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REVIEWS

A new approach to the role of antagonist muscle contraction synergism in plyometric training

O nouă abordare a rolului mușchilor antagoniști în sinergismul contracțiilor, din perspectiva antrenamentului pliometric

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Abstract

Plyometric training is a training method dedicated specifically to high performance athletes, involving a general effort of psycho-physical commitment, with explosive movements being executed or repeated at very short time intervals. The main goal of plyometric training, through its systematic organization, is the induction, over time, of structural and functional changes in the muscle groups of interest, with optimizing influences on individual sports performance, especially from a topokinetic perspective.

The primary requirement in plyometric training is that the time parameter between two consecutive executions must be permanently measured and controlled by the coach, with an aim for the involved duration defined as the latency time to achieve an ideal of zero seconds.

The defining feature of this training, given by an extremely short temporal relation between an overcoming movement phase (e.g. upward jump, push, extension) and a yielding movement phase (e.g. damping, flexion), implies that the duration of the two phases is of the order of fractions (tenths or hundredths) of a second. The ideal minimal pursued time is “zero” seconds, the muscle contractions in the two phases usually having the same direction but opposite senses.

Plyometric training does not specifically require the development of muscle mass or volume (muscle hypertrophy), but the development of an extremely powerful and rapid explosive force, generated through the contribution of a minimum body muscle mass and maximum physical and mental commitment from an athlete.

Key words: plyometric training; vectorial magnitudes; muscle synergism; eccentric workout.

Rezumat

Antrenamentul pliometric este o modalitate de pregătire sportivă, dedicată în mod special sportivilor de performanță consacrați, desfășurată cu un efort general de mare angajament psiho-fizic, mișcările explozive fiind executate sau repetate la intervale foarte scurte de timp. Scopul principal al antrenamentului pliometric, prin organizarea lui sistematică, este producerea, în timp, a unor modificări structurale și funcționale la nivelul grupelor musculare interesate, cu influențe optimizante asupra performanței sportive individuale, mai ales din perspectivă topocinetică.

Cerința primordială în antrenamentul pliometric este aceea că parametrul durată dintre două execuții trebuie măsurat și controlat în permanență de antrenor, durata respectivă, definită ca timp de latență, trebuind să tindă spre un ideal de zero secunde.

Caracteristica definitorie a acestui antrenament, dată de un raport temporal extrem de scurt dintre o fază a mișcării de tip învingere (ex. desprindere, împingere, extensie) și una de tip cedare (ex. amortizare, flexie), presupune ca durata dintre cele două faze să fie la nivel de fracțiuni de secundă (zecimi sau sutimi). Idealul temporal minim urmărit este „zero” secunde, contracțiile musculare din cele două faze având, de obicei, aceeași direcție, dar sensuri opuse.

Antrenamentul pliometric nu urmărește, în mod expres, dezvoltarea masei sau a volumului muscular (hipertrofia musculară), ci dezvoltarea unei forțe explozive, extrem de puternice și rapide, realizată prin contribuția unui minimum de masă musculară corporală și a unui maximum de angrenare fizică și psihică, din partea unui sportiv.

Cuvinte cheie: antrenament pliometric; mărimi vectoriale; sinergism muscular; lucru excentric.

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Theoretical background

As it is known, *plyometric training* (PT) is a training method dedicated specifically to high performance athletes, which involves a general effort of psycho-physical commitment, with explosive movements being executed or repeated at very short time intervals. The main goal of *plyometric training,* through its systematic organization, is the induction, over time, of structural and functional changes in the muscle groups of interest, with optimizing influences on individual sports performance (Chu, 2016), especially from a topokinetic perspective (Neagu, 2010). It is mainly recommended in explosive force and speed sports (e.g. athletics – jumping and sprint).

The fundamental characteristic that defines *plyometric training* is the *extremely short duration*:

a) between *two extremely rapid and strong consecutive explosive executions*;

b) between *two phases* of a particular exercise, i.e. *the overcoming phase and the yielding phase*, and /or vice versa.

The primary requirement in *plyometric training* is that the *time* parameter between two consecutive executions must be permanently measured and controlled by the coach, the involved *duration* defined as the *latency time* having to aim for an ideal of *zero* seconds. Manual or electronic timing is an omnipresent prerequisite for the conduction of the plyometric training process.

Another important characteristic of executions in *plyometric training* is given by *extremely strong and rapid muscle contractions,* defined by us as *ballistic executions*, in the context of an athlete's jumping and take-off, during the specific physical training process.We took the concept of *ballistics* from mechanical physics, because we found similarities in the mechano-kinetic analysis of explosive movements in sports to the analysis of the two phases or components of the ballistics of objects moving at an extremely high speed, i.e. the analysis of internal phenomena – *internal ballistics* – and external phenomena – *external ballistics*, which generate and influence the trajectory of a bullet, shell or rocket (the field of ballistics), compared to the bio-mechano-kinetic analysis of body segments involved in explosive actions during jumping, take-off. Hence the name given to *plyometric training*: *jumping training*. The same ballistic situation is found in the case of throws in different sports such as javelin throw, discus throw, weight throw, baseball throw, etc.

A series of *physical magnitudes*, with important applicability to *plyometric training,* are *vectorial magnitudes* (Jalbă & Stănășilă, 2015), graphically represented by *vectors* $\left|\rightarrow\right|$, of which the most frequently used are: force $\left|\vec{F}\right|$, velocity $\left|\vec{V}\right|$ and acceleration $\left|\vec{a}\right|$. For example, the *force vector* $\left|\vec{F}\right|$ has the following components (Fig. 1):

a) the point of application or *the origin* = the point where the *force* acts*;*

b) the force module $\left|A\right|$ = the nominal value of *force*, expressed in newtons (*N*);

c) direction = the straight line on which the force acts (or a straight line parallel to it);

d) sense = in which the *force* acts, along the *straight line-direction*.

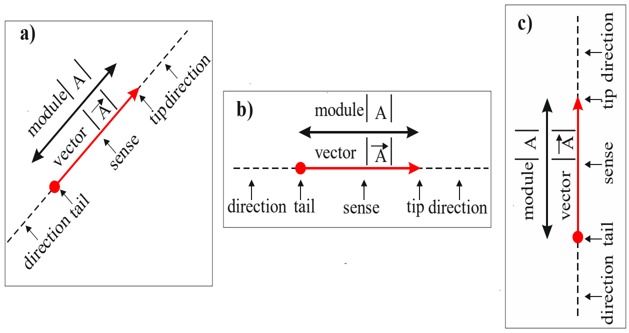

Fig. 1 – The relationship between vectorial magnitudes involved in overcoming-yielding movements. Three situations in which the movements have: a) oblique; b) horizontal; c) vertical directions

It should be mentioned that the most common *overcoming-yielding* movements in plyometric training are movements in vertical and oblique direction. These movements, termed by us *biphasic* (phase 1 – overcoming / phase 2 – yielding) and analyzed from a plyometric perspective, are unidirectional, but oriented in two opposite senses. In the context of module $\left|A\right|$, in addition to the *initial vector* $\left|\vec{A}\right|$ (generated in our case by *overcoming* muscle contractions), there is another component, the *opposite vector* $\left|\overrightarrow{-A}\right|$ (generated by *yielding* muscle contractions), which has the same *module* $\left|A\right|$ and the same *direction*, but its sense of movement is opposite to that of the first (Fig. 2, a).

When the nominal values of the vectors $\left|\vec{A}\right|$ (*initial vector*) and $\left|\overrightarrow{-A}\right|$ (*opposite vector*) are equal $\left|\vec{A}\right| = \left|\overrightarrow{-A}\right|$, a *parallel translation* finally occurs, which generates a vector $\left|\vec{B}\right|$ equal to the initial vector (Fig. 2, b).

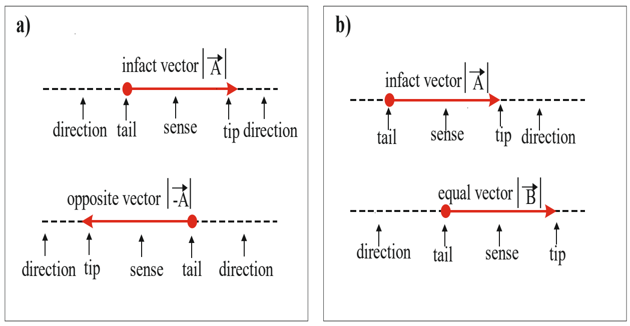

Fig. 2 – The relationship between vectorial magnitudes involved in overcoming-yielding movements. a) The situation in which movements generate the opposite vector; b) The situation in which, following parallel translation, a vector equal to the initial one is generated

Only such an analysis, based on *physical vectorial magnitudes* involved in *biphasic overcoming-yielding movements* in sport, will allow understanding the internal mechanisms that generate the *force vectors* and thus, will enable us to act effectively on the plyometric construct of maximum explosive force training, with special individual sports performance results.

The characteristics of this type of training include the *biunivocal relationship* between the *maximum explosive force* and the *minimum duration of execution*, i.e. *the speed and* *strength* of contractions of the involved muscle groups (both of which are physical magnitudes, with high values) and the extremely short duration of the *latency time* (LT) between two consecutive contractions, which most frequently generate *unidirectional movements* but act, as mentioned before, in opposite senses: *overcoming* ↔ *yielding*.

In sports practice, this motor sequence – the overcoming-yielding bio-mechano-kinetic (BMC) couple is not of particular interest if considered in isolation. The major interest, as a fundamental goal in plyometric training, resides in the extremely rapid transition from the yielding phase to a new overcoming phase. This aspect becomes essential in structuring plyometric exercises with effects on the pursued performance objectives.

If, during the succession of several motor actions (cyclic or acyclic), an extremely rapid shift from one phase to another or from one couple BMC1 to another, BMC2, is not pursued, the main objective of the plyometric training concept will not be achieved (Fig. 3).

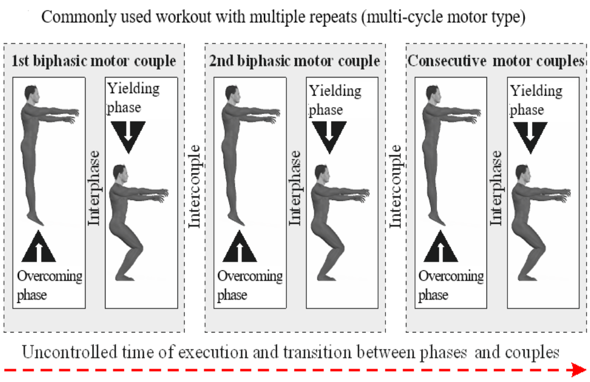

Fig. 3 – Uncontrolled time transition between two consecutive phases

This is a key element in the design and implementation of plyometric training in sports practice, which involves continuous instrumental monitoring of execution times as well as latency times (Fig. 4).

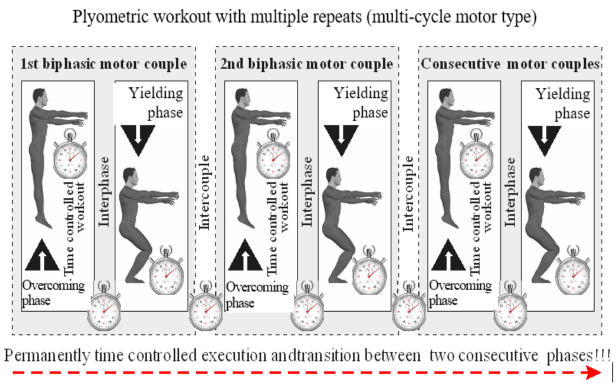

Fig. 4 –Time control execution and transition between two consecutive phases

This methodological requirement is maintained in the case of plyometric training with bars, dumbbells, sandbags or weights, elastic bands or other objects. The opposing internal forces (e.g. body weight) are complemented with resistance generated by the additional nominal weight of the objects used (e.g. weight bars or free weights, medicinal balls, etc.) or by resistive forces (e.g. elastic bands). To all these opposing elements, gravitational acceleration, omnipresent in any motor environment, is added.

This real biphasic motor repetition, yielding-overcoming or overcoming-yielding, which must tend towards zero seconds between the two phases, represents the fundamental objective of plyometric training in sports in which maximum explosive force MEF (take-off) is the predominant objective to develop the motor skill concerned and is determinant in obtaining exceptional performance in a particular sport.

In the literature, *plyometric training* is also known as *stretch-shortening cycle exercise training* (Faigenbaum, 2011; Ryoichi et al., 2016; Guex et al., 2016). In fact, this involves a short series of extremely rapid and strong successive muscle contractions (with more or fewer repeats), all of them *eccentric*, performed as single executions or series (cycles) of executions, ending with an equally rapid and strong *concentric muscle contraction* (Bullimore et al., 2007; Kosterina et al., 2008; McDaniel et al., 2010; Cadore et al., 2014; Franchi et al., 2017).

This *bio-mechano-kinetic pattern* or *couple* (BMCC), produced by *two antiparallel forces* of opposite sense and possibly, of equal intensities, can be just a sequence of several motor actions that repeat in a kinematic chain, characterized by a high *execution speed*, *maximum explosive force*, and exceptional *adrenergic engagement*. The resulting force is much greater than that produced in the absence of muscle stretching, *eccentric muscle workout* (EMW) (Herzog, 2014; Walcott & Herzog, 2008; Baroni et al., 2015; Coratella & Schena, 2016; Douglas et al., 2016), which precedes muscle shortening, through *concentric muscle workout* (CMW) (Fig. 5, Fig. 6).

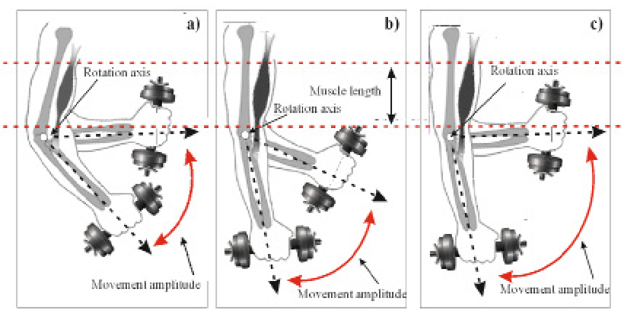

Fig. 5 – Eccentric workout procedure – three situations.

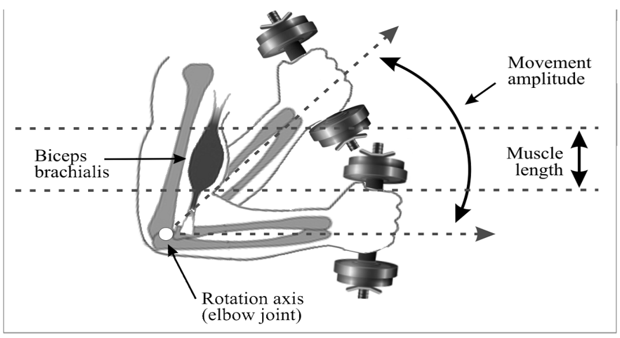

Fig. 6 – Concentric workout procedure

Referring to plyometric training, Zatsiorski stated as early as the seventh decade of the 20th century that the force produced by plyometric work is about 1.5 times higher than that produced by isometric work (Zatsiorski, 1966).

In a book on plyometric training for the development of maximum force, Gill Cometti maintained that plyometric muscle work is more important than isometric muscle work (Cometti & Cometti, 2012). In order to differentiate plyometric training from other muscle work modalities, Gille Cometti describes plyometric muscle action as occurring when a muscle in tension is first subjected to lengthening (eccentric phase) and subsequently contracts, undergoing shortening (concentric phase).

Eccentric workout (EW) is defined as considerable internal tensioning of a muscle, through voluntary contractions, with the muscle in a lengthened position, having a significantly elongated length of constituent fibers (Fig. 7).

In contrast, *concentric workout* (CW) is defined as considerable internal tensioning of a muscle, through voluntary contractions, with the muscle in a shortened position, having a length of constituent fibers below their length limit at rest.

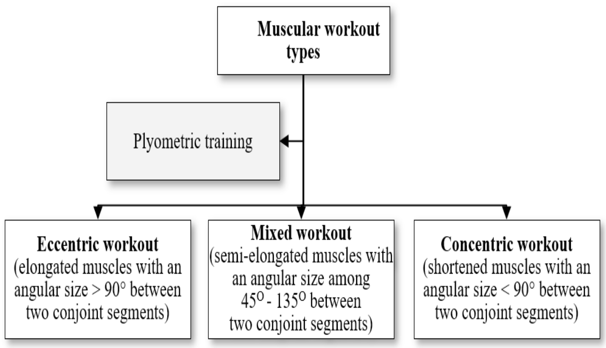

Fig. 7 – Muscle workout types in plyometric training

At the same time, in such a situation, this succession should meet at least three conditions in order to fit into the plyometric training pattern (Fig. 8).

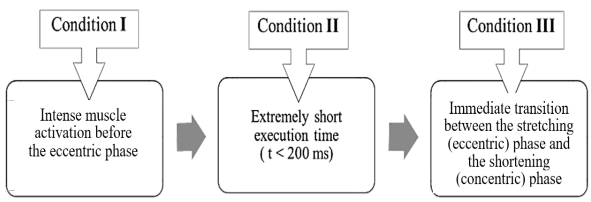

Fig. 8 – The three conditions for the succession of phases of a plyometric muscle action (Cometti, 2004)

The mechanical couple of antiparallel forces, resulting from a stretch-shortening muscle activity or, in other words, the eccentric-concentric action essentially underlies the development of the *plyometric training* concept. A sometimes overlooked particularity of plyometric execution is the fact that the involved dynamic forces are minimized or even suppressed at the end of the muscle action (Fig. 9, Fig. 10) (Gambetta, 2001).

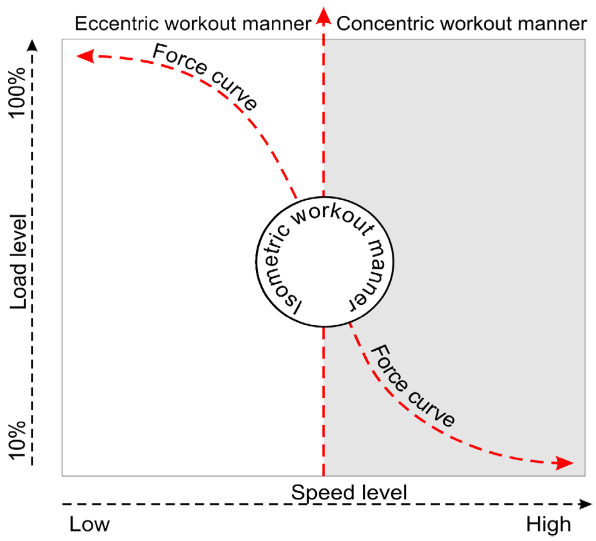

Fig. 9 – Force development in relation to the type of work, load and speed. Adapted from Edgerton's model (Edington & Edgerton, 1976), modified by Miller (Miller, 1997)

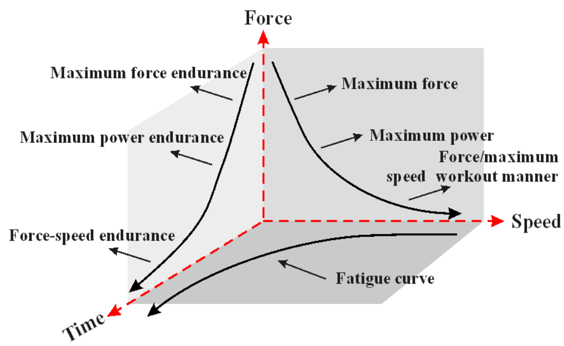

Fig. 10 – The theoretical model used by Edgerton (Edington & Edgerton, 1976)

As mentioned before, the defining feature of plyometric training, given by an extremely short temporal relation between an overcoming movement phase (e.g. upward jump, push, extension) and a yielding movement phase (e.g. damping, flexion), implies that the duration of the two phases is of the order of fractions (tenths or hundredths) of a second. The *ideal minimal pursued time* is "zero" seconds, the muscle contractions in the two phases usually having the same direction but opposite senses. In the analysis of movements, the chronological order of the two types of contractions can be reversed: overcoming ↔ yielding; yielding ↔ overcoming (Fig. 11).

In the case of exercises performed in the absence of loading (e.g. without weight bars, dumbbells, sandbags, etc.), *the opposing forces* that should be overcome in plyometric training are most frequently:

a) body weight – during take-off and landing, the impact/collision of the person who performs a plyometric exercise with the ground or the equipment used;

b) gravitational acceleration – the force of reaction of the support surface or the training track.

The obstacles to overcome are the sports equipment and devices – on which, over which and from which an athlete performs various jumps or pushes, on both legs or on one leg (the overcoming phase) – followed by landing or impact with the ground, with an extremely short duration (Schmidtbleicher, 1992) - t < 0.25 sec - of that contact (the yielding phase).

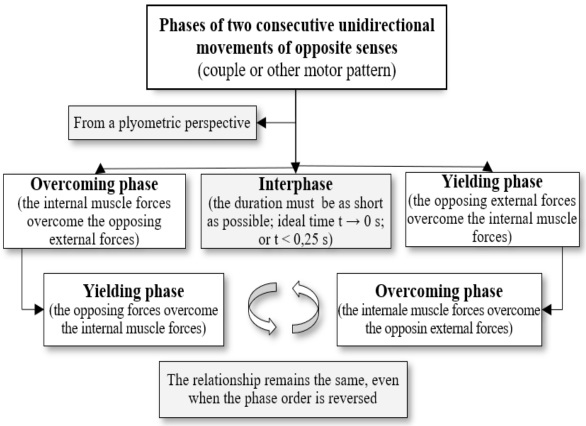

Fig. 11 – Phases of two unidirectional movements of opposite senses, from the perspective of plyometric training

Effects and objectives pursued through plyometric training

Due to the particular aspects presented above, plyometric training does not specifically require the development of muscle mass or volume (muscle hypertrophy), but the development of an extremely powerful and rapid explosive force, generated through the contribution of a minimum body muscle mass and maximum physical and mental commitment from an athlete. This force should be greater than the maximum voluntary force of that athlete. If this requirement is not met, plyometric training does not achieve the fundamental objective for which it was designed.

In chronological order, the manifest effects produced by a plyometric training system can be grouped into three moments (Gambetta, 2006; Gambetta, 2007):

- M1 – during and immediately after a training session, termed *immediate acute effects*
- M2 – after a certain training cycle – stage or period – called *cumulative late effects*
- M3 – effects maintained after the interruption of a training cycle (usually, meso- or macrocycle) – termed *residual effects* (Fig. 12)

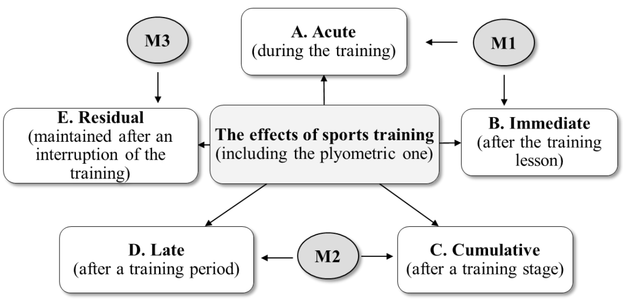

Fig. 12 – The moments and effects of sports training (adapted from Gambetta, 2010).

One of the effects of plyometric training, which is not treated from a temporal point of view, is *collision impact control* (CIC), achieved by athletes on the body and body segments of interest during plyometric exercises. Also, muscle stretching followed by muscle contraction – if correctly performed – leads to a significant increase in *dynamic forces* produced by muscles, determining the development of the vertical or oblique upward movement capacity and, extremely importantly, to a *reduction of the action of impact forces* (RAIF), which have negative effects on the joints (particularly the knee and ankle joints), as well as on the bones involved (e.g. the tibia and fibula), at the time of the contact with the track surface. The increased incidence of chronic tibial periostitis (e.g. in triple jumpers) is an example and an undesired consequence of disregarding the principles and methodological requirements of sports training in general and plyometric training in particular.

Awareness of the execution of take-off, by jumping or bouncing, takes place in a setting that is permanently controlled by the athlete – motor control and progressive interrogation (Proteau, 1992) – which will subsequently allow the athlete to automatize that execution at maximum explosive force parameters and to focus on the execution technique of muscles initiating the movement concerned (e.g. agonists and synergists), as well as on the correlation of their action with that of partner muscles (e.g. antagonists), which become *cooperating* muscles helping the execution of agonists, and not necessarily *opposing* the action of agonists (Fig. 13, Fig. 14).

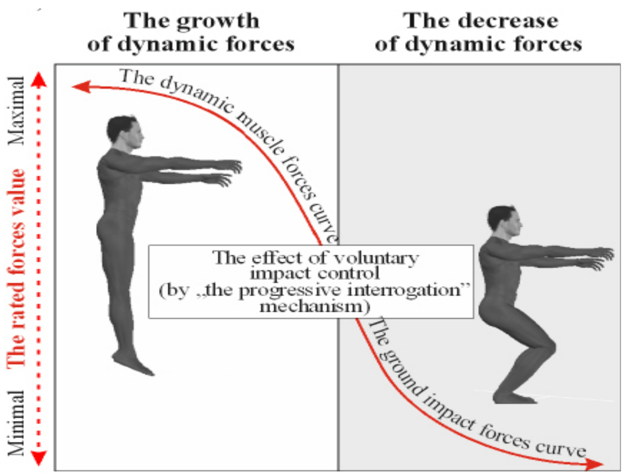

Fig. 13 – Effects of voluntary impact control by the athlete, based on the progressive interrogation mechanism

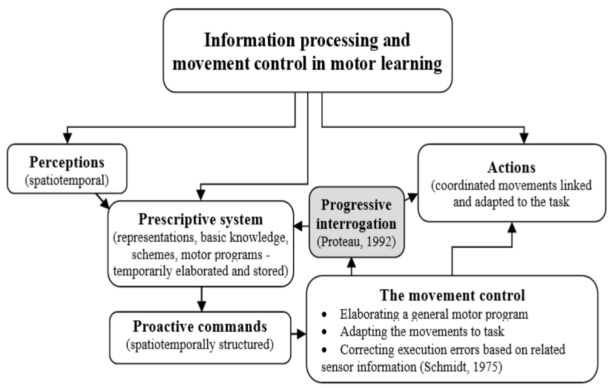

Fig. 14 – Information processing and movement control in motor learning

This effect, termed by us *mutual reinforcement* (Neagu, 2010), is particularly beneficial, especially in sports where jumping plays an important role, such as athletics, basketball, volleyball, artistic gymnastics, aerobic gymnastics, figure skating, etc. – where the lower body is involved, or in martial arts, throwing in athletics or sports games, tennis, baseball, rounders, boxing, etc. – where the upper body is involved (Fig. 15).

Plyometric training enables athletes to enhance the power of the muscles concerned (strength-speed), even at a maximum or extremely high execution speed, in which situation it is known that the "power" parameter is not at its maximum level in conventional sports training.

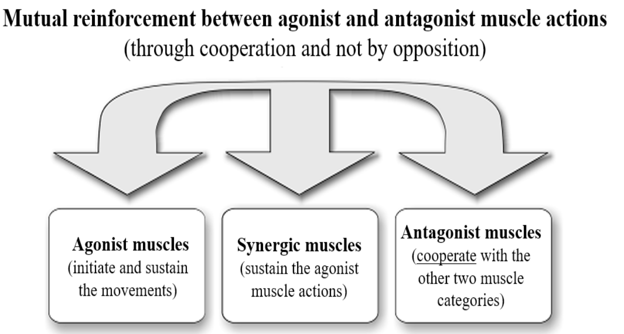

Fig. 15 – Mutual reinforcement between the three categories of cooperating muscle groups in a plyometric exercise, including antagonist muscles

It is possible that during the extremely rapid execution of a movement, the high execution speed – i.e. the muscle contraction speed – may not be accompanied by adequate power that equally manifests at maximum parameters. Hence the concept of *plyometric movement*, which is less used by Romanian trainers.

Muscle synergism in plyometric training

Any theoretical approach to muscle contractions and the actions of muscles participating in various movements discusses three basic concepts: *agonist muscles, synergistic muscles and antagonist muscles* (Fig. 16, Fig. 17).

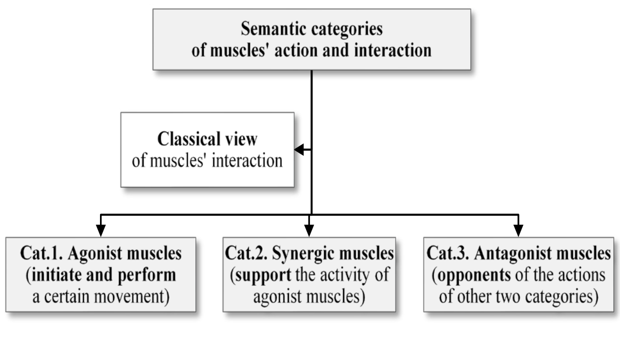

Fig. 16 – Semantic categories of muscle action and interaction, according to the classical approach

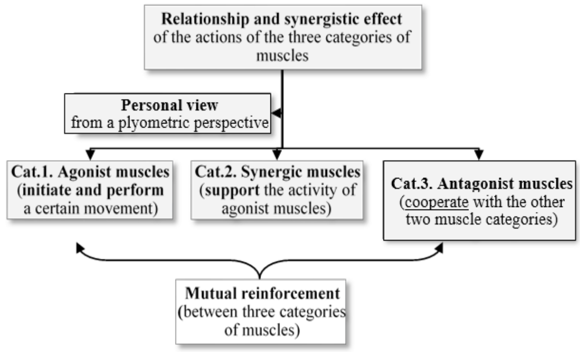

Fig. 17 – Relationship and synergistic effect of the three categories of muscles, from a plyometric perspective

In the plyometric approach, as shown by the comparison of the two figures above, antagonist muscles are not seen as *opposing muscles*, but as *buffer muscles,* which through their action become *muscles cooperating* with the other categories involved in a particular movement. Thus, a *mutual reinforcement* relationship forms between the three categories of muscles, with beneficial effects on the explosive force developed by these.

A frequently neglected aspect is the lack of knowledge or awareness or the extremely limited use of two other concepts that we wish to introduce in the terminology of plyometric training. These are *proximal muscle synergism* and *distal muscle synergism*, in the analysis and execution of movements, from the perspective of plyometric training.

When referring to the *proximal synergism* of muscles participating in a certain movement, the usual semantic interpretation, known by specialists in this area, is that of the action of *synergistic muscles*, adjacent to *agonist muscles*, which initiate and execute a movement that is immediately supported by the action of *synergistic muscles*.

In about 25 years of career as an athletics coach and professor, we observed that the concept – here defined by us as *distal synergism* – was rarely analyzed in detail as potentiating the execution of agonist and synergistic muscles. In other words, only *combined work* or *arm-leg coordination* – termed *opposite arm-leg work*, during running, or *arm work* during run-up before take-off or during flight and landing, in jumping, was and is discussed (Fig. 18).

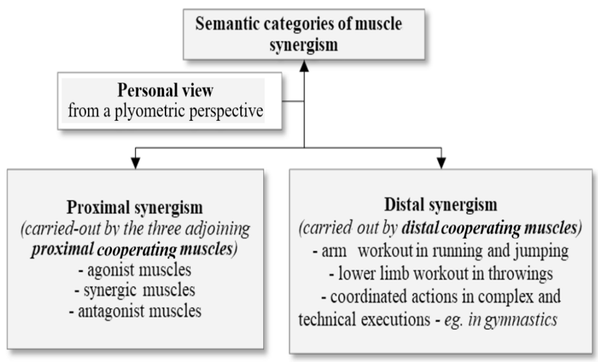

Fig. 18 – Semantic categories of muscle synergism, from a plyometric perspective

Conclusions

1. The major interest, as a fundamental goal of plyometric training, resides in the extremely rapid transition from the yielding phase to a new overcoming phase. This aspect becomes essential for structuring plyometric exercises with effects on the pursued performance objectives.

2. This is a key element in the design and implementation of plyometric training in sports practice, which involves continuous instrumental monitoring of execution times as well as latency times.

3. Plyometric training enables athletes to enhance the power of the muscles concerned (strength-speed), even at a maximum or extremely high execution speed, in which situation it is known that the "power" parameter is not at its maximum level in conventional sports training.

4. A frequently neglected aspect is the lack of knowledge or awareness or the extremely limited use of two other concepts that we wish to introduce in the terminology of plyometric training. These are proximal muscle synergism and distal muscle synergism, in the analysis and execution of movements, from the perspective of plyometric training.

Conflicts of interest

Nothing to declare.

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