Force, work, power

I. Aims of the practical

Getting acquainted with the concepts of force, work and power. The properties of the physical concept of work and of muscular effort; their connection to power. Introduction to the use of the *Biopac* measurement system.

II. Background

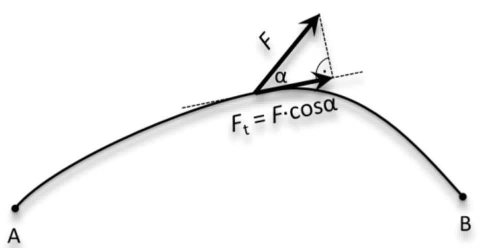
In the physical sense, work is done when a force acting upon an object causes the object to be displaced. In the simplest case, when the force stays constant regardless of displacement, we can define the *work* done as the product of the force and the displacement in the direction of the force:

$$W = \mathbf{F} \cdot \Delta\mathbf{s}.$$

The physical concept of work is the scalar product of the force vector and the displacement vector.

If the direction of the force makes an angle α with the direction of the displacement, it is not the full magnitude of the force F we should take into account, but only its projection in the direction of the displacement, that is, the work done in this case is

$$W = F_\mathrm{t} \cdot \Delta s = F \cdot \Delta s \cdot \cos\alpha.$$



In a general case, the force is not constant but changes with displacement. Then the displacement between endpoints A and B can be divided into n small constituent sections with length Δs_i within which the instantaneous value of the force F_i and its tangential component F_{ti} can be regarded as constant. Taking the sum of the work values in such small displacements we can obtain the work done for the displacement from point A to point B:

$$W = \sum_{i=1}^{n} F_{\mathrm{t}i} \cdot \Delta s_i.$$

If we choose the width of the constituent sections to be very small, almost zero, that is, we refine the partition of the displacement beyond limit:

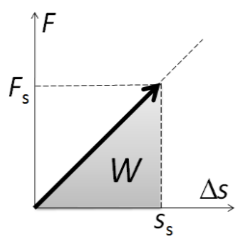
$$W = \int_A^B F_\mathrm{t}(s)\mathrm{d}s.$$

That is, the area under the force-displacement curve yields the value of the *total work*.

The magnitude of the force F_s exerted by a *spring* is proportional to the extension s_s of the spring:

$$F_\mathrm{s} = D \cdot s_\mathrm{s},$$

where D is the *spring constant*, that is, the force required to produce a unit extension of the spring. This force changes as we keep stretching the spring. Consequently, we must use the area under the force-extension curve (see figure) to obtain the work required to stretch a spring by s_s:



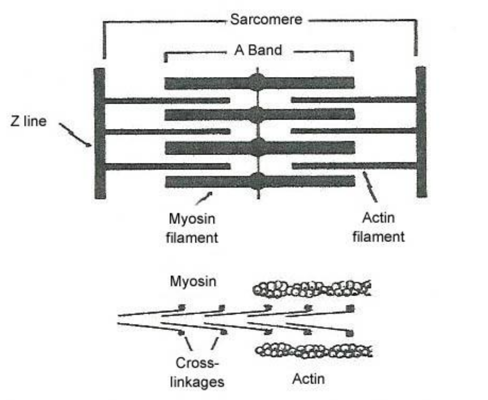
$$W_s = \frac{1}{2} F_s \cdot s_s = \frac{1}{2} D \cdot s_s^2 = \frac{1}{2} \frac{F_s^2}{D}.$$

Power characterises the time rate at which work is done, and is defined as the work done in unit time:

$$P = \frac{W}{t}$$

The quantity given by the formula above is the *average power*, which is equal to the instantaneous value of the power *only if* the work done is constant in time. The definition of *instantaneous power*, which is universally valid regardless of time dependence, involves the time derivative of work:

$$P = \frac{\mathrm{d}W}{\mathrm{d}t}$$



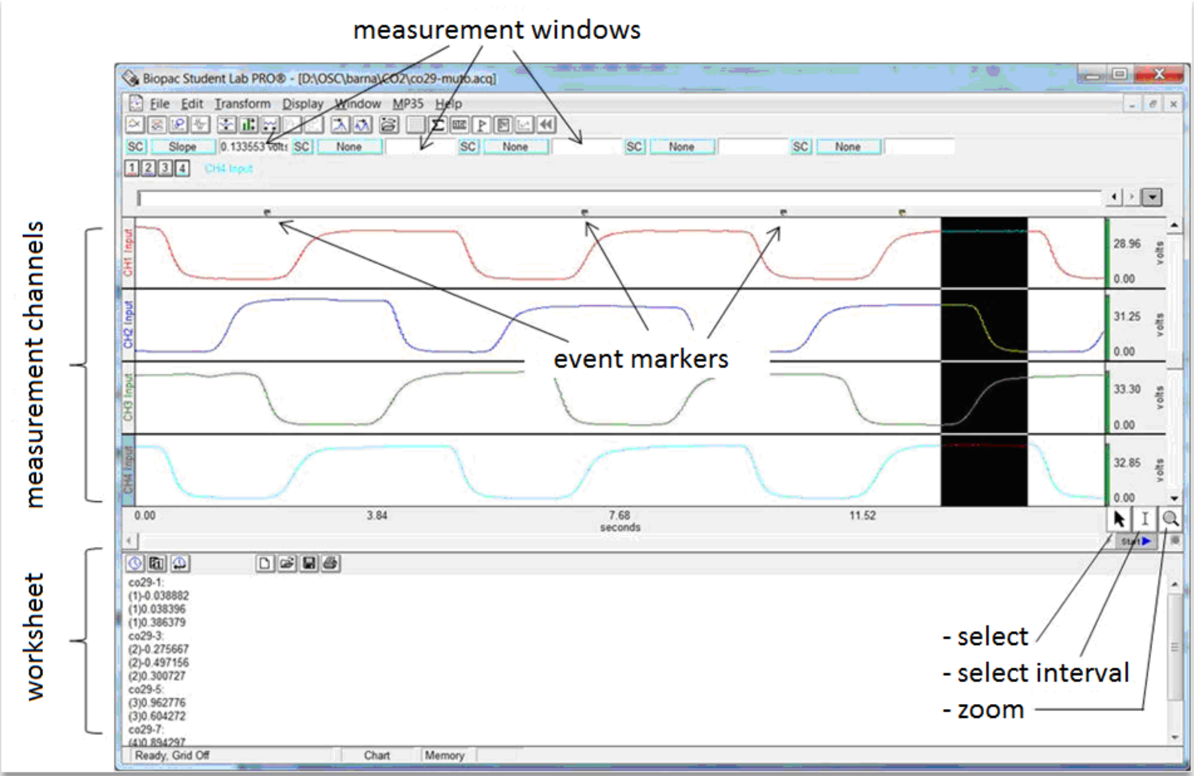
In skeletal muscles, physical work is related to the activation of striated muscle fibres. The muscle converts chemical energy into mechanical energy. This conversion process is facilitated by the internal structure of the *sarcomere*, the periodically repeating base unit of skeletal muscle fibres (miofibrils). The mechanical work done by a muscle can be explained as the result of the relative positions of the *filaments* within a sarcomer and of their displacements relative to each other. The sarcomer is comprised of two basic types of filaments. The thick filament is mostly made up by *myosin*, whilst the main constituent of the thin filament is the protein *actin*. These filaments overlap each other in a spatial grid. According to one of the models, the contraction of the muscle (which is the basis of its ability to do work) is brought about by a telescope-like sliding of the two filament systems over each other *(sliding filament mechanism)* that occurs as a response to a stimulus. This sliding proceeds as the cross linkages protruding from the thick filaments repeat a cycle of attaching to the thin filament, performing a paddling motion and then detaching.

Both muscle length and muscle tension change as the striated muscle performs its function. Though during *in vivo* operation these two processes are intertwined, we can study them separately and define two categories of muscle function: *isometric* contraction (in which muscle length stays constant) and *isotonic* contraction (where muscle tension is unchanged). The physical concept of work can only associated with isotonic contractions; during isometric contractions, no work is done *in the physical sense.*

III. Measurement tasks

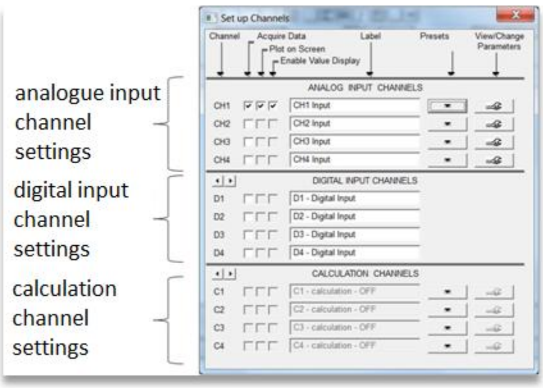
A. Getting acquainted with the basic functions of a data acquisition and processing computer system

1. User interface of the Biopac Student Lab Pro program



2. Defining the input channels (MP35/Set up channels ...)

In the Biopac data acquisition system, we can choose between three types of input channels. There are four *analogue* channels associated with the analogue-to-digital converters; through these, we can acquire electrophysiological signals, pressure or flow signals, or the signals of dynamometers or analogue microphones. *Digital* input channels receive digital signals directly. In *calculation channels*, we can record signals derived from the signals of primary input channels (such as the heart rate derived from an ECG recording).

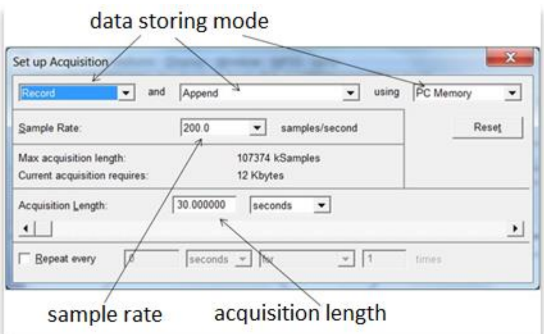


3. Setting up data acquisition parameters (MP35/Set up acquisition)

Data storing mode: in memory or on hard disc.

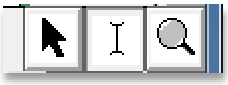
Sample rate: should be greater than twice the maximum frequency within the signal.

Acquisition length (data acquisition can be aborted before its completion).

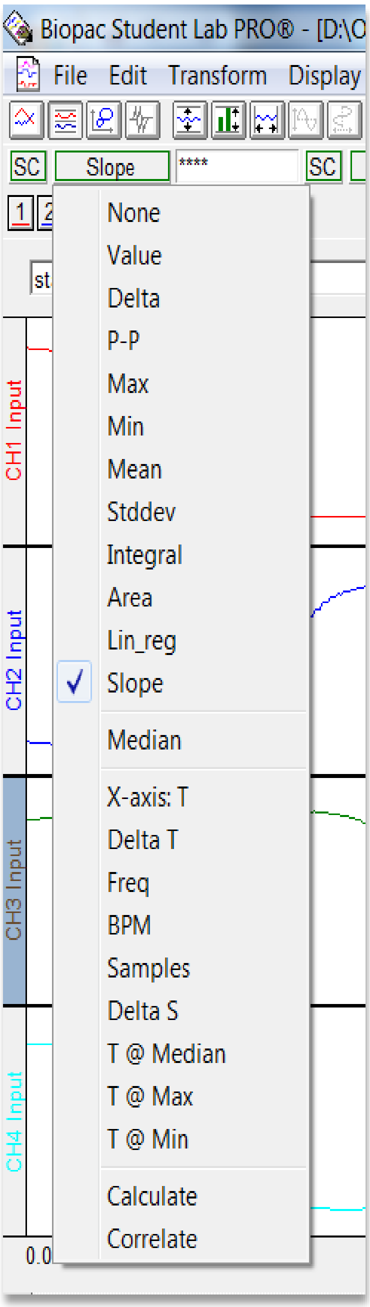


4. Data acquisition

5. Data display settings



6. Data evaluation



1. Channel selection (1, 2, etc, or SC: selected channel)
2. Evaluation of parameters:
   - *None*: no parameter read
   - *Value*: the value at the position of cursor I
   - *Delta*: the difference between the endpoints of the interval
   - *p-p*: peak-to-peak value within the selected interval
   - *Max*: maximum value within the selected interval
   - *Min*: minimum value within the selected interval
   - *Mean*: mean of the values in the selected interval
   - *Stddev*: standard deviation of the values in the selected interval
   - *Integral*: area under the curve between the endpoints
   - *Area*:the area above the line connecting the endpoints
   - *Lin_reg*: the slope of the best fit line
   - *Slope*: the slope of the line connecting the endpoints
   - *Median*: the median of the selected interval
   - *X-axis T*: the position of the cursor along the time axis
   - *Delta T*: the length of the selected interval
   - *Freq*: the frequency of a periodic signal
   - *BPM*: recurrences per minute
   - *Samples*: cursor position expressed as a sample index
   - *Delta S*: the length of the selected interval as sample count
   - *T @ Median, Max, Min*: the times associated with the median,
   - maximum or minimum, respectively
   - *Calculate*: calculation using a custom formula
   - *Correlate*: correlation between channels

B. Determining force, muscle effort and power

1. Data collection

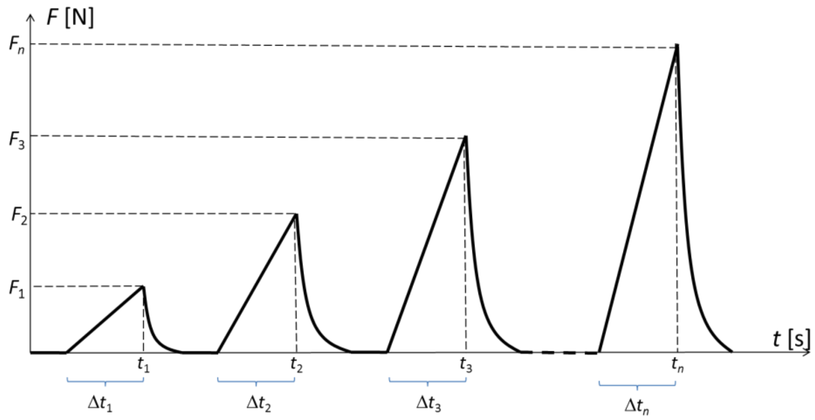
a) Start data collection

b) Exert an increasing clench force on the manual dynamometer using your dominant hand

c) build up the initial F_1 clench force gradually, in about 2 s

d) exert increasing values of maximum clench force F_2, F_3 … F_n gradually, also in about 2 s (*see figure*)

e) Inform your instructor when data collection is complete



2. Data analysis

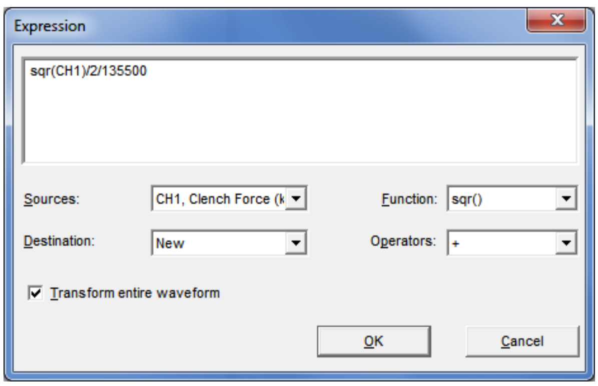
a) Turn on the computers, start the English version of the Windows XP operating system. Novell network login: lab/biopac; Windows login: stud/-

b) Launch the Biopac Pro (BSL Pro 3.7.3) software from the desktop

c) Open the measurement data file from C:\TEMP\MEASURE

d) Practice the main functions of the Biopac program (zoom, scaling, channels, setting-up measurement windows)

e) Set up a new Biopac channel to calculate the instantaneous value of work



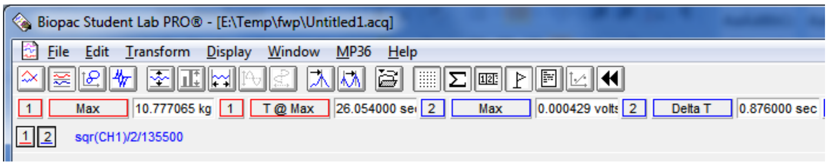
(Transform/Expression). The spring constant of the clench force transducer: D = 135500 N/m.

f) Determine the maximum clench force in each manoeuvre (F_1, F_2, F_3 … F_n)

g) Read the time instants of these maxima (t_1, t_2, t_3 … t_n)

h) Determine the work done on the spring during each manoeuvre (W_1, W_2, W_3 … W_n)

i) Calculate the average power in each manoeuvre (P_1, P_2, P_3 … P_n)



j) Fill in and submit your laboratory report