested e.g. by the work of Tihanyi et al. (1982) who used an ingenious but somewhat complicated measurement apparatus. With an improved protocol and a more sophisticated data analysis the present pneumatic device might provide a convenient measurement setup for assessing some gross muscle characteristics.

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