

BIOL 411 Animal Physiology

Brief notes on the measurement of force, work and power using SI units.

MASS is measured in kilograms (kg)

ACCELERATION = change in speed ($\frac{m}{s}$) per second (s) and is measured in $\frac{m}{s^2}$

FORCE = MASS x ACCELERATION and is measured in Newtons (N)

$$N = \frac{kg \times m}{s^2}$$

WORK = FORCE x DISTANCE and is measured in JOULES

$$J = N \times m$$

POWER = WORK/SEC and is measured in WATTS

$$W = \frac{J}{s}$$

One watt will accelerate one kilogram by one meter per second squared, over a distance of one meter in one second.

$$1 \text{ W} = 1 \frac{\text{J}}{\text{s}} = 1 \frac{\text{kg} \cdot \text{m}^2}{\text{s}^3} = 1 \frac{\text{N} \cdot \text{m}}{\text{s}}$$

One myofiber can exert a typical force of $0.3 \mu\text{N}$

The maximum force generated by a muscle depends on:

1. Cross sectional area of the muscle (**Physiological strength**)

Hypertrophy (increase in cross sectional area) of a muscle in response to training is due to increases in the actin and myosin filaments within individual myofibers, increasing the size, rather than the number of myofibers. Some hypertrophy is also due to increase in noncontractile sarcoplasmic volume of cells. With extreme development of a myofiber, it

may split (**hyperplasia**), causing an increase in the number of myofibers within a muscle.

2. The way in which the muscle is attached to the bones that it moves (**Mechanical strength**).

For a given force generated internally within the muscle itself, the angle of attachment and the length of the level arm will affect the motions and forces and motions generated externally.

3. The efficiency with which motor neurons stimulate the muscle (**Neuromotor strength**).

Rapid initial gains in functional strength when training are usually due to better neuromotor stimulation ('learning to use the muscle'). Slower gains then follow, from hypertrophy.

Some interesting factoids:

The masseter (jaw) muscle exerts the greatest external force of any muscle in the body (4337 N), because it is attached to a short level arm.

Example of force-velocity relationships in contraction: The muscles controlling the eyeball are very large, given the mass of the eye. This allows very rapid movements of the eyes, known as saccades, needed when scanning scenes, scanning faces, reading.

Typical power output of the human heart is 1-5 W. Other muscles have far more power (quadriceps can put out ~100 W). Because the heart is continuously exerting this power, it does more work in the long run than any other muscle. (See equations above, power x time = work).