INTRODUCTION

Unlike in purely mechanical description of movement, where the power appears and disappears instantly, in the biomechanical treatment of the movement, the effect of muscular contraction does not take into account the inertia of the chemical processes in delivering energy and neuromuscular commands. This means that we have to take into consideration a transient phase until the power enriches a stationary regime. If the effort continues, due to the homeostasis manifested by tiredness, the power decreases continuously, in spite of the volitional commands.

Three phases of the muscular effort become obvious. According to the power variation, these phases can be ordered and characterized as follows: the starting phase of the muscular effort, the phase of the maximal effort (somehow stable) and the phase of tiredness (if the effort continues).

THE STARTING PHASE OF MUSCULAR EFFORT

The main characteristic of this phase is the preserving of the force. The net force \( F_n \) cumulates under the form of inertial reactive force \( F_{ir} \):

\[
F_n + F_{ir} = \text{constant}
\]

The duration of this phase depends of the inertial mass that will be moved, of the total force, and of the way in which the input of the contractile medium is changing, especially due to the synergic time and space recruitment of the neuromuscular synapses and its instances. Practically, this time extends from a few tens of milliseconds, like in the case of stereotypical gestures to a few tens of seconds, like in the case of pulling heavy vehicles (buses, planes etc.) in unconventional sports (like in competitions for the title of “World’s strongest man”).

Figure 1: The phases of the muscular effort

THE MAXIMAL MUSCULAR EFFORT PHASE

Characterizing this phase is the fact that the power reaches its maximum value (for a certain individual, moment or situation). The power preserves, meaning that the multiplier between the force and the speed remains the same:

\[
(F_n + R)(V_n + V_{ir}) = \text{constant}
\]

The sums in the above relation are vector sums, in that the reactive resistance force \( R \) is negative and opposed to the active net force \( F_n \). A.V. Hill’s law is reflecting the same hyperbolic relationship between resistant weight (force) and its speed, and can be expressed as:

\[
(F+a)(V+b) = \text{constant}
\]

Figure 2: The relationship between force and velocity during the maximal biomechanical effort

In Hill’s mathematical pattern “a” is weight of the body segments involved in the movement and “b” is a theoretical minimal speed for the isometric contraction, when the applied power is not zero. This phase of muscular effort, in which the power reaches maximum levels, pseudo constants (tens of seconds for the human species) are a characteristic of many sports and have been intensively studied. Other models take
into account the effector’s temperature, the rate of decreasing of the ATP reserves from the muscles and its recovery, of the conventions of the classic mechanics, etc. The essence is always the same - the speed of execution decreases while the resistance force decreases.

THE TIREDNESS MUSCULAR EFFORT PHASE

Most often the tiredness syndrome is invoked if there is insufficient rate of ATP resynthesis, but hypotheses of specific autointoxicaction, of heterochronous, the psycho volitional, or even the cellular metabolism are not rejected. In any muscular effort which lasts a relatively long time, there comes a moment when the emitted power begins to decrease. This moment depends of the magnitude of the effort, meaning the value of the net power \( P_n \), and the available amount is obviously characteristic for every individual and situation.

From the biomechanical point of view, and ignoring the psychometric aptitudes and attitudes, when the duration of the effort increases, the net force \( F_n \) and its speed \( V_n \) decreases. The relation between these two values is also hyperbolic, with the asymptote towards the reserve energy (which can be accessed only in special conditions):

\[
P_n \times t = \text{constant} + \text{reserve energy}
\]

Theoretically, this means that the spent energy preserves. Practically, the above relation says that the exhaustion time appears before the reserve energy is exhausted, most probably as a homeostasis effect of preserving the body.

\[
P_n \times t = \text{constant} + \text{reserve energy}
\]

Figure 3: An example of three effort phases in a virtual athlete who hypothetically holds the all world records of track running, from sprint to marathon. The maximal muscular effort phase stands between 10 to 30 s.

OVERVIEW ON THE PHASES OF THE MUSCULAR EFFORT

A first observation, surprisingly, is that the preservation of some components of kinetic energy, while at the same time increasing the effort time. At the beginning of the first phase, only the force is preserved, then, in the second phase, the force is multiplied with the speed (meaning the power) and in the third phase, the force multiplied with the speed and the time (the energy).

A second observation is the similarity with the Newton’s laws of classical mechanics. The first law of mechanics refers to the law of inertia and reflects the tendency of preserving the state of non-movement, which suggests the idea of absorption of the net force by the activated body, under the reactive form of inertial force (the so-called pseudo-force in the classic mechanics).

Another similarity of the phases of muscular effort refers to the envelope (the graphic sum obtained through experimental studies) of the anaerobic processes, mixed and aerobic processes of the ATP recovering (Howard, 1976). It is in fact normal that the two aspects, chemical and mechanical, vary almost in the same way, considering the extraordinary efficiency of conversion of the chemical energy into muscular mechanical energy.

Another thing to note would be that professional sport has created different branches for efforts that imply mainly the force, the speed and the resistance, and that nature has given to the human being multiple mixtures of these three movement qualities that some how individually compensated. We also underline the fact that in some efforts, like the ones in the professional sports, not all the phases are necessary, but the order is undisputed. As is shown in the Figure 1, the total force remains unchanged because the inertial component does not contribute to the flow of mechanic energy. The variation in the power is made because of the speed of movement. Less important practically is the fact that the mathematical model describing this transitory phase may be approximated by a third degree equation or a Lagrange differential equation, both offering a graphical form shaped as “sigma”.

In the second phase, as shown in Figure 1, both the net force and the net speed don’t vary at all, which implies that their multiplier is in some way constant. The efforts in this phase, if they exist, can be maximal. Beyond a certain period (individual, genotypically and phenotypically determined), both the net force and its attendant speed decreases because of fatigue, causing a decrease in the power curve. This is the third phase, and if it exists, can last a relatively long time and it is related to the endurance efforts. Stopping activity and exhaustion don’t imply the complete exhaustion of the total energy supply, but only that which is available in normal conditions. Doping and other prohibited methods in sports may allow the athlete to use the spare energy, but never without a payback, which is sometimes even the health.

In Figure 1, the colored two equal areas suggest that in fact, in this third phase, the available energy (without the spare energy) looks to be a constant. In other words, a large power output can only be possible on short terms and vice-versa. For example, a sustained fast running rhythm can’t be occur over long periods of time, while a slow rhythm of running can be done over a longer period of time.