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ANALYTICAL BIOMECHANICS

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Foreword

Biomechanics is mostly known as an applicative discipline. Their applications are shown in sports, physical education, traumatology, orthopedics and in the field of amelioration of the different movement dysfunctions.

- *Why to study biomechanics?*

Because of the fact that correct application of the biomechanical knowledge improve the efficiency of the sport training, improve the techniques of capitalization of the trainings in competitions, improve the physical education lessons and prevent the injury at practitioners, shorten and ameliorate the quality of recovery after traumatisms, accidents or surgery, reduce the complex of infirmity etc.

- *Who are interesting in biomechanics?*

First of all, the students in the field of anthropology and their professors are interesting in biomechanics. The future teachers, the trainers and other specialists in the physical education and sports or in kinetoteraphy, but also the physicians, biologist or scientists needs the veracious knowledge of biomechanics.

- *Where can find the systematic knowledge of biomechanics?*

The scientifically literature offers many books of biomechanics, mostly of them wrote by prestigious authors. Some books are truly guided for efficient applications of the knowledge of biomechanics.

- *Why does necessary a book of analytical biomechanics, knowing that are so many other good books of biomechanics?*

We have to confess that is difficult for us to give a fully satisfactory answer. No doubt that any successfully practice is based on a valid theory. It is true that all the books or courses of biomechanics, no matter how far regarding to practice, are adherent to a theory. The reciprocity is also valid, as it was formulated by Albert Einstein: ”Any knowledge about reality is started from a practical experience and is going and ending to the practice” (About the theoretical Physics Methodology).

The theory of biomechanics shown in our book is trying to detach from the classical formula, because is respectfully giving back to the great Newton a lot of what was borrow from the mechanics. We have to pay praise for the help of mechanics in enlightenment of some biomechanical event, but now is the right time for the biomechanics to have carry itself, to promote own laws and to consolidate intrinsically principles. Probably, only for the experts is coming clear that a large part of the analytical items exposed in this book are original; but each person who studied a book of biomechanics, we suppose, is able to observe a new architecture of the present book. It will be seen on the future if the new phase theory of muscular effort and the new lows of biomechanics (shows in the VI chapter), exposed for the first time in this book, will resist to the critics. We don’t know how far the biomechanics will extend its limits to the molecular motor of ATP and to the computerization of the analysis of the movement, so that the solution will be offered automatically. (For instance, it is no indispensable to be on familiar terms with the reason of null acceleration, as a theoretical condition, in the case of constant speed of movement). We completely agree with the well known scientist, Karl Popper, when he said: “Who don’t want to submit own opinions to the risk of rejecting, is not a participant to the science” (The Logics of Scientifically Discovers).

We express our hopes that this short digression in theory of biomechanics to be useful and we would be very grateful to whoever will send us substantial critics.

CONTENTS

I.	THE SYSTEMICALLY TREATMENT OF BIOMECHANICS	9
		9
1.1.	Argument	10
1.2.	The System of Biomechanics	
1.3	Other Scientifically Disciplines which Study Movement besides Biomechanics	15
1.4.	Brief History of Biomechanics	20
1.5.	About the Utility of Biomechanics in Sport	21
1.6.	About the Academic Position of Biomechanics	24
		21
II.	MOTION IN BIOMECHANICS	26
		26
2.1.	General Consideration about Motion	28
2.2.	Motion on Muscular Contractions	28
2.3.	Movement in Biomechanics Practice	30
2.4.	Movement Regarded Vectorial	33
2.5.	Inertial Motion	34
III.	MAIN BIOMECHANICAL DIMENSIONS	43
3.1.	The Minimal Lexis of Biomechanics	43
3.2.	Irreducible Main Biomechanical Dimensions	43
3.3.	Reducible Main Biomechanical Dimensions	44

IV.	THE PHASE TEORY OF MOVEMENT	49
4.1.	The Starting Phase of the Muscular Effort	50
4.2.	The Phase of Quasi Constant Maximal Power of the Muscular Effort	51
4.3.	The Tiring Phase of muscular Effort	54
4.4.	Overview on the Phases of the Muscular Effort	55
V.	BIOMECHANICS OF MAIN MOTRIC SKILLS	58
5.1.	Introduction	58
5.2.	Biomechanics of force	59
5.3.	Biomechanics of speed	74
5.3.	Biomechanics of endurance	88
VI.	THE LAWS OF BIOMECHANICS	98
6.1.	Borrows and owners laws of biomechanics	98
6.1.	The Law of Preserving the Force in the Movement's Start	101
6.2.	The Law of Preserving the Power in the Maximal Efforts	109
6.3.	The Law of Preserving the Energy in the Tiring Efforts	
6.4.	Survey on the Laws of Biomechanics	116
VII.	THE TYPOLOGY OF MUSCULAR CONTRACTION	121
7.1.	Isometric Contractions	124
7.2.	Isotonic Contractions	126
7.3.	Isokinetic Contractions	128
7.4.	Auxotonic Contractions	130
7.5.	Pseudo-contractions or Eccentrically Movements	132

	with Overload	
7.6.	Supra-contractions or Movements at a Supra-maximal Speed with a Negative Load	135
7.7.	General Considerations about the Types of Muscular Contractions	138
VIII.	THE TRANSMISION OF MOVEMENT THROUGH LEVERS AND KINEMATICS CHAINS	141
8.1.	Clarifications Regarding the Transmission of Movement	141
8.2.	Some mechanical Properties of Biological Structures Involved in the Transmission of Movement	142
8.3.	Levers	144
8.4.	1st Rank Levers	152
8.5.	2nd Rank levers	156
8.6.	3rd Rank Levers	157
8.7.	Kinematics chains	162
IX.	THE EQUILIBRIUM AND OTHER STATIC ASPECTS	170
9.1.	Generalities Referring to Equilibrium	170
9.2.	The Equilibrium in Biomechanics	172
9.3.	The Determination of the General Weight Center	182
X.	THE BIOMECHANICAL ANALYSIS OF MOVEMENT	185
10.1.	The Purpose of the Analysis	185
10.2.	The Qualitative Biomechanical Analysis of the Movement	187

10.3.	The Quantitative Biomechanical Analysis of the Movement	194
XI.	COMPUTERIZED BIOMECHANICAL ANALYSIS OF MOVEMENT	201
11.1.	Biomechanical Parameters Acquisition Systems	202
11.2.	The luminescent trajectory marking technique	204
11.3.	Displaying of results of computerized acquisitions of biomechanical parameters	206
11.4.	Interpretation of the results of computerized acquisition of biomechanical parameters	211
XII.	THE BIOMECHANICAL SYNTHESIS OF THE MOVEMENT	215
12.1.	Synthesis as a Progressive Instrument	215
12.2.	Concepts of the Methods of Segmental Synthesis	216
12.3.	The Synthesis of the Vertical Jumping without Rapid Flexion	219
	SHORT BIBLIOGRAPHY	227

I. THE SYSTEMICALLY TREATMENT OF BIOMECHANICS

1.1. Argument

Biomechanics is a scientific discipline or a science to be born, which studies the movement of biological structures produced especially by their internal forces.

In a human being these internal forces are generated by the mechanical tensions of the muscular contraction and are transmitted through tendons, bones, body fluids and joints, which act as levers and cinematic chains.

Often, to the movement other forces contribute or are opposing it, such as external forces: the gravitational force, the centrifugal force, the inertia, etc. Some times the forces and the moments of forces can generate equilibrium, pressure about the soft biological tissues without movement or can slow down the extra loud eccentric move.

From an etymological point of view, the word "*biomechanics*" comes from Greek, where "bios" means life and "mehane" means machine.

Generally, it is said that biomechanics is a science, having as object of study the movement of matter and living organisms. As far as we are concerned, biomechanics cannot be yet a science as long as it does not have its own principles and its validated laws.

On the other hand, biomechanics does not study any movement of matter and living organisms, but only the change of positions that has as main cause the internal forces of the system in movement, and as effect, the effectiveness of these.

There are many other reasons, except for effectiveness, which could justify the interest for the study of biomechanics. One of these would be simple curiosity, another – the need to expand the knowledge of the adjacent information with the field of biomechanics, and, at last, the hope to find in this discipline the concrete means to grow up the capacity of effort and performance in sport competitions.

1.2. The System of Biomechanics

We remind here that the *system* is a theoretical concept (tool) of simplifying what is real, elaborated for the purpose of facilitating the knowledge (the rule of justification) and formed by at least two non-trivial (the rule of surveillance) entities (the rule of consistency) and a relation (the rule of persistence).

In the case of biomechanics, the primary system, the one of causes, processes and effects, is formed by internal and external forces, processes of transmitting or conserving and, respectively, movement and equilibrium.

This system is the main tool of knowledge in biomechanics, besides other tools of study extended to the effects of movement (technique) or the provenience of the force (the neuro-muscular converter). The grapho-analytical tools, the cinematic procedure of synthesis and analysis, as well as the logico-mathematical modeling, if they refer to the movement in sports, extend the object of biomechanics towards the sportive performance, justifying thus the denomination of biomechanics of sport. If the extensions of study tools of biomechanics are heading towards the neuro-muscular converter, with the (psycho) motory, sensory, stato-kinezical, etc. feed-backs, then biomechanics almost overlaps with kinesiology.

The study of movement does not only have different tools and means, but also different viewpoints or different purposes. In biomechanics, the interest for the study of movement focuses on the efficiency of the movement. In science, when the talk comes to efficiency, its reference or guiding mark must be mentioned, as well. If the talks come to the biomechanics of sports, then the efficiency is given by comparison with the technical execution of movements, and by technical (but also by other components, such as tactics, strategy, etc) sportive performance can be reached. Only rarely the efficiency of movement in sport can be referred directly (and not by technical execution) to the energetic economy, esthetics and spectacular. Anyway, it must not be lost from account that the care for the prevention of accidents or the diminishing of negative effects of biomechanical overloading.

That is why it is helpful, even from the beginning, to clarify that the purpose of biomechanics is the one of studying the movement from the efficiency point of view, referring it to the performance and or referring it to normality. The performance to which we are referring is the human one, in general, and in particular, the sportive one. On obtaining the performances a series of factors contribute, among which the psychical and physiological ones are very influential and inseparable of the biomechanical ones.

Some authors consider that the movement itself can be looked at from three different angles: biomechanical, physiological and psychological. We do not share this position, the purpose of movement being something else than movement as purpose. We clarifies this in order to justify why biomechanics is different form other disciplines which study movement, too, so they have a mutual object of study, but they have different viewpoints about movement, different purposes or they use different logical tools. The reference to normality is a practice of biomechanical undergoing, in the pathological zone (the one of congenital affections, skeletons, traumas, dysfunctions, etc). Rarely the purpose of the biomechanical study is reduced to the stopping of locomotors involutions, to

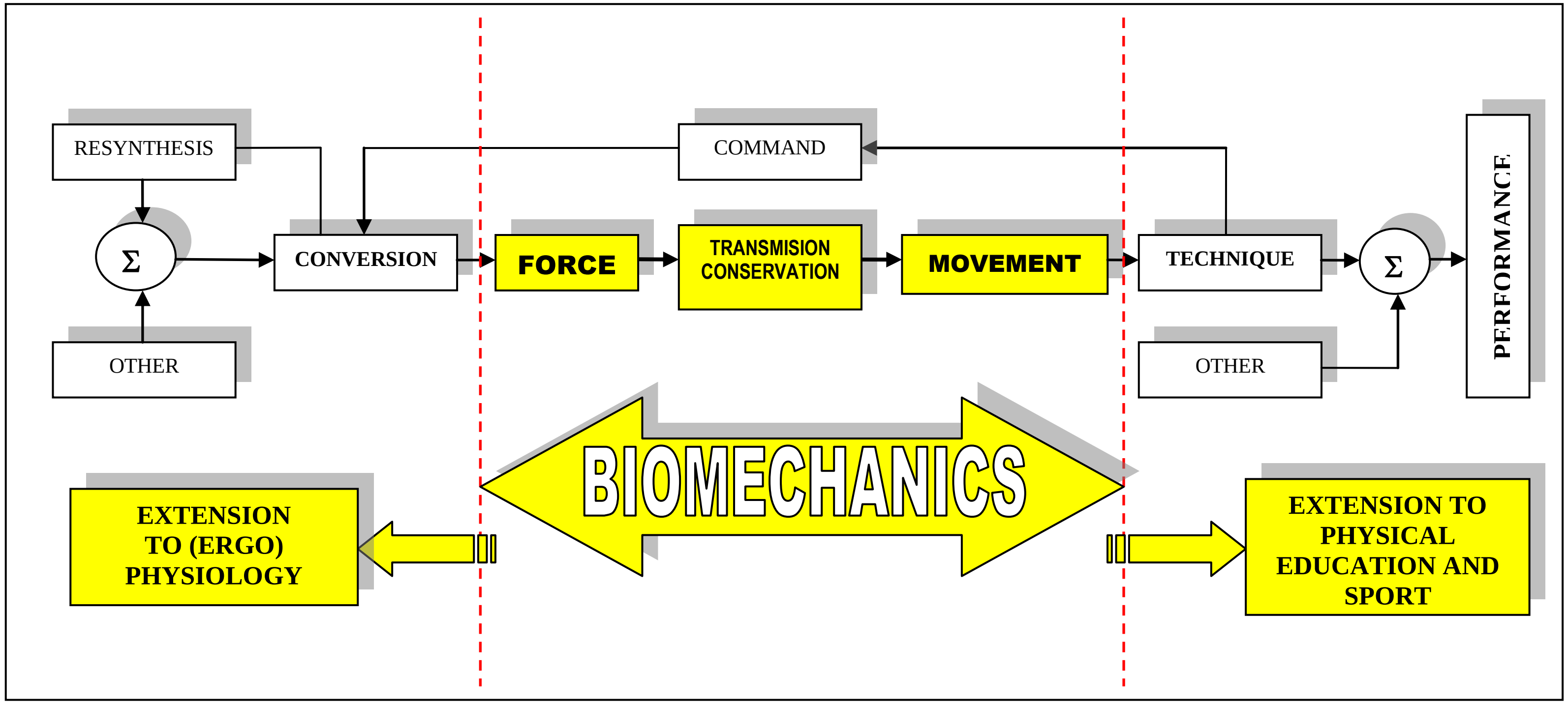


Fig. 1.1. System of scientifical discipline biomechanics

In the following, biomechanics is dealt with systemically (but also systematically) treatment of the movement and equilibrium. Other saying, the analysis and the synthesis of the movement and equilibrium is regarding to the processes of transmitting and conserving of their causes; especially these of mechanical tension generated by the muscular contraction.

1.3. Other Scientifical Disciplines which Study Movement besides Biomechanics

We insist upon the fact that not only biomechanics has as object of study the movement. By the fact, more other 16 scientifical disciplines are also study movement, but, as we were saying above, they study it from different viewpoints, with different purposes or different means.

Among these, biomechanics is most frequently mistaken for functional anatomy or descriptive anatomy, because in biomechanics very often specifications are needed about the structures that participate in the movement.

When, by example, the movement of some body segments while running is studied, it is very useful to mention which are the muscles that generate this movement. From the description of the movement and the biological structures which are participating and till the description of a movement is a difference of proportions, which is, in fact, what makes biomechanics different from the functional anatomy or the descriptive one.

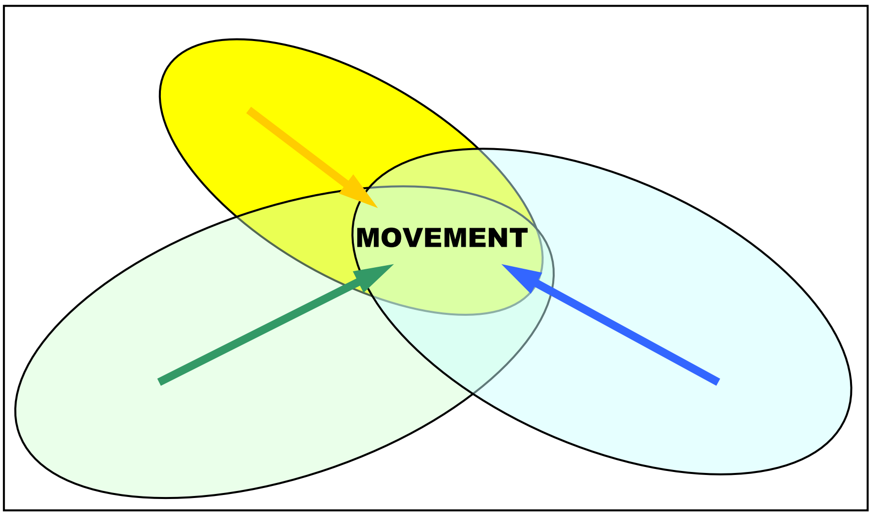


Fig. 1.2. Illustration by sets of elements defining to some scientifically disciplines which study the movement

It is clear that biomechanics and functional anatomy are interwoven, but they cannot be mistaken one for another; it would be wrong to be believed that they overlap, they don't have different positions from where one object of study can be seen: the movement. The anatomies see movement from the standpoint where biological structures are important, while biomechanics sees the movement from the standpoint in which the efficiency of the movement is important.

Another frequent confusion happens in the case of mechanics applied to bios (particularly, in the case of athletes), when this is considered biomechanics. In applied mechanics to biological structures or to ensemble of athlete and equipment, accessories or technical sports, the viewpoint upon movement is different from biomechanics. In the case of these theoretical disciplines, the external forces are found in the center of attention, and not in the internal one, as is the case with biomechanics.

One example would be the one when the body of the athlete (by his center of weight), during the jump, follows a parabolic trajectory (due to the gravitational force), regardless of other forces initiated by the muscular contractions during flight; another example is the leaning forward of the body of the athlete while running on the curvature, which is the effect of the counteracting of centrifuge's forces and it is studied by mechanics, not by biomechanics. It is very true that, if it cab be put this way, biomechanics takes the help of mechanics laws, it uses them to full extent, but it would be an improper, we consider, that biomechanics be mistaken for applied mechanics to bios, particularly to athletes, that is in sports.

Many of the movement problems in sport have different solutions from the viewpoint of biomechanics, as compared to applied mechanics (in sport). Also, a series of grounds and laws in mechanics cannot even be applied to biomechanics. By example, in mechanics forces appear and disappear instantaneously, while this theorization would be unacceptable, even inappropriate, if it were applied to muscular contraction and its forces. In mechanics, the lack of place changing means lack of mechanic work and, implicitly, of energy consume, while in biomechanics, lack of movement (as when a big weight is maintained unmoved) means consume of muscular energy, means fatigue. More than this, mechanical properties of biological tissues cannot always be simplified to mechanical models, to which laws can be applied, as for elastic bodies or absolutely rigid ones, etc. Some tricks of mechanics, such as the one of infinitesimal deformation of fictive forces, are not fir for biomechanics, fact which will be augmented in the next paragraphs.

Now we will present other scientific disciplines which study movement, but which, being obviously different, cannot be mistaken for biomechanics. But, their links with biomechanics being more obvious, even though they interfere with it more or less, could be asserted as being not disjunctive. Their presentation is, in fact, an attempt to underline differences and resemblances, and is not meant to be taken as a list of definitions.

Briefly, the following scientific disciplines or sciences to be born have, among other things, a mutual object of study with biomechanics (that is movement), but they have different viewpoints, different purposes and means:

Kinanthropologie, a branch of Anthropology, which studies movement viewed as effect of all biological functions involved. Movement is extended to groups and sets, having a social character;

Kinetotherapy, a discipline where movement is studied and utilized as main means of recovery and rehabilitation after trauma, locomotory affections etc. The study of movement does not have as purpose the performance, as is the case biomechanics, but the habitual normal, or a minimum of losses of motory abilities;

Kinetoprophylaxis, - where movement is studied and utilized as prophylactic means, meaning that the vector of interest is permanently in the normality zone (not in that of pathology, as is the case of kinetotherapy);

Kinesiology, or the "science of movement" (as it is called by some authors) is often considered synonymous with biomechanics. We believe that this scientific discipline looks at movement from a qualitative and phenomenological point of view, insisting on its spatial shape and it has amore didactic role than a practical one; by difference from this, biomechanics is concentrating its attention on practical performance;

Ergonomics, (ergon = work, nomos = laws) where the movement is studied through the eyes of professional efficiency, for the physical work efficiency;

Ergophysiology, where movement is studied as a physiological mechanism and as biochemical processes;

Ergometry, where movement is normalized and standardized by physical work efficiency;

Biophysics, where movement is studied as particularity of bios; its causes being extended to biochemistry and bioenergetics. The systemic treatment of movement has a discontinuous character, taking the help of subsystems. The interest for movement is focused towards the clarifying the mechanisms. Some authors consider that biomechanics is really a branch of biophysics;

Biokinetics studies the phenomena generated by the movement in bios;

Bionics studies, besides other phenomena, the sensorial movement in bios (especially the locomotion of evolved human subspecies), with the revealed purposed of copying it in the technical domain;

Robotics, where the movement in bios is studied with the purpose of replacing or automating it by technical devices;

Functional anatomy (comments in the above given text), where movement is studied from structural and kinematical point of view;

Descriptive anatomy (comments in the above given text), where movement is studied from a structural and geometrical viewpoint;

Orthopedics, especially in its part dealing with mechanical prostheses and biomaterials, studies movement in order to imitate and substitute normal movement in case of deficiencies, dysfunctions and amputations;

Mechanics applied to bios (in sports, cosmonautics, etc) – comments in text given above – where movement is studied as effect, mainly, due of external forces;

Kinematics applied to bios, as part of physics, studies trajectories and velocities of movement, without taking into account its causes that is the forces which generate it.

In this context, it can be also talked about an eventual belonging of biomechanics to consecrated sciences, such as anthropology, biology, or even physics. Anthropology, the same as other nature sciences, being itself a not a science, undoubtedly includes more sciences and scientifically disciplines; but this fact must be looked at, rather, as a belonging to a family and not as a relation degree. As far as biology or physics are concerned, the denomination of biomechanics suggests ascendant links with biophysics, for the most part with the “substantial” biophysics.

Physical education and sport are, undoubtedly, the scientific domains in which biomechanics developed and in which it has the most spectacular applications. Biomechanics and physical education and sport evolved together and, probably, the symbiosis will last yet longer time.

It also must be mentioned that the association of biomechanics with iatrophysics and iatromechanics (pseudo-sciences which reduce bios to purely physical and chemical mechanisms) would be an immense mistake. Of course, for didactical purposes, we can simplify the biological reality to mechanical or chemical patterns (such as the muscular converter of energy), but we cannot lose sight of the eutrophical character of the evolution of the muscular “engine” which, apart from usury, produces overcompensation, as well.

1.4. Brief History of Biomechanics

It is known that the first serious reports about what today is considered as biomechanics were made by Aristotle (384 - 322 BC), in his treaties about animal parts and their movements.

The description of some muscles' actions, utilizing geometrical sketches, is amazingly precise, but we are most surprised by a reference to the athletes' technique of jump: "…the athletes will jump further if they hold in their hands weights which they will put in motion during the jump…" We will come back to this thought when we will try to explain the role of inertial masses in velocity changes.

Extremely known for his principles form hydrostatics, Archimedes (287 – 212 BC) is the author of some studies about the movement of the swimmer, studies that refer to a notion which can be translated as "center of gravity" of the human body, having a very similar meaning with the one from today.

Maybe nobody is surprised by the fact that the genius of Renaissance, Leonardo da Vinci (1452 – 1519) took up in his studies to talk about, besides other topics on art, technique and inventing things, the movements of the human body. He describes anatomically and functionally the synergy of muscles, noting with letters (at that times very less muscles had a name) every muscle which participated in walking, jumps, standing form sitting position, etc. Perhaps, trying to improve the efficiency of human movement, Leonardo da Vinci imagines links of ropes in the insertion and origin zones of some muscles. His sketches with propulsion mechanisms by human force are famous, both as graphic expression and as proof of his genius intuition and the understanding of the principles of mechanics at that time. Some device for developing the metrical quality from our time is amazingly similar with his sketches.

All remarkable studies of biomechanics consider the treatise “"De motu animalium" by Alfonso Borelli (1608-1679) as a reference work. Borelli proved that bones and segments of the body are, in fact, levers put in motion by muscles according to mechanical principles. He introduced the notion of resistance of air and water and made correct energetic accounts of human movement, even though his explanations may today seem naïve: "…reaction of spirit with the substance of the muscles produces fermentation which leads to contraction…"

We should remember the work of Nicolas Andry (1658-1742), who names and defines, even from his title, Orthopedics, as "art of prevention and correction of deformities of the child's body…"

No matter how brief would a history of biomechanics be, the contribution of Isaac Newton (1642-1727) cannot be omitted; only a small number of physicians know that his famous laws were illustrated by their author himself and by analogy with the disc throwing, besides the examples usually known.

Another work which, according to our opinion, must not be omitted is the *Kinesiology* of Arthur Steindler (1878-1959), in which the author systematized for the first time the methods and means of movement study.

In the last decades, biomechanics developed and extended because of the growth of interest for professional sports, for solutions of rehabilitation and amelioration in cases of congenital pathology, of recovery after trauma, orthopedics, etc. as well as for the technical copying of mechanisms and effects in bios.

The study of biomechanics became increasingly organized and coopering with other disciplines. There have appeared bodies and international societies such as, by example, the International Society of Biomechanics (ISB), founded in 1973 in Pennsylvania, USA (of which the author of these lines had the honor and privilege to be member from the beginning), the International Society of Sports Biomechanics, the European

Society of Biomechanics, as well as others. In a short period of time, by international synergization of activities and by interdisciplinary exchange, these societies have won a refutable prestige. There were thus created facilities of changes of specialty information by periodical publications, in a coopering and competition environment, such as: Journal of Biomechanics, the Journal of Applied Biomechanics, Clinical Biomechanics and the Journal of Electromyography and Kinesiology etc. Other opportunities of promoting biomechanics, of scientific confrontation, were given by the congresses and annual symposiums of these societies.

Even now, from the names of the scientific reunions themselves from the above given examples, the tendency to substitute the appliances and implications of biomechanics with the discipline itself become transparent.

The diversification and reunification are natural historical tendencies of any scientific discipline, and we should not be amazed at the coming up of “new” biomechanics (as a substitute of appliances), such as, by example, the knee biomechanics, the shoulder biomechanics, etc.

The importance, we underline, are another tendency of contemporary biomechanics, the one of identifying its own personality, of making an attempt to become an independent science, with principles, laws and own rules.

1.5. About the Utility of Biomechanics in Sport

The knowledge of biomechanics in sport is useful, obviously, for the specialists in this field, probably mostly to trainers and doctors. We mention, though, that they can be useful, by analogy, in other domains, such as orthopedics, kinetotherapy, aeronautics, cosmonautics, etc.

The specialists in the field of sport can use this knowledge for:

- Improvement of efficiency in the growth process of effort capacity, by increasing the energetic deposits and by increasing the energetic debit (muscular power), or by prolonging the time of effort;

- exploiting to maximum the effort capacity in competitions, by adapting the techniques to somatic and functional characteristics of the sportsman, or by developing new solutions;

- improving the criteria of primary selection for the professional sport, or by compensating the characteristics, within certain limits, or by reorientation towards other sport branches of the beginners;

- Individualization of solutions of sport training, taking into consideration the equifinality of these in performance; by example, an athlete with relative less strength, but with high speed, can obtain the same performance at the throwing of the weight as another one, who has grater strength, but has a relatively small speed compared to the first one. This reality implies, therefore, individualized solutions for the training;

- Maximum exploitation, for the benefit of the performance, of skills predominantly genetically, such as joint mobility, muscular elasticity, some length proportions of the body segments, etc.

Finally, we want to underline especially the role and the importance of the biomechanics knowledge which the doctors in sport can use in sport traumatology. The knowledge and study form a biomechanics viewpoint of the way of occurrence of accidents, wounds, muscular or bone breaks, etc. play an extremely important role in the avoidance and prevention of these. Also, recovery and therapy in these cases are improved if the biomechanics causes of accidents are known as well as the effects of some recovery solutions which limit the movement (prosthesis, plasters, devices for fixing and stretching, etc.). These, used inadequately, can have bad side effects.

It is useless to insist upon the fact that like orthopedics and kinetotherapy (applied especially to deformities induced by the practicing of some sports) can only have advantages, if they were supported by a good knowledge of biomechanics.

1.6. About the Academic Position of Biomechanics

The biomechanics knowledge in sport can come from the observance of the movements in this field. It happened many times that the specialist, means the one who would have offered new solutions in performance, found himself in the uncomfortable position of explaining some new styles and techniques to some performers, without being capable of foreseeing them, let alone develop them theoretically (as it happened in the case of jumping with the back towards the lath in the so called "Fosbury" style – after the name of the American height jumper who invented it and used it for the first time; this style brings a height gain of 20 – 30 cm as comparable to other known techniques).

Nothing stops us to believe that it is possible that this style could not be the best one and another one must be searched, means another biomechanics source of improving performance. In other words, the biomechanical sources of improving performance are not negligible, even though, in general, the biomechanical sources and methods are richer.

The study of the principles, laws and relations between the fundamental measures applied in biomechanics can lead to the elaboration of logico-mathematical patterns, the simulated behavior of which (especially computers) could offer new scientifical information, with the condition that this behavior to be put into practice. In other words, the passing of a hypothesis to the level of thesis goes beyond the phase of the hypothesis confirmation and, so, it needs to be proved.

Finally, the experimental research with sensorial means, such as the measuring of the space, speed, force, etc. can lead comparatively (by reference to some logical or statistical grounds) to the labeling of the sportive performance from a biomechanical viewpoint.

We are of the opinion that the academic position of biomechanics must go beyond the diagnosis and prognosis faze of traumas in professional sport and it is high time it brought a more substantial contribution to the thesaurus of knowledge about the human performance, in general, and sportive performance, in particular.

On the other hand, the current performances of computers open new ways of biomechanics movement study. The computer simulations could bring new information about the control and regulation of movement, as well as physiological limits and resistance of biological materials.

II. MOTION IN BIOMECHANICS

2.1. General Consideration about Motion

Motion has been a very controversial subject as far back as in antiquity. For example, Aristotle said that, during falling motion, “heavy bodies fall more quickly”. It is known that this assertion is false; the scientific truth about the falling of the bodies contradicts this apparent perception of Aristotle’s, in which, to the surface of the body and to the resistance of the medium, are not granted the roles they have. Aristotle could have referred to kinetic power or could have used the verb “to fall” in the sense revealed by Lucretius, that of advance through an opposing medium.

We aren’t trying now to revise all the historical meanings of the notion. Our intention is to stress the fact that motion is a very complex phenomenon, despite appearance.

Some important authors grant motion the primordial role, the one that determined time apparition and others equate motion with life itself. Although for a modest application, like biomechanics, motion can be defined very simple, the phenomenon of motion, in a philosophical sense, is still a controversial subject. Is motion a cause or an effect? Who could say that motion, as the existing form of matter, is a thesis and not a hypothesis?

We continue to appeal to the ideas of some famous thinkers, but this is not an inroad in philosophy history, it’s just an intention to urge the readers on their own reflections. Thus, Galileo considered that falling motion is uniformly accelerated, final speed being, in this case, proportional to time’s square. Aristotle said about uniform motion that it necessitates the constant action of a force (impetus), which is false. Not to speak about inertia, which, in almost all the books, is considered exclusively a quality of bodies? Rarely the inertia is considered an opposite force of the agent of the motion.

We remind that inertia, as it was axiomatically enunciated by Huygens, resuming almost completely the definition given by Descartes and raised to the rank of firs law of mechanics by Newton, seems to be the quality of each body to maintain the rest or motion state in a straight line, excepting the situations when the body is subject to some constraints.

If, to the didactic level, can be accepted definitions in which are not specified circumstantial elements, to a scientific level is not accepted only the interpretation of the effects, without referring to process and cause. As there is no memory without the substantiate matter to memorize, inertia can't be part by the force that acts on the body. We consider that *inertia is a reactive characteristic of bodies only in the presence of a force*, as the capacitive reactant of a condenser makes sense only in the presence of electric power. We will come back on this subject in the next chapters.

Trying to synthesize the essential, results that a strict definition of motion appeals to exigent expressions and that urges us to refer to *genus proximus*. This means that we have to take a short plunge into philosophy.

From an existentialist point of view, it is known well enough that matter, in its modal forms of substance, energy and plasma, modifies, changes, transforms itself etc, meaning that it moves. The ontological point of view is, in our opinion the energetic entropy, and the gnoseological viewpoint is the informational entropy. We consider that motion is a modal attribute of matter and not an existential form of it.

2.2. Motion on Muscular Contractions

As regarding muscular contraction, the kinetic energy of the corporal segment or of the entire body comes, in general, from the conversion of the chemical energy of acto-myozinic processes. We remind and stress the fact that only ATP and in a little extent, ADP, produces energy and the anaerobic or aerobic processes that accompany contraction refer only to ATP resynthesis, not being direct energy sources.

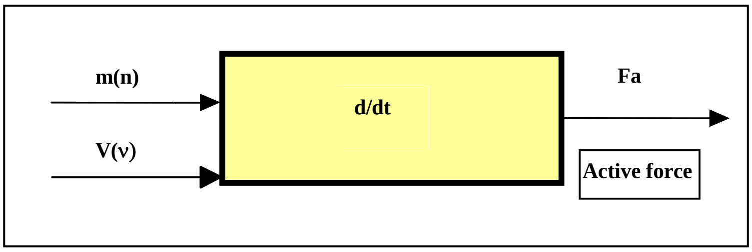
At a cellular level, not taking into account every organism's type of cells, ATP synthesis is based on the rotary engine effect, produced by the protons attached to the transporters through mitochondrial membranes. Recently (in 2001), a researching team at Keiko University from Yokohama, using nanometric technology of attaching a gold colloid to the rotor of the molecular engine, was able to visualize the rotary effect of macroergic molecules. The experiment has shown that the rotary model is a multiple of 30 degrees, each step meaning ADP or AMP delivery. It resulted, a new fact for science, that the parts are interconvertible with a little energy consumption and that resynthesis is a reversed spinning process, with 90 degrees.

Probably that, in the near future, the study of ATP molecular engine will belong to biomechanics; meanwhile, people are not very interested in the way of producing net power, that shortens the length of the muscular fiber, but in the operator of the mechanic dimensions that generate this power. Starting even from electrochemical tension or from the difference of electrostatic potential, you reach the basic dimensions of biomechanics, through the muscular mass put into motion. On this process, we have to remind that the motion of muscular mass depends on temporal and spatial recruiting of synapses (n) and the frequency of vibrations (ν), neuromuscular commanded.

To explain the isometric contractions that lack shifting, it's important to emphasize the fact that the speed vector on the rotation of interpretation of myosin and actins filaments changes its sense periodically, and the resultant is void. In this case, the positive vectorial speed, as a consequence of surpassing the resistive force, means concentric motion, and the negative one has the meaning of eccentric, submitting motion.

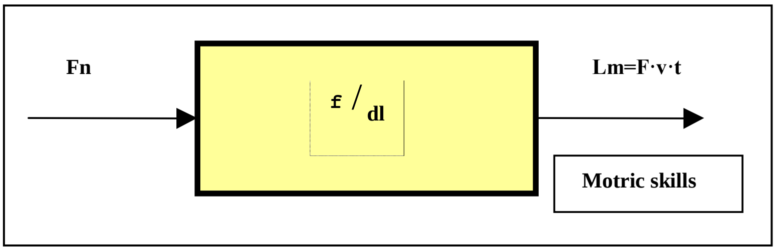
Vibrations we are speaking about are of a special type, of relaxation (are not harmonics), so spectral Fourier tests can't be applied; they represent, in a philosophical sense, in our opinion, the sudden change from bio to mechanics. When analyzing speed resultant, can be taken into consideration at most combined dimensions, as fill in values.

In the first stage of derivation, of rapid conversing chemical into mechanical energy, the operator of the mechanical dimensions that generate force is one variation:



We call the difference between active force and resistive force, net force (Fn). The movement or other mechanical effect is produced by the positive net force.

The mechanical work accomplished by the muscles (at a local level) is the effect of active force that acts on the distance during contraction time:



It results that the muscle in contraction develops three basic motric skills: force (strength), speed (velocity) and endurance (resistance); whose product is an individual constant, like their structure.

2.3. Movement in Biomechanics Practice

We remind that the meaning of the word motion is very complex, although it seems very simple to recognize motion around us, as variation, change, transformation, modification etc.

In biomechanics practice, we can say that motion limits to its most evident form: movement. It represents a particular aspect of motion that combines the main characteristic of the evolved species' biology, muscular contraction, as main characteristic of terrestrial mechanics, space.

Next, in respect for tradition and for simplicity, when we don't make other specifications, motion will mean movement in Euclidian space (in a rectangular system of axis) of a material, segmental part or conventional body (point that fictitiously concentrates masses or weights).

Consequently, biomechanical motion is a movement, a position change. To eliminate redundancy from this definition, we have to use a brief comparison between the basic dimensions of mechanics and biomechanics. Thus:

- Physical time is a continually increasing dimension. The basic notion of biomechanics, extracted from the physical time is *duration (t)*. Duration is the difference between two moments of continual passing the time and always has a positive value. According to

International System of Measurement (S.I.), duration is measured in seconds (abbreviated s, not “sec”);

- Euclidian physical space is used in biomechanics by the notion of *position*. The position of a material body, a corporal segment or the entire body, is most frequently esteemed in rectangular coordinates x, y, z, as according to a reference system, pre-established. The difference between two positions is a length and a proper space (s). The sequence of spaces represents a trajectory and its length between two considered positions is a *distance (l)*.
- In biomechanics, material bodies always have a volume and a density of the matter in that volume, so they have a mass. Gravimetrical mass is a dimension of the force with which the earth attracts material bodies. The measure of weight (W) in biomechanics is a product between mass and gravitational acceleration ($g = 9.81\ m/s^2$, on the average). Consequently, it is a force. The weight of an athlete, for example, is usually measured in kgf, but it would be correct to be used S.I. unity, named Newton (N). One kgf is equal to 9.81 N, so an athlete who weights 70 kg (kgf) has a weight of 687 N.

Turning back to biomechanical motion, we can now make the specification that biomechanical motion is an observable movement (of certain duration) from a position to another of a weight (usually a body or corporal segment). Thus, biomechanical motion makes use of concrete notions, has a duration (is not sudden), refers to a real body having volume and density (not hypothetical) placed in the gravitational Euclidian space (terrestrial speeds).

We have to notice that behind this definition stay the geometric considering and the kinematical or dynamic considering of the movement. As regarding the process of transmission and preservation (inseparably connected to motion), classical mechanics laws apply, and as regarding power, are implied the laws of biology, that refer to chemical energy conversion into mechanical energy.

Human natural motions as walking, running, jumping, throwing etc. have been completed in physical education and sport with atypical motions, specific to every physical exercise or sport. Thus, in physical education and sport, we distinguish motive gestures, acts and motive exercises, all of them being forms of corporal or segmental motion, oriented towards a goal, as a rule, the increasing of physical effort capacity. When the exercises are oriented towards a goal of physical education and sport, these become training tools. In fact, all the exercises of physical education and sport are training tools, but not all the training tools are exercises (as already known, in physical education and sport are used other means, too, as pedagogical, psychological etc.).

Movement in biomechanics, even it is mainly based on idealized concepts from kinematics, has a particular meaning, because it also uses concepts borrowed from biology and physical education and sport.

We also remind that kinematics is the part of physics that study motion geometrically, using the notion of vector and other idealized concepts, as material point. If we take into consideration also the cause of motion, which is a force, then physical motion is studied by dynamics.

Movements from biomechanics are classified according to some criteria; some of them are borrowed from mechanics (translation, rotary and combined – helicoidally motion), others are taken from descriptive anatomic (flexion, extension, adduction, abduction motions, those referring to a conventional plane – sagittal, coronal or transverse) etc.

Specific for biomechanics is the classification of movement in concentric or eccentric (referring to the acting direction of muscular contraction) and in simple or complex movements, subdued to synthesis or analysis (both steps being qualitative and quantitative).

2.4. Movement Regarded Vectorial

Vector is an artificially created notion, to synthesize the idea that some physical dimensions besides magnitude (dimension) has direction and sense. Probably vectors appeared for the first time in navigation where, besides a distance (for example 5 miles) direction has also to be specified (for example 5 miles north). Vectors are graphically represented by arrows, having an application point, a length, proportional with magnitude and sense on the direction of needle body, indicated by its point. Symbolically, vector is represented by a line with or without needle, overcharged to a letter or abbreviation.

Space, speed, acceleration and forces are vectors and dimensions as mass, power, energy are scalar (having only magnitude).

Vectors are composed by geometrical rules, as for example, parallelogram's rule. By this kind of rules is obtained a resultant vector or, briefly, a resultant that replaces the combined effect at the composing vectors.

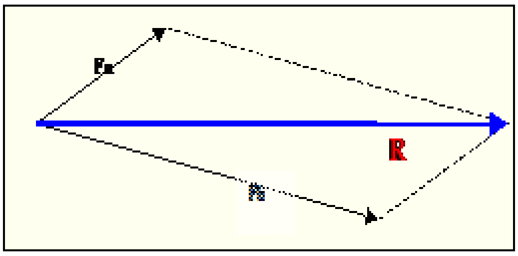


Fig 2.1. Vectors' composing illustration. The resultant R is an intuitional force that replaces the action of Fa and Fb forces.

The most suggestive illustration is that of composing of two forces that act vectorial, meaning on different directions.

***Force** is the cause of motion*. The entire classical physics is based on the principle according on which, a body preserves its rest or motions as long as on it doesn't act any force. About force we have to mention that no scientist has measured force yet, but only its effects (especially movement or deformation). That's why many important dictionaries define force very vaguely, for example *Oxford Dictionary*: "Force is the cause of all effects".

Regarding to muscular contraction, characterized by the relative movement of some corporal segments (as a result, a mechanical effect), the *cause* of movement is an electrochemical potential or an electrostatic force, however a cause of another kind than a mechanical one, other than the one known as its dimension: $F = m \cdot a$.

2.5. Inertial Motion

According to classical knowledge each body tends to continue its motion in a straight line or to remain in a rest state excepting the situations when it is subject of some constraints. This characteristic of the bodies is called *inertia*. Some authors consider that inertia is an opposite force to the tendency of varying the net force. The first veridical assertions about inertia are know from Galileo; then comes Descartes, who brings adding about constraints and Newton formulates the first law of mechanics, that raises inertia at a rang of principle.

Galileo's argument, according to which a body that moves on an inclined plane will continually increase its speed and a body, thrown up on inclined plane will continually decrease its motion to a end, leads to the conclusion that a body thrown on a horizontal plane will keep on moving with a constant speed. The fact that its not specified if the motion with constant speed is rectangular or curvilinear, parallel with ground surface (which, in Descartes opinion is a constraint), puts in difficulty the definition of inertia.

The original formulation regarding inertia, in Newton's *Principles*, which also specifies that motion is natural (uniform and in a straight line), has been (and probably still is) a fact far from being evident from every-day observations. Even nowadays it's hard for those uninformed to think that a body let for itself will continue its constant motion, meaning that it will not decrease it and will not stop. In exchange, the effects of inertia, met very often, starting from the pushing in the bus that brakes, to the flywheel of the toy-cars, that are propelled with a kinetic energy, accumulated by rapid movement, from the trips in football to bobsleigh pushing etc., don't surprise and are not contested by anybody.

Inertia, as Newton himself said, is a passive characteristic; motion is not due to inertia, but to the lack of an opposing force. Inertia shows the tendency of the mass' body to be in opposition to the changing of the speed. Inertia can neither be defined, nor explained only by their effect; that's why, in our attempt to go deeper in the essence of inertia (addressed to curious readers, who are not in a hurry), we also make use of other notions, as *space, inertial system, ether and mass* that we can't but take into account. We mention that the followings lines are not absolutely necessary for biomechanics study, they are only supplementary readings, referring to its basic notions.

Along the history, opinions about *space* have suffered major changes. Today, if a common person would be asked what space is, he would probably give an answer based on two ideas: that space is void (as a recipient in which matter can find room), continuous (endlessly divisible), the same everywhere (homogenous) and that it doesn't have a favorite direction (anisotropic) or that it is composed of elementary particles (discontinuous), that is limited and, in general, has a certain geometry.

In fact, these diverging opinions about space, copy almost holographically, the history of philosophical controversies: physical space *versus* mathematical space (independent by matter) *versus* relative space (positional, of the objects) etc., these, as Einstein said, shouldn't be but work hypothesis. From this point of view it's interesting the definition of space, formulated by Einstein himself: „…conceptual object, presupposed real, that determines the behavior of the real objects, without being influenced"; or „…space is determined by matter distribution". It's a pleasure for us to remind you a scrupulous definition of space, given by the great physician Heisenberg: „space is blue and is the place where birds flay".

The issue of space connected to inertia it's not contained by its definition, but by its quality to transmit forces: *instantaneously*, at any distance, as resulting from the universal law of bodies interaction or *ondulatory*, which means a speed dependent on body and medium density. To argue any of these solutions of force transmitting, it was necessary to invent a virtual medium, called *ether*, which to posses, theoretically, a function of dilution for the matter that fills space, or a function of oscillations agent, co-existing with the space, with or without matter included.

It is known that electromagnetic waves propagate through void space, meaning through mediums that practically lack matter, producing at distance, some effects, motion being one of them. The consequence of such knowledge acquired experimentally, was the apparition of some *models of ether* (as that of Poisson's, as an elastic solid, compressible, Mac Cullagh's – containing potential energy, dependant on the rotation of its elements, or Thompson's, Maxwell's, with different spheres, canes or hypothetical flywheels) which explains, between other things, the fact that motion can be induced by other means than pressure and impact.

Therefore, the space is additive, no matter if it is considered continuously or discretely, no matter if it is absolute or relative; space respects the rule of addition. The following reasoning can be skip by the readers, without any lost of biomechanical meaning[1].

By other hand, we have to say that the postulation of cumulative mass is disputable. In the terrestrial space and according to the classical mechanics the discrete mass of molecule cares the substantial identity, as well as the atomic mass defines the matter's structure.

For instance, let us consider a substantial object of volume *vol* and mass *m*, no matter what. This object can be theoretically divided in two or more parts of volume, which, in the cumulative way can rebuild the whole, as well as it can be divided in two or more part of mass; the minimal being the mass of one molecule.

From the practical rationally point of view, the mass should be concentrate in a single point (centre of mass). It is to understanding that this point of mass is not a mathematical one (without any dimensions), however is a point with infinitesimal volume consisting from a group of molecules (more that one), hereby the substantial understanding of the object's nature to be not compromised. (By our opinion, it is meaningless to concentrate the whole mass into a molecule, but is reasonable to consider that the biggest part of mass of the object is concentrated into a group of molecules - belongs to the centre of mass of an infinitesimal volume - and the rest is dispersive into the additional volume). It's result a fictive object (model), as a work's premise, having a average density of two extremes densities.

We underline that, in our grounds, the tendency of cumulative volume is evident, the tendency of partition mass is stipulated by the nature and structure of the object and the density has the tendency to rich the (conventional) average.

Otherwise, the density is a (negative) entropic characteristic mutually for energy and information.

Different saying, this fictive object (model, which is simplifying the real object) has an average density consist of a small part of extreme height density and as less as one part of lowest density. As a result, lifts the possibility of a reaction of the force's momentum, depending of the distance between the conventional parts of the object.

[1] Every where the text is writing in small fonts

This is the circumstance of to say that any force action applied to the center of mass m_c of an object, can be a cause of producing a quantity of movement propagate into the body of the object as follows:

$$d(mv) := k \cdot \int_{vol} div \cdot grad\left(m_c\right) d(vol)\, dt$$

If the force's action is time's independent, then:

$$\frac{d}{dt} mv := F \qquad\qquad F := m \cdot a$$

This is meaning that the object takes an instantaneous acceleration without of inertial moment. Otherwise, a latency of effect is appear, most probable equivalent of rest inertia.

About inertia, it also has to be cleared out the fact that the difference between rest state and uniform motion is given by the position of the observer, who can be placed in an *inertial or uninertial point*, as he moves with the body speed or an accelerated speed, as regarding the body. Newton intuited that a space, in which the centre of the universe is always in a rest state, is an essential hypothesis to convey the law of inertia an operational content.

Another adjacent motion, about inertia, which has to be clarified, is *inertial mass*. Even if we adhere at the assumption of mass gravimetric as a measure of resemblance with the quantity of matter contained in a body, resulting from its density and volume and formulated by Newton, still, the impossibility of identifying a quantitative difference between the dimension of gravimetric mass and of the inertial one, leads to the idea that inertial mass is just a relative expression, explainable by Einstein's theory of relativity. However, we don't have any other reason to believe that it would be two kinds of mass.

As a consequence, inertia even if it's judged at the level of impulse or force variation, appears as a reactive measure, accumulating in the discrete structure of the body. It can be accumulated in motion's start or can be released at motion's brake, as an inertial force or as rest inertial energy (in both situations). Besides, we don't have any basis to justify why it would be necessary for biomechanics to transcend a deductible-axiomatically of inertia explanation.

We present however, to readers' attention and imagination an intuitive hydrodynamic model of defeating inertial force in starting of a motion, due to muscular contraction. In this model, as it is shown in the figure below, the chemical energy that enters the system is symbolically represented by a hypothetical fluid, whose level is *Fa*.

Fa is also the difference of potential, meaning the force that produces the conversion of this energy in mechanical energy at neuro-muscular command, symbolized by a clack that opens, starting with *t* moment and having the effect of a variable admittance *Yd(t).*

The effect will be the passing of the hypothetical liquid in the inertial recipient with the physical dimension of inertial mass *(m),* when the entire force (explicated by the fictitious speed *Va*, the admittance *Yd*, mass *m* and time *t*) will be transformed into *inertial reactive force* (explicated by the inertial fictitious speed *Vir*, of the same mass, *m* and of duration *t*).

In fact, by speed should be understood hypothetic debits, as by forces are understood levels of hypothetic liquid.

For the beginning, as long as inertial mechanical force, represented by the level of the liquid in the inertial recipient, doesn't surpass the resistive force *R*, the vector of the inertial speed *Vir* increases, but kinetic speed *V* remains null (because the exit from the system illustrated by the mobile sliding valve, remains blocked).

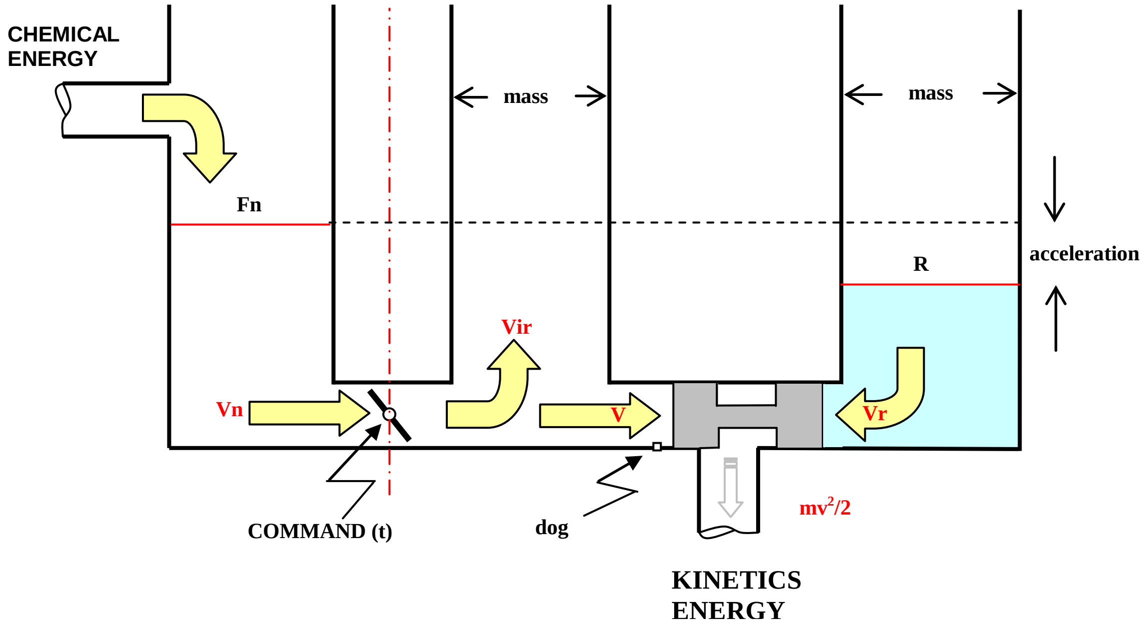


Fig. 2.2. The effort's intuitive inertial model (of a hydrodynamic type). Explanations in the text

In the picture is also represented a dog, that blocks the motion of the sliding valve, pushed by the resistive force, meaning impossibility (in this case) of eccentric motion (of muscular submitting). We can also notice in the picture a vertical line (red and broken), which fictitiously marks the "body" that act from the acted body, even if the moved mass includes also the active muscular mass. When the "fill" of the body acted with inertial reactive energy reaches a level in which the inertial force surpasses the resistive one, the exit from the system blocks, by the sliding of the valve on which have already acted, from opposing directions, disequilibrated forces. Thus appears the motion (characterized by the kinetic energy from the system's exit), in which speed will be a vectorial sum between two speeds *(V* and *Vr),* placed, respectively, on one side and another of the sliding valve and will increase up to the moment *Fir = Fn*. Then motion enters a stationary working condition. From the moment of starting the neuro-muscular commands, to the stationary condition, motion is retarded and the starting is made progressively, thus being simulated the phenomenon of inertia. The duration of this transitory condition in which is manifested „accumulation" of inertial force or impulse depends on the body weight (which is identical with that generating the force of resistive weight) and on the difference between net and resistive force. According to the principle of dynamics, this difference generates acceleration *a*. We further present a diagram of motion quantity variation. By it we try to illustrate the transitory condition of rest inertia (hard starting of motion) and also the transitory condition of continuing the motion after the stop of net force action (tendency of prolonged brake).

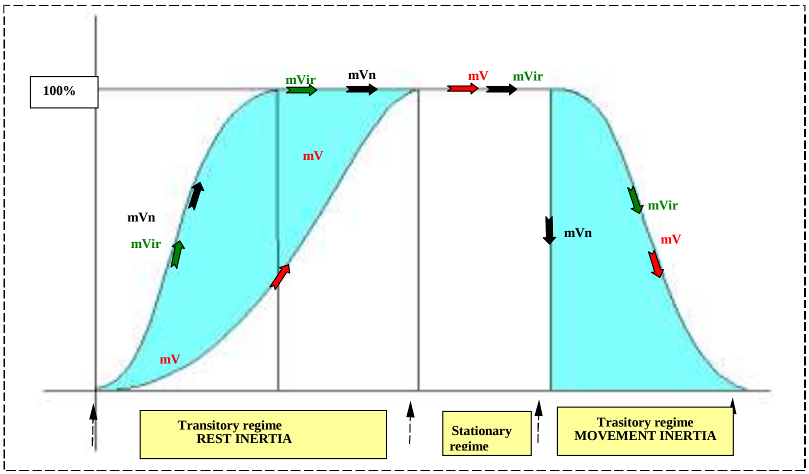


Fig. 2.3. Diagram of the inertia in different regime of effort

As seen in the diagram, in the transitory condition of starting the motion, nominal speed (*Vn*) is retarded, because of the quantity cumulating, of motion (or energy), inertial reactive (proportional with the shaded surface). The same quantity of reactive inertial motion (or energy) is discharged as kinetic energy in the transitory condition of motion inertia, although the action of the net force ceases suddenly. Durations of these inertial transitory conditions will be equal only if the resistive force will be constant.

Presentation, in this book, of motion equations (of a Lagrange type) of transitory conditions is not necessary; we could also consider useful to emphasize that the variation way of the admittance mainly depends of the neuro–muscular commands, on the temporal-spatial recruitment of synapses. So, the admittance can’t be a constant coefficient of these equations.

III. MAIN BIOMECHANICAL DIMENSIONS

3.1. The Minimal Lexis of Biomechanics

Biomechanics can be better understood or studied thoroughly only if there is an agreement regarding the notional matter of some words or expressions, considered basic. Otherwise, confusions can rise or, more injurious, can be lost the important contribution of biomechanics to the progress of other disciplines, as for instance, physical education and sport.

Probably, the most used term of biomechanics is *motion*. Although it may look ordinary to deal with the particular meaning of motion in biomechanics, we still believe that some clarifications are necessary.

3.2. Irreducible Main Biomechanical Dimensions

Sometimes, in the case of didactic level are accepted definitions without any circumstantial restrictions. By opposite, at the scientifically level it is necessary to judge the effect taking into account of the process and cause. As for instance, it is unacceptable to describe the memory without any physical support, or electrical resistance without resistor or electric current, similarity in biomechanics the inertia can't be depart from the force acting upon an object, including, of course, his mass.

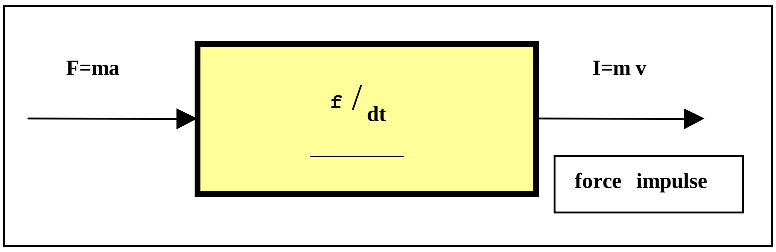
In any scientific approach, the start is represented by notions axiomatically accepted. In the case of motion (no issue if it is displacement, extension–compression, condensation–dilution, division–combination etc.), we believe that *time* is the axiomatic physical dimension (continuous, positive and increasing) of reference for *variation* (change, modification etc.). In the biomechanics the variation starts, conventionally, from the time zero and has ***duration (t)*** till to the final. If variation has a spatial sense, this becomes *movement*.

From the easiest notable forms of movement, the most frequent is *shifting*. Shifting of an object, thing, or, in general, of a mass is the change *of position* in Euclidian space.

Every shifting (as changing the positions) is characterized, exactly enough, by *trajectory* and *momentum speeds*. The length of the trajectory represents the biomechanical ***distance (l)*** between two conventional positions: initial and final. The simplest movement from the initial position to the final position is the rectilinear one and represents the geometrical distance, not necessary the biomechanical distance.

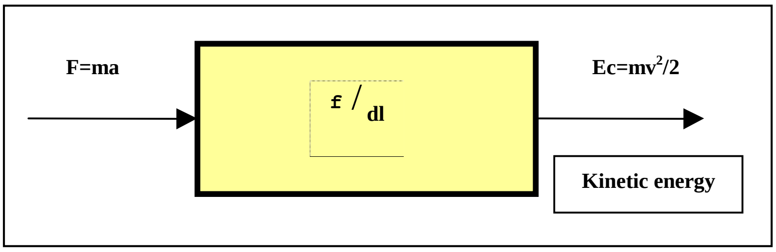
Practically, the movement is characterized by distance, or duration and average speed. By consequence, the speed is an attribute of the shifting that is giving us information about the rapports between distances and its related durations.

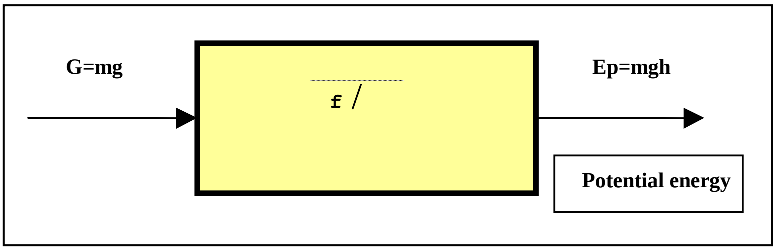
Force is the cause of all the effects. If the effect is the variation, in general, then force's operator is *time* and force's integral in time is called *action*.



The measure of force in biomechanics is mass acceleration, and force's action is named *impulse (I).*

If variation is a shifting, then force's operator is space and the effect is energy (of the mass), this energy being kinetic or potential.





Shortening, the main biomechanical dimensions are the following:

- *Distance* - as the length of the trajectory. In the case of a rectilinear movement, shifting a body from initial position to the final position, the biomechanical distance is equal to the geometrical distance.
- *Duration* – as an expression of the flowing the time during the movement between initial and final positions. The duration also refers to the impetus of a force that produced equilibrium or a pressure into deformable biological tissues.
- *Force* – as a cause of movement. The weight is also a force, usually a resisting force. We underline that the movement is given by the net force or its momentum as a vectorial difference between active forces and resistive forces. Force can also produce equilibrium,

a pressure into deformable biological tissue and can slow down the overload eccentric movement.

2.5. Reducible Main Biomechanical Dimensions

The basic notions of biomechanics, shown in the previous paragraph are also irreducible dimensions (the simplest) of biomechanics. Let us revise them: *duration* or moment, *distance* or length of trajectory, *force* or weight. From them are composed the main reducible biomechanical dimension. These are:

2.5.1**.** ***Movement's speed (v)***, as a ratio between the length of trajectory or distance of the movement and its duration. For example if movement is an athlete's running on 100 m distance and running time is 12 s, than average speed is:

$v = l/t \quad v = 100/12 = 8.33\ m/s$ (on the average).

The unit of measurement of speed is also noted ms^{-1}**.**

In a simple, but correct statement, ***speed*** is an attribute of the movement that informs us on the relationship between distances and corresponding durations. The limit of the relationship when duration tends to be very, very small is a momentum speed, otherwise is a medium speed.

Expressions like: "speed is the quickness with which…" or "speed is motion's quickness…" are unacceptable redundancies. Although speed measurement in time unities ("speed of 10.2/100 m…" or "reaction speed of 180 ms") is incorrect. Some times the instantaneous speeds, for simplification, can be replaced by *average speed* (s). In biomechanics also very slow movement (as snail displacement) is speeded.

2.5.2. ***Mechanical work (L)***, (or the effort done by the athlete) to lift a weight to a certain height.

Coming back to the example above, on which the athlete's own body weight G = 700 N is carrying horizontally (not vertically) onto a distance of 100 m; where motion is generated by successive muscular propulsion at each step, under a certain angle to the horizontal line, the mechanical work is proportional (not equal) with the product between athlete's body weight and the covered distance:

$$L = k \cdot G \cdot d$$

where *k* is a coefficient of proportionality which in a rigorous expression includes angles, resistance etc. The unit of measurement is N · m, named Joule (J);

2.5.3. ***Power (P)***, as a debit of mechanical work, as an effort done in a certain time and direction:

$$P = k \cdot (G \cdot l) / t \quad \text{or} \quad P = k \cdot G \cdot v$$

Note that power is the product between net force (including resisting force G) and speed. Its unity of measurement is Watt (W), $W = N \cdot m \cdot s^{-1}$

2.5.4. ***Energy (E)***, as a total labor or as a power discharged by definite duration:

$E = k \cdot F \cdot v \cdot t$. Unit of measure is Joule (J).

Let's revise: the athlete that runs certain distance consumes energy proportional with the product between his body weight, the average speed of running and the duration of this running.

If he runs with a constant speed then mechanical power discharged, meaning the debit of energy is proportional with the product between his body weight and the average speed of movement. We can notice that the product between force, speed and time is similar with the product between length, width and height for a geometrical volume, suggesting an intuitional form of enclosed space for the energy consumed by the athlete. Not accidentally, the three basic motric skills of one sportsman are force (strength), speed (velocity) and endurance (resistance). In other words, a volume of carried-out effort would always contain amplitude, in most of the cases named intensity, which is in fact a *resistive force* (load), or the so-called resistive ”charge” which is to be surpassed, a *speed* or a density and a *duration* (a time of resistance).

IV. THE PHASES THEORY OF MUSCULAR EFFORT AND THE LAWS OF BIOMECHANICS

The muscular effort for defeating a resistance force like pulling a weight, like overwhelm the medium's resistance during running or swimming, the friction force against the ground etc., might be better described by phases of the variation of power.

Different as in the mechanical treatment of the movement, where the power instantly appears and disappears, in the biomechanical treatment of the movement, resulted from the muscular contraction, we can't make abstraction of the fact that the chemical processes of producing energy and it's nervous command, has a certain inertia and need a slight time to reach a stable effect. This means that these processes are going through a *transitory phase*. In the same way, after a steady state of delivering power, due to the homeostasis, shown meanly through tiring, is coming another transient phase in which the power decreases constantly, despite of volitional commands are still rich.

Three phases of the muscular effort become obvious:

- The first phase, a transitory one, easily to nominate it *"the starting phase"* begins from the rest or relaxation and finished when power improve a constant value (mainly the maximum one);
- The second phase, a *quasi stable* one, of delivering different rate or constant maximum rate of energy;

- The third phase, so call *“phase of tiring”*, when power decries continuously due to the problems of resynthesis of ATP.

4.1. The Starting Phase of the Muscular Effort

The main characteristic of this phase is the *preserving the force.*

Inertial force (Fir) is conflicting to the growing of active force (Fa), resulting a delay and a slow rising of the net force that produce movement. Apparently, the active force cumulates under the form of reactive inertial force:

$$Fa + Fir = const.$$

As a consequence, the starting speed is retarded, and then progressively grows up as an effect of increasing the net force.

We suppose that this process should be better understand by accepting the analogies with the process of filling up of an artificial lake in an energetic system or with the raising up the electric voltage at a condenser’s electrodes.

At the beginning of the inertial “powering”, the speed is non positive or lowered, and then grows progressively while the net force defeats the resistance force (for example the friction force).

The power as a debt of kinetic energy rises as well, of course, for the reason of speed rising. The kinetic energy grows while the power is rising and, also, while the time is passing.

The duration of this phase depends of the (inertial) mass or weight which is moving, depends of the net force magnitude and of the way in which the admittance of the muscular contraction is changing. We remind that the *admittance* is a passive characteristic of the muscular effecter, resolute by the manner in which the synergic neuromuscular synapses are recruited (in time and in space).

Practically, this duration is extended 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 the competitions for the title of "world's strongest man").

An amusing complement to this idea, as we appreciate it, refers to an unwanted incident happened to the author of these lines in the Danube Delta at a fishing party; when a huge plaurus (some king of floating island made of roasts and vegetal pieces), the size of a handball arena, due to the wind has blocked a lakes entrance. My friend, a powerful Lipovenian fisherman, surely not knowing the phase's theory on which the force preserves, but having experience, has pushed the plaurus with a gonder (a stick for launching and stabilizing the boat) insisting constantly for a few minutes. To my surprise the plaurus began moving slowly, freeing the pass way .At that time I didn't believe that the starting phase of physical effort could last for so long!

4.2. The Phase of Quasi Constant Maximal Power of the Muscular Effort

If this phase is reaching after the start's transitive increasing of the net force, then power has the tendency to be constant (for a certain biological entity, moment or situation).

Because of the fact that the net force becomes maximum force, the measure of the debt power can be wrote as follows:

$$P_n = F_{max} \cdot V_n$$

All debt power is transformed in utility power used for lifting the resisting force or loud (L) added to the body weight (G):

$$P_{util} = (G+L) \cdot V_n$$

As follows:

$$P_{max} = P_n + P_{util}$$

By this way *the power preserves,* and this effect shows that the net speed of the movement depend of the load and body or segmental weight:

$$V_n = P_{max} / [\ P_{max} - (G+L)\ ]$$

Practically and predictable, the preserves of the power means that any increasing of the load or of the resisting force (as for instance in lifting an increasing weight, the speed of movement decrease as a result.

The speed of movement decrease nonlinear and this effect is showing graphically as a part of a hyperbolic curve.

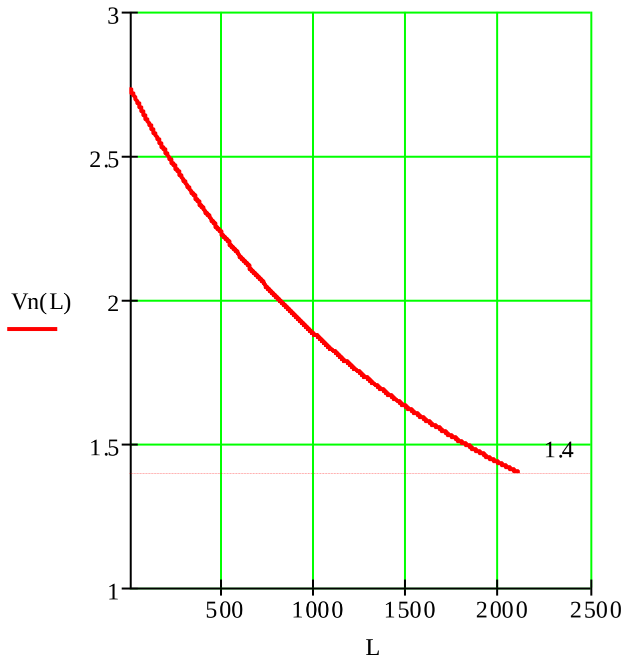


Fig. 4.1. The graphical expression of the power preservation during the maximal effort. Explanation in the text.

The allure of the descendent curve from the above graphic represents usual values for the triple extension of a virtual athlete in the height jump. The relationship between resisting force and the speed of movement (done by concentric contraction) is analogous with the very well know mathematical pattern establish by V.A. HILL[2].

He experimentally observed that this relationship between extra weighed down muscle and its speed of shortening is very close to a hyperbolic one, graphically meaning that the area closed by the respective pears of coordinates is a constant:

$$(F + a) \cdot (V + b) = \text{const.}$$

In athlete, the constant *a* from Hill's relation has the meaning of body weight or of any corporal segments involved in the movement and *b* has the meaning of a theoretical minimal speed for the isometric contraction; in the intention to evict the multiplication between resisting force and movement speed (power) to be zero.

The duration of this phase is about 30 seconds for the professional athletes and in the speed running it is installed in a couple of seconds from the start.

The aroused energy during a maximal effort can reach extraordinary values, some times being above 200 kJ! This phase of the muscular effort, in which the power reaches maximum levels, pseudo constants (tens of seconds for the human species), is characteristic for many sports and has been intensively studied even after Hill's model. 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 mechanic etc. The essences are always the same: the speed of movement decreases while the

[2] V.A. HILL, quoted by very many authors; the hyperbolic relation is well know as HILL low.

resistance forces increase. We will come back to this important idea in the chapter about the laws of biomechanics.

4.3. The Tiring Phase of muscular Effort

General causes that produce the tiring syndrome are known. Most often the energetic aspect is implied, situation in which the chemical energy (ATP resynthesis) does not stand up for the conversion into mechanical work (net power and the time of its flowing). Also, we have to remind the hypothesis of the specific autointoxication, of heterochronics, the neuronal one, the psycho volitional or even the cellular metabolism, as causes for the tiring syndrome.

In any muscular effort which lasts relatively long appears a moment when the aroused power begins to decrease. This moment depends on how big is the effort, meaning on the value of the net power (Pn) and, obviously, on its active "amount", characteristic for every individual and situation.

Biomechanicaly speaking, making abstraction of the psychomotric aptitudes and attitudes, of effort sustains and stimulators etc. (considering them normal), when the time of the effort increases, the net force (Fn) and its speed (Vn) decrease. The relation between these two values is also hyperbolic, with the asymptotes towards the spare energy (which can be accessed only in special conditions).

$$Pn \cdot t = \text{const.} + \text{Spare energy}$$

Practically the above relation says that the exhausting time (t_{cp}) appears before the spare energy exhaust, most probably as a homeostasis effort, of defending, generated by the neuronal system.

4.4. Overview on the Phases of the Muscular Effort

A first remark, apparently surprising, is that referring to the enlarging of the preservation of some components of the kinetic energy, at the same time with increasing the effort time. At the beginning, in the first phase only the force preserves, then, in the second phase, the force multiplied with the speed, meaning the power and in the third phase, the force multiplied with the speed and the time, meaning the energy.

A second remark may, also surprising maybe, is the similitude with the laws of classical mechanics, with their original author Isaac Newton. The first law of mechanics refers to *inertia* and reflects the tendency of preserving the state of non-movement or constant speed, which suggested to us the idea of absorption of the net force by the manevrated body, under the reactive form of inertial force (the so-called pseudo-force in the classic mechanics).

Another similitude of the phases of the muscular effort refers to the envelope (the graphic sum) of the oxygenate processes, combined and anaerobic processes of recovering the ATP (Howard, 1976), obtained through experimental studies. It is, in fact, normal that the two aspects, chemical and mechanical, vary almost the same, considering the extraordinary efficiency of conversion of the chemical energy into muscular mechanical energy, the efficiency being 99.8%.

Another thing to add would be that the professional sport has created different branches for efforts that imply meanly the force, the speed and the resistance, and the natural practice has given to the human being multiple mixtures of these three motric qualities, some how in compensation from individual to individual.

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 it is shown in the following figure, the net force remains the same, because the inertial one, reactive does not contributes to the flow of mechanic energy, the raising of the power being made because of the speed. Less important for the readers are the fact that the mathematic model which describes this transitory phase may be approximated to a third degree equation or to a differential equation type Lagrange, both offering a graphical form shaped as "s".

In phase II, as it is shown in the same figure, both the net force and the net speed practically don't variant at all, which implies automatically that their multiplier is in the same way constant. The efforts in this phase, if it exists, should be maximal. Beyond a certain period (individual, genotypically conditioned and phenotipicaly conditioned), both the net force and its attached speed decrease because of the tiring, causing a downfall of the power line. This phase, if it exists, can last relatively long and it is connected to the resistance efforts. The abandon and the exhaust don't imply the complete exhausting of the total energy, but only the one available in normal conditions. The doping and others, usually prohibited in sports, may reach to the emergency energy of the organism, but not without a following payback, which is sometimes even the health.

In the figure 4.2., two equal areas are colored, trying to show the fact that, in this third phase, the available energy (without the emergency - spare - energy) is constant. It is to say that releasing a big power can be possible on short terms and the other way around.

For example, a sustained running rhythm can't be done over long periods of time, while a slow rhythm of running can be done over a longer period of time than in the first case.

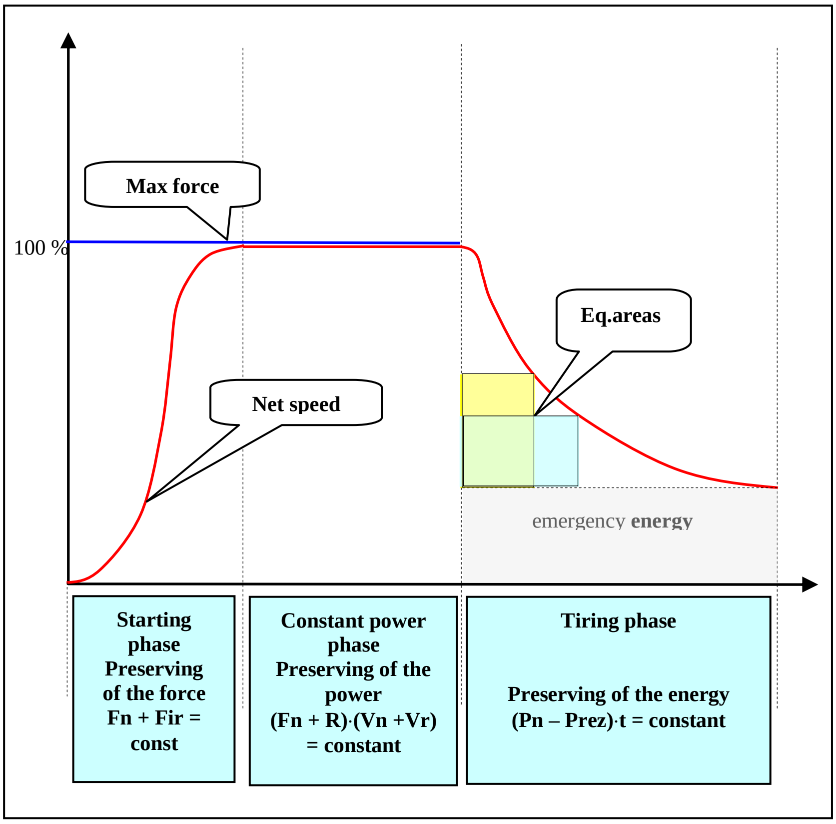


Fig.4.2. The phases of the muscular effort. See explains in the text.

Overlapping this phase is an aggression against the normal functioning of the neuromuscular system and can have irreversible destructive repercussions against the body.

V. BIOMECHANICS OF THE MAIN MOTRIC SKILLS

5.1. Introduction

We have to remind here that physical effort, especially the one employed in sports, is didactically characterized by *specificity*, *complexity* and *motricity*. Motricity which a physical effort made possesses, regardless of whether it is a physical exercise or a complex training means is measured by a virtual energetic potential[3], structured as a result of multiplying force (F), speed (V) and the time of employment (t):

$$E = F \cdot V \cdot t$$

The similarity of this structure with the one of the *amount of effort employed* (Vol), which comprises means as *force, velocity* and *endurance* (duration of the effort), is hardly circumstantial and the illustration of this by the volume of an orthogonal three-dimensional geometric figure (height, length and width) allows us to more simply explain why the same quantity of effort may have different structures and why when the intensity of effort is increased so is the quantity of the effort, subject to the simple condition that the quantity of effort is not confused with its duration. What we mean is that any physical effort comprises a certain consumed power (F·V) as a measure

[3] It's not about potential energy!

of intensity and that it lasts for a period of time (t) as a measure of endurance, rather than quantity.

Consumed energy or power flow is sometimes characterized by a predominance of force, so that speed may be disregarded; other times speed is dominant so that force can be disregarded. Finally, the duration of the effort may be so short that endurance may be disregarded. The considerations herein above justify why force, speed and endurance are, for didactical purposes, treated separately. Coordination, under its different manifestations is the fourth main quality of the movement. It has a strong qualitative character, imposed by the inferential references, in a manner that its active aspect can be disregarded.

5.2. Biomechanics of force

Force, as seen by mechanics, is based upon the *evidence* concept, where effect is so manifest that there is no need to be demonstrated. All observations and experiments have shown that a certain *mass* is as much more accelerated as the force is greater, so that such a result is rejected without denial. Consequently, in mechanics, the notion of force is appreciated by its effect and measured by the acceleration *"a"* which an object having a mass *"m*". This standpoint is also called *Newtonian*.

Newton, describing what is currently considered the universal principle of physics, avoided saying that two objects are attracted to each other by a force ….; he mentioned, mostly due to scientific preciseness than out of modesty that *"two objects behave as if they were attracted to each other by a force …"*

To our days, nobody knows what force is. Nobody ever measured force, only its effects were measured, thereof the best known being *movement, deformation* and *equilibrium*. This is why the definitions in the most prestigious dictionaries restrain themselves to considering force as a cause, a cause of movement, *a cause of all effects.*

By the extension of the vocabulary, due to a natural tendency to develop a language, there are several expressions which include the word *force: to force a confrontation, production force, to force a card* etc.; in these combinations of words, the word force has meaning completely different that the force we refer to herein.

In physical education and sports, *force* is the image of muscular contraction. By contracting, the muscle transforms chemical energy, deposited in its macroergic compounds in mechanical energy. Force is perceived as a motric characteristic of the person making a physical effort, and is measured by the magnitude of its resistive force overcoming effect, be it a weight or another external force. As a rule, the effect is a motion, with a certain speed or a certain variation of speed, a time for equilibration of opposing forces, a static pressure etc. Often enough force is connected to the muscular mass, i.e. the dimensions of the muscles, especially their section. The expression *mass* related to musculature is different that the same applied in mechanics. *Muscular mass* contributes to the dimensioning of the cause producing the *mechanical mass* acceleration effect.

In biomechanics, because of the innumerable restrictions upon the effectors the *evidence of the acceleration effect* concept is less relevant. This is the reason why in our opinion the *potentiality* concept is less adequate for the characterization of the effect of the force. Active biomechanical force, Fa(t), the one produced by the muscular converter has, conceptually, a *maximum virtual potential,* i.e. a magnitude (F_{max}), depending on the converter substrate, and a *manifestation potential* ($y_{(t)}$), i.e. a certain value of the momentum:

$$Fa_{(t)} = F_{max} \cdot y_{(t)}$$

If Fa(t) is greater than the load, the weight or, in general than a resultant of the resistive forces (G+L), than the difference mentioned above, named net force [4] Fn(t), produces a motion on a certain trajectory and with a certain speed, depending on the manifestation potential [5] y(t):

$$Fn(t) = F_{max} \cdot y(t) - (G + L)$$

The *virtual maximum potential* may be illustrated by the capacity of a container, as is the fuel reservoir of a car; *the manifestation potential* may be assimilated to the section of the conduit connecting the reservoir to the carburetor, together with its control. In fact, it's all about the different meanings given to the notions *capacity* and *capability* both existing in English.

The *virtual maximal potential* of the biomechanical force and its *manifestation potential* are notions not as abstract as they seem on first sight. It is known that muscular tension, regardless of whether of an electro-chemical or electro-static nature, occurs due to the actin's and myosin's degrading of the ATP by rotating these molecules. Consequently, it is about a certain *capacity*, represented as a *limited stock* of the conversion substrate (of an individual, existing in a certain part of the body, and at a certain time); this notion also included the *length of the levers* formed body segments (the structure of kinematical chains) and certain individual biological *structural qualities* transmitting force.

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[4] *Fn(t)* is a vectorial result of the all forces acting upon the object of mass *m* and imprinting an acceleration *a*, lengthwise the force's direction (D'Alembert principle)

[5] In the case of classical mechanics the force appear and disappear instantly, therefore y(t) = 1.

In as much as regards *capability*, this notion refers to the re-composition of the ATP, to the manner in which the neuro-muscular synapses are recruited, to the overcoming of inertia forces etc., all these with reference, as with capacity, to a certain individual, a certain part of the body and a certain time.

Beside this biological considerations related to the manifestation of force, the major restrictions imposed by the manner in which of the segments of human body *severely limits the scope of action* of net force, in fact the time during which net force acts upon the resistive one. Consequently, the acceleration effect is, according to mechanics, very difficult to observe, while following the trajectory and speeds in the significant sequential moments, i.e. in the majority of the points of the trajectory becomes convenient.

We need to emphasize the fact that, in biomechanics, force manifests itself *concretely* either by displacing a weight (the overcoming of a resistive force) or by a static equilibrium (as a null resultant of the action of multiple forces and associated force momentums), or by pressure upon easily deformable biological structures; very rarely force manifests itself by slowing down the effect of another force, opposing contraction (yielding).

Biomechanical movement, in its most frequent form - motion – is characterized by *trajectory*, s(t), and by *momental speed*, v(t). Both characteristics full define the *duration* of the movement, its *form* (most frequently the variation rate and the inflexions), as well as *magnitude*. It is noteworthy that, from a mechanical point of view, *vector components of the Frene trihedron*[6], define movement not less fully; however, in our opinion, these components are not as practical as the *trajectory* and *module of momentum speed.* As an argument, it should be said that computerized analysis of biomechanical movements is,

[6] Referential tri-orthogonal axes, movable on all points of the trajectory

for the time being based upon video acquisition of successive positions, which allows for the facile construction of the trajectory and of the rate at which positions change.

The changes of speed apply only to certain brief circumstances of manifestation of force, the so-called *explosive forms* of manifestation. Alternatively, (and mostly in competition sports) of concern are the manifestation of force when *speed regime* as well as when *resistance regime* are involved.

Consequently, in biomechanics measure of force may envisage a certain *variation of speed*, a *maximum* speed maintained constant or a certain *length of the trajectory.* The length of the trajectory may also be expressed in terms of duration of qualitatively unimpaired movement. In other words, biomechanical force has three manifestation regimes:

- maximum acceleration;
- maximal speed;
- maximal distance or duration (in which movement is neither distorted nor impaired).

On may infer a mathematical rule from the considerations herein above, i.e. that depending on the purpose, the measurement of force may refer to the *variation in time of the speed*, namely the second derivative of space, which means *acceleration*. Measurement of force may also refer to the *variation of the space in time,* i.e. its first derivative of the same, which means *speed.* In its third form of manifestation, the measurement of force may simply refer to *space* (distance).

As regards the relationship with muscle strength, force manifests itself in the so-called *PID mathematical regime* (proportional, integral or differential). It is noteworthy that in biomechanics the idea of proportionality is hardly accepted, precisely because of the restrictions on the transmission of force. What we mean is that segmental movements in humans are limited by the length of the skeletal levers (which measure, at most, tens of centimeters), the slenderness of the muscles, the mobility of the joints, etc. In phasic (acyclic) movements this means *non-linear* transitions of the active force values, from low to the highest values (which may be maximal) and the other way round.

One may conceive, by simplification and for didactic purposes, transitory variation forms of speed of the *linear, canonical (3rd grade functions) exponential, logarithmic* etc. types. As we intend to perform a more profound analysis, the mathematical models we will use are of the type *sigma* or *Hoerl*, which we consider "*both necessary as well as sufficiently"* precise to express the non-linear variation of the segmental speed. The main reasoning for this option is, obviously, the fact that contrary to mechanics, relative movement limits of body segments impose that transitory variation of speed have at least one inflection, i.e. a maximum of acceleration[7]. Moreover, we believe that it is expedient to note that, from a biomechanical standpoint, the generating of mechanical tension in the muscles is not instantaneous and that the mass of body segments and active musculature (G) and the load (L) do not abruptly set into motion. Therefore, the acceleration produced by the active force depends on the manner of activation of the mechanical tension in the muscle and the manner in which the same propagates in the kinematical chain formed of the skeletal levers.

Herein below we will attempt to illustrate the idea of non-linear variation of the speed of the biomechanical movements, as a mathematical model of the vertical jump, generated by the triple extension of the body segments in the legs' joints, the so-called *"Sargent Jump".* The greatest muscle groups of the human body are involved in the impetus of the vertical jump, without rapid flexion in short time and to a relatively small distance. This, as well as the simple execution

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[7] A rigorous analyze of the movement causes, meaning forces, need to take into account, as a rule, of a maximum acceleration

of the movement was the factors that made Sargent Jump famous. It is very often used as an example of action in explosive force, as a measure of maximum (instantaneous) anaerobic power or, simply, as a measure of the swing.

First of all, in analyzing this movement, we need to consider that the temporal and spatial activation of the synergic muscles' synapses is not instantaneous. Secondly, in case of repetitions, we need to take into consideration the fact that the ATP re-synthesizing process has moments of latency, and, as of a certain moment, it cannot resist the effort, the active force Fa(t). being diminished. To observe scientific rigorousness, we also need to take into consideration the fact that in initiating the movement, the active force overcomes (experiencing difficulty) the inertial force, Fin, delaying and diminishing even more the increase of the speed.

We sufficient factual and logical support to consider that the manner of variation of the speed depends upon the net force and is mediated by a factor (measure) herein referred to as *admittance (by analogy* with other consecrated sciences).

We need to remind here that admittance is a characteristic of the substantial medium through which a force propagates. In case of electrical circuits, admittance is the reciprocal of impedance or (very often) of electrical resistance and associates electrical current with electrical tension (electromotive force). If admittance is high so is the current.

In the case of biomechanics, if admittance is high, the speed of the movement due to muscle force is to be also high. In our opinion, admittance (the manner in which speed depends upon force), is conditional upon several factors, as are the forces resisting movement, gravitational acceleration, duration of the action, promptness of neuro-muscular commands, the condition of the contractile effector, the manner in which the energetic substrate is resynthesized, etc. Admittance has, as regards biomechanics, the dimension $[T \cdot M^{-1}]$ and appears as a variable coefficient or an individual constant (in case of maximal speed).

The considerations herein below address matters for the use of specialists only, the usual reader may disregard these pages, as well as others, written in small case, the interpretations given to biomechanical measure not being impaired by this[8].

Net biomechanical force, Fn(t), when inertial force Fin(t), is also considered, depends on the difference between the active force and the total of the forces (vectors) that oppose movement (in its direction):

$$Fn(t) := Fa(t) - [(G + L) + Fin(t)]$$

Inertial force, it is known, opposes change of speed, including the null one (idle interval) being proportional with the mass of the body and the transitory variation of the active:

$$Fin(t) := -k \cdot \frac{(G + L)}{g} \cdot \frac{d}{dt} y(t)$$

One may observe that, in the absence of rotation movements, the logical-mathematical model of the movement starts from an differential equation:

$$Fn(t) := Fmax \cdot y(t) - k \cdot \frac{(G + L)}{g} \cdot \frac{d}{dt} y(t) - (G + L)$$

Rate of travel (travel speed) as a consequence of the action of biomechanical force can be deduced from the mechanical work done by the net force on the *limited* distance *s:*

[8] Only paragraphs written by small font

$$Ec(s,t) := \int_0^s Fn(t)\,ds$$

Consider, practically for our example, that s = 0.4 m, the distance on which the net force acts; representing the uplifting by 40 cm of the body's weight center, in the impetus of the jump, i.e. in triple extension. The action of the net force is abruptly interrupted after the impetus distance s, corresponding to the duration t = 0.21 seconds, when the take off from the foothold (flight) starts:

$$Fn(t) := \left| \begin{array}{l} Fa(t) - [(G + L) + Fin(t)] \\ 0 \ \text{ if } \ t \geq .21 \end{array} \right.$$

Mechanical work, as well known, is equal with the variation of the kinetic energy, where from:

$$v(t) := \left| \begin{array}{l} \sqrt{Ec(s,t)\cdot\left[2\cdot\frac{g}{(G+L)}\right]} \\ [\,v(.20) - g\cdot(t - .21)\,] \ \text{ if } \ t \geq .21 \end{array} \right.$$

In jumping, the ascension speed declines in a linear manner until the value 0, when the maximum height is reached.

The functions of which the variation of the active force, as well as the admittance mainly depend are the *sigma models* of the manner of spatially and temporally recruiting of the muscle synapses upon staring the effort, (ynm(t)), and the manner in which weariness appears due to the ATP re-synthesizing deficit in case of tiresome effort *(yodo(t)):*

$$ynm(t) := q - q \cdot \exp\left(-a \cdot t^{b}\right)$$

$$yodo(t) := (w - yem) \cdot \exp\left(-c \cdot t^{d}\right) + yem$$

$$y(t) := ynm(t) \cdot (yodo(t))$$

The parameters a, b, c, d which appear in these mathematical models personalize the performer (having a very important genetic character) and particularizes the moment and the conditions of the physical effort. The mathematical model of spatially and temporally recruiting the muscle synapses, y_{nm} also contain a factor *q*, the significance of which is related to the quality and promptness of muscle commands. The model of the effector's tiring, y_{odo} contains an individual constant (y_{em}), having the significance of a power reserve for special situations, as is an emergency case.

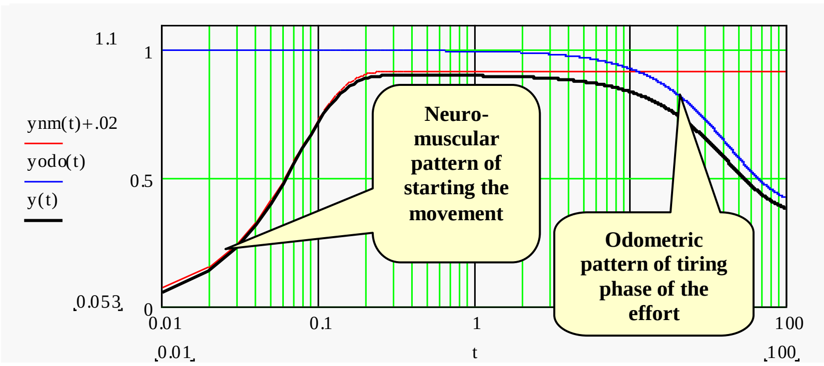

Fig. 5.1. Variation of the manifestation functions of net force. The integral functions, together with other variables, determine the value of the speed admittance

Consequently, admittance, or the factor connecting speed to the active net force on a biologically limited distance is:

$$Y(t) := \frac{\sqrt{[\,Fa(t) - [(G+L) + Fin(t)]\,]\cdot s\cdot\left\lfloor 2\cdot\frac{g}{(G+L)}\right\rfloor}}{Fn(t)}$$

The biomechanical effect, in our case the increase of the speed (of the weight center) is due to the action of the net force and depends upon the admittance. The restrictions of the kinematical chain (length of the levers, the kind of the joint, etc) limits the duration of the action of force (the amount of motion), as well as the increase of speed (in our case up to the value of 3.82 m/s). The height of the jump will depend only upon the square of this value of the take out speed, and evidently, the gravitational force which opposes the ascending motion. After approximately 0.39 seconds, the ascension speed is annulled, the maximum height of the jump, of approximately 80 cm, being reached.

In the chart herein below the biomechanical factors are represented at different scales, in order to be visualized together. It can be observed, from their simultaneous presentation, that the overcoming of the inertia of rest is, in fact a non-instantaneous disappearance of the reaction, that biomechanical force reaches its maximum value after several tens of hundredths of second, while speed increases continuously, although not-linearly until take out from foothold. When motion is started, net force and inertial force tend to conserve.

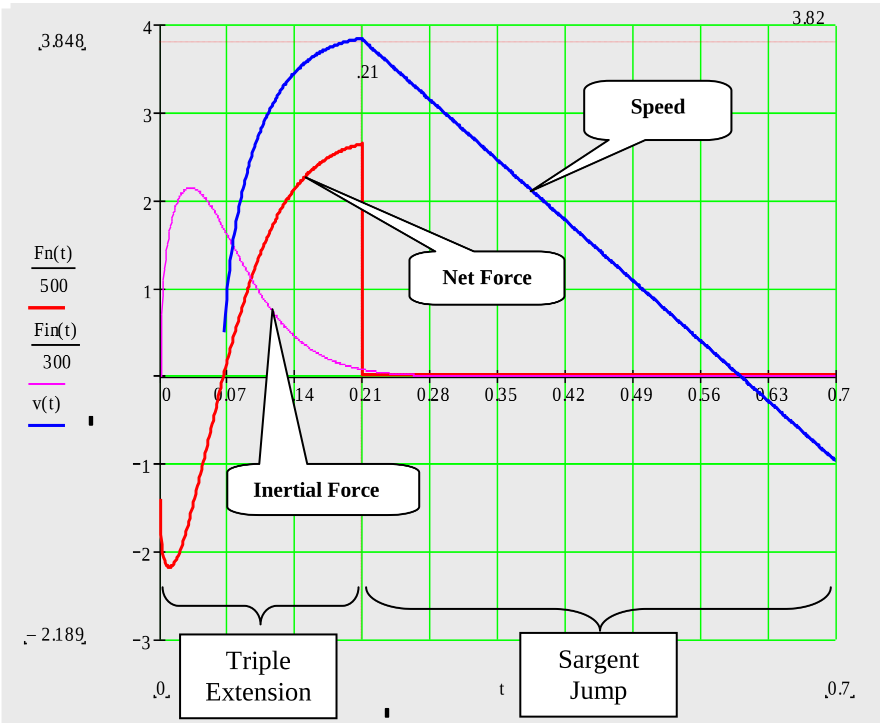

Fig. 5.2. Theoretical variation of the main biomechanical factors in the vertical jump by extension of the joints, without rapid flexion (Sargent jump). Explanations in the text.

Variation of speed and force that generates it represents, in this chart, an example of the jump of a fictitious athlete, having characteristics very close to the reality. For instance, the athlete has 71 Kg body weight, he is 1.80 m tall, and lifts 163 Kg in semi-flexion, uses approximately 80 % of the virtual potentiality of the maximal force, and approximately 90% of the propelling potentiality of the same. We have chosen these values in order to simulate the behavior and the expected effect (maximum height of the vertical jump) modifying, in turn, the different parameters both facilitatingly as well as restrictively. Some explanations are required: thus, we are aware of a certain significant correlation between the height of the body and the maximum amplitude of flexion (30 cm at 1.70, 40 cm at 1.80, 45-50 cm at 1.90 m etc.), while the anaerobic maximum power *constant* in the case of this (and any) athlete, bodily location and a certain chosen moment, - show that he can lift with a low speed a weight heavy enough not to exceed, together with the athlete's body weight, his maximum force.

Based upon computerized simulations, made for this logical-mathematic model, we observed several interesting hypostases which deserve, in our opinion, some attention. Thus, if the athlete had used the entire virtual potentiality of maximum force and propelling manifestation, he would have jumped 120 cm! if he gad used only the maximum capability of acceleration corresponding to the same extension, he would have jumped 96 cm. Finally, if he had been 1.90 m tall, and had had a impetus corresponding to this body height, but the same body mass and maximal force, he would have jumped 118 cm. We need to remind here that the logical-mathematical models are simplifications of reality, and that transfer to reality of the conclusions drawn following computerized simulations of behavior involves risks. Paradoxically, risks as much more significant as the model is more sophisticated. In the logical-mathematical model a multitude of factors were ignored, thereof jumping technique, temperature of the effectors and the milieu, the psychic attitudes and aptitudes, etc. We were only interested in the bi-mechanical approach to active force as compared to other standpoints as are the mechanical, methodical and anatomic and functional standpoints. As a curiosity, such a model may explain why a flea jumps 200 times its height, a wild cat can jump 6 times its height or why an athlete, I needs to have a certain somatic configuration in order to be a good high-jumper.

As mentioned before, admittance $Y_{(t)}$ connects the effect to the cause; in our case it connects the take out of the weight center during impetus of the jump to the net force:

$$v_{(t)} = Y_{(t)} \cdot Fn_{(t)}$$

According to our calculations, in explosive manifestations of the force, admittance varies differently from the active force and depends upon the resultant of the resistive forces. Admittance characterizes mostly the structural aspects, potentially the genetic one of the manifestation milieu of the active force, and less the difference between active force and resistive forces. In other words, the height of the high-jump as a measure of the swing may be different for two athletes having the same (capacity of) maximal force, but who are different as a manifestation potentiality (capability).

These biomechanical considerations regarding the manifestation of force in a maximum acceleration regime, translated into methodic language as explosive force, show the necessity and the possibility that body-building trainings of the high jumpers and throwers (as well as those of other athletes who practice abrupt segmental movements) orient themselves to the increase of admittance. In simple words, this means the judicious use of means that address neuro-muscular commands; for instance, the rapid lifting of relatively small weights, starting upon command of the trainer. Each series of lifts has to be commanded, and the frequency shall be low.

We insist on emphasizing that the relationship between the speed of travel in the direction of the net biomechanical force which produces it and the respective force is one of pseudo-proportionality. More precisely, the *maximum travel speed on the distance restricted due to biological considerations is proportional with the square root of the resultant of the forces* *generating the motion, on its direction.*. The higher the net biomechanical force, the higher the square of the respective body's travel speed. The increase of the speed is non-linear as compared to the increase of net force (due to admittance, depending, in its turn, upon the net force and the individual structural factors); it is, however, extremely slow, which proves that speed is a motric quality very difficult to perfect. By emphasizing this we wish to avoid confusion of interpretation regarding the resistive force, to which the formula of V.A. HILL[9] is applicable; this formula says that the more the resistive force increases the maximum travel speed decreases. We wish to also specify that, in certain cases, *net biomechanical force is the resultant of all the acting force, those facilitating motion included,* so they do not necessarily refer only to the active muscular force and the resultant of the resistive forces.

The similarity of this relationship (between the travel speed on the direction of the net biomechanical force producing it and the respective force), with others from consecrated sciences, as is the law of OHM[10] from electricity or the relationship between the debit of the fluids and their hydrostatic pressure is not accidental.

In the same manner as in acyclic motions, where inertia and admittance oppose the increase of speed (acceleration) at the start of speed track events, inertia, but mostly the slow increase of admittance, allow maximum acceleration to be reached only after a few seconds. The phenomenon is treated as a transitory phase.

To illustrate the manner in which net force acts in the transitory phase, and how it gives the body of the athlete an

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[9] The HILL relationship will be discussed in the paragraph referring to the speed.

[10] Local form of OHM law is showing that the electric current is proportionally depending of the admittance and electro-motric force (voltage).

acceleration, i.e. a progressive increase of the speed in sprint, we simulated the behavior of a fictitious athlete who theoretically is a world record man in all possible short distance sprints.

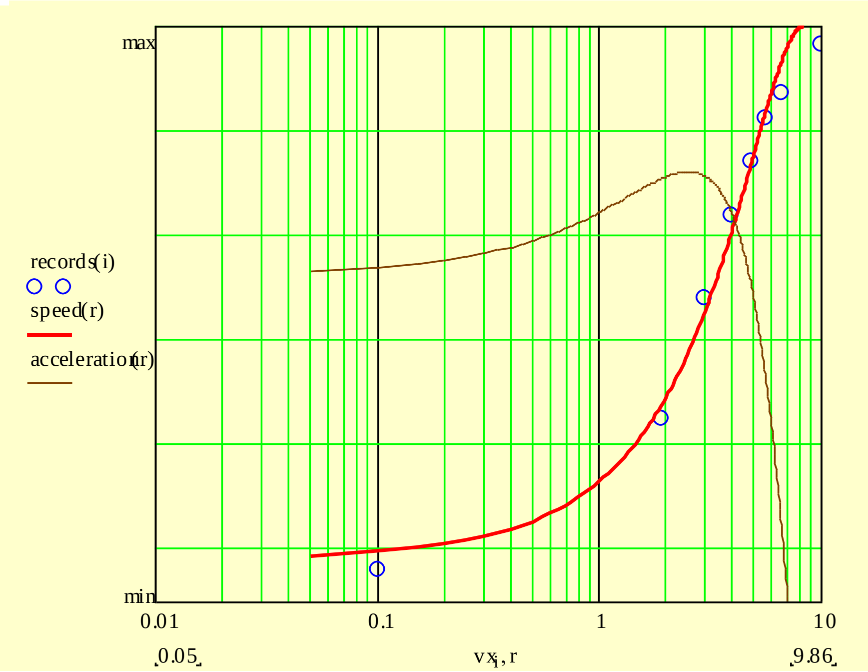


Fig. 5.3. Fitting of the short distance sprint records of up to 100 m, show that the athlete's speed increases in a non-linear manner, continuously (red line), motion being, in the beginning accelerated, then decelerated. A maximum of acceleration is to be observed after 2-3 seconds after the start

The chart of the acceleration (continuous black line) in Fig 5.3. herein above suggests that the manifestation of force in the case of the fictitious athlete is in a maximal acceleration regime. It is not accidental, that in sprint, the maximum of acceleration is reached after 2-3 seconds as of the initiation of the motion; the same applies, physiologically, to the maximization of anaerobic ATP degradation processes. Consequently, starting in sprints can also be appreciated and measured as a manifestation of the explosive force. Theoretically, the measure of explosive force should be the time of increase of the acceleration until it reaches the maximum point. In practice, however, even after accelerations starts decreasing, the speed continues to increase, true, a bit more slowly, and stabilizes at a maximal value. Thus, the moment when speed becomes maximum is easier to observe and coincides, in acyclic motions, with the take off in the impetus of jump or the moment when the object thrown an athletics. With motor vehicles, the characteristics of acceleration are conventionally measured by the time it needs to reach 100 km/hour. With humans, the distance on which force acts is relatively short, and differs much from one motion to the other.

The *measurement of explosive force* may be done indirectly, by the *effect*. For instance, the height of the jumps without running in impetus depends on the final speed of the motion, i.e. the speed as at the moment of take off, the same as do the distances of the throwing without impetus. This is the reason why it is easier to calculate the *final speed* that it is to calculated the moment of maximum acceleration. This final speed analytically expresses the average acceleration throughout duration or the distance of the mechanical work. When exhaustion is not considered, the correlation between the average acceleration and the maximum one is significant at a very convenient threshold, which allows the replacement of one factor with the other. In other words, and revisiting the first example, the maximum height of the vertical jump without impetus can be a measure of the explosive force, the maximum instantaneous anaerobic power or the swing, in case we are interested in the cause, process or the effect of the same.

After the transitory phase there follows a quasi-stable phase during which the maximum speed depends on the net biomechanical force which reached its maximum and, somehow constant value, however included in the measure of admittance.

The quasi-stable phase represents the *maximum speed manifestation of the active force,* which, in our opinion is worth discussing separately under the title the biomechanics of speed.

5.3. The biomechanics of speed

In physical education and sports, speed and velocity are considered a motric quality or an aptitude that characterizes muscular contraction. Thus, if the time necessary to reach total contraction is short, speed is high and vice-versa. This characteristic of the effectors or the person making a physical effort is transmitted by levers and kinematical chains to a body movement or an object moved, where speed becomes an *execution characteristic* of a motric act, as is for instance running. Under certain circumstances, speed may characterize the repetition or alternation of a motion during a conventionally determined interval of time, replacing frequency and known under the name of *repetition speed* and which potentially can replace the latency of the motric reaction, and known under the improper name as *reaction speed.*

In biomechanics, speed is a characteristic of the motion produced by the net force. According to this causal specification, biomechanical speed is closely connected to the anatomic and functional characteristics of the person making the physical effort, and therefore is different from the mechanical speed of a movable object or a material point.

Biomechanical movement is perfectly determined if the momentum speed and trajectory are known. Mechanics also describes motion precisely, as rule by vectors with the aid of mobile *Frene trihedron*. In fact, and somehow a little more complicated, vectorial form tells the same thing about trajectory and momentum speeds.

Besides the momentum speed form, which refers to the speed in each and every significant position or in each and every temporal sequence of the motion, biomechanics also utilizes the *average speed* form and the *final speed* form (especially for limited segmental movements).

The measure of the *biomechanical average speed* is a ratio of the distance, or the length of the trajectory, and the time needed for covering such distance or trajectory. *Final speed* or the speed in any one moment of the motion is defined by the *derivative*[11] of the respective position. The derivative, this apparently very complicated mathematical convention, should not scare anybody, as computers can calculate it almost instantly, upon a simple command.

In case of abrupt segmental movements, when such movements immediately follow rest, the final speed is excellently estimated by the double of average speed. For example, is the duration of the impetus in a standing jump is 0.5 seconds, and the weight center heightens 0.40 m, then the average speed is 0.40/0.5 = 0.8 m/s, and the final speed is 1.6 m/s. In sports, for a simplification of communication, one can hear that a sprinter has a speed of, let's say, 10 seconds per 100 m. Due to the same reason the expression "good reaction speed" is used for instance to characterize the latency of the motric reaction of 140 milliseconds. It is incorrect to express speed by using time units, however it is not a serious mistake if the distance it refers to is constant or conventionally predetermined.

In most sports, performance is based upon *maximal speed* and the *time* the former or a similar speed can be maintained. From the standpoint of biomechanics we know that maximal speed is reached at the end of the phase in which acceleration is positive (the end of the action of the explosive force), and that its duration is relatively short, between a few

[11] The limit of the proximal length variation reported to the corresponding duration, when the duration tend to be minimal

seconds for the usual person and up to 30 s for competition athletes. From a causal point of view, maximal speed is determined by the *difference between the active force* and the resultant of the resistive forces (i.e. net force), using as a means the personalized measure called *admittance*:

$$v(t) := Y(t) \cdot Fn(t)$$

Without detailing the calculation and without invoking the premises of the logical-mathematical model which connects the execution speed with the active force, we may say that *maximal speed* depends especially on the value of *active force*, the weight of the body segment or the object (G) set into motion, the *load or the opposing forces (L), the distance* of the mechanical work, *and the individual factors (for instance q) included into the admittance, etc.* Important to remember is that, from a causal standpoint, *maximal biomechanical velocity increase along with the active force.*

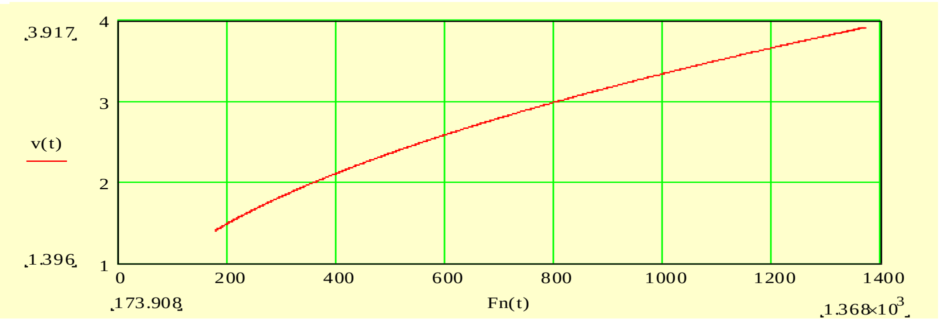


Fig. 5.5. The representation of the increase of the maximal biomechanical velocity along with the increase of the net force. Example for the impetus of the standing jump with a flexion of 0,40 m

Both from the example herein above as well as from other movements, we may infer that the *progress rate* of the maximal speed in relation to the increase of the maximal active force is low. Consequently it confirms that velocity is a motric quality or an aptitude difficult to perfect, having a significant genetic character. For instance, for an increase of velocity, as measured by a difference of spring from 78 cm to 134 cm (which means achievement of a world record) the athlete should progress from the lifting of a weight from semi flexion from 163 to 263 kg! This condition is still not sufficient as the modification of the admittance, as a factor of contractile environment, is yet unknown in case of a 100 kg progress of the active force manifested at extremely low speeds.

On the other hand, if the *load* (L) or the resultant of the resistive forces *increases*, net force decreases and implicitly, *decreases the maximal speed of the respective movement.*

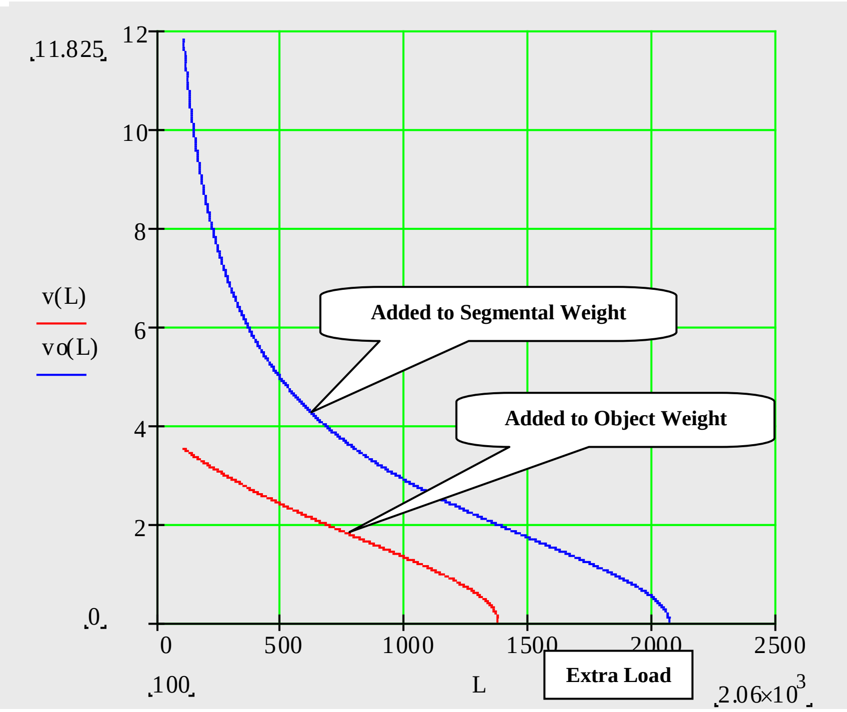


Fig. 5.6. An example of decrease of the execution speed while the load or the resultant of the resistive forces increases. Reference to triple extension

As one can observe from the figure herein above, the decrease of the *execution speed is indirectly proportional with that of the resistive force. In other words, if the athlete lifts, in triple extension, only his own weight, the maximum speed come close to* 4 m/s, while if other weights are added, his lifting speed decreases, and the athletes is not able, at limit, to raise from flexion (red curve). If we were to particularize for the example herein above, we need to show that if the athlete's own weight of 700 N (71 kg) is added another 1600 N (aprox. 164 kg) weight, the athlete will not be able to straighten up, his execution speed becoming zero (calculations took into consideration admittance, too).

This relationship of indirect proportionality between the execution speed and the resistive force has been studied by many authors, the best known being A.V. HILL. It was deducted in the laboratory based upon the so-called rabbit-preparation, meaning a disinserted live rabbit muscle. The muscle was excited to contract with several weights pendent, and contraction speed was measured. The chart obtained was appreciated to be a equilateral hyperbola, concisely described by the following equation:

$$(F + a) \cdot (V + b) = (F_{max} + a) \cdot b = const.$$

where F is the pendent weight, generally being the resultant of the resistive forces themselves; V is the contraction speed of the striated muscle, being in general the respective motion's speed in the direction of the net force (resultant of all forces). The constant "a" also appears in the equation, signifying the muscle's own weight, representing the weight of the segment set in motion or the object set in motion, as well as constant "b", signifying the minimum travel speed of a maximal load.

We need to remind other mathematical models of the relation of indirect proportionality between the travel speed and the resistive force opposing the former. To this effect the exponential model of FENN & MARSH, according to which $F = F_{max} \cdot \exp(-kV)$, is known, and so are the empirical models of PALLISAR or AUBERT etc. All these models describe, in fact, the tendency of conservation of the maximal power, while as charts, they almost can be confounded.

We dare to add another theoretical model to the above mentioned empirical ones, a model deducted rationally from the example herein above, the example of the standing jump (Sargent Jump).

Let us consider the maximum power[12] generated by the muscular contraction to lift, by triple extension of the body weight G on the distance s in time t_e, resulting the average speed V_{med} and the final speed V_{max}, approximately equal with the double of the average one. After take off from the foothold, the kinetic energy transforms totally into potential energy, when the maximum height of the vertical jump, h, is reached.

$$P_{max} = G \cdot s/t_e + G \cdot h/t_e$$

By simple transformation we reach the formula:

$$P_{max} = G \cdot (V_{med} + 1/2g \cdot k/s \cdot V_{med}^3)$$

And eventually the formula:

$$(F + a) \cdot (V + b) = P_{max}$$

The expression herein above is resembling to that of HILL: constant "a" has, in the same way, the significance of the athlete's own weight, (a = G, in our case), F is a resistive force (may be an additional weight added to the athlete's own weight) V is the average speed of the extension movement, while "b", as apposed to HILL's equation, signifies a parameter ($b = 1/2g \cdot k/s \cdot V_{med}^3$) which depends on the gravitational acceleration g, the potentiality of manifestation of the active force k, the distance s of the motion, and finally, the third power of the average speed. For a graphical representation the following forms were preferred:

$$F1(V) := \left[\frac{(Fmax + a)\cdot b}{V + b}\right] - a$$

$$F2(V) := \left(\frac{Pmax}{V + c\cdot V^3}\right) - a$$

[12] Named by us "maximum instantaneous anaerobic power" (Gagea, 1995)

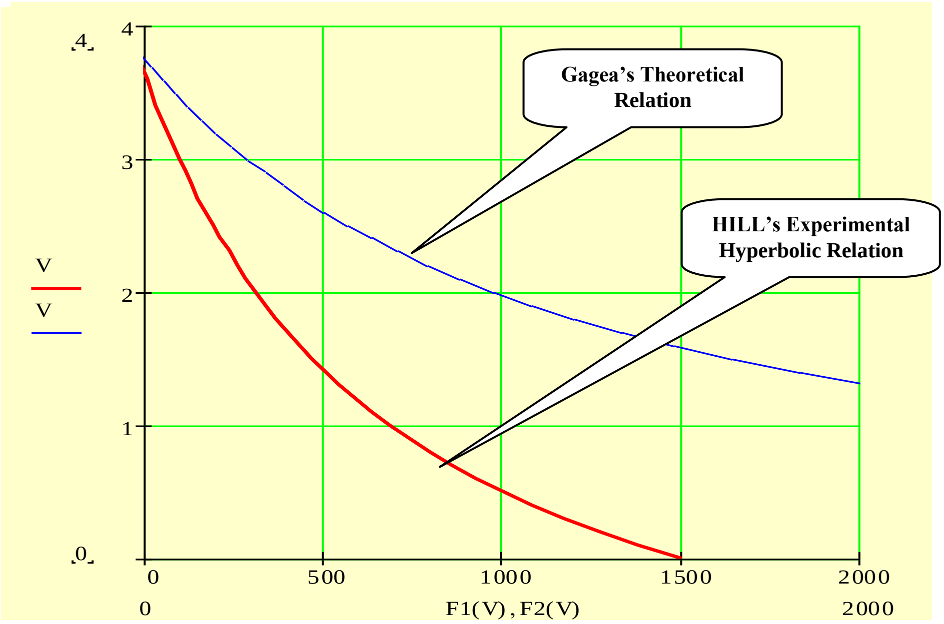


Fig. 5.7. Illustration of the way execution speed decreases when the load or resistive force increases

The main property of the hyperbola is that in any point of it the products between its coordinates tend to be constant. In other words, the products between the resistive force and the execution speed is constant, which is concordant with the premise [13]. As an example, let us imagine an athlete that makes a physical effort with a body-building apparatus (an helcometer, an ergometer, etc). The athlete pulls the handle tied to a cord and lifts a certain weight F_1 with the speed V_1. Theoretically, if the weight is double, i.e. $F_2 = 2 \cdot F_1$, then the speed it is lifted with shall be reduced to half, i.e. $V_2 = 0.5 \cdot V_1$. The hyperbolic

[13] For a certain given time, place of the body and the same individual the power is a constant

relationship of HILL shows that the product $F_1 \cdot V_1$ is equal with $F_2 \cdot V_2$ and tends to remain constant, as the athlete's power, until weariness appears, is constant. Due to the constants introduced by HILL in the hyperbolic relationship mentioned herein above, the products between the *resistive force* (added to the athlete's own weight "a") and the *execution speed* will never reach zero. Consequently, even if there is no additional load F, the athlete has to set in motion the weight of the body segment or the weight of his own body.

In the case of isometric effort, it is considered that the pressure in the deformable biological tissues involved in the effort is equivalent with a displaced with a minimum speed "b". The theoretical relationship between the net force and the execution speed presented by us, beside Hill's equation, is an attempt to argument the fact that the ratio of modifications of speed/ resistive force is, at least in the case of the triple extension motion, lower when the limitation of the distance of the mechanical work is taken into consideration.

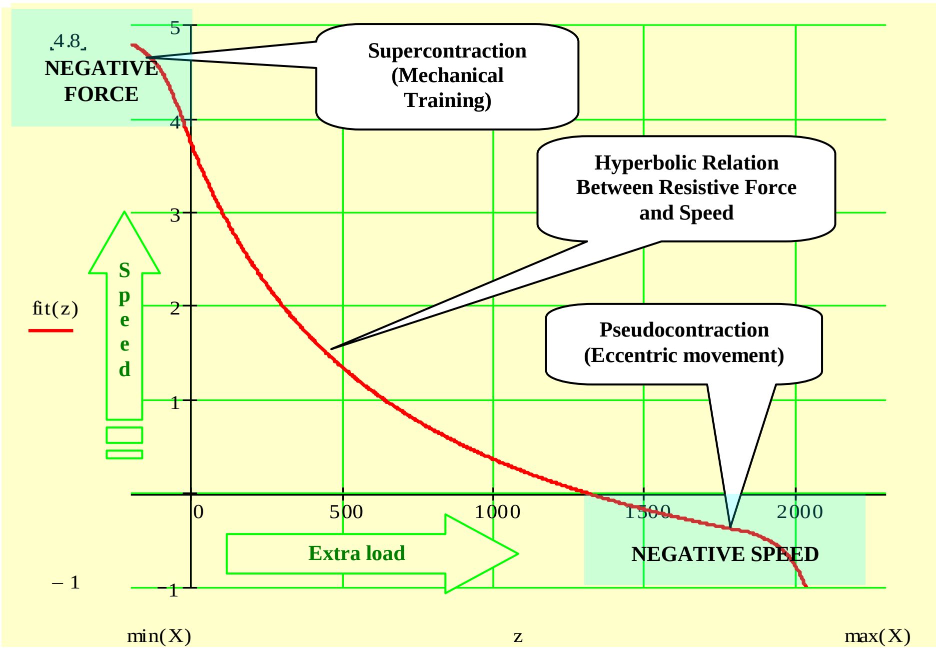


Fig. 5.8. The hyperbolic relationship between the execution speed and the resistive force is being altered in quarter IV (negative speed), when the movement becomes eccentric (letting out). The same happens in quarter II (negative force) when speed exceeds maximum speed as the resultant of the external forces facilitates motion instead of opposing it). Additional explanation in the text

In practical, limit, situations, the hyperbolic relationship of HILL, as well as other theoretical mathematical models which connect execution speed with the resistive force do no longer correspond to reality. That is, when the load and the resultant of resistive forces is higher than the active force, a yielding motion occurs, speed becomes conventionally negative and the hyperbolic curve is distorted, moving to the fourth quarter of the Cartesian representation. We named this motion *"pseudo-contraction".* In pseudo-contraction, the yielding speed increases along with the increase of the load, which becomes extremely hazardous for the segmental and bodily integrity (we refer first of all to accidents). For a load by 15% at most heavier than the maximum one (corresponding to isometry), the advantage of efficiency of force development is so tempting that it abolishes risk.

In the other extremity of the hyperbolic curve it may happen that resistive forces actually aid motion instead of opposing it, becoming thus conventionally negative. In other words, movement instead of being braked it is accelerated beyond the effector's natural possibilities. Under such actual circumstances, (as are, for instance, mechanical training behind a bicycle), the hyperbolic curve is distorted and moved to the second quarter, and the speed becomes super maximal. We characterized the motion as a "super-contraction".

Super-contractions address directly the development of the speed. Trainings and other ways of producing super-contraction are known as *"mechanical trainings or means"* and are successfully used in the methodics of development of speed, in spite of the risk of injuries. An example which has become classical argues that, if the athletes in a group make 8 to 10 special pliometric jumps at the end of a training, for a period of 6 weeks, the progress of the execution speed, measured by swing, may be, on an average, up to 30% higher than that of a tester group practicing the same training, however less the special pliometric jumps.

The fact that the pliometric jumps are "special, means only that the same refer to *super-contractions.* Actually, these super-contractions may be obtained with the aid of tourniquets suspended at one end and fastened to the athlete's girdle at the other end. When the athlete jumps "down" from a high foothold the tourniquet is stretched the further vertical jump being, thus, facilitated. Biomechanically, this means that the tension in the tourniquets adds to the active force, and the force of the impetus grows to become super-maximal. Another, simpler modality, for facilitating take off in jumping is the one based upon the help of two partners who help up the athlete in the moment of the take off, by pushing him up by his arms.

In conclusion, we would like to summarize the main ideas regarding biomechanical speed:

- Maximum biomechanical execution speed is in a direct proportional dependence with the active force, and the admittance of the contractile environment. Progress rate, in its development, decreases along with the increase of the active force, proving its closer relationship with the genotypic rather than the phenotypic factor.
- Biomechanical execution speed is in an indirect proportional dependence with the resistive force. The heavier the weight top be lifted, the load or, in general, the resistive force, the lower is the execution speed, so that their product is always constant (according to the premise providing that a certain given time, place of the body and the same individual).
- When the resistive force exceeds the maximum active force, the motion becomes eccentric (letting out), the biomechanical velocity increases uncontrollably, in the same time with the increase of the load or the resistive forces (accident risk).
- When the resultant of the external forces does not oppose movement, it rather facilitates it (becoming conventionally negative), then the biomechanical velocity increases uncontrollably beyond natural limits, becoming super-maximal. This circumstance is propitious for the development of maximal

execution speed; however it involves significant accident risk.

5.3. Biomechanics of endurance

Etymologically, the term *endurance* comes from the Latin word *indurare,* meaning painfully enduring fatigue or pain. In many languages it was probably introduced to differentiate the motric quality of *resistance to a relatively high effort* from *the resistance to a long term effort*, both producing tiredness with a feeling of discomfort and exhaustion similar to pain.

Resistance decreases along with the increase of fatigue and ends when unbearable fatigue occurs. In biomechanics, resistance refers to the unacceptable degradation of the motion and the physiological causes producing it. Each sport or physical effort has its specific forms of physiological or psychological manifestation of fatigue, of degradation of motion and, especially, of motric coordination. Consequently, a standardization of biomechanical resistance is difficult to achieve and probably useless. As opposed to biomechanics, in a fairly independent discipline was developed in mechanics, called resistance of materials, in which the term limits of resistance refers to irreversible degradation, as is tearing of materials, a fact that cannot apply to living humans. It is true, however, that in humans, the limits of mechanical resistance of the bones and other biological tissues is known[14], but such characteristic of resistance has nothing to do with the resistance we refer to herein.

The syndrome of fatigue has varied manifestations and innumerable causes. From a biomechanical standpoint, increase of fatigue and decrease of endurance is considered as a decrease

[14] Deduse din încercări pe materiale nevii.

of muscular power, as incapacity to make a physical effort of certain intensity, for a longer period of time. We accept that the excessive focalization of biomechanics on the energetic aspect of the physical effort makes it difficult to explain the unacceptable degradation of the motion in certain sports as target shooting or other similar sports based upon precision. Alteration of coordination or behavioral problems associated to the energetic of physical effort suggest other forms of endurance, which disciplines close to biomechanics have already approached (ergo physiology and the methodics of development of motric qualities.

In biomechanics, the decrease of muscular force during tiresome physical effort is considered a natural phenomenon, wherein consumption exceeds energetic intake. A minimum of seven hypothesis explaining this are known. The most plausible refers to the *incapacity to re-synthesize* ATP quickly and fully, a molecule which, by degradation, produces the energy for the muscular converter. It is adequate to emphasize here the hypothesis of *self-intoxication* with energetic residues, or the hypothesis of the homeostasis processes. The decrease of force determines also a decrease of velocity,

The higher the intensity of the effort, for instance running velocity, the sooner occurs the exhaustion of the energetic reserves. The body's natural homeostatic defense system , which manifests itself by the fatigue syndrome, causes the athlete's automatically reducing the power and his renouncing making that effort, prior to the full exhaustion of the energetic reserves.

As mentioned herein above, the execution speed diminishes along with net force and admittance. We wish to exemplify the manner of diminishing of muscular power with a beginner athlete, who runs 400 m in approximately 90 s.

$$v(t) := Y(t) \cdot Fn(t)$$

$$Fn(t) := \eta\, Fa(t) - \mu\cdot(G + L)$$

$$Y(t) := \frac{\kappa(t)\sqrt{Fn(t)}}{Fn(t)}$$

$$P(t) := Fn(t)\cdot v(t)$$

In the equations herein above, as opposed to those in the prior paragraphs referring to high jump, the coefficients η, μ, κ appear and signify the fact that in running forces are collinear.

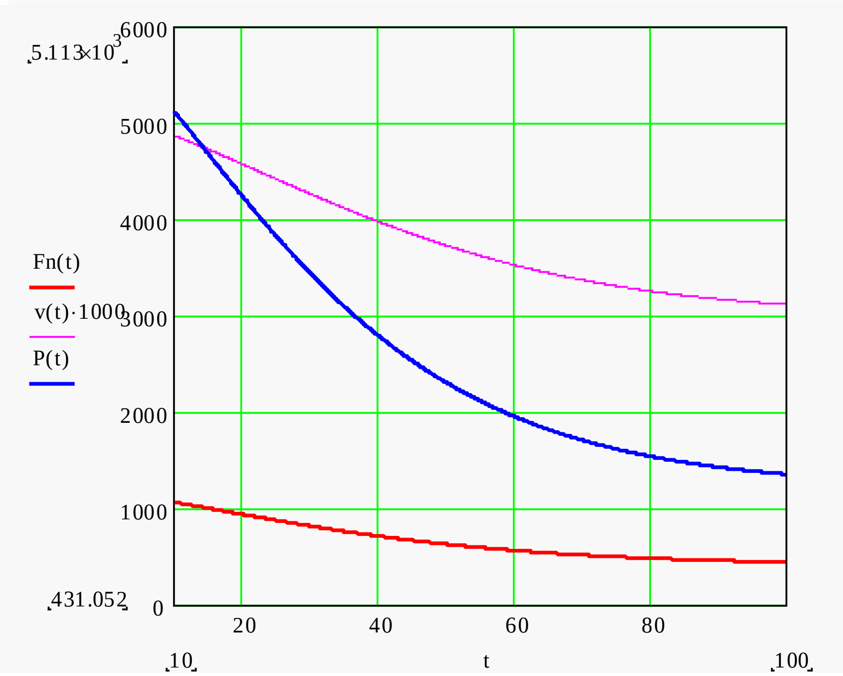


Fig. 5.9. Representation of the manner in which diminish force, velocity and power of a beginner athlete who runs 400 m approximately 90 s. After approximately 10 s as of the start, fatigue occurs and the velocity is diminished to less than 5 m/s.

The chart shows that the athlete is to finish the race almost exhausted.

For the athletes of the international top, the diminishing of power begins after the first 30 s of running, i.e. after approximately 280 m of running with a maximum of speed, and it is a characteristic of all athletic events, from the 400 m to the marathon (lasting over 7000 s).

We can demonstrate the manner of diminishing of the muscular power in running by a theoretical experiment, in which a virtual athlete hold, fictitiously, all world records of track running belonging to the athletic events based upon endurance. Fitting the curve of records, we remarked that the theoretical mode of approximating the rate of reduction of the power in running for athletes of the world top, may be described as a equilateral hyperbola:

$$(P - P_{rez}) \cdot t = \text{const.},$$

Where P is total power, P_{rez} is the power reserve (inaccessible under normal circumstances), therefore $(P–P_{rez})$ is the power generated, while t is the duration of the generation by the muscular effectors. In fatiguing efforts, net force diminishes due to the diminishing of the active force which is supposed to overcome the forces of friction with the soil and the air, i.e. to move body weight G with the speed v. The reduction of net force, and, not less, that of admittance, determines the reduction of speed and implicitly that of the muscular power. The formula herein above concisely expresses the fact that, if effort intensity, in our case the generated power, is high, than the duration of the effort is low. Put in another way, *energy tends to conserve itself in fatiguing efforts.*

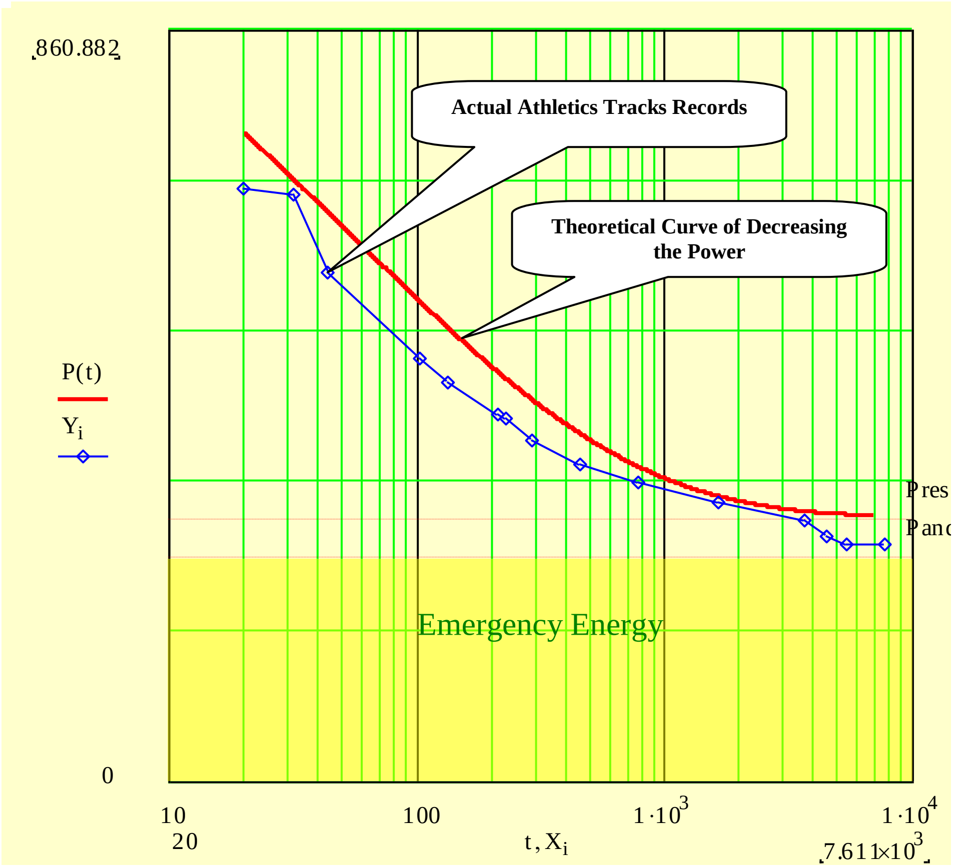


Fig. 5.10. Theoretical characteristic of energy conservation in fatiguing efforts, as deducted by fitting world records in athletic events of running medium and long distances

In Fig. 5.10. one can also observe that the points on the actual records curve do not line up (they differ from the row of points of a theoretical hyperbola).

Explanations may be oriented in two directions:

- the current athletic records do not represent, as yet, the limits of human performance, the actual energetic system is not perfectly conservative, and, probably, the declaration of the moment of exhaustion is subjective, psychogenic;

- the hyperbolic model is not sufficiently true to the law stated.

The most important issue to be observed is the fact that both the experimental model based upon the actual records, as well as the hyperbolic curve approximating it, tend, in a asymptotic manner, towards a power reserve P_{rez}, which, if generated during a time t, would represent a surprisingly high energy reserve.

This energy reserve, as in almost all physiological situations[15], (approximately 40% of the total energy) has, probably a preventive, survival and emergency role. One may suppose that, along with the development of resistance and endurance, this reserve increase proportionally, as it is possible that partial access to it is feasible by training.

Logically, one may infer that the *measure of resistance*, in general, and especially the *endurance* is the energy available or consumed until one reaches the proximity (limit) of the reserve energy. It is defined biomechanically in all fatiguing efforts, by the product between the two dimensions of energy: the power generated ($P - P_{rez}$) and the duration of generation, t. Two ways of measuring appear consequently: either by the duration of the effort made with a certain power (intensity generated), or by a maximum power generated during a predetermined period of time.

[15] The human brain is using only quite a few percent of its energetic potential, the liver can assure surviving only with 10% of its function, and a top athlete can have a cardiac charge more than ten times higher as a normal person etc.

With a certain amount of tolerance, one can make an analogy between the measure of resistance in fatiguing efforts (especially in sports) and the measure of autonomy in motoring. A motor vehicle can cover 1000 km if its consumption is of 5 l / 100 km, and a 50 l reservoir, with an average 100 km/hour speed. The same motor vehicle may taxi with a maximum speed of, let us say, 160 km/hour, when the consumption is 10 l/100 km, and covering 500 km or covering the same distance in 3 hours and 8 min.

If we accept the convention according to which endurance applies to long duration and relatively low intensity efforts, than its measure could be the duration of a conventionally low intensity effort or the time necessary for covering a relatively long distance (meaning that the speed is relatively low). It is understood that at the end of the effort the person who made it should look or declare that he/she is exhausted.

Resistance, as opposed to endurance, applies to efforts of relatively high intensity and, necessarily, having a short duration.

Consequently, the same amount of energy available may be consumed within a relatively short time with a relatively high intensity or within a longer time with a relatively low intensity.

Unfortunately, in physical education and sports the intensities at which the duration of the effort made measure resistance or endurance have not, as yet, been determined, let alone standardized. The difficulty of standardization of the measure and procedures of measuring resistance and endurance is understandable, of course because the diversity of the fatiguing efforts, but mostly because of the subjective character of the appreciation of fatigue. Practical solutions utilized currently are numerous, but they reflect specific resistance and endurance so specifically that a consensus regarding the concept is difficult to attain. For example, biochemical tests of humors, the respiratory activity and reactivity tests, the tests performed on the nervous and muscular systems, etc evaluate or measure the biological impact of the fatiguing efforts. Within a systemic analysis, such biological tests refer to the reactivity of the body, as a functional whole; to this effect, the measure of resistance or endurance should refer to the input in, and output of the system. On the other hand, not all frequently applied biological tests are correlated significantly, and at a significant threshold with resistance and endurance. Thus, the maximum consumption of oxygen appreciated by a correlation with the measured cardiac frequency, and then proportioned with the capacity for making an aerobic effort of resistances a hardly acceptable approximation (in the absence of a certain conventional spread). Nor goes uncriticized the identification of blood lactate accumulation (lactic threshold) as a procedure for the appreciation of resistance and endurance.

The well know COOPER test (applied mainly to football players), measures resistance by the distance covered in running with a relatively low intensity (approximately 90 s/ 400 m, meaning an average speed of 4.5 m/s) or conditional upon the duration of the running (5 min). Performance standards for football players exceed 1350 m, which means an average speed of 4.5 m/s maintained for a period of 300 s.

In rowing, certain proposed strokes and rhythms achieved (cadence, beat) corresponding practically to certain durations for conventional distances. In other words, it is all about certain average speeds, by all means intensities, maintained on predetermined distances or for periods of time.

In middle-distance and long distance running there are, also, some predetermined training intensities and speeds; for example, according to Gabriela SZABO, a well-known Olympic and World Champion, it is about a 3 minutes and 40 seconds' / 1000 m duration or about a 4.5 m/s average speed maintained for several kilometers. In the first formula, it is about a ratio of *time/distance*, while in the second it is a ratio of *distance/time*, which is nothing else than speed.

When efforts are repeated or are cyclical, we speak about period, beat, cadence or, respectively, frequency, rhythm and pulsations. Tests made on ergometric, cycloergometric simulators or on treadmill, seem to be more objective in appreciating of resistance by the acceptable precision of the measuring of mechanic work. Knowing the power generated, the duration of the effort may be measured until the moment when motion becomes unacceptably distorted or rhythm can no more be kept; there is also the situation when the subject abandons. Even if these apparatus measure sufficiently precisely the *consumed energy*, i.e. the product between the *power generated and* the *duration of the generation, only the ratio of the two can be used to pinpoint the difference between resistance and endurance*. The ratio between power (usually expressed in Watts), and the duration of the effort (expressed in minutes) can discern the difference between resistance and endurance. Practically, however, there needs to be a certain intensity (not less than 67% of the maximal one), while resistance is evaluated by measuring the duration of the effort. Thus, if maximum power is measured and then an intensity of the effort is imposed as 33% of the maximum (sometimes even 50%) *endurance* will be evaluated by the length of time of the constant intensity of the imposed effort.

As regards the standards, they vary so much in relation to sports training experience, age, sex etc, that, from a biomechanical point of view searching for ratios (between the power generated and the duration of the generation) becomes useless in differentiating the measure of resistance from that of endurance.

As conclusions:

- the biomechanics of endurance is not different from that of resistance. From the standpoint of the training methodics, resistance to exhausting efforts practiced with a relatively high intensity and, necessarily, of short duration, while endurance refers to relatively low intensity efforts made during a long span of time.

- In exhausting efforts, if the power generated is high, the duration of the effort is to be short and vice versa; the consumed energy tends to conserve itself. The expression to be met in methodics *"increase intensity, decrease volume"* reveals the same thing regarding energy and is valid only in running, where duration has the meaning of volume (minutes or hours).
- Resistance and endurance end in exhausting efforts when motion is unacceptably compromised and rhythm decreases under a pre-determined level, and when the subject looks exhausted or declares to be exhausted.
- The power generated decreases continuously when the duration of the exhausting effort is increased and tends to access the power reserve. Power reserve, with professional athletes, is approximately 40% of the maximum one. Access to the reserve power is hazardous. It is probable that doping and other prohibited means elude physiological and psychological barriers, however not without unfortunate consequences.

VI. THE LAWS OF BIOMECHANICS

6.1. Borrows and owners laws of biomechanics

It is incorrect to consider the laws of biomechanics as the laws of mechanics applied to “bios”. This inaccuracy is frequently met in the books of biomechanics, mainly when they refer to the athlete’s movements and to its corporal segments. No any doubt, the laws of Newton are frequently applied in biomechanics, are valid for the movements in which the external forces are bigger than the internal ones, but are not characteristic for biomechanics. We sustain and attempt due to scientifically prove that the biomechanics has its own laws and has the right to be considered as a new science.

The nowadays biomechanics evolutes from the form of a border scientifically discipline to one of a becoming science, using beneficially a series of borrowed laws but, also, consolidating its own laws.

We don’t refer to transmissions because, like everywhere in the terrestrial area, the principles of transmission and preservation of the power and energy are valid. The same thing happens in biosphere. We refer to the causes of the movement which, axiomatically speaking means that the possibilities of the muscular converter of flowing energy over a certain period of time are limited depending on the sources and resources that this converter has. It also means that, through bonds and biological tissues, the mechanical tension from the muscles is transmitted to the resistance forces, preserving the moments of the forces (in the case of isometry or equilibrium) and amplifying the speed or the force in a compensative manner. The bonds become in these way mechanisms of preservation of the muscular power (the multiplier between the force and the speed). The gained force, in the practical case of the bonds is made against the distance which is known from the antiquity as golden law of mechanics.

The main law of biology, the one of the irritation of the living tissue is also present and valid in biomechanics. Especially its reactive effects of homeostasis and heterotrophy are obvious when the movement tends to overcome the available energetic possibilities or the limits of mechanic resistance of the biological instances implied in the effort.

The main law of the physical education and sports, the one of overcompensation made by the complex reactor, in other words the leaded and graded effort, acts as well in biomechanics when it comes to the efficiency of the movement.

The own laws of biomechanics, coming from the taking into account of the cause of the movement have the advantage of being outside the sphere of the scientifically polemic regarding the measure of the movement quantity from mechanics. Even if D'Alembert has persuasively argumented the reason for it is a nonsense to talk about the form of impulse variation (Descartes) or the kinetic energy variation (Leibniz) of the measure of the movement, still in mechanics persist questions referring to pseudo-forces (inertial, centrifugal, centripetal forces etc.).

We insist over the fact that the laws of biomechanics regard only as an overview and in a concrete manner the efficiency of movement, not needing tricks like in mechanics, because the muscular contraction which generates the concrete and net force is limited in time. That's why, the energetic flow, biomechanical speaking has a limited period of time set into two transitory phases, one of increase of the energetic flow and one of decreasing of the energetic flow (shown through tiring).

Our belief, having practical reasons, is that the biomechanics has the following three laws:

1. The law of preserving the force in starting of the movement.
2. The law of preserving the power in maximal efforts.
3. The law of preserving the energy in the tiring efforts.

All these laws refer to the total capacity of effort of the organism or local (in segments), meaning to the potential of making mechanical work.

In very many dynamic circumstances, like the ones in the professional sports, the general capacity of effort is composed, theoretically and in individual proportions, out of three conservative forms, that every individual can be characterized through a certain maximal power, maintaining a part of it (conventionally ½). In the next paragraphs we will keep going to the idea of why the analogy with the three main characteristics of a cars engine – the power (or its maximum speed), the time of acceleration till a certain speed and the fuel consumption (or its autonomy) is a pertinent ones.

The idea of general capacity of effort may be put clear and concise in mathematical language through an equation integro-differential (PID type) with constant coefficients (for a certain moment) and individualized:

The general capacity of effort = $\alpha/(\alpha+\beta+\gamma) \cdot P + \beta/(\alpha+\beta+\gamma) \cdot dP/dt + \gamma/(\alpha+\beta+\gamma) \cdot \int P dt$

The specialists will easily recognize the meaning of these coefficients whose relative sum is unitary. (P being the flowed muscular power).

The above grounds tries to suggest the fact that the flow of energy, meaning the muscular power, is essential in human motricity, that it can appear in different forms (like the ones from the well known expressions: the force in a speed regime, the speed in a resistance regime etc), taking into account the proportions for every term.

6.2. The Law of Preserving the Force in the Movement's Start

In the movement's start, produced through muscular contraction, the net force tends to preserve under the form of inertial force.

It is to mention that one should understand through net force the cause that produces the shrinking of the muscular fibers and through inertial force a cause that produces the accumulation of the movement quantity or of the energy under the reactive forms in the body complied to move. In the movement's start the inertial force, known in physics under the name of "pseudo-force", tends to continue the resting state of the body opposing to the cause not to the body, opposing to the change of speed not to the rest. The effect is the delaying and the rough start of the body movement.

The variation of move's quantity (measured by mass multiply by velocity) is owing to the cumulative force that is acting in the short time of movement's start and to the resisting forces. In the case of muscular contraction, the speedy shortening of muscular fibers are owing to the electrochemical tension produced by the rotation of the ATP molecules and to the variation of the admittance (the antonym of impedance, sometime of resistance) of the contractile medium. As it is known, the admittance is a medium's feature which, generally speaking, intermediate an effect to a cause, as for instance, link the magnitude of an electric current to the electric potential into a circuit. The admittance's variation of the contractile medium is closely depending of the neuro-muscular commands of time-space recruitment of the synapses and contractile instances. As consequence, the beginning of the mechanical muscular tension depends of the vectorial sum between the net force and reactive inertial force and, as well of the admittance's variation. The acceleration of the body complied to move will be depending of the difference between the inertial and resisting forces and, obvious, will be inverse proportional to the body mass.

It is coming out that the most important characteristics of the biomechanical movement's start is the fact that its time's interval (transitive regime) can't be ignored and also the fact that the net force is cumulating under the form of reactive inertial force. The result is a constant sum, that is to say a preservation of the force. Indifferent of the kind of simplification of the reality by patterns a thing is sure; the transitive regime of biomechanical movement's start link two stationary regime, rest and the powerfully movement. Often, these transitive regimes are practically denominated in the top sports as pure force domains (weight lifting, throwing etc) and, when the resisting force is even the athlete body the domain is denominated explosive force (sprint, jump, boxing etc).

Even if the classical laws of mechanics, on which the instant variation of the force is acceptable, are applied to the movement's start, still persist two biological arguments that lead to the idea of a "sigma" variation of the power. First, due to the fact that mechanical tension produced by rotation of the ATP molecules are not the cause of the energy stored in the elastic mechanical structure and second, that the spatial recruiting of the synapses and contractile effectors is asynchronous. We believe that also the phase shift of the forces determine the duration of the transient regime, indifferent if the reasons are regarding to the admittance or to the geometrical parameters.

We illustrate this low by an electrical pattern which, in our mind, simplify acceptable the reality. The commentary of this pattern seems to be a requirement for the specialists of biomechanics and can be ignored by most of the readers.

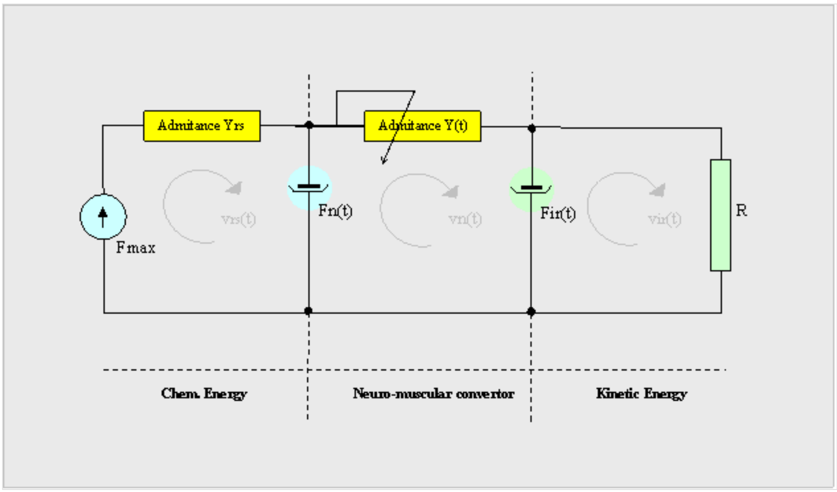
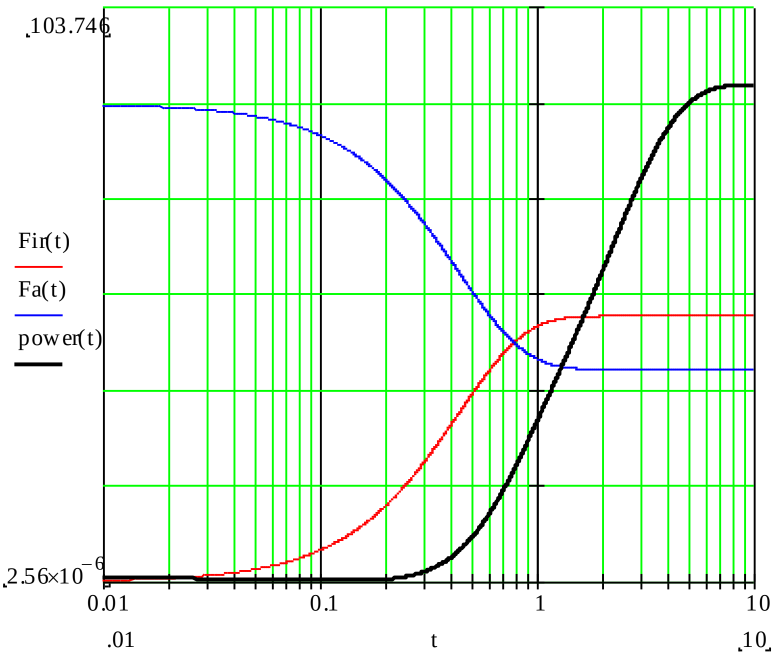


Fig. 6.1. The electrical pattern of the starting's movement due to muscular contraction

The simplification of the effect of muscular contraction seems to be reasonable as less as for didactic reasons. In the above picture, the potential of force (as an electrochemical cause) is assimilate with a generator of continuous electrical voltage (Fmax) which supply and compensate the energy consummation. It's meaning the of the spare energy of macroergic phosphoric compounds represented by the electrical capacitor with the Fn voltage on its electrodes. The resynthesis is limited, fact implied by the admittance Yrs. The mechanical tension in the muscle fibers grows up at the same time as increasing rate of temporal - spatial recruitment of the synapses and afferent instances. This transitory process is illustrated thru the variance of the admittance (Yt), of which the initial value is negligible and the final value is maximum. Practically, this it is a mater of the reaction of the contractile instances to the nervous command. When the inertial force overtake the vectorial sum of resisting forces (R), then the heavy body (of mass m) loaded acceleration, conforming to the D'Alembert principle.

Whatever of the analogical model of the conversion of the muscular energy used, a think is very clear; the starting movement is a transitory regime, between two stationary regimes: (usually, the rest and the maximal power regime). In these circumstances, the classical mechanical lows undergo some amendments, marking out a kind of variation of the power acting over the mentioned body, anyhow a non instantaneous variation. The simplification thru the instantaneous variation of the power is unacceptable for biomechanics, not only because of the mechanical inertia, but due to the inertia of the neuro-muscular converter of chemical energy to kinetic energy. No less as two biological reasons and one mechanical are understandable regarding inertia of neuro-muscular converter. First of all, the mechanical tension into muscular fibers produces by cumulative rotation of the ATP molecules (30^0 for every losing P) can't be assimilating with the force that produces the accumulation of energy into elastic mechanical elements. Secondly, the recruitments of synapses and afferent contractible instances are, by meaning, asynchronous. It is possible to add the plausible hypothesis, conforming on with, the nominal force do not changes instantaneous into inertial force and become numerical equal to the value of total force. We suppose that the changing of the phase of the forces determines the duration of the transitory regime, irrespective of its pass on to the impedance or geometrical parameters.



6.2. Graphical representation of the low of preserving the forces during the starting phase of the movement. The sum of inertial force and active force *tends to be constant. The increasing power follows a sigma curve, according to speed increasing and admittance variation.*

As it is shown in the above figure, the simulation of the comportment of the electrical model of muscular energetic converter reveal a "sigma" curve of power's variation, as well as for the admittance. The sum of the nominative force and inertial force has a tendency to be a constant.

Regarding the mathematical pattern, we have sufficient basis and arguments to consider that the energetic stock, that is to say, the potential of nominative force decrease during the starting movement as follows:

$$Fn(t) := Fmax(t)\cdot e^{-\left(\ln\left(\frac{Y(t)}{C}\right)\right)\cdot\frac{t}{Ttr}} + Fmax(t)\cdot\left[1 - e^{\left[-\left(\ln\left(\frac{Yrs}{C}\right)\cdot\frac{t}{Ttr}\right)\right]}\right]$$

The C and T_{tr} constants from the above equation determine the decreasing rate and the duration of the transitory regime, and the admittances $Y_{(t)}$ and Y_{rs} controls the rate of conversion, respectively, the energetic resynthesis.

The mathematical pattern of the admittance variation can be acceptable simplified by taking into account the hypothesis of accelerating rate of spatial - temporal recruitment of the contractile instances at starting movement and of decelerating rate at the end of transitory contractile regime. Concise, this is to say:

$$Y(t) := k\cdot(nm - no)\cdot\left(1 - \exp\left(-a\cdot t^{b}\right)\right) + no$$

The constants from the above mathematical expression of the admittance characterize the conjuncture contractile medium from the point of view of geometrical structure. The variation of the admittance may suggest a hypothetical vent for the debt of energy transmitted to the inertial body.

The inertial reactive force grows up while the nominative force decreases:

$$Fir(t) := Fmax - Fn(t)$$

According to the D'Alembert principle, the acceleration of the body depend of the magnitude of $F_{(t)}$:

$$F(t) := Fir(t) - R$$

R – represent the vectorial resulting of resistive forces.

The variation of the speed and the power follows the admittance variation.

As it is shown in the above figure, in our pattern the power increases exponential-logarithmic, linking two stationary regimes. From the relative point of view, the relationship between the inertial velocity, admittance variation and constant difference of the forces is identical with the relationship between inertial velocity, a constant admittance and a variation of the difference of the (unbalanced) forces. Both situations produce a phase shift of the movement quantity, similar to the ones produced by the electric current flowing into a capacitor due to a transitive variation of electric potential. A hydraulic pattern on which the debit of a liquid (hypothetical power) depends of the variation of flowing area or of the pressure variation or of both is offering simile assessments.

We have to comment that any pattern of the variation of the power during the transitory phase of movement's start simplify the reality in different measures. For instance, in the above pattern, the mechanical inertia admittance and the odometry admittance are negligible; therefore the total force is shown as a constant. A little bit more complicated and more accuracy seems to be the pattern on which the relative admittance relate the speed to the force, as in electricity the electrical current is interrelated to the difference of potential.

As an argument, in the following pattern, build by us, the speed $v_{(t)}$ is interrelated during the transitory phase of movement's start to force (F_{max}):

$$v(t) := k\cdot(Ynm(t)\cdot Yodo(t)\cdot Ymec(t))\cdot\frac{Fmax}{G+R}.$$

Because of independent variable, the neuro-muscular command admittance (Y_{nm}), the odometry and resynthesis of chemical converter admittance (Y_{odo}) and the mechanical inertia admittance are serial connected. The speed is limited by the segmental or body weight (G) and by the load (R) if exist. In a canonic mathematical pattern, the individual constant k represents a minimal negligible speed near the forces equilibrium. In a "sigma" pattern the *k* is a function of cubic speed. In mechanics, as an acceleration effect, k means the integral operator. These examples try to underline that the same phenomena can be explain in different kinds and different accuracies.

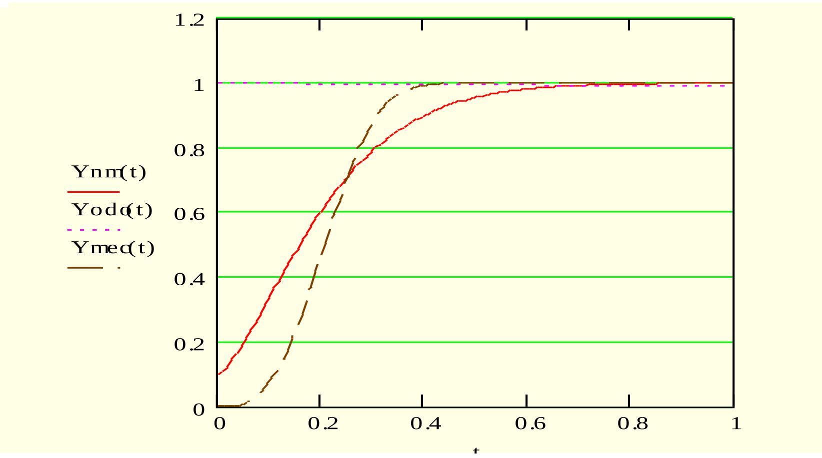


Fig. 6.3. The variation of the admittance during the transitory Phase of the movement's start. Related to the above pattern

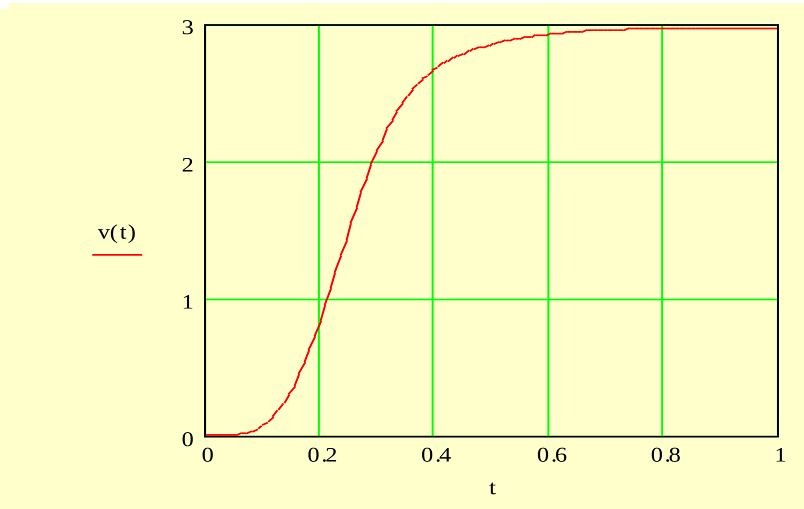


Fig. 6.4. The variation of the speed during the transitory phase of the movement's start. Related to the above pattern

As a strong argument we offer the result of the follows theoretical experiment. Let us consider a super athlete who is the hypothetical holder of all world records in short sprints. The fitting of the speed and power diagram is shows very clear that the acceleration is growing up on the beginning of the movement and decrease on the last part of the transient phase, generating a variation of the power in a “sigma” graphic form. Indifferent of the suppositions of average speed or of maximum speed the conclusion is that that the mechanical inertia and the inertia of contractile effectors leads the rate of energy to grow up from a negligible value (as in the sprinters) to the maximum values in a transient phase (which is about 10 s in this example).

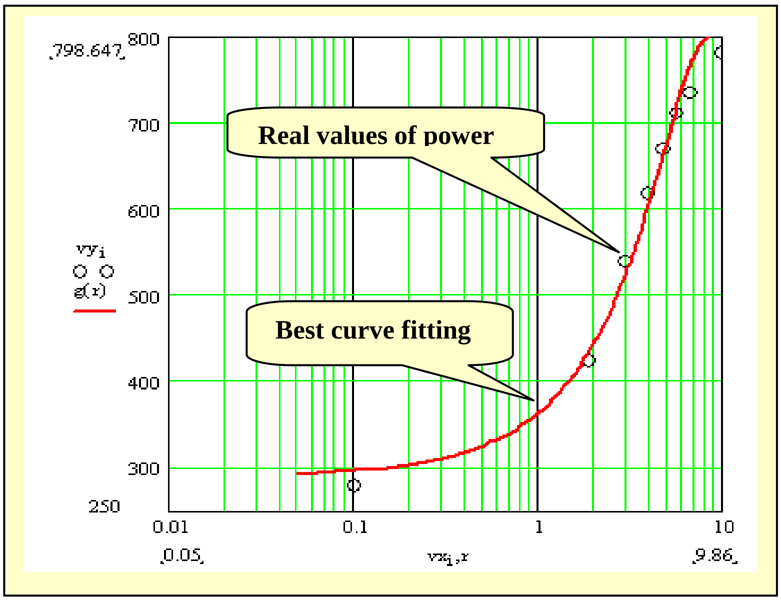


Fig. 6.5. The power variation of a hypothetical athlete, holder of all world records in short sprints, during the transitory phase of movement’s start

Summarizing; the posse's biomechanics law of force preservation in the movement's start explain the inertial effect of delaying and the rough start of the body movement based on the morphological characteristics of the neuro-muscular system.

6.2. The Law of Preserving the Power in the Maximal Efforts

The mechanical power flowed in the maximal muscular effort tends to remain constant.

This law refers to stationary regime of the effort, which is coming after the transitory regime of increasing the active force at the maximal value. The maximal force produces a movement having the net speed (V_n) according to effectors admittance and resisting forces.

All the debt net power transforms in utile power (P_{util}) and is used for overcome the resisting forces (G+L):

$$P_{util} = (G+L) \cdot V_n$$

As consequence:

$$P_{max} = P_n + P_{util}$$

By this way the power is preserved, and it's usefully effect can be observed measuring the net speed of the movement:

$$V_n = P_{max} / [\ P_{max} - (G+L)\ ]$$

Of course, this item is valid for a relative short period of time when the maximal power of an individual is constant and tiring process is not yet visible.

This law says that while the resistance forces increases, the contraction speed decreases. The multiplier between the resistance force (G+L) and speed V_n of movement (transmitted from the muscles through bonds) tends to remain constant and equal with the maximal power.

Comparing it with mechanics this law says, in a specific form, the preservation of the power. But, unlike the mechanics where the preservation of the power can be presented concise (mathematical) in such a relationship:

$$P_{max} = F \cdot v = \text{const.}$$

in biomechanics some difficulties appear in defining the preservation of the power because the force doesn't appear instantly, zero speed doesn't mean zero power, and the power isn't constant except on a phase bordering by two transitory periods (one of its procuring and one of its exhaust). To apply the mechanical form of preservation to biomechanics is beyond belief, for instance, in the case of isometry or of eccentric movements, where the power would become zero or negative, which would be impossible.

The relation between the resistance forces of contraction of the striated muscle has been studied and experimentally deduced in the laboratory (on different parts of the body and especially in rabbit) by several scientists; V. A. Hill being the most popular. He proposed a mathematical pattern of concise writing of the relation, under the form of equal lateral hyperbole:

$$(F + a) \cdot (V + b) = (Fmax + a) \cdot b = \text{const.}$$

where F is a resistance force (practically a weight to lift or to move), V is the speed of the movement (of pulling up or moving the weight), *a* is a constant which signifies the weight of the corporal segment (or of the bonding system) moved, and *b* is another constant signifying the minimal speed of the movement of a maximum resistance force. The mathematic pattern belonging to Hill solves in a smart way the difficulties of writing the law of preserving the power in biomechanics, because it uses the constant with the above significance.

It is to mention other mathematical patterns which describe the relation of the resistance force with the movement speed (transmitted from the muscles to it) and which, also, has the name of its authors (for example the exponential pattern Fenn and Marsh : $F = F_{max} \cdot \exp(-kv)$, Pallisar pattern or Aubert model). All these empiric patterns describe, in fact, the same thing, that is to say, the tendency of preserving the maximal power during the maximal muscular effort.

Graphically, the curves of all this patterns have the tendency to be almost the same.

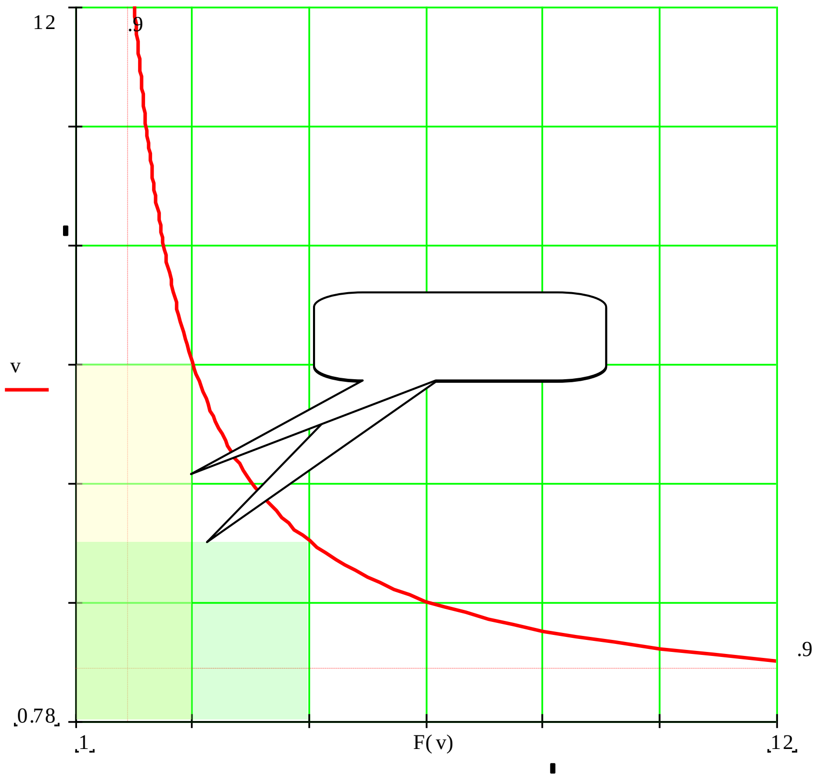


Fig.5.6. The hyperbolic relationship between resisting forces and movement speed. The constant areas signify the preservation of the power in the maximal efforts.

The main characteristic of the curves in the above graphic is that, in any of its points, the multiplier between the coordinates tends to be constant. For easing up the comments, let's imagine the situation in which the sportsman does a physical effort with a machine that develops the force (for example, in the simplest case, a pulley over which a rope is passed and has weights on the opposite side, but that could also be a helcometer or an ergometer). The sportsman pulls the rope and lifts a certain weight F_1 with the speed V_1. If the weight is bigger, namely F_2, then the speed of its lifting will be lower, namely V_2.

Hill's relation shows us that the multiplier between F_1 and V_1 is equal to the multiplier between F_2 and V_2 and is in the same time constant, because it represents the maximal power of the sportsman.

Synthetically speaking, the law of preserving the power in the maximal efforts refers to the stationary regime, when the inertial phase of starting the movement has been passed, but it hasn't jet achieve to the tiring phase. In real meaning, this law sustains that, if the resistance force is big, the speed of the movement will necessary to be low (relation which is valid the other way around too). Ignoring this law in the method of sports training can be harming for their efficiency.

6.3. The Law of Preserving the Energy in the Tiring Efforts

It is normal to say that the tiring efforts are those efforts (over a relative long period of time) in which the maximal power decreases bit by bit (it can't be considered constant any more). For a world's top athlete, the decrease of the power begins after the first 30 seconds (about 280 meters) of running and it is present even for marathon (which lasts over 7000 seconds). In general these efforts are called efforts of endurance (resistance).

In these efforts, in which the flow of mechanical energy is bigger than the energy produced by the ATP resynthesis, when, out of physiological reasons, homeostasis usually, a constant maximum power can't be maintained, the available muscular energy itself tending to be a constant. In other words, the bigger the level of the flowed power, the faster the possibilities and biological reserves are exhausted. When it comes to running, it may be said that an athlete which runs with a height speed exhausts faster (meaningly, after a shorter period of time) than if he would run with a lower speed.

The available mechanic energy for the tiring efforts tends to remain constant.

This law has its source in the principle of kinetic energy preservation and reflects, biomechanicaly speaking, the spirit of the second law of Newtonian mechanics. In other words the multiplier between the available power and interval tends to be a constant. A simple mathematical model of this law is the hyperbolical one:

$$(P - P_{rez}) \cdot t = \text{const.}$$

Where P is the flowed available power, P_{rez} is the stock of power (inaccessible in normal conditions), so $(P - P_{rez})$ is the unconsumed available power, and it is the period of time of its flowing by the muscular effectors.

Simulating the way an ideal athlete acts, which fictionally would keep hold of all the worlds' records in the track and field competitions; we realized that the real values differ very little from the ones of a hyperbolic model of the law of preserving the energy of the tiring efforts. The differences can be seen in the below graphic, where the way in which the real values of the consummated energy vary is close to the theoretical model, meaningly a hyperbolic curve.

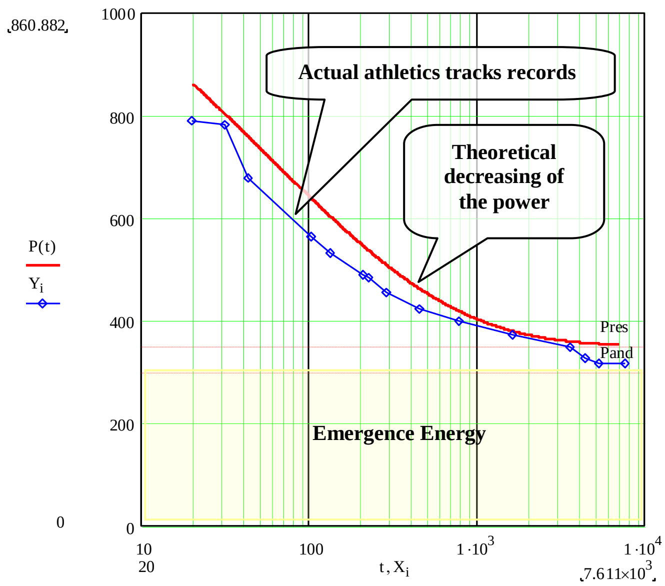


Fig. 6.8. The graphical illustration of the law of preserving the energy in the tiring efforts. Explains in the text.

It is also observed that the points of the power curve (the real values) are not aligned (they differ from the points of a theoretical hyperbola).

The explanations can be oriented in two directions:

- The actual athletics records are not yet the limit of the human performances, the real energetic system is not perfectly conservative and the declaring of the exhaust is subjective, psychogenic.
- The hyperbolic model is not perfectly satisfying for the law.

Anyway, we believe that the exponential mathematical model of this law, model which we present here, is more appropriate for biomechanics than the hyperbolical one:

$$P(t) := (Pmax - Pres)\cdot \exp\left[-\left[\frac{Pmax}{Pand}\cdot\left(\frac{t}{tand}\right)^{k}\right]\right] + Pres$$

Where P_{max} is the maximal power, P_{res} is a reserve power, inaccessible in normal conditions, P_{and} is a physiological and psychogenic frontier corresponding to the duration of the effort (t_{and}) and *k* is an individual constant. This equation put in evidence that the next future athletics records would depends not only of the maximal power developed in the training process, but mainly of the new ways of access in the spare (emergence) energy or by genetic influence over the individual *k* factor. This spare energy (or power, as it is presented in the above graphic) refers to a virtual period of time, which could last the effort, if this would be continued. The human organism, instead, being well equipped with sensors, knows, in normal conditions, when to command that the effort be stopped, that the risk of some harming effects is acceptable. A plastic comparison of this effect may be done with that red light from many automobiles, which shows us that the gas tank is almost empty, but there is yet a little spare. The virtual time of exhausting this spare, if is correctly estimated, can lead to appropriate decisions.

We add to the ones said before that, for running efforts of the level of top athletes, the relative short periods of time are tens of seconds (anyway more than 30 seconds), and the long periods of time are of thousands of seconds (as in marathon race). The intervals of time shown in the above graphic starts from 20 s (200 m) and ends at 7611 s (marathon race).

In other words, the law of the preservation of the energy in the tiring efforts is applied to all types of physical effort, no issue of their difficulty, and is valid for periods of time of the effort in which the power can't be maintained to maximum level. This means that the law is addressed to the endurance's efforts (physical resistance of long-term effort), and suggest that the endurance can be measured in a conventional limit of decreasing the power or in the duration of effort in which this limit was got.

In any case, this indetermination can be eluded by using a combination between power and duration, meaning energy.

We propose to measure the endurance of an athlete at the half of decreasing of the total energy. The reason for this opt is not only the similitude with the half period of decreasing the natural radioactivity, but especially the fact that it's covered a lot of different manifestation of the endurance in sport and because the risk of attainment the dangerous limit of exhausting is far.

6.4. Survey on the Laws of Biomechanics

The speedy movements are met everywhere in sports: at jumps without any jerk, at the start of sprint running, throwing, lifting, kicking etc., and is known, as we said before, as force movements. They are defined as being of "short period of time" or of "force in a speed regime". Expressions as the ones above, even if they are intuitive, are too vaguest to be used in biomechanics, which determined us to go to the zones of the muscular contractions.

So, through force movements we understand those movements that are produced in the transitory phase of powers variation, until the maximal value is reached. Characteristic for this phase is the tendency of force's preservation and the fidelity of the muscular effectors in which they act towards the first law of biomechanics.

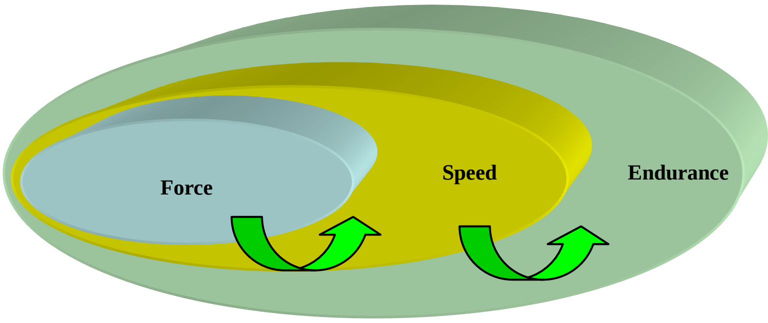


Fig.6.9. Illustration for the phase theory of the laws of biomechanics. In the first phase of the movement the preservation of the force is dominant, then power (force · speed), and last, in the third phase the preservation of the energy is dominant (force · speed · endurance).

In the second phase, if exist, when the power become maximal, the movement transforms in a speeding one, the tendency being of power's preservation, meaning of the multiplier between the force and the speed, and the mode of how the muscular effectors acts, sustaining the second law of biomechanics.

In the tiring phase of the effort, the movement becomes an endurance one; the tendency being the preservation of the energy, meaning of the multiplier between the force, the speed and the time duration, and the fidelity of the muscular effector's act regarding the third law of biomechanics.

The different forms in which the power acts, as a variation (force type), as a maximum power (speed type) or as a quantum (resistance type), characterize together, but in different proportions, the capacity or the capability of a person to do a physical effort. In extension, and regarding to the physical education and sport, it can be said that each physical exercise has a certain motricity component, taking into account the predominance of the one of the forms of power described above.

A person or an athlete who practice physical exercise or physical education and sport, theoretically, has a specific physical effort potential, available in a certain amount and prearranged in a certain way. The availability differentiates the maximal capacity of the movement capability (itself being dependent of the state of the organism, the anterior effort etc.).

From the biomechanical point of view the physical effort potential of a person or an athlete refers to the three terms of the effort's capability and its coefficients:

- the force – represented by the variation of power in the inertial start's phase and the coefficient *beta* $/ (\alpha+\beta+\gamma)$;
- the speed – represented by the maximal power and the coefficient *alpha* $/ (\alpha+\beta+\gamma)$;
- the endurance – represented by the cumulus of power or available energy and the coefficient *gamma* $/ (\alpha+\beta+\gamma)$.

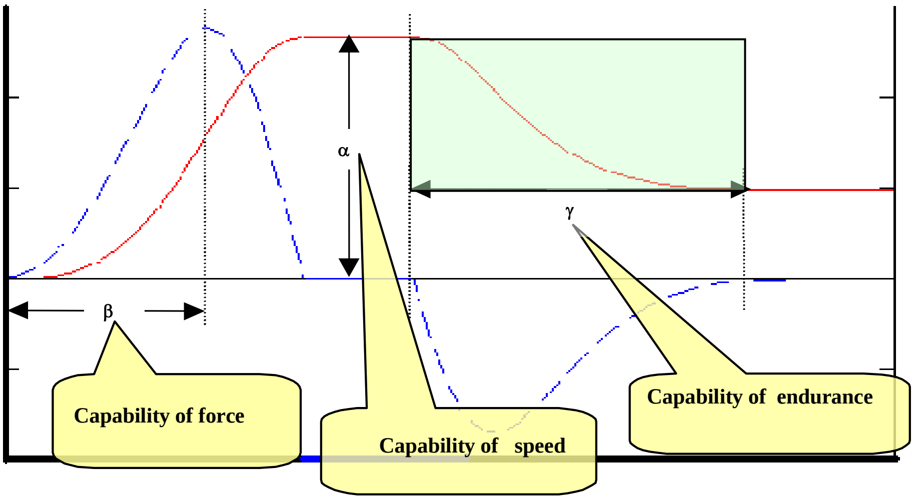


Fig.6.10. The athlete's capability of doing a physical effort, structured in three components (and its coefficients): of force, speed and endurance. Explains in the text.

The analogy of the athlete's capability of doing physical effort with the usual expression of the characteristics of a car engine, expressed through:

- the maximal force, expressed through the starting acceleration (conventional, the time needed to reach 100 km/h);
- the maximal speed at the standard weight, meaning the maximal power;
- the maximal endurance, meaning the combustion consumption (relatively to 100 km or to conventionally autonomy), seems to be not a occurrence.

In sports domain, many forms of how to measure the capability of effort have been imagined, sometimes, for the specificity, reaching redundant situations. We underline again the fact that, entirely, the capability of doing a physical effort has only three different forms of manifestation: the promptitude, the power and the quantity of available energy. These forms correspond to the laws of biomechanics and to the phase's theory of the muscular contraction. As systemic biological responses, probably, this fact can be considered the main difference between biomechanics and the theoretical mechanics (where the response is idealized).

Every sport, through its specific measurement characteristics, should identify at least one of every form of effort's capability acting, of course, completed by the psycho-coordinative actions.

VII. THE TYPOLOGY OF MUSCULAR CONTRACTION

Strictly speaking, the muscular contraction means shrieking the muscle, comparatively to its rest state. The *prima facie* cause of this shrieking is, as well-known from the physiology and other connected disciplines, the rotation of the ATP molecules. Very briefly, we can state that this muscle shrieking produces mechanic tension that is transmitted by tendons to the application points and by lever to the load that is going to be moved. Further details of this phenomenon, such as the role of the ligaments and of other cartilage's in guiding the tension, other application points than those on the bones (such as the skin or organs) other contractions, different from those of the skeletal muscles are not necessary in this contest.

In respect for the tradition, we shall also make further use of the term "muscular contraction" for the movement of *going* out or for the equilibrium state, sharing the opinion that there are three kinds of muscular contractions:

1. Concentrically;
2. Static (isometric);
3. Eccentrically.

From a biomechanical point of view, the concentrically contractions are produced when the net force *Fn*, released by the mechanic tension in the muscle, is higher than the resistive load, briefly: $Fn > R$.

The static contractions appear when the net force equal, at most, the resistive load or the resistive load is restricted at its opposite movement: $Fn = R$

The eccentrically contractions, in fact the lengthening of the muscle even starting from another length than the relaxation one, are produced when the net force cannot overtake the resistive load and the latter one is not restricted by the opposition movement: $Fn < R$

We can also mention, as Hill showed before, the very low amplitude contractions (such as muscular *twitch*, where the shortening is not evident but as a change is section size), the fast contractions and the ballistic contractions, when the movement is made by a protagonist muscle, assisted by other synergic muscles. We consider the notion of *synergism* as having been fully understood, so there is no need to further explain it. Yet, we must emphasize that the use of the term “synergism” for the resultant action, of the agonistic and antagonistic muscles is not widely accepted by the specialists, they sometimes prefer the resultant to be called, according to the case of:

- action;
- stabilization (fixation, support, etc.);
- neutralization.

The resultant of the contractions is an algebraic sum of gradate contractions of a variable number of muscular fibers, from order thousands (as in the case of biceps br., 600.000), or of a larger number of pairs of muscles (as, for instance, 74, in the case of the biped posture of human).

The mechanical tension in the appliance point, for example in the tendon, depends on the quality of the muscle, the number of muscular fibers implied (willingly excited) and on their length and geometry. Certainly, the background conditions, especially the temperature, influence the contraction, but other factors can be also added, as the previous effort or the quality of the innervations. Whatever the athlete has to do before any physical effort, which is the warm up. This is, exactly, a rising of their body temperature (locally, up to 41-42 grade C), as well as a preparation for effort by blood irrigation, bringing in an under layer of energy and catalyses etc.

In this respect, it will be useful to mention that a significant correlation between the maximum tension developed by a muscle and its cross section has been identified. In other words, the massive muscles are more powerful, but the mass artificially acquired (especially by thickening the collagen's support) as in the case of some body builders, sometime infirm this observation.

The muscles, in as much as professional athletes are concurred, may weigh up to 45% of their body weight and may represent over 50% of their basic metabolic activity. The muscular work can be impressively great with the athlete, compared to the people who do not practice physical effort as professional. For this reason, the biomechanics of muscular contractions often refers to sport and tends to be a science meant more for exception than for the normal.

Coming back to the muscular contraction, generally considered, we can mention the fact that *Fick* make distinction of five conventional lengths of the contraction, as suffered to the length of the relaxed state. One of these is the shortening thesis, that can be to 57% (in the can of the *sartorius* muscle) and another shortening refers to the disinserted muscle (or the broken tendon), when its length lowers to more than a third. The maximum lengthening of the muscle by external forces (as in the case of stretching), even with the contractile mechanical tension, it is considered another conventional length. The fourth conventional length, beside the resting on, but pathological or *sacrificial* for the sake of science, it is that of prepared, when the muscle is artificially stretched by the disinserted tendon.

As it has been already mentioned in the previous chapters, *Hill* experienced the relationship between the size of the resistive change / load or the disinserted muscle (a weight hung from the tendon) and is speed of contraction, when the muscle was electrically excited. His conclusion, that is an inverse proportion between the size of the change / load and the speed of contraction, of a hyperbola equilateral type, is precisely the second law of biomechanics. We shall remind that this means preserving one's power until tiredness appears.

From a biomechanical point of view and referring to the resistive load and the contraction speed, muscular contractions may classified in:

1. isometric contractions;
2. isotonic contractions;
3. isokinetic contractions;
4. auxotonic contractions;
5. pseudo-contractions or eccentric movements (of yielding) with overload;
6. over-contractions or movement at an over-maximum speed, with a negative load.

7.1. Isometric Contractions

Their very name suggests that in these contractions the length of the muscle does not change and that means cancellation of the movement, balance or static position being ensured.

Although the pairs of tonic muscle that control the bipedal posture fulfill static contractions, they are not isometric, because they do not oppose to an external or internal additional load.

In sport, isometric contractions gradually take the mechanical tension of the muscle to its maximum value, being considered means of training. As means or exercises of training the isometric contractions begin at a well or very low tension and increase progressively for 4-6 seconds, to the maximum tension, keeping it for 3-6 seconds whereupon the tension decreases back to normal in 2-3 seconds. Accordingly, the isometric contractions keep up (for a few seconds) the mechanical tension in the muscle at a higher level than the relaxation tonus, either because the resistive load is immobile, or because the net force transmitted through the levers to the load is equal to it.

Isometry or practicing isometric contractions was a fashion once in sportsmen's training, especially when increasing the strength was a goal. Inadequate use or exaggerated grading rapidly put an undeserved and to it. In our opinion, daily practice of at most one isometric maximal contraction for each large group of muscles is benefic in most sports, especially when these contractions are followed by relaxation or stretching exercise. Isometry can also be practiced by fixing the point by help of the antagonistic muscle or by using one's other muscular groups in an opposition.

The figure below shows the relationship between the resistive force and its speed of displacement. If we have in view the mechanical tension in the muscle, then the speed represents the shortening of the muscular fibers in the time unit. Measurement units are relative (F / F_{max} and V / V_{max}).

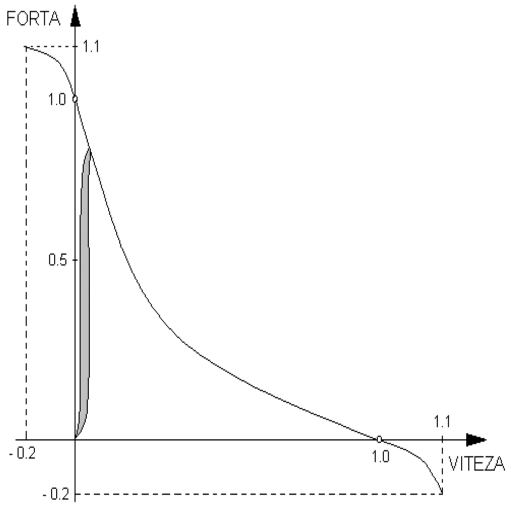


Fig. 7.1. The diagram of the isometric contractions. The darkened areas indicate that the net force can increase without the speed having practically a decelerated value. The length variation of the muscle is negligible in this case.

7.2. Isotonic Contractions

Theoretically speaking, the isotonic contractions keep the mechanical muscle tension constant all over the shortening of the muscle; the speed of contraction may vary to the maximum value corresponding to the displacement of the respective load. But practically, every muscle has areas of contraction for which the corresponding net forces differ significantly. These, the majority of the phasic muscles in the human locomotory system have force peaks at 2/3 of their relaxed length. On the other band, the changes in shape of the levers that transmit the movement to the load during the contraction, as well as the changes in position of the resistive force in connection with the gravity make the isotony be, in fact, a were acceptable approximation. For instance, raising a weight from hanging, by flexing the elbow, will be reflected at the level of the biceps muscle, the protagonist of the contraction, as a variable resistive force, with a maximum opening of 90 grades at the elbow, where the moment of the resistive force (the arm of the levers) is the biggest. The approximation is accepted in the case of weight lifting training sessions, too, when the weights are considered constant resistive forces, and consequently the muscular contractions are isotonic.

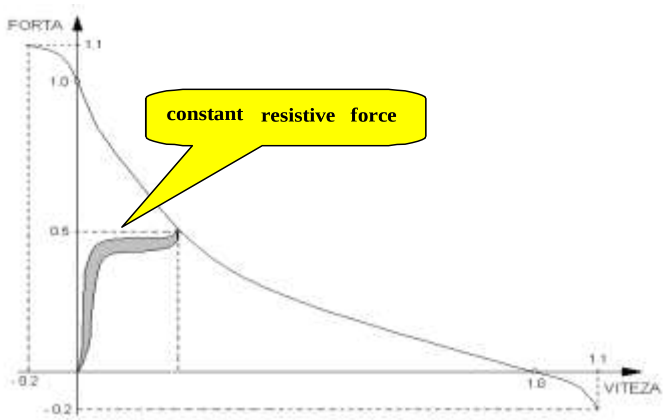


Fig. 7.2. The graphic of the isotonic contractions. The blackened area on which the isotonic contractions develop shows that the resistive force is constant, excepting the transitory phase of movement start

Irrespective of the theoretical or practical point of view, in isotonic contractions, the contraction speed may vary willingly up to the size corresponding to the resistive force; this means that, in the case of a high resistive force, the variation chart is low, while in the case of low resistive forces, the variation chart is high.

7.3. Isokinetic Contractions

When the contracting speed is constant, we call this isokinetic contraction. All the natural movements of our locomotory apparatus, as other numerous common contractions of the human muscles do not have a constant speed, first because of the speeding up in their start stage, then because of the change in position of the levers in the kinematics chains, changes referred to the own weight or to the carried weight. Isokinetic contractions can be realized with invented tools, especially for sportsmen's training that eliminate or limit the accelerations. A lot of research showed that training's with movements produced by isokinetic contractions have a few outstanding advantages compared to these that use heavy weights, loads pushing or generally, isotonic contractions. We should remind that heavy weights lifting training's, adequate and well dozed, lead to considerable progress in maximal strength or in strength connected to slow movements.

Sometimes, in these training's, the increase in muscular power cannot catch up with strength increase and consequently the speed will decrease. In case of training's with isokinetic contractions, the increase of muscular power is obtained both by the progress in maximum strength and by maximum speed, which means a considerable advantage. Another advantage refers to the protection against accidents that isokinetic apparatus can ensure. They also ensure a permanent agreement between the speed of movement execution and the resistive load.

The simplest isokinetic apparatus are those of a helcometric type. When the sportsman gently pulls the handle of the isokinetic helcometer, that is at a low speed, the resistive load paradoxically becomes lighter and lighter and when he pulls quickly, the resistive force becomes (almost instantly) heavy and limits the speed. This unusual fact happens due to some conical inertial masses in the apparatus that, when quickly spun, intercross producing friction and these hardening movement. Modern isokinetic apparatus have, as a rule, a computerized electromagnetic command, being able to generate any relation between the speed of displacement and the resistive force. Safety belts in cars behave somehow similarly; when the movements are show, they can be extended, but when the movements are accelerated they get blocked. On the other hand, the effects of practicing isokinetic contractions can be compared to those of isometric contractions, on condition the latest could be realized in all the successive positions of the movements.

In the image below the darkened area shows a sample of quasi-constant speed for which the contraction is isokinetic. It makes an exception in movement to start.

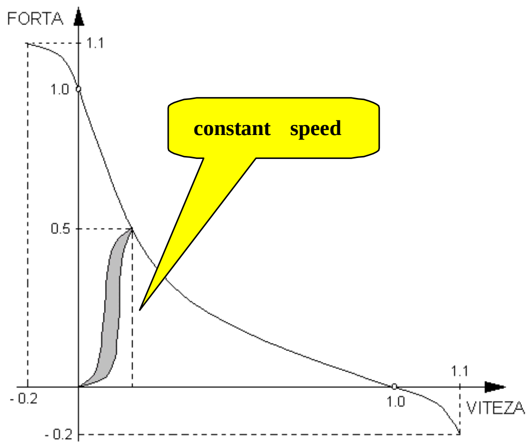


Fig. 7.3. The diagram of isokinetic contractions. The speed of the contraction in quasi-constant the load is adjusting automatically. The only exception is the starting stage, which, as known, is transitory, the force being not conservative

7.4. Autonomic Contractions

In auxotonic contractions, both the speed of the movement and the resistive force vary independently, uncountable empirical connecting rules between them being possible. The majority of the movements that do not take place all the time at a maximum force are auxotonic. Practically, almost all locomotory and natural human movements may be considered auxotonic, the few exceptions are isotonic, isokinetic, isometric etc. movements.

The connection between the instant speed of contracting and the movement trajectory is done by the *decider*, being labeled as "*coordinated movement*". Practically, any smaller or bigger deviation from this empirical connection makes the movement be, accordingly, more or less close to the reference, briefly, to have a certain "*degree of coordination*".

Auxotonic contractions are the more reproducible the away from from the maximal values of their power components (speed or force). We do not have in view the multiple psychometric aspects of coordination, but the motricity "*comfort*" of the coordinative movements. It is well known from the practice of sportive competitions that those athlete who have not enough power training, that is who cannot ensure "the comfort" of the coordinative movements, have difficulties in fulfilling their technical movements, they make mistakes more frequently; anyway, their efficiency is lower.

In the image below, the darkened area shows the geometrical place of the uncountable relationships possible between the resistive force and the muscle speed of auxotonic contraction. For example, once a model of movement trajectory established, according to its difficulty and the psycho-coordinative ability of the performer, the real trajectory may be closer or farther from the pattern. On the other side, irrespective of the real trajectory and even if this coincides with the preestablished pattern; it is possible that the instant speeds of the movement should differ significantly. Practically, the difference can be sensed in point of rhythm, breaks, accelerations or decelerations etc., which is in the typology of the contractions, meanings an auxotonic relationship between the resistive force (the weight to be carried) and the speeds of all the successive moments of its displacement.

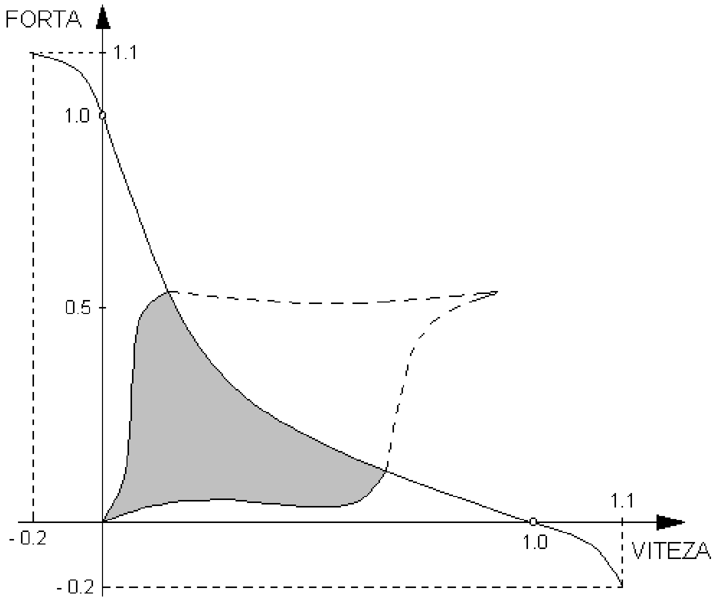


Fig. 7.4. The diagram of the auxotonic contractions. The darkened area shows the geometrical place of the different relationships that may be established between the resistive force (the load to be displaced) and the momentum speeds of its trajectory. We should mention that only the psycho-coordinative qualities of the performer can delimit this area; theoretically, auxotonic contractions may cover the whole area under the hyperbolic characteristic

7.5. Pseudo-contractions or Eccentrically Movements with Overload

Once accepted that the giving in movements, in which the muscle lengthen, that is it does not get shorter, may be considered contraction, we can identify a category of pseudo-contractions that represent the lengthening forced by a resistive overload. Thus, instead of appearing as a speed of shortening a muscle (conventionally pre-established as a positive one), we deal here with a movement of a giving in type; contrary in sense, in which the speed is negative. We under-mean that the pseudo-contractions are limited in amplitude, as a rule, by system of cartilage's and ways of bone attachments as well as by the tension in the antagonistic muscles.

Anyway, at the end limit of the muscular stretching, pseudo-contractions can produce traumatisms and pains. From the data in the specialized literature we can infer that the stretching, which mean an acceptable risk of accidents, should not exceed 15-20% of the maximum length under nominal conditions. In the case of pseudo-contractions that start from an already shortened position of the muscle, the acceptable risk is expressed by the overload, for example 10-15% of the maximum load that can be (supported) hold up in isometric contraction.

Pseudo-contractions are not natural movements; they probably represent the biological reserve for emergency cases or the opportunity ones, at the limit. In the methodology of sportive training's they represent a relatively recent discovery, being especially efficient in developing the maximal force.

Unfortunately, their efficiency in use is compromised by the risk of accidents. But, if safety measure can be taken, as the ones offered by the devices of limiting the run and trajectory of the resistive loads, then the pseudo-contractions can be used, together with other kinds of contractions, to develop the muscular strength, their efficiency being some 20-30% higher than that of using isotonic contractions (from lifting up heavy weights).

In the image below, the geometric place of the pseudo-contractions is shown by the darkened area. As it can be seen, this area is placed under the second quadrant, which means that the speed has a negative sign that is the movement goes backwards as to the shortening one.

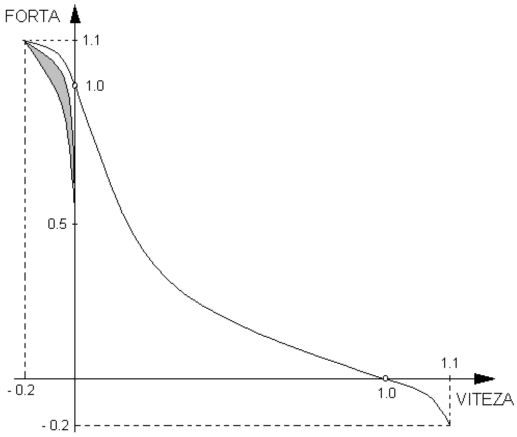


Fig. 7.5. The diagram of the pseudo-contractions or excentrical movements (of giving in) with overload. Explanations in the text

The characteristic of the relationship between the resistive force and the speed of the contraction does no longer have the appearance of an equilateral hyperbole; it has the tendency of limiting, leveling. This tendency is given by the resistance of the biological tissue implied in the movement, the limit of the tissue resistance, in its turn, being difficult to predict when the overload gives far beyond 10% of the maximal load held by an isometric contraction.

The stretching, when it is not used for detensioning the muscle or for relaxation it, may be assimilated to a pseudo-contraction and it is used together with other types of contraction, as for instance the isometric ones, during the process of developing the muscular power.

7.6. Supra-contractions or Movements at a Supra-maximal Speed with a Negative Load

In a voluntary movement based only on muscular contraction, the maximum speed of contracting can be obtained only if the external load is naught, and the muscle must overcome only the force given by its own weight and of the body segment put to move. In the case of running, the muscles implied in the effort displace a resistive load mode up of the weight of the whole body, in including their own weight. According to the law of the conservation of power, if the weight specific to the sportsman's body who is running gets another external load attached or if running is performed on a leaning plan (up a hill), then, of course, the speed of running will decrease.

In the opposite way, if the movement is supported by external forces, as, for example, running down wards or running by traction, behind, a bicycle or motorcycle (the so-called "mechanical training"), them the speed can become supra-maximal, because the load (one's own weight, the one to be displaced) is "dislodged". The locomotory muscles, in this case, get helped from the outside by synergical forces, performing contractions at supra-maximal speeds, and their contractions become what we call supra-contractions. The external force that helps the movement has the same direction, but another sense as compared to the resistive one. For that reason the resultant bears, conventionally, the minus sign in front, briefly, it is called "*negative load*".

Supra-contractions or movements at supra-maximal speed are possible only by help of some synergical exterior forces. Under certain conditions of diminishing the influence of the gravity forces or of imponderability, as it happens with the pilots or astronauts, the load to be displaced becoming lighter and lighter, supra-maximal speeds of contraction may be obtained, a phenomenon that can be assimilated to supra-contractions. Sometimes, the same thing happens when the body is submerged, although the resistive force of the water is bigger than that of the air.

During the sportive training, supra-contractions are successfully used especially when we want to achieve speed development. As already known, the speed is, from the sports theory point of view, a motrical quality difficulty perfectible, being mostly genotypical. By supra-contractions the muscle is compelled to activate under an abnormal regime, that scenes to be for the neuro-muscular commands, and the ratio of the speed progress increases considerably, more than the corresponding ratio of the training with weights (for example, the isotonic or isokinetic one).

The training's with pliometric movements or jumps are, in fact, training's with supra-contractions. In pliometric jumps, the sportsman is helped to displace by an elastic force, as a garrote stretched by jumping down from a step or gym box etc. or by partners who propel him upwards, immediately, after landing. This help is, in fact, a synergic force that makes the speed of contraction become supra-maximal, and the jump higher. Experimentally, there has been stated that the ratio of progress for the springing by practicing pliometric jump may be with 30% better than the one, obtained by classic training's with usual jump. The springing, as known, is the exclusive effect of the taking off speed, uninfluenced by the resistive force.

We should remind the performance sportsmen that not only the specificity of the means used can influence the progress rate, but also the judicious dosing and the adequate iteration, without forgetting, of course, the association and succession of the means used.

Another important practical aspect of the supra-contractions refers to the size of the out force which disloads the resistive force. This cannot be more than 20-30% of the resistive force, as it increases the risk of accidents to an unacceptable degree and makes the movement become passive, without the role of the muscular contraction. In other words, the movement becomes uncontrollable if by the strength the muscles or the voluntary neuro-muscular command of the contraction the dynamics of the movement cannot be controlled anymore.

In the figure below, the geometric place of the relationship between the resistive force and the speed of the muscular contraction is represented by darkened area. We should emphasize that it is situated in the 4^{th} quadrant, where the force is negative. As in the case of pseudo-contractions, the hyperbolic characteristic that graphically represents the law of the conservation of power is no longer preserved for the supra-contractions, becoming, as a rule, uncontrolled when the outside force overtakes 20-30% of the resistive one. The limit it tends to is the passive movement, at dangerous speeds for the integrity of the tissues implied in the movement.

The negative force mentioned in the figure is, in fact, the negative load obtained from the vectorial addition with the resistive force.

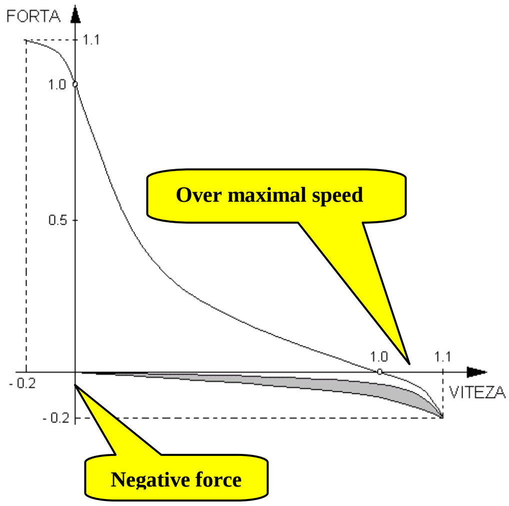


Fig. 7.6. The diagram of the supra-contractions or of the movements at supra-maximal speed owing to external auxiliary forces

7.7. General Considerations about the Types of Muscular Contractions

We should mention that above the unique taxonomic criterion is the relationship between the resistive force and the speed of contraction with the human skeletal muscles. The relationship *resistive force – speed of contraction* refers to the maximal efforts, when the power is conserved. The zone of the maximal efforts is subject to the 2nd law of biomechanics, and the best known relationship force-speed is called *Hill's law.*

From this point of view we can distinguish 6 types of contractions, three of which have severe restrictions of variation of at least one of the components of the muscular power:

- constant resistive force = isotonic contraction;
- constant contraction speed = isokinetic contraction;
- constant length = isometric contraction.

Another type of contractions, the auxotonic one, makes use of empirical relationships between the resistive force and the speed of contraction, relationships determined by the psycho-coordinating pattern of the movement and the last two refer to the extremes of the characteristic force-speed: the pseudo-contractions and the supra-contractions. The pseudo-contractions are, in fact, movements of giving out, that is eccentrically, having thus negative speeds (contrary to the shortening ones) and the supra-contractions are owed to the contribution of some synergic external forces that can make the load become negative, that is to help and not oppose the movement.

The utility of this classification, besides its didactic form, is obvious, especially in performance sport practice, that is in the case of the movements to be found is the so called "exceptional normal" zone. We should also mention that lately the kinetotherapy has also become interested in certain types of contractions, of course, as means of getting out of the pathological area of movements.

In many sports, the performance practice relies on specific forms of manifesting maximal power and the training sessions have often as on dim development of basic motric qualities.

The trainer and the athlete, as the main decision takers can thus face a matter of adequate decision as to the types of contractions to be used as specific means. As the theory of coaching teaches us, the efficient solutions depend on the assumed objectives, on the level of training etc., but, we must emphasize from the biomechanics point of view, on an acceptable compromise between the rate of the expected progress and the risk factor, too, on an adequate association and succession, on an optimism dosing and iteration etc.

For example, supra-contractions are the must efficient in the process of improving the speed and the pseudo-contractions are the must effective in improving strength; the only problem is that both of them are risky, being able to bring an accidents. Then, isometric contractions should be unique for each large group of muscles and be practiced only as the last theme in a training session; their association with stretching would impose a certain strict order and so on.

Also, it seems that for kinetotherapy, the choice of isokinetic contractions would be an adequate solution both from the point of view of a low risk for new traumas and as efficiency in concomitantly increasing the muscular strength and speed etc.

Coming back to the typology, we should emphasize that the above mentioned are true for the stationary zone of the muscular contractions. The transitory zones, that of starting the effort and that of tiredness after the relationship between the resistive force and the contracting speed so that there cannot be established any rules.

VIII. THE TRANSMISION OF MOVEMENT THROUGH LEVERS AND KINEMATICS CHAINS

8.1 Clarifications Regarding the Transmission of Movement

The transmission of movement is usually handled by physics. If the movement is a change of place, and the mediation is made through a geometrically rigid body, then the problems of transmission belong to mechanics.

From the biomechanical point, movement is transmitted from muscles, through tendons and bone levers, to the resistive charge (process which isn't very different from the problems of mechanics). Therefore, the knowledge in mechanics regarding the transmission of movement, except for rare cases, is valid and applicable in biomechanics. These exceptions and some particularities will be commented upon in the following paragraphs. They appear due to the essential features of the resistance of biological materials, the method of guidance of movement through ligaments, cartilages, menisci, fasces, etc. and the amortization of movement through the tendons' elasticity, the action of antagonist muscles.

We can discover a *lever* every time we identify a point of support, a point of application of an active force and another point of application of a resistive force, in the case of a solid body. Levers can amplify force at the detriment of speed or reshuffle of forces; they can amplify speed or reshuffle at the detriment of force and can change the direction of movement.

A *cinematic chain* is a schematic representation of some rigid and articulate structures. The cinematic chain simplifies reality in the purpose of facilitating understanding, by connecting articulations with imaginary lines, which represent distances.

In mechanics, levers, along with other devices such as the inclined plane, the screw, the wedge, the pulley or the wheel are considered *simple devices*. The concept of simple device includes a location of a motric force, a way of power transmission and a location of resistive force. In practice, simple devices are combined; such is the case of the automobile, where the motor is assimilated with the source of motric force and the resistor – with the friction forces between the wheels and the road and between the body of the car and the air. Between these devices comes a complex system of movement transmission “organs”, in a logical way.

In biomechanics, the distribution of *machine organs’, mechanisms’ and simple devices’* names is not recommended to the biological structures which transmit movement, even if the functioning of the latter can be described by the same physical laws. Theoretically, any combination of simple devices can be regarded as a cinematic chain or can be reduced to a concatenation of levers.

In the human body there have been identified numerous bones and articulations which work as levers, pulleys or wheels. In the following paragraphs, we will be using only the names of “lever” and “cinematic chain” for any structure with mechanical or machine functions.

8.2. Some mechanical Properties of Biological Structures Involved in the Transmission of Movement

We are able to recall from the theory of the resistance of materials that exterior forces, which actuate on materials, inducing deformations, ruptures or fragmentations are called *requirements*.

The main types of requirements are:

- the stretching;
- the compression;
- the shredding;
- the bending;
- the torsion;

During requirements, in the material bodies appear deformations that can be plastic deformations or elastic deformations, as the body can be viscous, elastic or viscous-elastic.

The reaction of biological materials to requirements has the same evaluation method as the technical materials. For instance, the elasticity of the human bone is two times smaller than pine tree wood's. The *hummerus* supports 800 kilograms at traction, 600 kg at compression, 200 kg at flexion and only 40 kg at torsion. Of course, these numbers are only for orientation, because the resistance of the bone depends on its structure, on its geometric dimensions, etc. The fact that the structure of biological materials is competing with the advanced technology of chemical compounds and the form (the spatial disposal of trajectories elements in the epiphysis or the tubular form of the long bones) is remarkable.

At the mechanical performances of biological materials the microstructure can also be regarded as a competitor, especially the knitting of macromolecules with fibrils or the alternation of crystalline structures with the amorphous ones and their oblique orientation in relation with the longitudinal axis (the same as the knitting of cables).

On the other hand, the degradation of the mechanical qualities of biological tissues rises with ageing or as the effect of sickness, such as osteopsatirosys (where the protean matrix of osein or collagen is involved), or osteomalacy (regarding the calcium impregnation), etc.

The impregnation of the bones with calcium also has a depositing role, and the judicious graded requirements, such as the ones in sports, produce simultaneously a reinforcement of the bones as well as an irrecoverable wear; it depends on a multitude of factors whether the result of the two antagonized effects is acceptable for the human body. The fact that repeated requirements, even if they are not at the upper limit of resistance, produce micro traumas, some of which accumulate and can facilitate accidents.

From the biomechanical point of view, especially the one of the transmission of movement, the reaction and the interaction between the structures which produce mechanical tension (the muscle through contraction) and the structures of biological elements, which transmits movement, are the most interesting. Thus, the stretching forces in the tendons produce a viscous-elastic deformation of these tendons, in which a part of the energy is stored as *elastic* energy, the movement being damped and temporized. Other biological formations, such as bursas, reduce energy losses through friction and the cartilages and menisci redirect the forces with minimal losses etc.

Before introducing the behavioral differences between the biological formations and the technical ones, we should remind and emphasize as is but natural some aspects of the transmission of movement through levers and cinematic chains, as they occur in technical mechanics, as well as in biomechanics.

8.3. Levers

We should recall that we are speaking about a lever only when we see a solid body with a point of support, a point of application for an active force and a resistive force. Levers play the role of transmitting movement by increasing its efficiency.

Depending on the situation, the efficiency can mean the amplification of the force, of the speed or the reshuffle, or eventually the change of direction or counterbalance of the movement.

The point of support or the *fulcrum* as it is called restricts the movement, except its rotation around itself. It can be regarded as an articulation, usually round, an axis or a peak.

The vector of the active force, as well as the vector of the resistive force can glide on their direction until each of them meets a fictive perpendicular line, which goes through the *fulcrum*. The lines which are perpendicular on the vectors of the force and which pass through the *fulcrum* represent distances and are called the *arms* (of the mentioned forces).

The product between the force and its arm is called a *moment (of rotation)* and is the measure of the cause which produces the rotation movement around the point of support.

In the case of levers, there are two important moments: the moment of the active force and the moment of the resistive force. If these moments are equal, the rotation of the solid body around the point of support is abolished (impossible).

From the condition of equilibrium results that the report of the two forces is inversely proportional with the report of the two arms:

$$F / R = b / a$$

Modifying the dimensions of the lever can thusly equilibrate different forces. The corollary of this idea has become the *law of the levers,* which can be written like this:

The nullity of the algebraic sum of the moments of a lever assures its equilibrium.

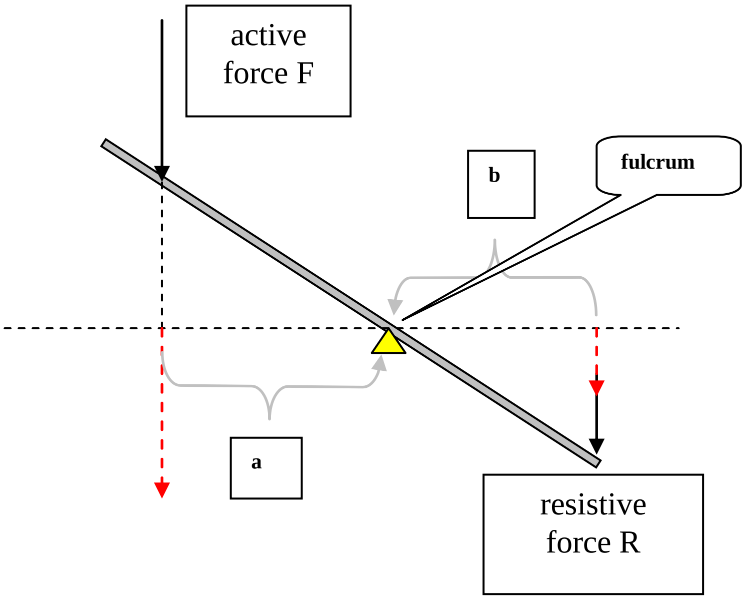


Fig. 8.1. The elements of the lever or any simple device reduced to a lever. The arm of the active force F (marked as a*) is the length of the perpendicular, which goes through the fulcrum. Identically,* b *is the arm of the force R. Explanations follow in text*

Almost all mechanical tools are levers. The body parts actuated by scheletical muscles behave exactly as the tools. The interest for levers is not granted to them due to their law, but by the multiple advantages the unbalanced levers offer.

The grouping of these advantages has led to their division in three categories.

According to the tradition, they can be grouped in 1st , 2nd and 3rd class (grade, type) of levers, in report to the structure of the forces and their point of support. We will return to these classifications later.

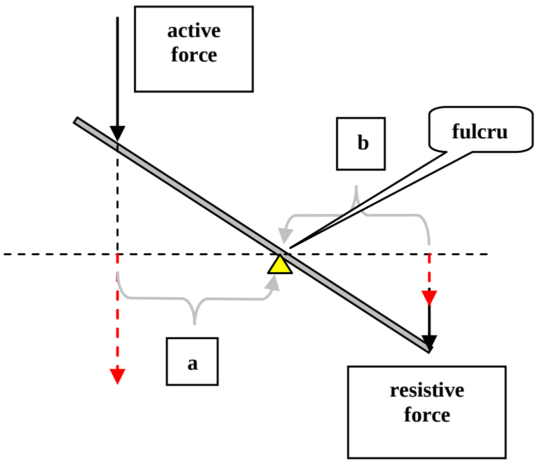
As for the evaluation of the advantages, the convention of calculating the momentum of the forces from the product between the force and the distance to the *fulcrum* will be put aside, introducing a new method of calculus, in which a correction of the perpendicularity of the force and the line which connects its application point with the *fulcrum*. The active force, as well as the resistive force, can be divided, according to the law of the parallelogram, in two directions: one which is perpendicular on the line which connects the application point with the *fulcrum* and another on its direction.

Our option, which not only seeks a change of the tradition, but also is different from that of the majority of the authors of prestigious books of biomechanics, is based upon the following arguments:

- the movement of rotation is not given by the direction of the force, but by the direction of the speed, which can only be tangential;
- biomechanical structures are not as rigid as mechanics would want them to be, as the radial components of the forces (in fact the requirements) are negligible;
- requirements are also transmitted tot the support point, which makes a different chain of important muscles and guidance structures to actuate, for the stabilization or control of its movement;
- the arms of the levers are real measures, much easily measurable than the imaginary arms of forces; in most of the cases resistive forces are weights (loads), and the rotation angles of the levers' arms are small, so that the mechanical work (toil) can be practically calculated and sufficiently precise measuring only the height at which the known load has been raised.

In the figure below the active force F is divided in the tangential component (the perpendicular), F_t (colour red) and another radial component F_r, which is oriented on the direction of the distance *l* which connects the application point of the force with the *fulcrum*. The same occurs with the resistive force, by identifying the tangential component R_t, the radial component R_r and the distance *r*.

Thus we consider that for biomechanics it is of greater advantage that the law of the levers to be expressed in connection with the moments of the perpendicular, corrected forces, with the product between the tangential forces and their concrete distances (not imaginary) to the point of support. The distances thusly defined will be called from now on *the arms of the levers* (not of the forces).



8.2. The biomechanical structures of the levers. The arms of the levers are marked with l and r, and the corrected forces with F_t and R_t. The components of the forces (active and resistive) along the arms of the levers produce compression and prolonging requirements, which cannot be neglected in biomechanics.

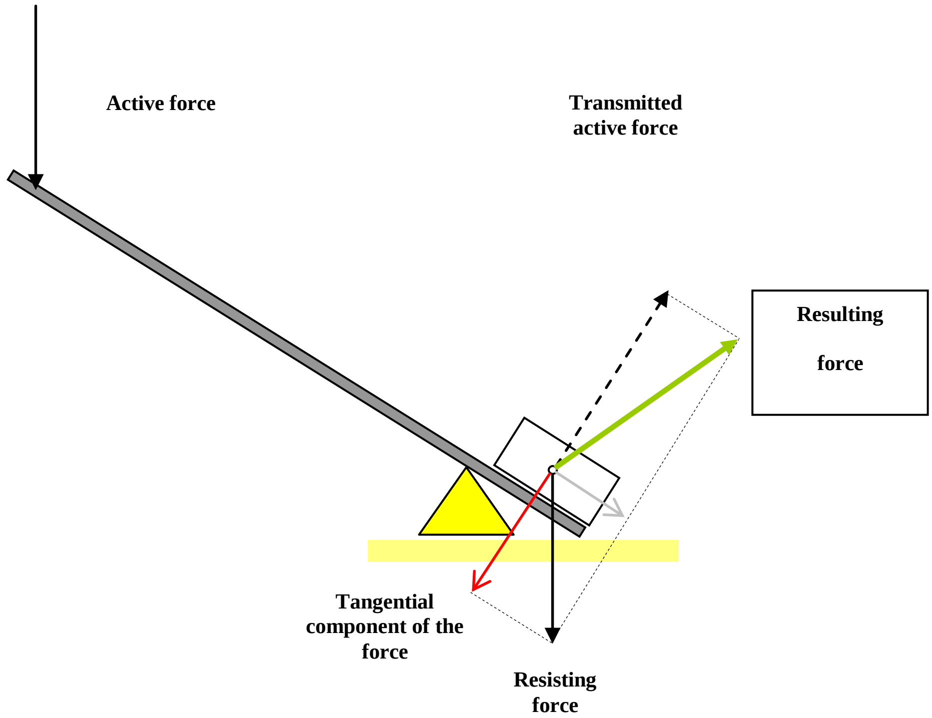
The decomposition of the forces on directions, which are perpendicular on and along the levers' arms, is, in our opinion, the only rational solution for biomechanics, because the tangential speed is always perpendicular on the radius and the components of the forces along the levers' arms induce requirements which are sometimes important on the bones or can generate tensions.

The requirements of the rigid are also transmitted to the points of support, so that in the case of biomechanics not only the bones have to suffer, but also the articulations. More important than the eventual problems caused by the resistance is the control of relative movement of the point of support which, due to solicitations, needs to be compensated by the action of muscular or guidance forces. Choosing a fixed position for the point of support can often become a more difficult task than the movement of the resistive charge.

All these aspects can be neglected in biomechanics, raising the need for a change between the theory of the levers' arms and the practice of the levers' arms.

On the other hand, the movement of rotation of the levers' arms transmits in the point of support of the resistive force, beside a greater force in absolute value than the resistive force, a tangential direction, different from the vertical axis on which the resistive force usually appears. As illustrated in the figure below, the direction of the movement of the point of support on the levers' arm can be different from the one it tends to use due to its weight (load). During the lifting the body can slide, can roll or be thrown, effects which would not be as obvious would the lever be analyzed through the theory of the levers' arms rather than through the practice of the levers' arms.

The lifting of a weight by amplifying the active force, as seen in figure 8.3, is one of the most frequent situations in which levers are of great use. The lever is usually positioned different from the horizontal axis so that the weight (load – which actuates always vertically) will also have a radial component, opposed to the force of friction. This can cause the sliding of the body its overturning (if the height of the centre of the load is large?). To make the figure simpler, all forces are applied in the centre of weight of the body and not in the point of support.



8.3. The image of the influence of the resistive force's components over the movement of the heavy body. Explanations in the text

If lifting a weight is made by the force of the biceps, as illustrated in figure 5.4, then the radial component will have to be compensated by other muscular forces of the shoulder, in order to stabilize the position of the *hummerus* and the articulation of the elbow.

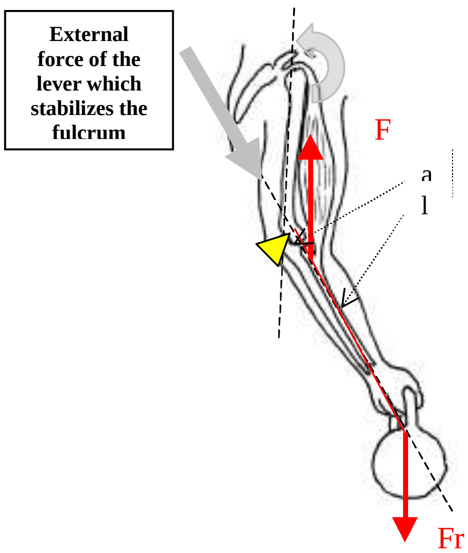


Figure 8.4. The illustration through a very simple situation of lifting a weight of the necessity of decomposing the active force of the biceps in two components, tangential and radial, the latter being opposed by an external force (the shoulder muscles).

If the description of the movement of lifting a weight would have been made in the classical way, based only on the moments of the forces, problems such as the stability or the control of the movement of the *fulcrum* would not have been obvious.

8.4. 1st Rank Levers

According to a traditional rule, 1st rank levers have the support point situated between the application points of the active and resistive force. If the point of support is closer to the resistive force, the advantage of the lever is the amplification of the force. If the point of support is closer to the active force, then movement is gained. The movement being made in the same temporal interval as the action of the active force, the speed increases, which cannot be regarded as a considerable advantage. A classical example is the crowbar.

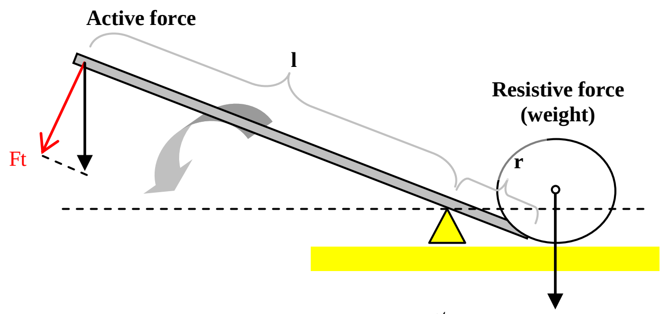


Fig. 8.5. A classic example of a 1st rank lever. Pushing the longer arm of the lever with little force, a heavy weight can be moved. Force is gained at the detriment of speed

The active force, if perpendicular, is transmitted tot the contact point of the weight, amplified n times: n = l/r, representing the rapport between the arms of the lever. Thus the amplification decreases by a practically insignificant degree in comparison to the cosinus of the angle the active force and its tangential component, F_t, form.

In the human body there are few 1st rank levers to be found, because the contraction of skeletal muscles is made on short distances and the anthropometrical evolution shows a need for proximal grouping of the muscles, the distal regions being used for the amplification of the speed. At the primitive human being, the weight centre of the head, regarded as the point of application for the resistive force, is placed considerably opposed to the area of application of the neck muscles is relation to the atlas (the cervical vertebrae which supports the cranium). Thus the part of a 1st rank lever, played by the active force of the neck muscles, was much more important at that time than it is nowadays, when only a situation of lifting of the head can be regarded as a 1st rank lever.

Unconventional situations of extending the members' segments can be generally equivalent to those of 1st rank levers. For instance the extension of the forearm when the elbow is lifted, the extension of the lower leg etc.

An amazing fact is not the number of cases, but the diversity of the morpho-functional solutions in which 1st rank levers are involved. To invoke the adaptive evolution and the homeostasis as causes is definitely insufficient. The functions of the fixed pulley or the wheel with centre axis are not human inventions, but were to be found in the human body before he started to use tools.

For instance, external mallow (*maleol*) of the ankle acts as a pulley in changing the direction of the traction movement of the *peroneus longus*; the patella muscle increasing just like a pulley the angle of traction of the femoral quadriceps in the extension of the lower leg on the upper leg; the spinal muscle acts on the *vertebrae*, using it as a central-axis wheel in the movement of rotation of the body, etc.

In figures 8.6., 8.7. and 8.8. are illustrated the examples above. Explanations are needless.

A general character of the 1^{st} rank levers in the human body is that they amplify distances rather than force, as happens in the case of tools. As it will be shown in the following paragraph, the amplification of force in the human body is also a general character of 2^{nd} rank levers.

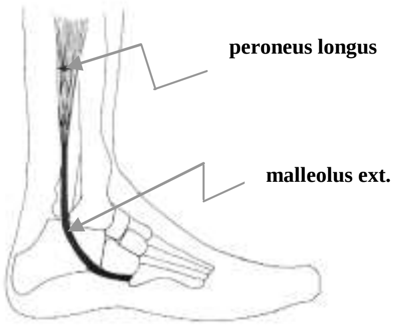


Fig. 8.6. Example of the changing of direction of the active force, the external maleol acting as a pulley

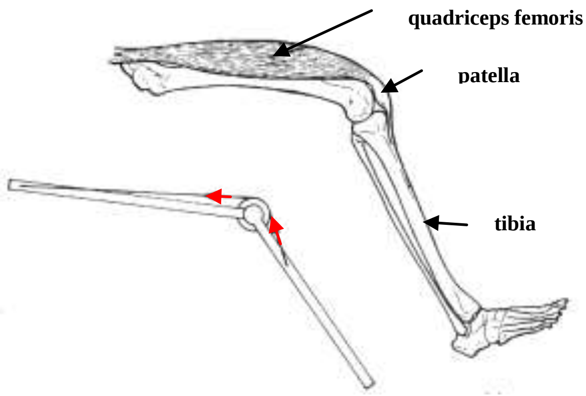


Fig. 8.7. The patella acting as a pulley and increasing the traction angle of the quadriceps muscle in the extension of the lower leg on the upper leg. The movement can be regarded as a 1st rank lever.

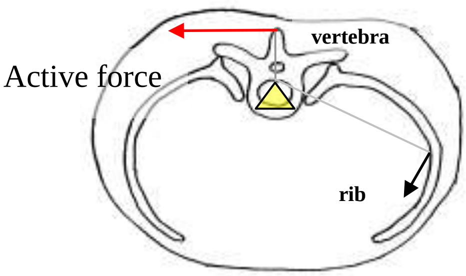


Fig. 8.8. Example of a 1st rank lever, acting as a centre-axis wheel. The momentum of the active force of the spinal muscle induces the rotation of the thoracic box

8.5. 2nd Rank levers

In the case of 2nd rank levers, according to the rule, the resistive force is situated somewhere between the point of support and the point of application of the active force. The closer to the fulcrum the point of application of the resistive force is, the more will the force amplify, to the detriment of distance of movement or speed.

The different means of lifting the body such as push-ups, standing on the toes, the extension of the body from a lying position, etc, and generally the movements in which the distal parts are fixed in the exterior, use the advantages of 2nd rank levers.

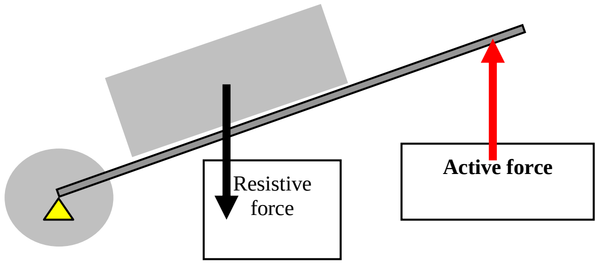


Fig 8.9. Example of 2nd rank lever. The amplification of the force represents the main advantage

A classic example is represented by the wheelbarrow and is illustrated in the following picture.

8.6. 3rd Rank Levers

3rd rank levers have the application point of the active force positioned between the fulcrum and the resistive force's application point. The closer the active force is to the fulcrum, in report with the resistive force, the greater is the speed and the distance on which the resistive force is moved. Most levers which operate the limbs are 3rd rank levers, increasing the speed of the distal segments through short contractions of the skeletal muscles. Natural movements, especially locomotion, benefit from the advantages of 3rd rank levers. A series of strong muscles in the human body, with relatively large transversal sections, as seen in the table below, have distal application areas which are very close to axis of rotation located in the articulation, amplifying, through the length of the bones they move, the tangential speed. This design is used in the sport selection, where it presents a considerable advantage, especially for jumps and speed running. For instance, at the same angular speed of rotation of the thigh of 6 rad/s, small somatic particularities can generate considerable differences of tangential speeds at the level of the foot, situated between 5.3 and 5.9 m/s.

Nr.	***Muscle(s)***	***Section (cm^2)***
1	gluteus maximus	58
2	soleus	47
3	vastus lateralis	41
4	diaphragm	36
5	levitor scapulae	35
6	levator scapulae	35
7	subscapularis	20
8	triceps brachii longus	14
9	flexor digitorum profundus	10

Table8.1. The main muscles which act as active forces on 3rd rank levers

A classic example of a 3rd rank lever is represented by the process of lifting a weight through the force of the biceps brachium muscle. What makes this fact interesting is that during the lifting process the angle the biceps muscle makes with the axis of the forearm is changing continuously, so that the report between the tangential component and the radial component of the active force varies from approximately 0 to a very large number, from the dislocating solicitation until the solicitation virtually disappears, and the entire force becomes tangential. The moment of the force varies ant proportionally, increasing as the angle decreases, without the maximum coinciding with that of the active force.

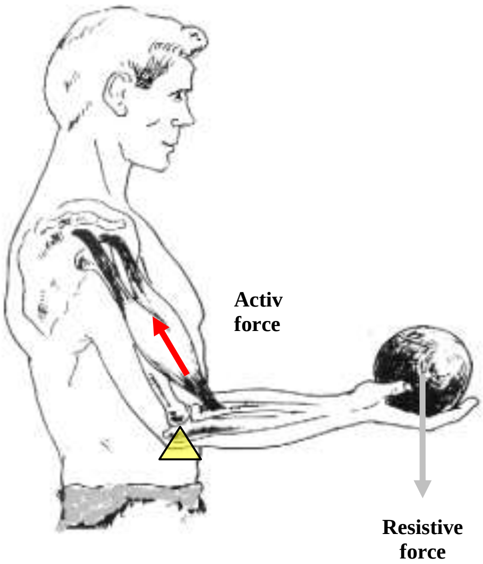


Fig. 8.10. Example of 3^{rd} rank lever.
Explanations in the text

The amplification of speed produced by the 3rd rank lever can be increased by using objects which increase the action of distal segments, such as: the tennis rocket, the fencing swords, the baseball bat, etc. As you already know, not only the movement components make a difference in sports, but also the coordinative ones, which in the case of 3rd rank levers are being more altered, the longer the arm of the lever is. Thus the conflict between effects, the greater speed and good coordination are solved, from case to case, through compromise solutions.

In order to lift a weight, as illustrated in fig. 8.10., the moment of the active force has to be greater than the moment of the resistive force. The mechanical work being conservative, we observe that the height at which the weight is lifted is in the same report with the contraction distance as the report between the arms of the lever.

The fact that the movement is a movement of rotation must not be lost from sight, because in this case the analytical measure of the mechanical work and the power is different than the ones of the rectilinear movement, although the values are equivalent.

For the movement of rotation, it is not the active force that produces movement (distance) but its moment, the product between the force and its arm.

Classical physics demonstrates that the equivalent of the power in the linear movement, $P = F \cdot V$, is the product between the moment of the force and the angle speed, $P = M \cdot \omega$. When the lever is not in equilibrium, as illustrated in figure 5.11 (the same weight lifting movement through the force of the biceps), a movement of rotation appears, in which an angle speed ω and a tangential speed V_t of the application point of the resistive force.

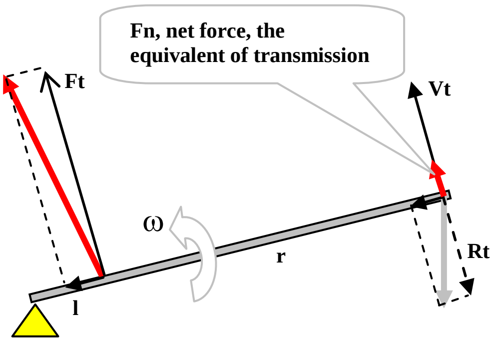


Fig. 8.11. The highlighting of analytical measures of the movement of rotation of the lever, illustrated through the classic example of lifting a weight by the force of the biceps. Explanations in the text

As seen in the picture above, the active force can be decomposed by the rule of the parallelogram in two components: the tangential component, F_t (perpendicular on the arms of the lever) with its arm, l, and the radial component (along the arm l of the lever). The same occurs in the case of the resistive force, observing the tangential resistive force, R_t and its arm r, as well as a radial component (along the r arm).

In biomechanics, the radial components (the correspondents for the normal components in linear movements) represent solicitors and cannot be transmitted.

The tangential components of the forces, together with the arms of the lever, result in rotation movements which are algebraically summed. The moments which turn clockwise are conventionally considered positive and the counter clockwise moments are considered negative. Being vector-based products, they have a perpendicular direction on the plane of the components. The algebraic sum, if not null, has a dimension of a moment $M = F_n \cdot r$, where F_n is an imaginary force, usually called the net force. She comes from the tangential force F_t which is diminished (by the l/r proportion) and transmitted to the point of application of the resistive force and algebraically summed with the latter:

$$F_n = R_t – (F_t \cdot l/r)$$

As a consequence, the moment M produces a movement of rotation with the angular speed ω, and the weight follows a trajectory of a bolt with the tangential speed V_t. The movement is perfectly determined is and when the tangential speed can be calculated (the arm of the lever or the radius being given). An important fact is that the moment M produces a large number of accelerations (each depending on r), of which only the tangential acceleration determines the movement. Details can be found in any important book on mechanics; here we ought only to highlight the similarities and differences between biomechanics and plain mechanics.

8.7. Kinematics chains

Let us consider biomechanical kinematics chains as artificial patterns of gathered rigid items, having limited mutual degree of movement, as consequence of joins. The rigid elements are usually bones, representing the distances between joins; practically make simpler the reality by considering the bones as non-deformable structures and the joins as punctual links. The reasonable reality simplifier is justifying by increasing the practice of the movement analysis and by transferring with tolerable errors the theoretical conclusions in practice.

It is to mention that the mechanical kinematic chains can be *opened* or *closed*. At a closed chain all its elements are linked thru joins to less than two other elements, otherwise the chain is open. Other classification considers chains as simple or complex, spatial or planar etc.

The study of kinematics chains belongs to the theory of mechanisms. The analytical ways of study the kinematics chains evaluated from the labor-intensive solving of the state or movement equations to the automatic computation; so that the analytical enlightenment of solving the equations becomes anachronous, no matter if is regarding to the mechanics or biomechanics.

It is to add the risk of redundant transfer of the important knowledge from the functional anatomy to the analyzing of kinematics chains movements. For instance, the biceps brachial is a double articulated muscle; crossing over too joins; of shoulder and elbow. In the folding the arm, the biceps brachial muscle act upon his two superior humeral heads, on the radial one and the radial burgee cord of the carpus of the front arm lever. Of course, other muscles, including antagonists and tonic muscles are participating for folding the arm and lifting a weight; these muscles constitute a *muscular chain* which is describing structurally, not kinematically, the relatively segmental movement.

We consider useful to underline, in the spite of enormous advantages offered by transferring the knowledge from the theory of mechanisms to the biomechanics that still persist some inadequate application of the theory of mechanism to the movement of biomechanical kinematics chains made from body segments and joins. For instance, and as an observance of levers, it is ought to explain what is happening when a level is moving itself the fulcrum. Generally speaking, if the moving of fulcrum is not limited, then the lever’s movement can’t be described. Practically, all fulcrums are linked to an exterior plane or point, submitting a reference of translation or rotation movement. The distance to the referring plane or point of rotation became another rigid item, and all the speculative structure can be taking into consideration as a kinematics (simple) chain.

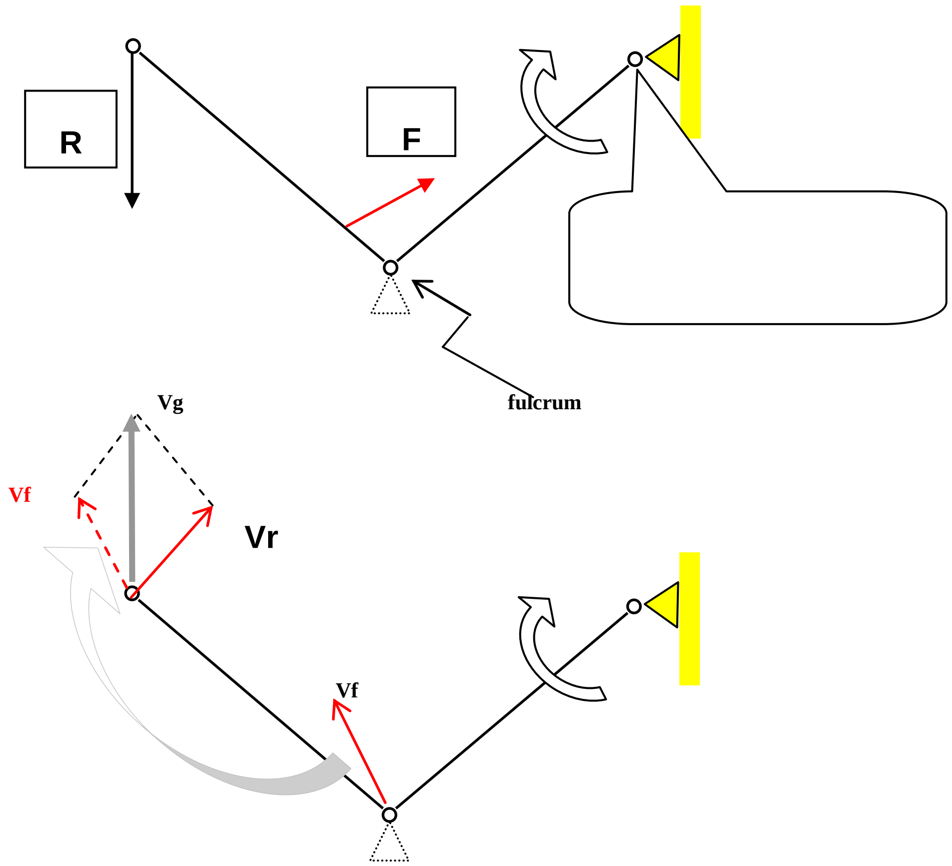


Fig. 8.12. Example of transformation of a 3rd degree lever in a kinematics chain (referring to fig. Xx- lifting a weight using the biceps brachial force). Explanation in the text.

As it is shown in the Fig. 8.12., the fulcrum representing the elbow is getting a rotation movement around the shoulder join at a constant distance and so it isn't more fixed. Coming back to the example of 3rd degree lever of lifting a weight (force R) by contraction of the biceps brachial muscle (force F), where the fulcrum represent the elbow join, the rotation of the fulcrum around the shoulder join at *humerus* distance generates a tangential movement speed Vf . By consequence, this speed is translated to the application point of resisting force R where, together with the tangential speed Vr generate a vector speed Vg on a different direction. From the above figure it is to watch that the weight is still lifting on vertical direction because of the compensation rotation movement of the elbow. For keeping the vertical movement of the weight it is necessary to change continuously the relative position between arm segments in a coordinated way. So, the in biomechanical chain movement equation is present a term of (neuro-muscles) coordination, as an important difference between mechanics. In mechanics the deterministic class of movement of technical mechanism is represented by a characteristic named desmodromic. We have to remind that for each moment and relative position of two segments of a desmodromic kinetic chain, a single position is obtainable for the rest of chain' segments. Otherwise, the movement of the chain is undetermined. For biomechanics, these desmodromic characteristics of some restriction of movement need to be re-definite by including the coordinative aptitudes.

For better understanding, let us take into consideration the most useful movement in sport of triple extension like a kinetic chain. The triple extension is the real meaning of jumps. As it is shown in the fig. xxx, the kinematic chain schematize the relative movement of four segments of the lower train of an athlete linked by tree joins; ankle, knee and hip - referring to a fixed contacting point with plane of ground. In the schematic representation of the movement it is to remark also a weight centre and a reaction force of the subtending ground. Because of coordinated action of the legs and back muscles, the angles between chain' segments grow up, generating a relative (to the fixed point) movement. As it is shown in the same upper figure, the relative segmental position of the kinetic chain segments is only a freezing snap shot of the movement done by the conjugated and coordinated action of the muscles (anatomic) chain. So, the biomechanics kinetic chains, due to the neuro-muscular coordinative action are different from the desmodromic mechanical chain and also different from the descriptive muscle chain.

Of course, for a real biomechanical analyse of the movement it is necessary many such successive snap shots.

All biomechanical kinematics chains haves a fixed point or planar support reference, usually situated at one of the extremity of the chain. In the theory of mechanism, the reference point of a kinematics chain is situated on so call *holster*, inadequate name for biomechanics. For instance, in the triple extension the fixed referring point is situated on the metatarsifalangeal zone.

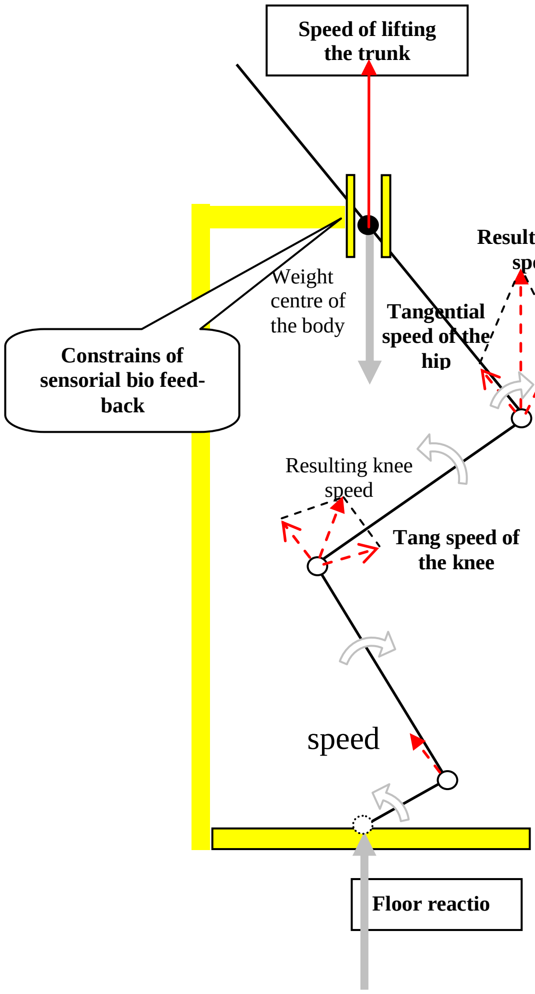


Fig. 8.13. The kinematics chain of the triple extension which is simplifying the vertical jump. Explanation in the text.

As regarding to the horizontal surface of this assign, all the body segments haves variable angle sequential position; because every pears of segments mutually vary angle of linking join. In the above example, the rotation speed can and seems to be independent; as consequence the joins speeds are consisted from tangential speeds and these related to the fixed refer. By this explanation we try to underline that the vertical lifting of the weight centre is a resultant of the all vectorial speed of the implicated segments of the kinematic chain. Due to the fact that, during the extension, the lifting of the weight centre need to be very close to the vertical direction, and exactly on the vertical direction on the start of the jump, result that the angular speeds are momentarily coordinated by the different feed-back, especially by mio-artro-kinetics ones. In this case, the constraint of verticality for the resulting speed allows us to consider the kinetic chain as a closed one. The closed characteristic of the chain is symbolized by the fictive guidance linked to the fixed reference point.

As a difference, in the mechanics the closing of a kinematics chain is done by devices of coupling to the holster. Only in advanced robotics using powerful computations the closing of the kinematics chains are made by constrains of feed-back (similar to the sensorial bio-feed-back). The bionics is copying a lot of constrains of sensorial feed-back from the nature and have a tendency to combine these with the mechanical guidance. Today, due to the powerful computation, the quality of movement control by feed-back of kinematics chains in the advanced robotics and bionics are much closed to the biomechanical kinetic chain.

It is impressive to observe, for instance, an artificial arm able to catch a ball of baseball, only by detecting and computation of the virtual trajectory in pseudo-real time. Already are present on the market advanced video cameras able to steadiness the involuntary movement of the operator. It is to understanding that behind these technical realizations are a huge now-haw knowledge not yet applied in the analytical biomechanics.

In the biomechanical movements, constrains or control of the trajectory are made by the join's forms, ligaments, cartilaginous tissues, meniscus etc. and by the sensorial feed-back; the real meaning of coordinative aptitudes. It is ought to point out the fact that only a part of bio feed-back from the biomechanics are yet capable to be copied by the robotics or bionics, except the anthropological feed-back of rational and instinctive movements. The movement in biomechanics are always coordinative, fact that implies constrains of trajectory, momentum speeds and some times of accelerations. Constrains of accelerations appears in special movement as shocks, actions of pseudo-forces as centripetal or centrifugal, Coriolis etc.

Let as come back to the above example, where the coordinative attribute of the movement is biomechanical represented by tendency of the resulting speed to have a vertical direction. The coordination of extensions for each segments of the chain isn't the major target for the movement. The most important thing for the preparing the jump is to grows up the speed of lifting the weight centre, till to the moment of starting the jump. The high of jump depend mostly of take off speed and lesser of its vertical direction.

Because of neuro-muscular controlling by multiple feed-back loops, the biomechanical kinematics chain are only implicit different from the mechanical desmodromic chain, where the severe constrains are mechanical guidance. A biomechanical kinematics chain is different from a muscle chain of the same movement. Some times the descriptive anatomy a muscles chain is very important for the structure of the biomechanical kinematic chain.

XI. THE EQUILIBRIUM AND OTHER STATIC ASPECTS

9.1. Generalities Referring to Equilibrium

The common farm of equilibrium is linked with gravity. An element is in equilibrium if the projection of its center of gravity falls inside the supporting area.

There are three categories of equilibrium: stable equilibrium, unstable and the lack of equilibrium. It is said that stable equilibrium is better when the center of gravity is closer to the supporting base.

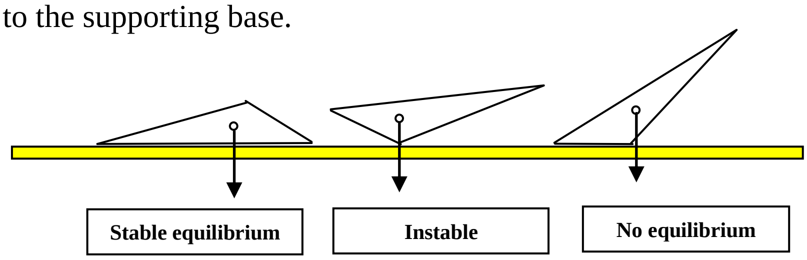


Fig. 9.1. Categories of elementary equilibrium

The triangle which has the connotation of *no equilibrium* in figure 6.1. will overturn, because the gravity force is not collinear with the supporting reaction and produces a rotation moment. This rotation moment can be compensated by another one, which is contrary, in fig 6.2. being thus reestablished the equilibrium.

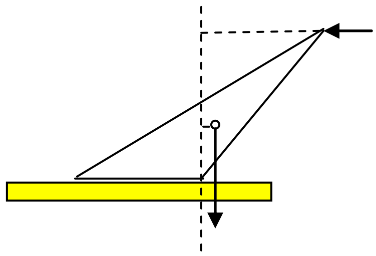


Fig. 9.2. The reestablishing of the equilibrium, by external forces, which produce different sign moments that have different sign than the weight force

The unstable equilibrium can be improved if the weight centrum is moved down artificially and brought as close as possible to the sustaining point or surface, as illustrated in Fig. 6.3. when the weight centrums can be moved down under the sustaining point the equilibrium becomes stable.

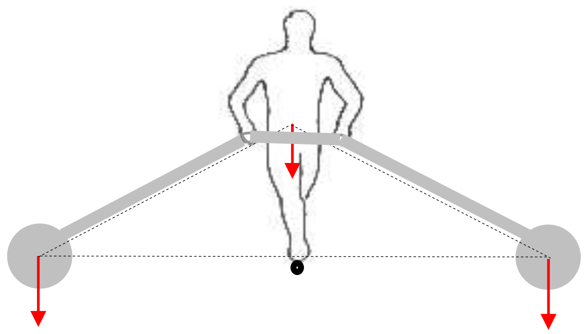


Fig. 9.3. The improvement of the equilibrium by the artificial coming down of the weight centrum with the equilibrium bar. Stylization after the model of the circus rope equilibrist

The weight center of a triangular homogeneous body stays at the intersection of the median lines. If the repartition of the weight is not equal as suggested in fig. 6.3., than the weight center moves in a certain proportion towards the biggest weight. We will come back upon to the way of calculus of the weight center to complex bodies.

9.2. The Equilibrium in Biomechanics

The things mentioned above can be applied to biomechanics too, but they are not a characteristic of this one. In biomechanics the equilibrium mostly refers to the internal forces generated by muscular contraction. When an adult stands up, his or her weight centrum is on his or her vertical axis of symmetry, at the level 1-5 where the sacral vertebra is located (to some centimeters near the navel) and his or her projection falls inside the aria which is bounded by soles, the equilibrium being this stable. Even still, human stability is not perfect; there will always be oscillations of the weight centrum projection because the command and control system of equilibrium relies on feed-beck corrections of some mistakes (involuntary movements that cannot be perceptible consciously). More then that, the voluntary changing of the positions of corporal segments or of the body itself modifies the position of the weight centrum and, implicitly, the quality of the equilibrium.

So, when talking about stable equilibrium we can identify different qualities of equilibrium; in other words, the equilibrium is a personal aptitude. We prefer appreciating the quality of the postural equilibrium by a relative magnitude, which asymptotically tends to a perfect stability witch, is the immobility of the weight centrum in comparison with footing. When the weight centrum is fixed, the development in time of any spatial component of the distance in comparison with the milestone is a straight line. In the plane of the maintenance surface, can be conventionally established two directions; for instance, N-S for the movements of the projection of the weight centrum forward and backward and E-W for left–right movements. The registered relative values of the oscillations of these movements will be proportional to the weight centrum instability, in fact to the instability of the body itself.

The measurable parameters of the oscillations conventionally, can label the instability in some categories. It is understandable the naught instability is the equivalent of the perfect equilibrium, and the most unfavorable category of instability is represented by the instable equilibrium. We have identified five categories of instability from the highest instability in the pathological area, the hyper, medium and hypo instability of the normal habitual human to the lowest instability, which characterizes the performance target shooters.

The utility of categorizing the postural instability becomes evident when me make casual referring to the performing and command mechanisms of equilibrium and the feed-backs that regulate and control the effects.

As it is known from the physiology the postural equilibrium is assigned to the *stato-kinetics* and it is accomplished by the dynamic of the mechanic strains from the agonistic and antagonistic muscles, voluntary or automatically command (cerebral, cerebellum, medullar etc.) and controlled by at least five kinds of the feed-back. Generally are accepted three regulated and controlled medullary levels.

- That one that depends on the neuromuscular shafts installed between the muscular fibers of the muscles and commanded by gamma and alpha motoneurons.
- That one that depends on the Golgi organs of the tendons, as an obstruction of extension.
- That one provided by the Ruffiny organs referring to the joints openings and the variation of the rotation movement's speed.

Other two regulated and controlled levels are in the internal ear and in the visual telereception from the *postrolandical* zone.

By this short description we want to show that the regulated system of equilibrium is very complex and the postural instability, by its parameters, can be allocated, in different proportions to the state of the effecters, the quality of the commands and to the five regulated and controlled levels.

For the biomechanics it is necessary and sufficient to interpretation systemically the criteria of the instability of oscillations of the weight centrum in the sustaining polygon of footing and to describe the most important experimental results. As a result of the application of veridical knowledge and performing in a casual way, there can be than made and used adequate methods of improvement of the sense of equilibrium and of execution techniques in the benefit of occupational or sportive performance.

Frequently the regulated system of equilibrium is treated as a mathematical model of the overturned pendulum, doubled articulated. This is composed by the trunk and the superior part of the body, as a strong segment with the concentrated mass in the general weight centrum and by the inferior part, doubled articulated at the level of the knees and hips, all together performing as a kinematical chain.

Experimental studies, referring to the registering of the pressure centrum oscillations on a strain gage platform in sagital and frontal plan (N-S, E-W), their conjuncture and exact interpretation, revealed that the postural *instability* varies:

- From person to person, meaning a *genotypical* conditioning;
- Depending on the age, the experience and the training, meaning a *phenotypical* conditioning;
- Depending on the medium conditions, the state of the body, the psychogenic influences, the medication, the

tiredness, virus aggressions, meaning a *paratypical* conditioning.

For instance, *Yamamoto, T.* (1980) finds that the most instable period on decades is that one between 20 and 30 years, the instability increasing with age; he also finds that the difference between sexes are insignificant and that the *mechanograme* realized with closes eyes have higher oscillations that those realized with visual control. *Braenber and Seidel*, (1979), find that oscillations have a power spectral density seized between 0.1 and 2.0 Hz with a maximum at about 0.25 Hz; undifferentiated statistically on sagital or frontal plans.

Other findings refers to ways of equilibrium improvement as those ones connected with the influence of some classical, harmless substances (the glucose, C vitamin, etc.) on the neuro-endocrine system (when talking about acute thyroidal disequilibrium) or those which remind of some prohibited substances as the alcohol. It seems funny the fact that the alcohol is on the “black list” because of its effect on the target shooters equilibrium. Some of these ones have said from their own experience that about 20 gr. of brandy improves the gun-shooter equilibrium, while this phenomenon does not occur to a high dose as 50 gr. for instance.

Our studies on well trained target shooters have shown that the mechanograme can provide useful information about the quality of shooting technique, the state of tiredness of the nervous instants implicated in the postural equilibrium and the gun stability and even about the specific training level.

Referring to the instability measure or testing we can say that not only the circumstances but also the techniques differ very much from one another; that even a simple inventory becomes inconvenient. We have to take out the concept and the essential parts, saying that majority of the authors agree with the idea on which the position oscillations of the general weight on the center of projection in the sustentation plan (the horizontal surface of the maintenance) are a true indicator of the instability. The registering of the oscillations can be done in Cartesian coordinates, separately, on N-S direction (the gun direction or sagital plane) and E-W, or together, in polar coordinates under the shape of a mechanagrame. Mechanagrams records the movements holographic, registering only the variation of the position of polar vector top comparing with a conventional point. We will come back to discuss about mechanograms.

The majority of authors think that the standing position with the sores spread at the width of shoulders and with the arms relaxed can be a reference position, a nominal one, otherwise the registrations are made in a difficult grades (with the closes eyes, on one leg, with or without appropriate shoes etc.). When a systematic fact comes up as, for instance, the training, than, conventionally, the immediate registration will be considered as a reference one.

Oscillations have a central amplitude or a spectrum of amplitude they have basic and overrated frequencies or a spectrum of frequency, they have a good direction or an anisotropy degree, they have the tendency to loose the central values in time or a certain entropic variation etc. All these characteristics certainly represent a big quantity of information, but , nowadays, a low volume of work of processing, due to the huge advantage offered by “on line” acquisitions (directly from the stability platform) and the automatic computer processing.

No matter what techniques of the processing are choosing, it is important to clarify what they represent, what the characteristics of the registered oscillations are measured. The following registering pattern may bring more clarity.

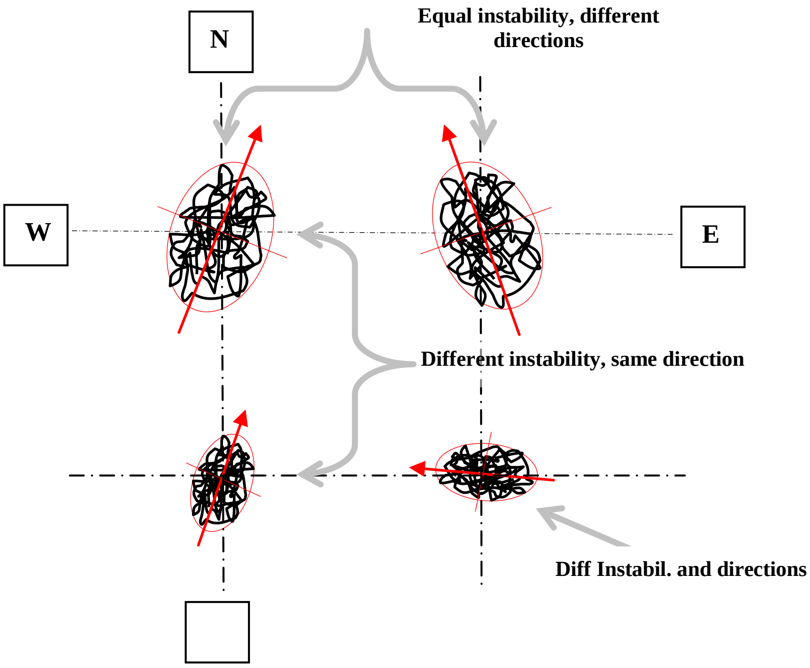


Fig.9.4. Patterns of mechanograms. The chaotically broken line, represents the trajectory of the general centre projection of weight centre in horizontal plane, when the subject stands still for 30 seconds. The four patterns are different because of the circumscribed area and the orientation tendency of oscillations. Further explanations can be found in the text

As it is shown in Fig. 9.4., the four patterns of mechanogram are different from a visible point of view, either by the circumscribed area or by the orientation tendency of oscillations or by both of them. The more a less circumscribed area the more we have a less instability, meaning that we have a better equilibrium.

Two persons can have the same postural instability but different directions of oscillations and vice-versa. The areas where the weight centrum projection oscillate, areas represented by mechanograms, are relatively constant for the same person if the registration time is the same. We use and we recommend reference registrations no longer than 30 s; because the tiredness comes up and the mechanograms alter.

In such short registrations we can notice the trajectory of oscillations with the makes eye and their dimensions is enough for statistical processing. Because of the fact that the modern stability platforms are connected with computers that automatically and rapidly gather and process the information, we can visualize them in a pseudo real time, so that the registrations and visualizations do not differ from one another at all, any more.

The registrations can be done separately in one of the two rectangular coordinates x(t) and y(t) as we can see in Fig.6.5. As it is seen in this registration or visualization pattern, oscillations differ from one direction to another, and their qualitative appreciation can be done by a relative difference of the respective length of the trajectories. A practical indicator can be obtained measuring (with a pedometer) the total length of the trajectory and the registration length. With the simple formula: $1_x = 100 \cdot (1 - 1_0) / 1_0$ (%), which percentage calculates the length of the first trajectory (the broken line) comparing with the distance of the 1_0 registration (the straight line) we can estimate the instability in both directions.

Consequently, from simple graphical calculations, simple qualitative appreciations of equilibrium can be made. Briefly these are the following:

- the size of the aria which is circumscribed to the mechanogram.

- the preferential direction of oscillations, offered by the big axis of the ellipse which registers the mechanogram.
- instability clues in N-S direction (the gun direction) an E-W direction or in sagital or frontal plan (for reference).

Besides these qualitative appreciation's (visible with makes eye) precise measurements can be done which are generally automatically processed on the computer.

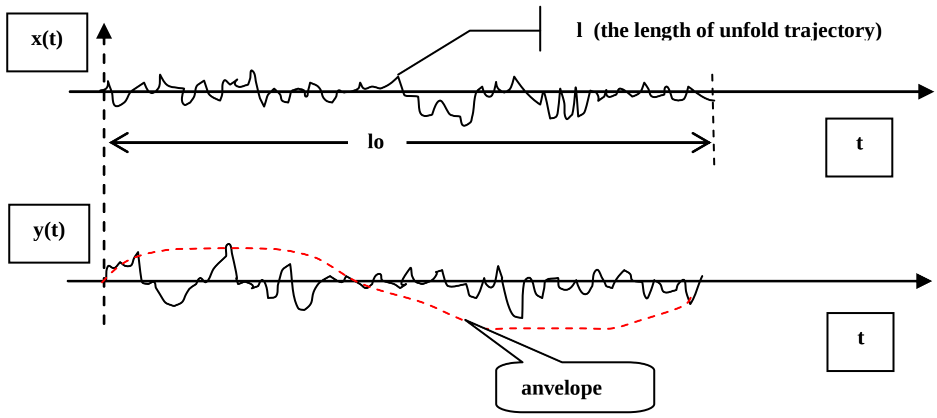


Fig. 9.5. Pattern of mechanogram namely the separate visualization of rectangular components x(t) and y(t) of the oscillations projection of the general weight centrum. Further explanations can be found in the text

It is the job of the informaticians to choose or to make adequate software which processes the postural stability but it's the job of the specialists in biomechanics to say what exactly have to be calculated. In our opinion it is enough to be acquired one by one, with a minimum frequency of 30Hz. (1000Hz assuring an excellent resolution) two rectangular coordinates, *x* and *y*, of successive positions of the weight centrum projections. The duration of the acquisition must be the same (30 sec. usually) for all the registrations: nominal (of reference) and with closes eyes, before and after a certain measure (a training).

The pairs of coordinates can be processed together, being known that their square roots sum is exactly the position module vector, and their proportion determinate the argument (the angle). Besides the observing form, the information can also be statistically analyzed, the repartitions of vectorial magnitudes and of variation speeds offering information for characterizing the instability.

The preferential direction of oscillations its variation from the natural, sagital tendency, can be taken out from the calculation of the highest relative frequency of the argument reparation.

The independent processing of the coordinates x(t) and y(t) gives information about the preferential frequencies of oscillations (genotypic), about the period of the outer covers of the frequency spectra (which are important for the cerebella's and reticular system instants, involved in the control and adjustment of equilibrium) etc.

Referring to the control and adjustment mechanisms of the equilibrium, biomechanics is interested more in the principal diagram of these ones than in the implied biological structures. Generally it is accepted that the whole diagram which has a control function is independent (as the gyroscope of the automate pilot) and that the disturbance of the system is applied to the neuromuscular command.

In Fig.6.6. is presented a cybernetic model of equilibrium studied and considered being simple and important. We have to mention that it is known tens of other models, some of them very complicated, on which different behaviors of equilibrium have been simulated and with whom have been realized performing bipedal robots.

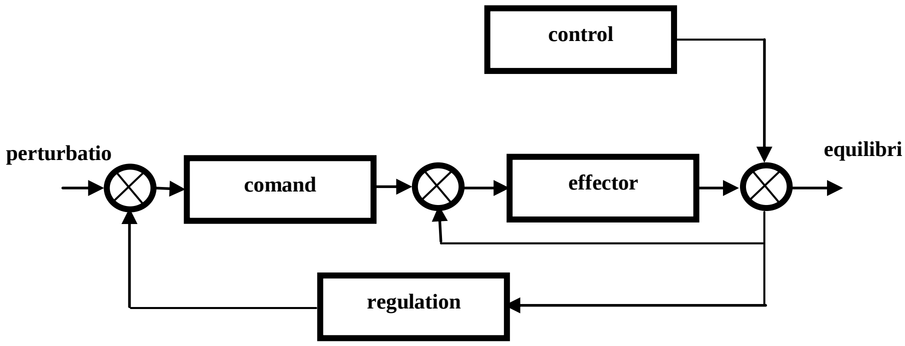


Fig.9.6. A simple scheme of the mechanism of postural equilibrium. The feed-back ringlet shuts down on the effectors, and the comparative adjustments (the labyrinthcal and visual control) compensate the perturbations

The cybernetic model shown above reason simplifies the reality, offering solutions of equilibrium correction too. One of these is quite simple transcendental relation *($2r \cdot cos^2(\alpha/2)$)* for the transfer function of the adjustment block. This solution varies, of course, only in normal states (not pathological ones which affect the control).

In simple words, the functioning of this scheme of equilibrium relies on the principle according to which the stable equilibrium is realized when the algebraic sum of the movements of forces comparing to the fix point or contact surface is zero. If a perturbatory force, even an interval one, of a wrong contracted muscle involuntary, modifies the equality of the movements, than specialized instances notice an error comparing to the independent reference and the feed-back ringlets confer correction information of equilibrium at the effectors system; these information are transmitted directly or by instants of adjustment and command.

The corrections have a certain *delay*, a certain dynamic; for this reason the mechanograms look like a scrawling and they differ, as we said before – from subject to subject, conditions, experience etc. The equilibrium corrections have a great influence from the psychological factors, mostly to the persons who are aware of the disequilibrium risk. Thus, a certain person would have great difficulties of maintaining the equilibrium if he would be suspended at heights, however the equilibrium conditions do not change. What changes is the risk factor and, with this one, the mind relation with the adjustment and control system of equilibrium.

9.3. The Determination of the General Weight Center

The general weight center is a statically imaginary location in which is conventionally concentrated the whole weight of the body. If the body is put to other accelerations than the gravitational one, than one can talk about a general center of mass, otherwise they coincide (with each other). In the human body can be identified other centers like: the volume one (useful in nautical sports), the surface one (useful in parachutism), the symmetry center etc.

The determination of the position of the general center of weight (g.c.w.) can be done physically (by weighing), analytically (by calculations) or graphically (from images).

We are convinced that the utility of determining the position has been remarked in the previous paragraphs referring to equilibrium. However, the principal utility of knowing the g.c.w. refers to the action of external forces over the body, to the dynamic of movement and will be commented in the chapter which refer to the analyze and synthesis of movements.

This subject of the determination of the g.c.w., probably has the greatest history of biomechanics' preoccupations. As a sign of respect we remind some of the well-known authors: Harless, 1860; Braune and Fisher, 1889; Hellebrandt and col., 1838; Demster, 1955; Hanavan, 1964; Drillis and Contini, 1967; Clauser, McConville and Young, 1969, Plagenhoef, 1971, Iliescu and Dora Gavrilescu, 1976; Stijnen and col., 1980 etc.

It is interesting that the experimental values, often made in charts and having the name of the authors written above, do not differ from one another with more than 1.5% which is practically negligible.

We underline once more, if it is necessary, that the computerized methods make useless the description of determination techniques by weighing or by graphical measurements from images.

What is common to all the methods or techniques of determination the g.c.w. position refer to the concept due to which the sum of the movements of all the weigh forces segmentary or partially annulated vectorial in g.c.w. This means that the g.c.w. position behaves like a fulcrum which equilibrates a first degree lever meaning that the right movements are equal to the left ones (negative, which rotates in opposite directions). For simplifying things, the axis on which is calculated the distance is chosen outside the body so that the movement created by the g.c.w. distance to this axis and the total weigh to equilibrate the sum of all the segmental and partial movements.

For y axis the distance is:

$x = (\Sigma g_i x_i) / G$

and for x axis the distance is:

$$y = (\Sigma g_i y_i) / G$$

where g_i are the partial weights and, x_i and y_i are their distances to the principal axis, and G is the total weigh.

So g.c.w. has the coordinates x, y and z of a Cartesian external system and imaginary concentrates the whole G gravity.

Body segments	Demster	Barter	Inreg. video
arms & ante	11.7	11.30	9.55
trunk & neck & head	55.4	55.53	57.53
legs & foot	32.9	33.17	32.92

X. THE BIOMECHANICAL ANALYSIS OF MOVEMENT

10.1. The Purpose of the Analysis

The importance of the analysis of the movement is justified by the purpose of growing the human driving performance and more than that, by the purpose of improving the sportive technique. Another purpose of the analysis of the movement is the optimization of the recovery or of the improvement of the human driving capacity in both congenital pathological and accidental traumas cases such as amputations, paralyses, acute dysfunctions and so on, with the purpose of correcting or stopping the involution.

Important to be mentioned is the fact that the analysis of the movement is only one step (important and necessary - we add) of the process of improving the performance or of recovering the driving deficiencies. This step directly refers to the identification of same systematic differences other steps, that we shall come back to, include the interpretation, the causal rationalisms, the implementation tactic and strategy, the dynamic corrections and reevaluation etc.

We find it useful to develop the terms "*difference*" - belonging to the analysis - no matter if it refers to the biomechanics or to other disciplines or sciences. The difference includes two aspects; one is the observation and the other is the interpretation. In other words, the difference can be remarked (noticed, observed, measured etc.) or not, can be interpretive as negligible or *non-signifiant*, or can be interpretive as significant, relevant, important etc.

In the practice of scientific research and of the biomechanics, which as known, are prevailing in general *a posteriori*, some differences are not noticed or observed, either cause of unfit scientific instruments (inefficient, insensitive), or because of unfit methods (procedure, concept, technique), or because the observer (the research worker, the operator) etc. The remarked differences can be also in their turn, significant (relevant, important) or non-important.

In certain circumstances, all these types of differences become undesirable or anticipated in a different way, so they are called errors.

Significant differences are divided into: systematic (*repetitive*, *iterate,* regular, a.s.o.) and non-systematic (accidental, without any summing rule).

Only systematic differences can be causally or correlatively interpretive. It will be seen on, that differences that can be etiquetted "*systematic*" (to an acceptable degree of risk), can have causal factors or explanations (of parallelism) similitude, a.s.o. belonging to heuristics.

By analogy, the logical-mathematical difference is a form of abstraction of a physical difference (class of equivalence) in witch the dissociation is a concrete operation.

Coming back to the analysis of the biomechanical movement, we notice that it can be qualitative or quantitative simple or complete, on line or off line, a.s.o.

Its taxonomy is interesting for the biomechanics only if the compromise that pulled out is acceptable for the practice and for the significance of the process of separating a whole into component parts, process that provides significant information that loaded the know-how aria. The analysis don't invent, only discover, and then justifies or critics; remaining for other rational methods of knowing to valorize its conclusions. It will be shown later that analysis and synthesis having logical forms of deduction, induction or inferential etc. can promote the status of one hypothesis to one of thesis.

In the analysis process the differences of the marks are empirical, evolutionary and apostolically. As a rule, if is speaking about top sport, the so called consecrated sport's techniques are pulled out as marks, techniques that have initially imposed themselves as styles. In fact, they are logical combinations of movements, as precise successions and simultaneities. When it is about correcting or repairing the movement, like in Kinetotherapy, marks are changed, statistically characterized as being normal and natural.

Analyses, being practical, generally speaking, in this book we are trying to draw out their essential and what it is common to all the analytic procedures, conferring them to the theory.

10.2. The Qualitative Biomechanical Analysis of the Movement

We consider that the first duty of the one who starts the biomechanical analysis of any movement is to integrate it into one of the big classes of movements and to describe it in the conventional language so that it can be identified with no doubt.

For example, simple movements can be integrated as being of translation, of rotation or helical, can be cyclical or non-cyclical can be described in basic terms such as flexion, extension, adduction, abduction, can be reported to the reference plans - sagital, frontal, transversal, a.s.o.

The modern tendency in the biomechanical analysis is the one of separating, from the beginning, of complex movements into successions and insertions of simple movements.

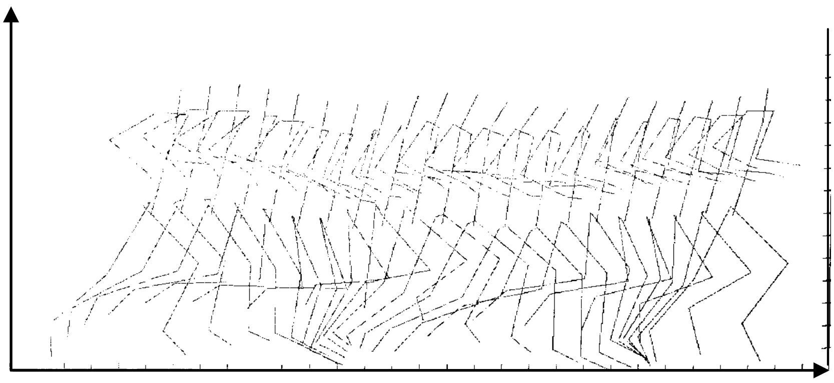


Fig. 10.1. Example of simple qualitative analysis by noticing and interpretation the angles and the relative positions of bodily segments and their trajectories.

If the biomechanical analysis of movement is qualitative (no matter if it is simple or complex), then its algorithm is very easy and begins with the attentive and repeated observation of movement, and continues with finding the position or movement differences to a conventional mark (the model of the champion, the statistic normality, a.s.o.) and the relative, eventually causal interpretation.

The observation in biomechanics is, as very known, a scientifically process only in the measure in witch it relies on visual proceedings; that means video recordings and processed images (so that the movement can be slowed down, eventually stopped). There is several software for processing images that have been, selected from the recorded movement and they are very comfortable and friendly at use software. Most of them *come* from the commercial sphere of processing images for making electronic games, cartoons, fiction movies and for *robotics.* The recording procedures are in general, those with sensors or lightening markers set on bodily segments the procession and the manufacturing of the bodies being computerized.

The procession technology reached such a high level that the bodies seem to be natural in spite of their unreal (sometimes monstrous) look, and the movement is so natural and continuous, that it can be hardly be told from a classic shot.

Dealing only with the theory of the analysis we shall draw out only the concepts of the methods of recording and processing images concepts that can be summarized as follows:

- Either from the beginning, or after a few visualizations of the material recordings, should be identified the segments and the interesting points of the analysis.

- The succession of the images in the scientific repeated observation should be reduced until the temporary stop-frame, with the purpose of noticing the longitudinal differences (in time) or the transversal differences (in space from a recording to another, from a subject to another).

- The speed of succession of the images in the scientific repeated observation should be grown, so that the visual analyses should memorize the trajectories of the segments or the interesting points in the technical analyze of the movement.

- The interpretation of the position (by reduced) succession or of the movement (by the speed of fast succession) differences, is always made comparatively and relatively in the qualitative analysis.

- In short, the purpose of the analysis determined the speed of the succession of the analyzed images.

Paradoxically, because of the advanced computer technology, the complex qualitative analysis, is surer and more efficient than the easy one, some recommendations and some explication for the algorithmic steps seem to be necessary as follows:

- Shooting plane movements, preferably with a digital video camera, should be made from a well-known distance (big enough to niggled the parallax errors perpendicular on the direction of movement);
- For spatial movements, the shootings should be made from two or even three directions, also orthogonal and from enough distance;
- The acquisition by the computer depends on the adopted technique. The only request refers to the frequency of the frames; correspond to the speed of movement;
- The processing, in the most efficient case, is done automatically, the points of the directions to be followed being established; otherwise these are marked manually on the frame. As it has already been shown, specialized software is already accessible, this being able to calculate and show automatically the significant moments of a complex image (execution techniques), the necessary moments for the quality analysis. Usually, the significant moments are the following:
  - the change of direction of the movement (null speed);
  - the top points of the speed (null accelerations);
  - the relative angles (between two articulations);
  - the relative distances (between two segments).

In a running movement, for example, the significant moments of the quality movement refers to the position of the knee and of the ankle belonging to the leg opposite to the one witch is in the final propulsion, to the position of the elbows, to the changes of direction of the rotation of the leg towards the rotation of the thigh, to the angle under which the attack of the soil with the sole is made etc.

- The analytical or the graphic identification of the difference of these moments towards the empirical points of reference has to take into account two aspects: one of resolution, and the other one of significance. In the first place, the points of reference are empirical ones (without this being a criticism), this meaning that we choose a movement model that is labeled a priori as being convenient. In the case of the professional sport, the points of reference are *validated techniques* of the champions, and in the case of the movement theories, the points of reference are the *normal statistical movements.* In the case of locomotion, the normal walk is such a model, towards which there is an asymptotic tendency, or, at least, locomotion without pain and the risk of accident is tried.

- The resolution that is referred to depends on the quality analysis. Anyway, the labeling of the observations is made in comparative terms, such as: bigger, smaller, much smaller, etc, which suggests the idea that there are sufficient five valor classes of the Fuzzy type, corresponding to some discriminatory possibilities of 20%. The significance is linked to the repetition of observations or to several cycles of the movement, such as not only the amplitude of the difference, but also its repeatability can insure the rightness of its labeling.

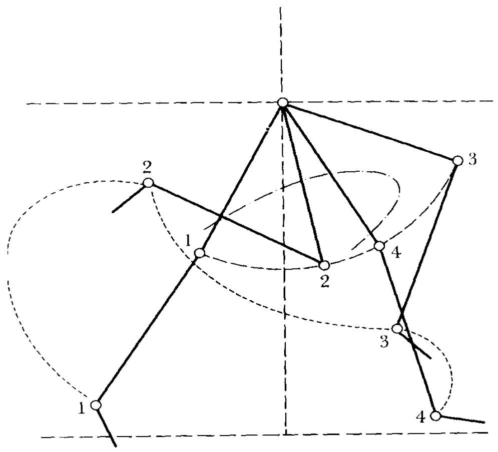


Figure 10.2. Example of quality analysis of the running movement in the case of the Olympic Champion runner N. B. The analysis refers to the identification of the body segments in the moments of change of rotation (numbered) and to the directions of the articulation.

- The differences towards these points of reference, in the direction of the quality moments above, are interpreted only in the case when they are significant; otherwise they are not to be discussed. They are attributed to some systematic factors, known in the common language as *technical mistakes* of execution. The causal explanations should be done under a careful form, being known that the analysis offers only arguments for the reasoning of the Aristotelian logic.

- The implementation of the conclusions of the analysis should have in view the fact that reaching the purpose, usually turning the movement into an efficient one, is combined, form one case to another, with the special and specific preparation, with the technique and the strategy, with the social and environmental factors. In fact, we want to stress once more the idea that *the biomechanical analysis cannot be directly linked to its purpose.*

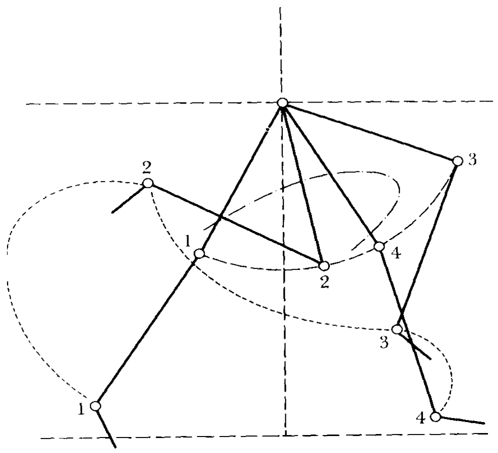


Fig. 10.3. Example of quality analysis of the running movement in the case of the Olympic champion runner C. N. In the same way as the preceding example, the analysis refers to the identification of the relative positions of the body segments in the moments of change of speed (numbered) and to the directions of the articulations. Besides that, differences are taken into account and interpreted.

10.3. The Quantitative Biomechanical Analysis of the Movement

The word *quantity* means that can be measured and it would be tempting to reduce the analysis to the measuring of the difference, which would not be enough. The solutions of the movement equation are time-dependent, thus they are functions, and only their instantaneous and local forms are numbers. The arguments of the significance of the difference can be found in the statistical tests that have a probabilistic base (of a certain degree of verisimilitude). These apparently sophisticated remarks should not worry us, because the calculations, recently, can be made through the computer by specializes software and programmers.

The fetishism of the computerized calculations is run down by the principle *"entry error = exit error"*, principle extended to the whole approach of the analysis. As it is already known, the analysis starts by the simplification of the reality that is by the elaboration of a cinematic chain which concentrates in a fictive way the masses, approximates the forms of articulation, attributes conventionally locations for the force vectors of segments etc. If the models of the cinematic chains are not evident enough or if they are misconceived, they can generate important errors at the end of the analysis, although a part of it is done through the computer.

As in the case of the complex quality analysis, quantity analysis starts from real data, which are technically realized trough a practical problem - that can be found in all the general biomechanics textbooks. The theoretical concept that we are dealing with refers to the obligation of knowing the angles and the distances of video recording, which, for simplification, is recommended to be straight (perpendicular and longitudinal on the direction of the speed etc.).

The processing of the registered images is normally done automatically, the interesting points in the case of quantity analysis being the following:

- The direction of the chosen points on the cinematic chain. In fact one, two and in some cases three coordinates and their sequential variations: x(t), y(t), z(t). The points can be chosen in articulations or in the centers of segmental weight (general, in some cases);
- The sequential variation of the angles of articulation or of the relative positions between some body segments;
- The graphic of the speeds, v(t), calculated in a grapho-analytical way, or deduced analytically (by the computer) from the space variations in the sequential durations;
- The graphic of the accelerations, a(t) calculated in a grapho-analytical way, or deduced analytically (by the computer) from the speed variations in the sequential durations;
- The graphic of the forces or of the moments of force, deduced analytically by the multiplication of the part masses and of their positions on the body segments (tabled values stocked on the computer) with the accelerations calculated beforehand;
- The graphics of the pseudo-forces (centrifugal, centripetal, Coriolis) deduced analytically from the relative movements and the longitudinal requests of the body segments.

It should be mentioned that the directions, the angles and the relative positions are calculated in the case of the cinematic analysis, and in the case of the dynamic (cause-effect) analysis, accelerations, forces and moments should be calculated, too.

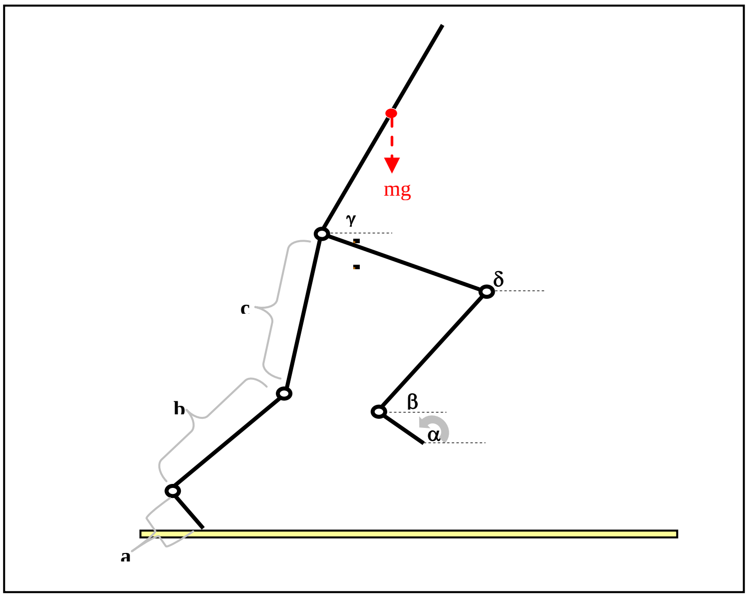


Fig. 10.4. The reasonable simplification that the quantity analysis done by the computer accepts in the case of the running movement. We assume that we know: the lengths of the segments, the whole weight, the positions of the weight-centers of the segments (from the tables) and of their relative weights (the same).

The changes of positions of the articulations or of the weight-centers generate graphics of the *directions*, and the changes of relative positions of the body segments generate graphics of the *angular variations.* From the directions of the articulations or of the weight-centers are calculated automatically, through suitable software and programmers, the tangential variations, the angular variations, accelerations, forces, moments of force are calculated.

The calculation, being done by the computer, is not interested. If the registering technique is correct, meaning the corresponding positioning of the marking-points and the filming (usually digital one, made in infrareds and with reflecting marking) from adequate distances and positions, then in the memory of the database is automatically built, which is applicable to some very efficient software, of the kind that make the animation of the fictive characters in cartoons or in computer-games. The only thing left is for the database to be used in a scientific way.

We should underline that, from the point of view of the analytical biomechanics, the interest is focused on the comparative interpretation of the database in the algorithmic process of analysis. For example, when the focus is on the correction of the running technique compared to a model of the champion, the registration of the variation of the angles of articulations of the inferior part of the body brings a reasonable amount of information for the comparative interpretation of the differences. The quality of the interpretation, again, is not the problem of theoretical biomechanics, but depends on the erudition, the experience and the intellectual qualities of the person deciding.

The role of the analysis of biomechanics is trait of, offering to the person deciding intuitive forms of interpretation and objective forms (scaled differences, dynamically visualized), in fact, to offer a scientific argument to the rational process of interpretation. The samples of biomechanical analysis presented in Figures 7.5 and 7.6 want to show that the variation of the angles of the segments of the inferior limbs in the running process differs in terms of quantity in the case of two runners: one an Olympic one, the other a beginner.

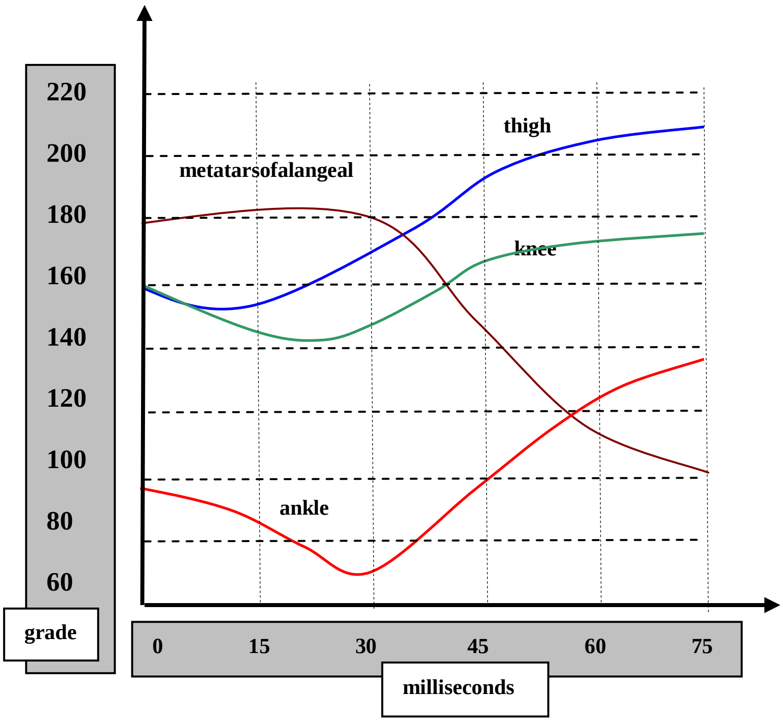


Fig. 10.5. Example of a graphic meant for the quantity analysis of the running movement in the case of the Olympic runner P. M. The appreciation is grapho-analytical and refers to the mode of variation of the angles of the main articulations involved in the motion.

If the interpretation would stop to this remark, otherwise argued objectively by the space and time coordinates, then the analysis work would be useless! The analysis is not only a procedure, a logical instrument, but also a way of thinking, of interpreting an amount of data.

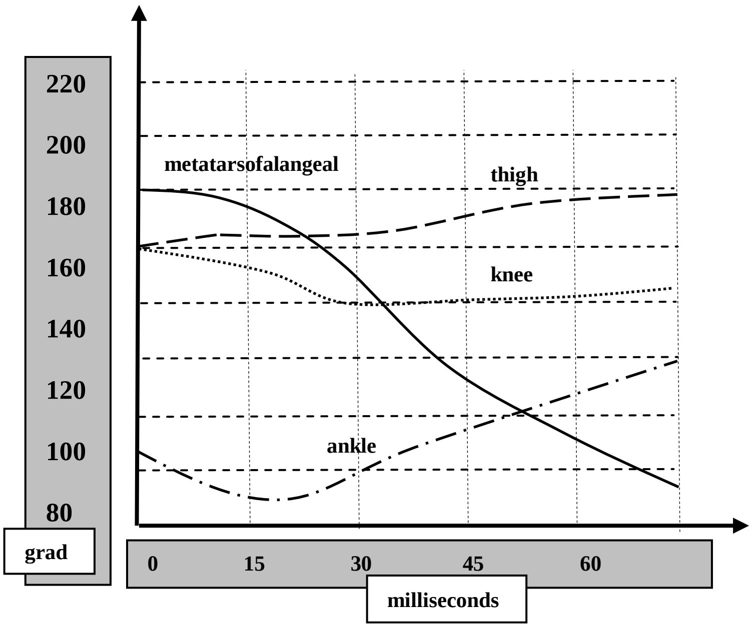


Fig. 1.6. Example of graphic for the quantity analysis in the case of a beginner runner. Reference to the mode of variation of the angle of the main articulations involved in the movement. . It should be mentioned that the interpretation should be made according to the running technique accepted as a model (the Olympic runner from the figure above)

The analytical way of thinking imposes, in the presented examples, to remark that the variation of the angle of the foot relatively to the soil, in the case of the Olympic runner (Figure

10.5., the metatarsofalangeal direction and the one of the ankle), show an attack of the soil without any use of the sole, which means a small gain of time at any step (gain measured in milliseconds); this time, added up, can mean a difference of some places in an Olympic final.

By comparison, the mode of variation in time of the angles of the inferior body limbs in the running of the beginner runner (Fig. 10.6.) show us that his technique is a deficient one, and is probably due to the reduced power of the quadrocipital complex, in fact, of the lack of proper training. The deep analysis of the registered data allows, when needed, the coming up of even more detailed conclusions, such as the ones related to the diagnosis and even the prognosis of the training preparation. Through these examples we wanted to underline the utility and the limits of the quantity biomechanical analysis, which, as it can be seen, refers to the analytical instrument of accounting, and to the analytical way of interpretation.

XI. COMPUTERIZED BIOMECHANICAL ANALYSIS OF MOVEMENT

It is well known that during the last two decades of the 20th century computerized technology has advanced extremely much, therefore biomechanical analysis has become a matter of routine, its performance depending only upon the quality of hardware/software and, implicitly, upon the costs related to the same.

It lies within people's cognizance that biomechanical analysis and synthesis software differ according to the applications required by the beneficiaries. They are, usually meant for the researches regarding the biomechanics of the technical executions in competitive sports, theoretical biomechanics, kinetotherapy, medial recovery, orthopedics and mobility impairment.

The first computerized processing related to biomechanics were, as known, online, i.e. they were based upon data processed graphically and analytically, directly on cinegrams or performed with analyzers of films projected on a scaled screen. Also used were hybrids, analogical and digital goniometric systems, the rule applicable to the same being the manual input of data in reaccessible files.

In the current stage of computerization, when available are high-speed processor possessing computer memory of dimensions and acquisitions rates unimaginable 20-30 ears ago, biomechanical analysis has evolved exceptionally, allowing the almost instantaneous display of time and place variations of positions, distances, momentum speeds, even of accelerations and forces, knowing however, in this last case, the masses involved in movement.

The benefits of the computerized analysis and synthesis of biomechanical movements do not only involve promptness, they also involve fidelity. Interpretation, however, notwithstanding the information standardization attempts, remained the perquisite of operators or deciders. Computers cannot, and will not ever be able, to automatically interpret biomechanical movements, as the optimization criteria are not always of a biomechanical nature, they are also of human nature, sometimes subject to rules and conventions.

11.1. Biomechanical Parameters Acquisition Systems

Computers store, process and display whatever the acquisition system converts into digital parameters and transfers as patterns. As a rule, acquisition systems are external devices or peripherals of computers having the form of acquisition boards, analogical and digital converters or microcontrollers. Consequently, computerized techniques of biomechanical analysis refer to the processing of digital or analogical data acquired and stored on computers.

All these techniques depend, however, on the manner of conversion of mechanical parameters into electrical signals, i.e. they depend on assemblers. For example, if angles between body segments are measured with galvanic goniometers set on a joint, then the electrical signals converted into sequential numeric data and stored in files are directly proportional with the measured angles.

If the angle is highlighted with luminescent or other markers, set on adjacent body segments as well as on the joint, then the processing technique will use analytical triangulation calculation until the angular parameter is being displayed. What we mean to say is that an important variable of computerized biomechanical analysis is the class of assemblers.

And we do not refer to the typology of the assemblers, as, for instance the galvanic or capacitive, presence, proximity etc, we rather refer to the relationship with the mechanical parameter; in such a case we refer to the proportional assemblers, differentials (variation assemblers), and the integrality (different order) one. For instance, acceleration meters measure the second derivative of position changes, while the position markers may sense the trajectory, in its simplest form, distance, without directly referring to time.

Time is shown by the acquisition rate or the internal clock of the computer. In the most frequent biomechanical analysis case, that of acquisition of images of the segmental movements of the body of an athlete, of an accessory or object, the frequency of slides, itself, represents a reference to the physical time, which resolves the relationship between space and time. The succession of positions defines trajectory, while the frequency of slides (frames) or the pace of acquisition helps determining time.

By processing, as is curvilinear integration, space is analytically determined, while the spatial sequences help determine momentum speeds, momentum accelerations and other parameters of biomechanical movement. The part represented by the acquisition of images and processing of the trajectories in relation to sequences (or frames) is known as 2D Analysis (two dimensions) or 3D (three dimensions) of the biomechanical movements (sports movements execution techniques). When the filming or video capturing is made by one single camera, i.e. in a 2D plan, the analysis is 2D, while when, for capturing video images, two cameras are used, mounted in such a manner as to capture movement spatially in three dimensions, then the analysis is 3D.

Markers may be luminescent, fluorescent, contrast etc; lately, however, advanced software can automatically recognize, in the succession of the frames, the variation of a randomly selected point. Recognition is made by the simple proximate comparison of the colors, brightness or contrast. Thus, quite impressively, the trajectory of a point is insulated from the milieu of the moving surface and can be analyzed and interpreted separately from the image.

11.2. The Luminescent Trajectory Marking Technique

The biomechanical movement analysis techniques have developed for the sake of animation, for such kind of films, for science-fiction films, TV ads etc. By visually marking certain joints and segments with luminescent contrast markers, one can perform video recordings of certain movements, while by processing based on software, as are, for instance, the poser procedures, fictitious segmental models of a human skeleton type, lay figures, even animals and fictitious characters can be created.

Scientific biomechanical analysis of certain technical executions in competitive sports also benefited of this technically advanced procedures; movement was visualized on segmental models, a kind of kinetic chains and mechanisms. It is much more evocative for sports specialists to visualize simultaneously animated movement and space charts, speeds and even forces, synchronously displayed, than to do the same for each of these biomechanical parameters, taken separately. For each plane or spatial position one may infer a Frene trihedron (comprised of rectangular coordinates in any point of the trajectory) having momentum speed and acceleration vectors.

These biomechanical data regarding competitive sports execution techniques and movements permit, actually, the optimization of the training and competition process, however subject to correct scientific interpretation. Considering the importance of a correct interpretation of the video processing, we will revisit this subject. It is, however, proper for us to offer details regarding 3 D video recordings with fluorescent markers, still a practice in the majority of the biomechanics laboratories.

Function of how advanced the hardware and software is, a higher or smaller number of fluorescent self-adhesive disks are placed on the main joints subject to biomechanical analysis. With two or three video cameras, placed usually orthogonally, movement is recorded in a diffuse light and synchronously, so that the florescent points are highlighted. Their position in relation to an external or relative reference point is stored in files, while with adequate software their trajectory in the Euclidian space can be re-enacted. As we were saying, animate movement can be visualized in pseudo-real time (with a slight delay, according to the patterning rate or the performance of the processor), in the form of segmental models or lay figures. For the specialists, more important is the mechanical or biomechanical features of movement, therefore the graphical and analytical processing of the data are preferred by the same.

When the movement is cyclical or harmonic, spectrum charts are being constructed or, more lately, real charts are fitted with mathematical functions theorizing movement. For instance, in practice, the impetus of shot put exhibits certain fluctuations of the increasing speed until the metal ball is released. If the variation of the speed is fitted with exponential functions, theoretically a conclusion is reached as to the fact that the derivative of speed needs to be, also, an exponential function, resulting corrections of the execution techniques.

Regardless of the video images acquisition or recording technique, a remarkably consistent rule is being observed, i.e. the one according to which a biomechanical time, having a conventional origin, corresponds to the marked points. In our opinion, such rule may be considered a principle of acquisition of images for the purpose of a biomechanical processing of movement, regardless of whether such processing is computerized or not.

In other words, the data chains acquired biomechanically are at least dual, one of them being the biomechanical time.
Another rule refers to the resolution of the processed image, which depends of the rate of patterning of the acquired signal and the power of the microprocessor. In the end, the quality of interpretation, i.e. the informational label, does not depend on the technology used for the biomechanical analysis, although the resolution and processing speed facilitates interpretation. We wish to say that, as in statistics, the quality of interpretation is perquisite of the operator or decider.

11.3. Displaying of the Results of Computerized Acquisitions of Biomechanical Parameters

The modern displaying solution is the windows-type one, with windows of different dimensions; they show the original movement, recorded by video or the movement of the dummy model, simultaneously with the space, speed or acceleration charts, synchronized, obviously. The parallel or superposed charts show, in animated form, the values adapted to the scale of the movement characteristics in pseudo-real time.

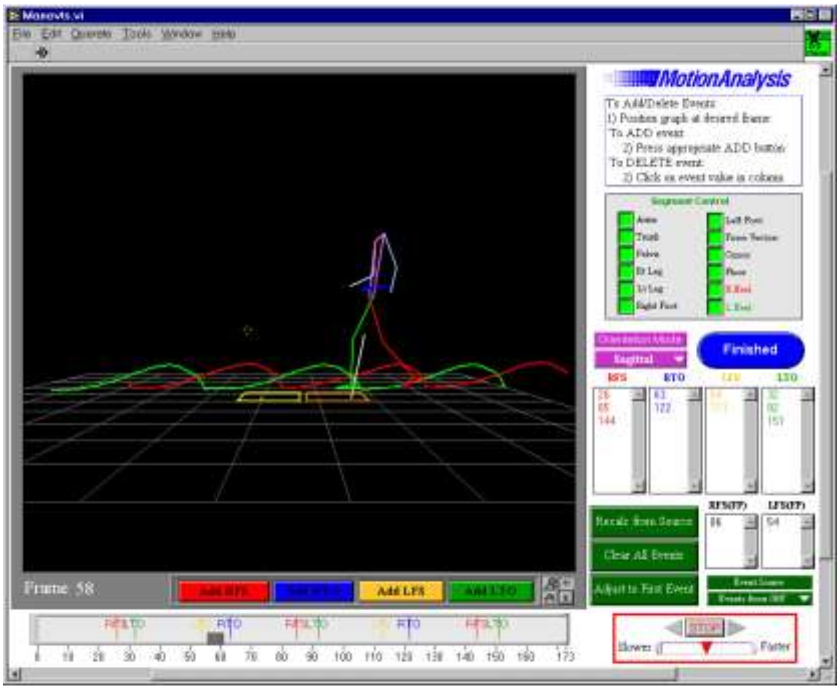


Fig. 11.1. Example of displaying the biomechanical computerized acquisition. Courtesy of Motion Analysis Corp.

Later on, by means of *stop frame* technique, the momental speeds, the accelerations and even the forces corresponding to the respective position can be visualized and slow pace re-visualization is also possible, which much facilitates the analysis of the movement, in fact of the sport execution technique.

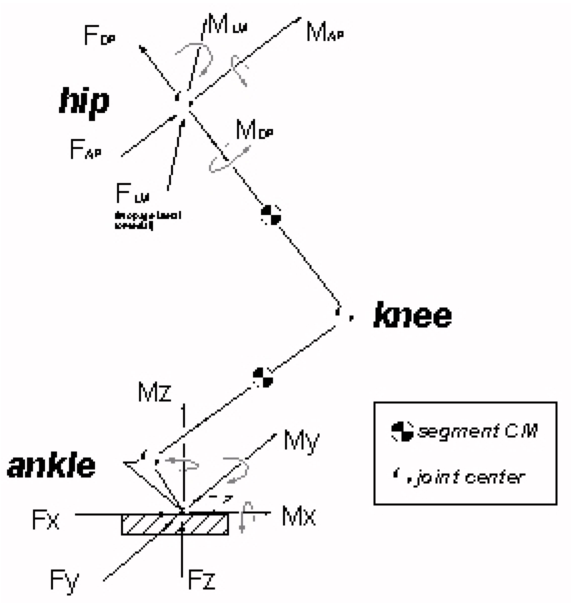


Fig. 11.2. Example of the positioning of forces and momentum in the triple extension

The representation of movement in polar coordinates is, sometimes, useful, as for instance of the angular variations of the body segments or in the so called *phase plane (space and speeds)*, when the movement is cyclical.

Ergometers, especially those utilized in rowing, show, according to position, mechanical work and variation of power. As for the training Ergometers, of body building or recovery after injuries, the effort is displayed as much as an outflow of energy (power) as well as odometrically (cumulatively), while the graphic presentation tends to be as suggestive as possible by way of colors and bars. The biomechanical parameters of movement and effort may be displayed simultaneously with the EMG, as an on-off indicator of the contraction interval of a muscle, or together with other physiological indicators as is the cardiac frequency, blood pressure, respiratory frequency etc. The simultaneous computerized processing of such parameters allows inputting on-line warning limits, sonorous or visual signals of alert for the situations when certain values in the pre-established range are being exceeded. In this way an alert signal can set off if the cardiac frequency has increased over a certain limit or if power has diminished or exceeded the critical point, which can happen in the case of the exercises recovery after injuries, etc.

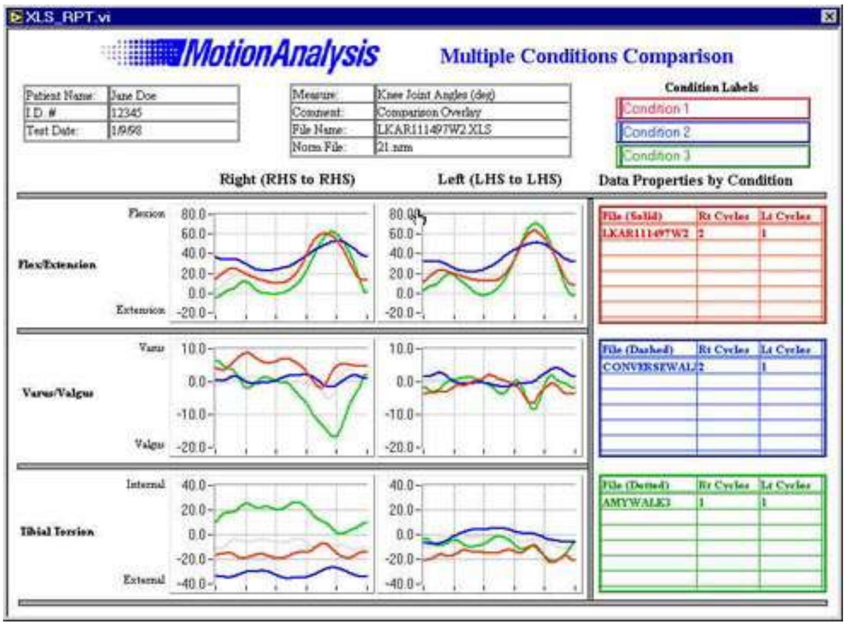


Fig. 11.3. Example of computerized biomechanical data. Courtesy of Motion Analysis Corp.

There are no standards for the actual display of the results of the acquisitions of biomechanical parameters, as there is, more often than not, a matter of aesthetics. However, the fact that not more than 5-6 simultaneous variations can be visually watched and that the processing of the parameters means a time lag (as compared to the video recording) which, if higher than 120 ms adversely affect visual perception should be considered. Selection of the resolution, especially of the number of frames per second in the video recordings depends on the purpose.

Thus, in order to visualize the growth of a plant a frame in hours is needed and for the impact of a bullet thousands of frames per second are needed, to visualize athletic movements 30 to 60 frames per second are sufficient. As many as 24 frames per second are also perceived as a continuous movement by the majority of the viewers, due to the remanence of the image on the retina, appreciated based upon the frequency of fusion of light pulses (SLI). Our data point to the fact that adult persons rarely have a critical SLI higher than 30 Hz, therefore they perceive a video recording of 30 frames per second as a discontinuous, non-uniform movement.

When pressure platforms are used to record the distribution of forces on a surface, their display may be of the topographical type, resembling curves and equipotent surface, marked with different colors. Sometimes it is convenient for the distribution of pressures to be represented by a grouping of vectors the magnitude of which is proportional with the pressure and which are oriented according to the direction of the reactive forces.

The fact that this type of representation has been perfected due to sponsoring by great footwear producing corporations tends to seem strange. In fact, the beneficiaries of such researches related to the pressure on the surface of the soles wanted, for commercial reasons, to perfect sports footwear and to diversify it for different sports.

Regardless of the manner of representation each graphic value is, in the beginning a digit of a matrix stored in special files. The length of the message, in fact, the number of bites of information, determines the graphic resolution. The graphic display of the results always has an optimum resolution in accordance with the purpose. In the biomechanics applied to sporting techniques, 16 bites seem to be sufficient for a reasonable visualization. It remains to be added that the tele-photo transmission is, currently, a quite simple issue; therefore the biomechanical analysis can be made quasi-instantaneously in laboratories, while images are being recorded in sports fields.

11.4. Interpretation of the results of computerized acquisitions of biomechanical parameters

In a broad sense, computerized acquisitions of biomechanical parameters can be considered *measurements* subject to metrology rules. We remind hereby that any measurement process is subject to aleatory and systematic errors that can be either insignificant or more importantly, they alter the result in an unacceptable manner. Without descending to particulars, the first question that comes to a biomechanics specialist's mind is whether the measured parameter is actually the one wanted. For instance, many installations that pretends to be measuring postural stability, i.e. the mechanogram of the load centre projection, actually measure the variation speed of the load centre movements in the sustention polygon as the accelerometer transducer units and not linear ones. For instance, also, we mention here a frequent confusion regarding the interpretation of mechanical strength in the tense muscle, which is usually seen as a parameter proportional with the amplitude of the global electromyographical signal. It's true that EMG amplitude, as well as the frequency of the spikes or phase changes, is proportional with the mechanical strength but only within very narrow limits, the linear correlation being thus insignificant.

Related to errors, an example of systematic error is the one related to parallax, i.e. the angle under which a planar motion is videotaped. It’s true that such systematic errors can be analytically corrected, most frequently by replacement of the value of cord (the length of the plane in which the motion takes place), with the length of the corresponding arc. It’s true that, more often than not, systematic errors, as are those worked in the inadequate standard, do not change the global interpretation of the motion as regards such motion’s form, but can generate erroneous interpretations when comparisons are made between different recordings.

Contingent errors, or non-systematic, have by definition, a multitude of causes as they are, in their majority, attributable to the operator. There are, probably, as many types of filters and the methods to control such errors - either automatically or determinedly, by the intervention of the operator who is considered, a priori competent and having the necessary statistical skills related to the respective phenomenon. For instance, according to the so called Grubs criterion for the control of aleatory errors, isolated parameters, the magnitude of which is beyond margin set by the arithmetic average plus three standard spreads, should be considered aleatory errors.

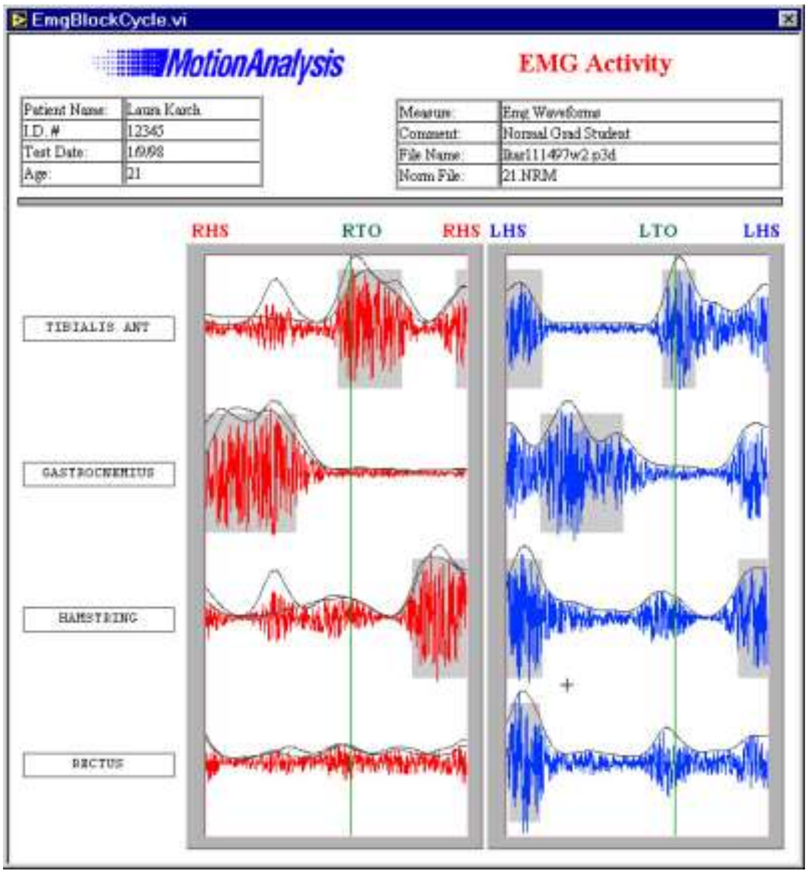


Fig. 11.4. Sample of recording of electrical muscular activity (EMG) for simultaneously analysis of biomechanical parameters. Courtesy of Motion Analysis Corp.

Errors may, sometimes, be apparent or may hide phenomena not yet elucidates, as the ones encountered by the author hereof when interpreting the EMG of the contraction of synergic muscles of an athlete. The spectral analysis of such EMG of the surface showed, in this case, a Gaussian curve with two clog, a fact initially considered as a metrological error. A more attentive circumstantial analysis showed that in fact, the excessive and compensatory specialization of the phase and tonic fibers of the two synergic muscles of the athlete, however well trained, resulted in two Gauss curves to be misphased, the result of it being the appearance of one spectral curve with two clogs.

Interpretation of a scientific acquisition of biomechanical parameters as is the athletic execution technique or movement, as well as that of any other phenomenon, should be both systematic and systemic. The characteristic “scientific” calls for a certain order and clarity of the rationings, but especially for a causal interpretation of the effect.

Aristotelian logic, connecting effect to the cause, seems to be insufficient for a correct interpretation according to the most advanced science, where a process (processor, mechanism etc.) may interpose between the cause and the effect. For instance, even theoretically speaking, the same training made by two different athletes conduces to two different athletic results. The differentiating item, in this case, may be the dissimilar talents of the two athletes, i.e. the individual factor (processor) of effort heterostasy. Under such circumstances, one may say that all biomechanical parameters measured gave a cause, usually the internal forces (muscular contractions), corroborated at least with the gravitational force.

The interpretation of the results of computerized processing of such parameters shall take into consideration the laws of biomechanics; we remind that the law of motion initiation, the law of power conservation and the law of fatiguing efforts. A correct interpretation does not have, however, to consider mechanical conventions in which, for instance, for instance, forces instantly appear and disappear or the mechanical work does not imply movement and causes no fatigue, etc.

We need to highlight again, even if this means to repeat ourselves, that a hypothetical reasoning, i.e. a hypothesis, even if confirmed by an experiment, cannot be turned into a thesis, i.e. a proven fact. Hypotheses are the particular premises in a syllogism. Without the main premise the syllogism does not resist logical reasoning. For a hypothesis to become a thesis it needs to be proven, a fact that is impossible from an experimental point of view. An experiment may only confirm a hypothesis and nothing more. The conclusion of such experiment is t\a confirmed hypothesis (i.e. still a hypothesis), representing, however, a significant progress for science. In other words, validation of a hypothesis needs practice, usually by multiple tests. To be able to prove something in an experiment, we should logically start form the major premise according to which the sample under research is indubitably representative for the population to which we refer. The reason for the experiment is that we do not know from the beginning, that we only intuit that the sample belongs to the statistical population.

One other thing is to be added i.e. the fact that optimizing of the biomechanical motion does not always mean the optimization of the athletic execution. For instance, the maximum speed of the tennis ball served is obtained when service is made with the arm outstretched and the racket collinear with it. Only, as practice shows, the majority of the well known tennis players serve with their flexed, probably to hide the direction in which the ball is to be sent and to surprise the adversary. The same is true regarding blocking in volleyball, when the flexing of the knees, although helpful to the height of the jump, is also hidden and reduced, again in order to surprise the adversary. It is understandable that in certain sports, as gymnastics, the optimization criterion is the aesthetic one, which, more often than not, is in contradiction to the biomechanical one.

XII. THE BIOMECHANICAL SYNTHESIS OF THE MOVEMENT

12.1. Synthesis as a Progressive Instrument

As a rational method, synthesis creates parts and turns them into wholes. Synthesis creates or invents, then it establishes and sometimes it criticizes. Although it looks like an opposite operation to analysis, it is not so; it is placed in quadrature with the latter. We want to say that synthesis not opposed to the difference, but to the *lack of similitude*, which is a completely different thing. Or, a thing or a phenomenon can be at the same time different from another, an also alike the latter. That is why, in the practice of research, generally in other sciences than philosophy, analysis and synthesis cannot be separated unless in an artificial way. All the synthetic approaches have an analytic part, and the other way around.

The synthesis of movement in biomechanics starts from a huge amount of knowledge already accumulated on the structures of movement, regardless the type of movement: natural movement – walking, running, jumping, etc. - or sportive technique, such as javelin throwing, blocking in volley-ball, free kick in football, etc. That is why synthesis seems to be more difficult than analysis, having something new and in the same time progressive to add at the general know-how.

For example, the ventral style of shot-put was successfully replaced with the O`Brian style, having the impetus is a pirouette. Without any doubt, the pirouette style will be replaced with a synthetic conceived one, having as a starting point the theoretical demands on the most efficient impetus. It is known, for instance, that the throwing distance depends on the speed of launching the weight. How should the acceleration be in the sport technics to make the speed increase more and more? A biomechanics specialist, by definition a physics expert, would probably answer immediately this way:"only an exponential mathematics model has exponential differentials, thus the movement must ensure an exponential increase of the speed".

The synthesis of such a movement is not an easy one, as the restrictive conditions of the cinematic human chain are severe, then the movement space is relatively small, out of athletic regulations considerations. That means that the task of theoretic biomechanics is to find solutions to problems of movement efficiency, and not at all to explain the solutions "found" by experiment, as we regretfully see that happened with the other styles of shot-putting.

12.2. Concepts of the Methods of Segmental Synthesis

The methods of analysis and synthesis of biomechanics are some of the principal beneficiaries of the impressive developments of the automatic techniques of image and computer processing. The analysis or the synthesis of movement by analytic calculations and graphic processing is more and more successfully replaced by animation procedures, by the making of electronic games, by robotics and biomimesis.

The commercial aspects which usually come before the scientific ones, generated hundreds of movement synthesis soft programmers, based on the recording of the segmental movements, marked with sensors or with reflecting signals. All these procedures can be applied in biomechanics for the synthesis or the study of some sportive techniques movements, of the correction of dysfunction's or of the improvement for the social integration of handicapped people.

As the procedures of movement synthesis belong to the practice, and the description of software facilities has not place here, we will refer only to the concepts of the methods of segmental synthesis, in fact to the frame of its problems.

- The frame of the synthesis problems can start from the question: what *kind of a movement is going to be synthesized*? Most of the movements already synthesized refer to the biped locomotion (walking and running) and are treated as oscillations of reverse pendulum, simply or complexly articulated (double, triple articulation, etc.). Other movements can be the acyclic ones: of translation, of rotation or helicoidally ones, possibly combined.
- The next question which delimits the problems refers to the type of optimum (minimum or maximum): of energy of informational entropy, of coordination or of complexity. For example, in the case of the throwing of the javelin it is requested that the speed (and implicitly the power) should be maximum at the moment of the launching, while in the case of the throwing at the basket it is requested that the precision (the informational entropy), generated by the visual coordination and by the tactile sensory, should be adequate at the moment of the launching.
- The delimitation or, in other words, the extension of the problem, refers to the number of masses (weight centers) chosen, to how many segments and articulations we use, and to how many supports we accept in the synthesis of the movement.
- As it is natural, we are supposed to bring into discussion the restrictive conditions of the problem, conditions that are given, usually, by the articulation (mobility) limits, by the relations and the concrete segmental dimensions, by the accelerations, by the

powers and by the limited energies (of talent and of preparation level).

On the other hand, the segments that we refer to are the conventional ones for a model of sportive motility. Such segments are the arm, the forearm, the trunk, the thigh, the shank etc. The articulated silhouettes have, conventionally, some dimensions and some relations that depend on the sex, the age, the somatic typology etc. High-quality software programmers have been created for the study of the articulated movements of the silhouettes, so that synthesis became a routine approach for cartoons of for electronic games, only the creation of the characters executing the respective movements being left to the producer.

Theoretically, the synthesis problems are based on masses concentrated in mass centers (weight), articulated segments and movement equations that have synthesized movements as solutions. The difficulty of solving them is not given by the number of concentrated masses and by the articulated segments, but by the imposed restrictions. The anatomic - functional particularities of the human organism, the articulator limitations, as well as the limited accelerations of the muscular effectors make only a small part of the solutions of the synthesis problems to be acceptable. For example, the man's biped running cannot be done under a very small angle, as it results to be efficient from the calculations, because the flexions of the segments the inferior limbs are limited, and the force of pushing the ground is relatively small, protecting the tendency of losing the equilibrium.

Most of the specialists in biomechanics accept the model of the reverse pendulum for the movement of walking or of the running. Bur it is not the same thing if we analyze the simple reverse pendulum, articulated or double - articulated.

For the high jump, the so called “Sargent jump”, the analytic model can concentrate the whole weight in *ccw;* it can have two locations of concentration of the weight, meaning that the movement of triple extension not only pushes up the weight of the superior part of the body, but also drags after it the weight of the inferior limbs; it can also have a third location, besides the two above, that concentrates separately in the arms a part of the weight, using it as an inertial mass.

Of course that the model with three locations of the weight centers is more complex, less concessive, which makes it more difficult to calculate; but, at the same time, it is more precise, closer to a palpable reality. We want to say that putting the arms up during the impetus, by the inertial moments that are created, contributes considerably to the growth of the amplitude of the jump, a fact that is easy to notice and that was registered since the Antiquity by Aristotle.

12.3. The Synthesis of the Vertical Jumping without Rapid Flexion

In the following, this jump is treated like a four-part extension of three centers of weight (masses): legs, trunk (including head) and arms.

The actions, that are the product of the net forces which achieve the extension and the duration of the impulse, are considered independent for the movement on the distances *x1*, *x2*, *x3* of the weigh centers. The cinematic restrictions refer to the limit of the distances between masses, to the angles between the segments and to the relation between these ones. The solutions of the movement equations are particular to the assumed parameters (masses, segmental dimensions, forces and known moments).

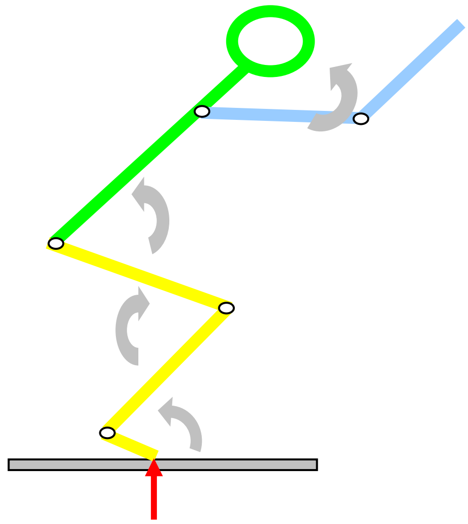


Fig. 12.1. The synthesis of the impetus movement in the high jump using three centers of masses (legs, trunk- including head – and arms) and four extension. Explanations in the text.

They come from the computer-based solution of a system of differential equations elaborated on the principle of the conservation of the movements. As we have already mentioned, the biomechanics specialist is not obliged to elaborate by himself the set of constrictions or the differential equations; the computer does this, but with a serious amendment: the entry error generates exit errors!

In the above picture, the extension of the elbows at the moment of lifting the arms creates an inertial moment which increases the speed of detachment of the articulated system. This way, the vertical jump can be considered a triple extension of a kinematics chain with the restriction of the lifting of the weight centre on the vertical (the paragraph on the cinematic chains in chapter III should be revised).

In the synthesis of the movement, the mechanic model associated to the movement equations is built at the beginning, and the restrictive conditions are set afterwards. The mechanic model consists of three groups of segments (different colors in picture 12.1.), of different masses, of three net forces acting almost independently and of other mechanic characteristic of structure (viscosity and elasticity), plus other geometric parameters. The main restrictive conditions refer to the differences of height between the mass centers, the relations between the body segments and the angles between the segments.

There are also conditions of control of the moving system, which, in this case, are *optimum* conditions. More exactly, how should the moments of the three segmental groups (that constitute the moment of maximum) vary, so that the jump should be as high as possible?

We insist on the fact that this optimum request is the main idea that makes the difference between synthesis and analysis. The request of optimum composes the moment variations, while the finding of the moment variations decomposes the maximum jump.

We come back to the idea according to which the synthesis, and also the analysis of the movements are simple approaches due to computer techniques, and only the setting of conditions and the identification of the optimum are difficult.

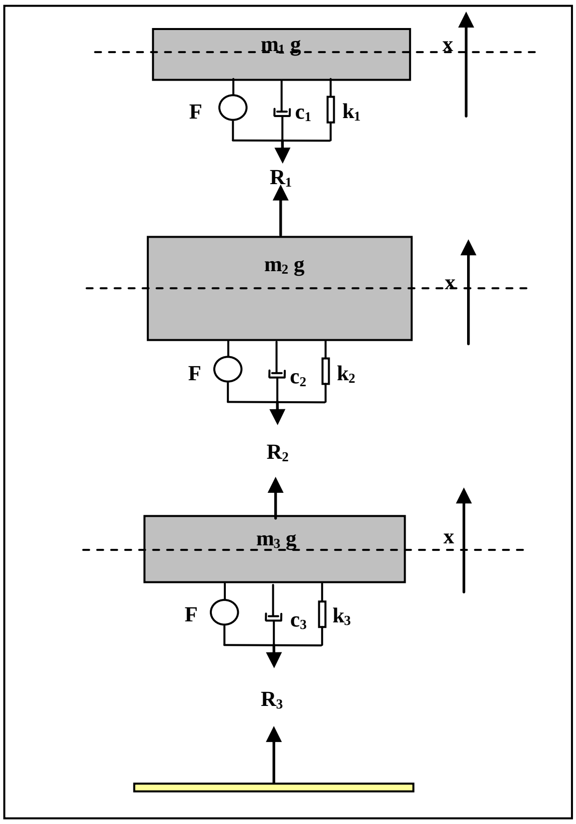


Fig. 12.2. The mechanic model of the impetus in high jump without rapid flexion. Explanations in the text.

The difficulties of the synthesis are important in the implementation of results, when the mechanic model is confronted to the reality (to what can be called the real model).

In the Fig. 12.2., three weight centers of some body segments in the impetus movement of the high jump are represented. Because of the action of grouped forces of the extensor muscles and of the moments created by the latter, these inertial masses move themselves restrictively, accomplishing height variations almost independent. The whole system will be propelled on the vertical because of the reactions of the grond and of the partial reactions.

The solutions offered by the computer are not numbers, but strings of pairs of numbers, that is curve. Each weight centre will rise almost independently on the vertical, which means that these three curves will have different variations during the impetus. In Fig. 12.3. the optional solutions simulated on the computer for the personal data of the restrictive sportsman are presented.

The *x1* curve (colored in red), which represents the weigh centre of the arms, goes down at the beginning of the impetus, and after about 0,5 seconds goes up rapidly, which means that the impetus with the arms should (theoretically) start before the getting up of the trunk, even in accentuated flexion.

This way, the simulation of the impetus movement shows, generally, the optimum way of comparative variation of the three groups of masses of the theoretical model.

It the sportsman followed the dynamics of these motile qualities and would jump as much as he could. In conclusion, the information taken out of the simulation of a synthesized movement, offers to the sportsman and to his coach information on the technique of the movement, in this case of the high jump.

The information is even more precious when the simulation, that is the synthesis, is judged in comparison with a real jump, considered a priori as the maximum, biomechanically analyzed.

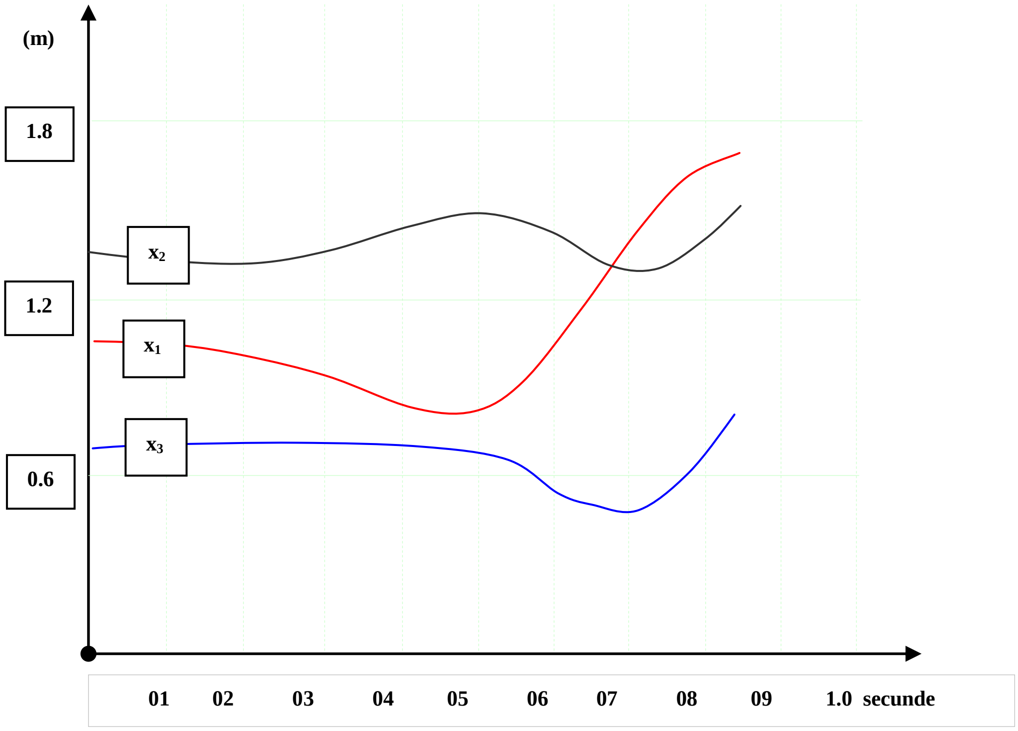


Fig. 12.3. The variation of the relative position of the height of weight centres in the impetus of the high jump, simulated on the computer. Explanations in the text.

The significant differences can be considered either technical errors, or reserves of biomotilic potential. As we believe, it is important that the second part of the synthesis approach, that it's putting into practice, should be adequate.

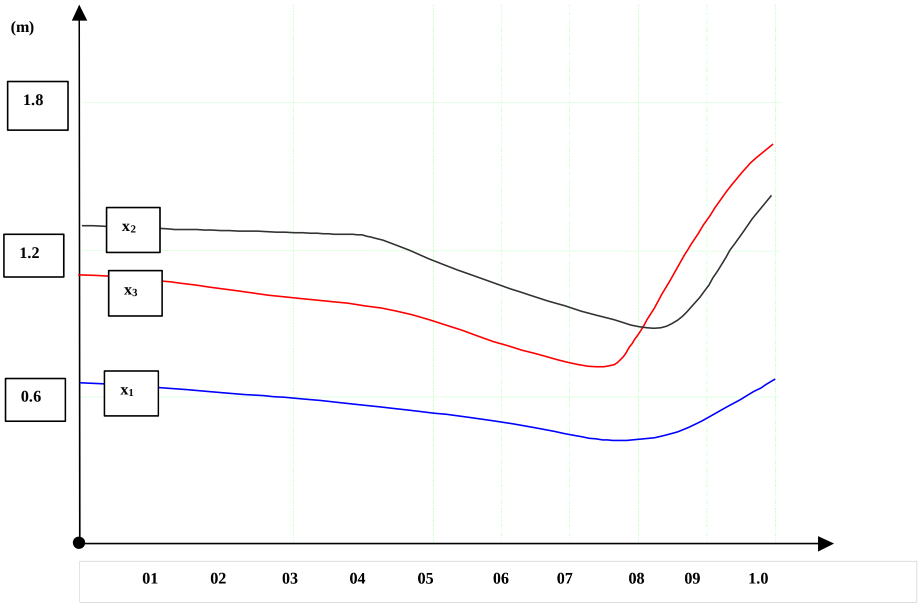


Fig. 12.4. The variation of the height of weight centers in the impetus of the high jump. The experimental data come from the analysis of a jump registered for a sportsman whose biomechanical parameters are known. The same biomechanical parameters were used in the simulation on the computer for the synthesis of the impetus presented in Fig. 9.3.

We don't have to forget that the synthesis is realized on theoretical models that approximate the reality. In the case of the example discussed by us, the approximation of the jump through three groups of masses (weight centers) is reasonable, resulting that the sportsman in this case either lifts his arms too slowly or too late in the extension, or that respectively to his possibilities, still has a significant biological reserve, as it comes out of picture 12.4.

If we take a look and we try to interpret comparatively the two pictures, one representing the synthesis of a fictive jump resulted of computer simulation, the other the analysis of a real jump, we can notice the differences of variation in time (the impetus of the fictive jump is of 0,85 seconds, while the one of the real one is of 0,98 seconds) and also in space (the arms and the trunk in the real jump go up in parallel, while in the simulated impetus, the arms should start the movement much sooner than the lifting of the trunk). Other minute differences can be remarked, probably unimportant ones; but the most important for the concept of synthetic method remains only one thing: the synthesis *creates* wholes by combining the parts, while the analysis discovers parts from wholes. Both the concepts are benefic for science, and, of course, for biomechanics.

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