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Plyometrics: past and present

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Translated by Alessandra Lombardi

The past...

The term «plyometric» first appeared in the literature of sports methodology in 1966, in V.M. Zaciorskij's work, «Fiziceskie kacestva sportsmena» (10). It is derived from two etymons «πλειωυ» and «μετρον», meaning respectively «greater, longer, wider» and «to measure, to appraise, to compare».

Zaciorskij used this term to indicate the greater tension expressed by a group of muscles when the working programme involves a quick stretching phase followed by an equally quick contraction.

With this procedure, the tension expressed by the working muscles, measured (metron) externally, is higher (plio) than the tension expressed using any other procedure (isometric, isotonic, auxotonic).

Zaciorskij studied human motor activity with a view to conditioning it. He therefore developed a classification, based on quantitative parameters, so as to be able to measure motor performance. The categories were denominated: «strength, speed, endurance, flexibility and skill»: apart from the last, they all allow a sufficiently objective measurement so that they were easily accepted in training methodology as indicators of the state achieved in motor conditioning. Although Zaciorskij's work contains a lengthy treatise on strength, speed, endurance and flex-

ibility, it does not analyze skill with similar thoroughness.

A quantitative interpretation of this last category is indeed difficult in that it can be accomplished only through the adoption of reference models which are not as easily standardized as those of the other categories[1] and therefore, tend to be arbitrary. At the time when Zaciorskij's work was published, however, sports training methodology was in great need of indications based on practical, easy to evaluate, parameters and so this inconsistency was overlooked and the work was accepted without criticism. The influence of this exclusively quantitative approach to motor performance evaluation went even beyond the world of sports. No one took time to think that the expression of each one of these so called physical «qualities»[2] involves a certain amount of skill, in other words coordination, so that without a qualitative analysis even the evaluation of the strength, speed, endurance or flexibility of a given movement, becomes extremely arbitrary.

However, in a very short time, such strictly quantitative categories were accepted and it was commonly thought that they perfectly described motor performances in the context of sports and in particular sports training, so that a large section of the sports literature of the 1970s deals with various methods for their development.

In particular, the physiological bases, assumed in Zaciorskij's work to support the adoption of the category «muscular strength» as the reference point for motor activity and for the plyometric expression of motor activity, are connected to the research carried out in Milan by Prof. Rodolfo Margaria's team on the physiology of muscular work. Margaria continued on the course outlined by Prof. Hill, his former teacher, trying to establish an adequate mechanical model of muscular work «in vivo» considering a whole muscular group as an isotropic system governed by the laws of mechanics; Hill had achieved such a model working in a laboratory on the isolated muscle.

During the 1960s, Margaria's school published a great number of highly interesting studies on human movement (5, 6), which culminated in a brilliant forecast of the best method to organize human movements on the surface of the moon; these were adopted by NASA at the time of man's first landing on the moon, in 1969.

All these studies were aimed at establishing the length-tension diagram of the working muscle; they brought such vast developments in the knowledge of the mechanics of muscular movement «in vivo»[3] that Prof. Margaria was able to come to the following conclusion:

«These experiments also allowed the construction of the length-tension diagram of a pre-stretched muscle and of a muscle that had not been pre-stretched. We observed what I consider

1 The parameters used in physics i.e. mass, time, space, were applied here.

2 The contradiction is apparent even in the title of Zaciorskij's work where he writes «physical qualities» instead of «physical quantities».

3 In 1964, a work by Th. Hettinger, «Isometrisches Muskeltraining», was published. It praised the isometric modality of muscular contraction as the best method for muscular conditioning, and had a great influence on the world of sports training, although it was clearly focussed on rehabilitation and this should have suggested greater caution.

an extremely important fact: the traditional, static, length-tension diagram is based on data obtained from isometric contractions of the muscle, starting from the muscle's length at rest. This diagram is not significant because it does not take into account the muscle's previous activity which influences in many ways the tension that a muscle is capable of developing at a specific length. In other words, a muscle's initial length is not the only factor that determines the tension it is capable of developing; the tension also depends on the muscle's previous activity. In the past, it was accepted that the area subtending the length-tension curve of a muscle, indicated that muscle's maximum working capacity (a - r in Figure A). This concept should also be modified because, on account of the greater tension that a stretched muscle can develop, a muscle's maximum work potential can reach values that are considerably higher than the one indicated by the traditional length-tension diagram, (areas subtending the curves included in the area a[4]): this increase depends basically on the degree and speed of the muscle's stretching.

These concepts are, in my opinion, highly important from a functional point of view: in the past, the widely accepted distinction was between isotonic contractions and isometric contractions, without giving any importance to isotonic contractions of a pre-stretched muscle. The latter is, I be-

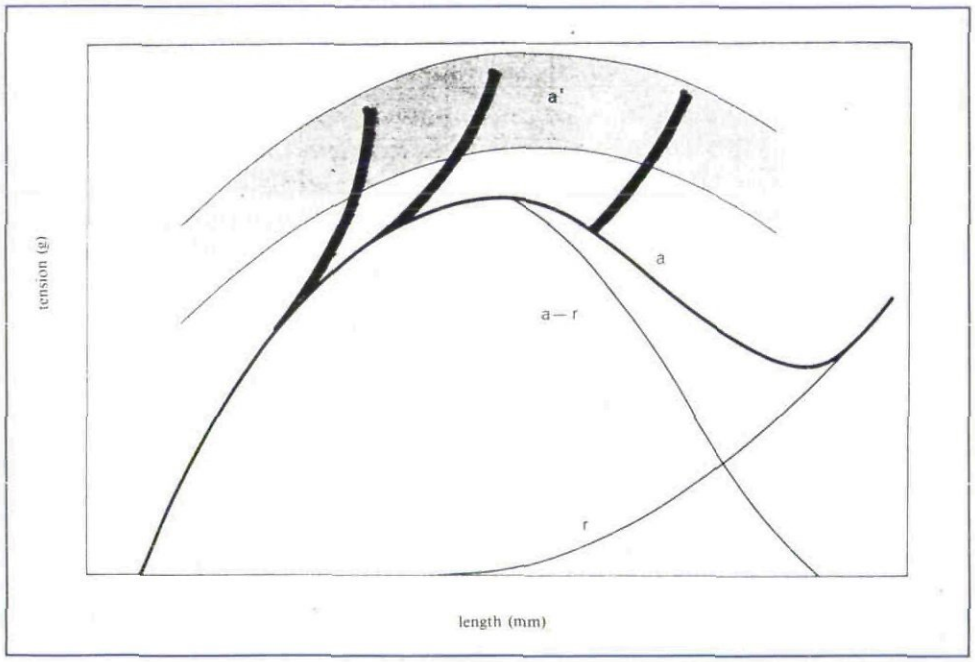


Figure A - Length-tension diagram of a muscle at rest (r) and of a working muscle (a, black line) during an isometric contraction. The curve a-r indicates the muscle's activity. The values of the tension produced by the stretching of the contracted muscle (boldpaced lines) fall approximately in the area a'; they are determined by the initial length of the muscle and by the speed of the stretching. A muscle's maximum work potential is indicated by the area subtending the curve a-r, by the coordinates in the case of a non pre-stretched muscle. *The area is significantly greater in the case of a pre-stretched muscle*

lieve, the most frequent type of muscular activity; it can be observed in running, in jumping, in most sports activities, but also in almost any type of muscular exercise: contractions that are merely isotonic or isometric can be considered an exception...» (7).

In the early sixties, a group of Soviet researchers was asked to elaborate a scientifically acceptable methodology for the development of the motor performances practiced in sports, since sport was increasingly becoming a state concern.

Zaciorskij's work, published in 1966, represents the first synthesis of a five-year effort, supported by an extensive debate on the magazine «Teorija i Praktika Fiziceskoj Kul' tury».

In the course of this debate, the works of Margaria and his school received such a wide echo that they became the foundation of the sports training theory that was being elaborated in the Soviet Union, especially as regards the part dedicated to the category «muscular strength» and to the various methods for its development.

While Margaria was engaged in the study of muscular contraction «in vivo» and the Soviet sports medicine institutions were working on methodological research, further impluse in the same diretion came from international research. Very briefly, the data collected was sufficient to form a sound basis for the widespread use of plyometrics for the development of muscular strength (9).

The theory of sports training takes into account the neurological implications of muscular pre-stretching (8), and prescribes a very careful dosage of the intensity and the volume of plyometric exercises and of the rest periods, according to a methodological differentiation based on the characteristics of each sports discipline (9).

Towards the mid-seventies, the interest surrounding this type of exercise was so widespread that it went beyond the context of sports training. Important biological research centres were involved in an effort to achieve a better understanding of the various aspects connected to plyometric exercises. Particularly important were the Scandinavian school and even more so the centre of biological research adressed to physical education at Jyväskylä, in Finland, where the research and publications of Prof. Carmelo Bosco, helped to combine the findings of scientific research on physiology and the practical methodology of strength training in sports (1, 2).

... and the present

At this point, a premise is necessary before examining the physiological and methodological aspects of plyometrics as a method for the development of specific strength in sports.

Physiological research on muscular activity in the context of sports is, nowadays, focused on the influence of pharmacological bio-kinetics on the external expression of muscular tension. Even though pharmacological applications practiced in the context of sports are illegal, they stress the inadequacy of the categories used in the 1970s to describe motor performances, particularly as regards the so-called muscular strength[4]. What was defined

4 In those years, various sub-categories of muscular strength were introduced, each having a particular development method, so that sports training became nearly undecipherable. We now have tonic strength, explosive strength, ballistic strength, initial strength etc. (9).

as muscular strength is in fact the response to an external stimulus, but the connection external resistance → tension expressed is hormone-dependent. This is why the line of research undertaken in the 1970s — aimed at finding the form of external resistance that would produce the desired muscular strength (9) — is no longer pursued.

Nowadays, the soundness of strength training is assessed on the basis of the lesser or greater influence it has on the hormone adaptation of the athlete concerned and, usually, only the plyometric method is used, with slight alterations, when required. An example will help illustrate this statement. Exercises with loads are a normal practice in strength training. In the 1970s various technical devices were investigated in order to manipulate the external resistance so that the type of muscular tension produced could be isometric, isometric with a sudden release of the load, ballistic etc. Today, the plyometric method (including traditional exercises with a bar) is widely used either on its own or, illegally, in combination with the intake of doping substances.

The use of illegal doping substances implies significant variations in the methodology of training and also hinders the circulation of information concerning training.

In fact, the present situation is such that the cultural debate in progress in specialist magazines and during seminars is becoming increasingly disconnected from what is the real practice in sports training. It has been observed that the progressive introduction of pharmacological support, although absolutely illegal, produces a surprisingly swift and significant enhancement of the sports performance. The consequence is that the specialist literature is now full of works describing training procedures, alledgedly responsible for such results, without of course mentioning the illegal substance used.

The result is a widespread diffidence towards official information so that more and more coaches are now turning to clandestine sources of information, with all the risks that such behaviour involves[5].

This observation certainly applies to the use of plyometrics in sports training as it is described in the more recent specialist literature and the following clarification seems timely:

1. Plyometric training in association with illegal pharmacological applications invariably produces a breakdown of the muscle-ligament juncture. In this case the conduct of plyometric exercises must be differentiated regarding duration and quantity, according to the dosage of the pharmacological substance. In any case, the intensity must be drastically reduced at least until the new neuro-muscular growth reaches an adequate functional stability, which can be achieved with appropriate exercises (3);

2. Plyometric training that is not associated with pharmacological applications certainly produces a development of the neuro-muscular function, it follows a cyclic oscillatory trend, within a three-week phase. The intensity of the load (for instance, the height of the drop jumps in the exercises illustrated on pag. 14-15) and the volume (number of repetitions) must be adapted to the

5 At present, the majority of knowledgeable coaches believe that the information on sports training methodology provided by the specialistic literature is not reliable.

progress of the cycle itself (increase for 10 days, decrease for 10 days).

Lastly, the use of plyometrics as a method for the development of a specific function cannot be separated from motor coordination. This is particularly true if plyometric exercises are to be considered within the framework of a classification that is not restricted to the muscular tension expressed by an isolated group of muscles, but is based on the activity of a number of joints (this indeed is the case for the plyometric exercises used in sports training). But this implies a number of difficulties which are well known since Bernstein.

Plyometric exercises are, biologically, very complex and a strictly muscular outlook does not provide a complete analysis.

The neurological implications for the central and peripheral nervous systems are quite significant. This should suggest great caution in the use of plyometric exercises in conditioning programmes for sports disciplines where there are no objective parameters. Even in sports disciplines where such parameters do exist, for instance Athletics, these exercises are not really adequate as tests to establish, empirically, the increase of an athlete's conditional state.

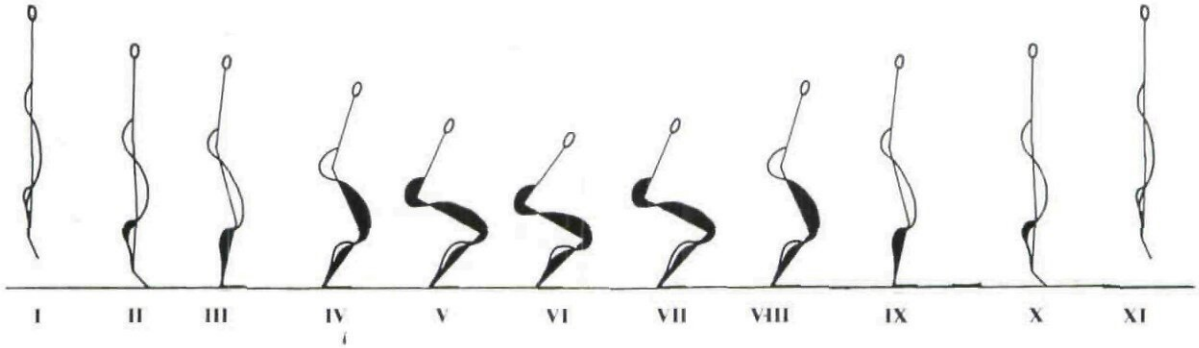
In conclusion, plyometric exercises have a great physiological efficiency; this is why they have played and continue to play a fundamental role in sports training.

Although lack of experience in the conduct and dosage of the exercises has caused a long series of muscle and tendon injuries, plyometrics remain an irreplaceable method for the development of strength. Special caution is advisable when these exercises are associated with substances which may cause an increase of the neuromuscular function.

However, plyometrics cannot be used for an accurate study of motor activities in general, mainly because the categories used as reference points are exclusively quantitative.

I wish to stress that no phyometric motor activity can be taken as a reliable indicator of the specific tonic-elastic capacity of working muscles. In other words, in the evaluation of a plyometric exercise, it is difficult to ascertain how much depends on the muscular capacity and how much depends on the structure of the skeleton, tendons and ligaments.

Examples of plyometric exercises currently used in track and field specific strength training

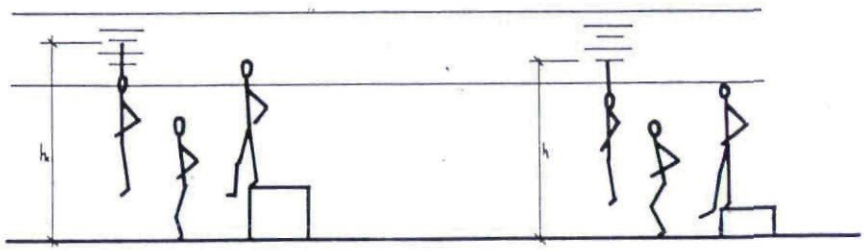


Muscle coordination during a typical plyometric exercise - drop jump with a half squat, followed by a double leg jump

II - contraction and stretching of the gastrocnemius muscle.
III - contraction and stretching of the soleus. The angle at the ankle begins to decrease.
IV - contraction and stretching of the quadriceps. The angle at the knee begins to decrease. There is a further decrease of the angle at the ankle.
V - contraction and stretching of the glutei. The angle at the hips decreases. The angles at the ankle and at the knee continue to decrease.
VI - end of the breaking phase; all the angles stop decreasing.
VII - contraction of the glutei and stretching of the quadriceps. The angle at the hips begins to increase.
VIII - contraction of the quadriceps and stretching of the soleus. The angle at the hips increases and so does the angle at the knee.
IX - contraction of the soleus and stretching of the gastrocnemius. The angles at the hips and at the knee increase further; the one at the ankle begins to increase.
X - contraction of the gastrocnemius. The angle at the hips stops increasing; the angle at the knee continues to increase; the angle at the ankle stops increasing.

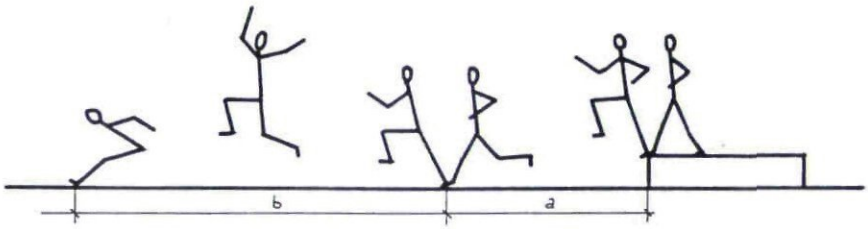
Plyometric exercises used for track events and for jumping events

Fig. 2



$h < h_1$

Fig. 3



$b < b_1$

Fig. 3a

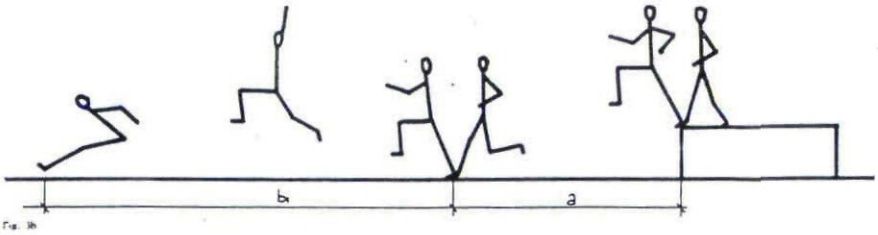


Fig. 3b

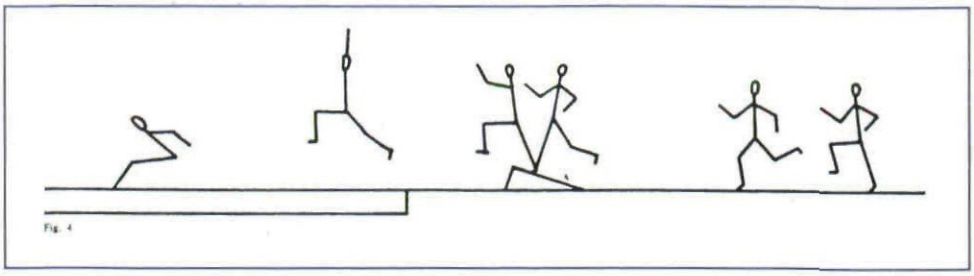


Fig. 4

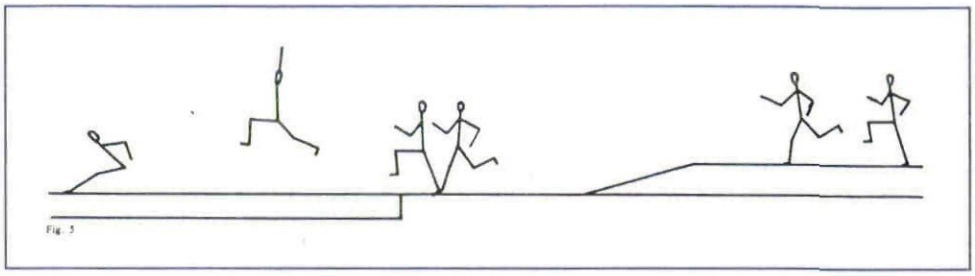


Fig. 5

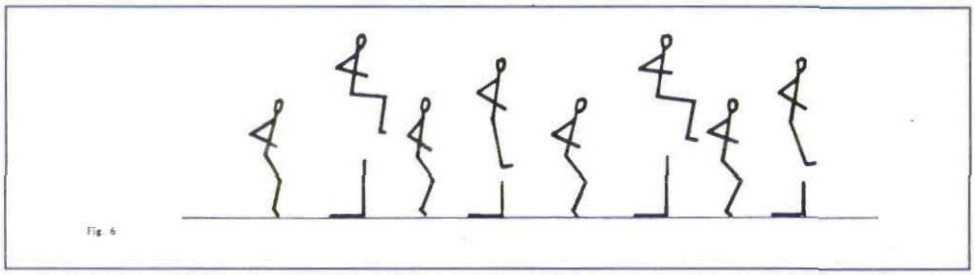


Fig. 6

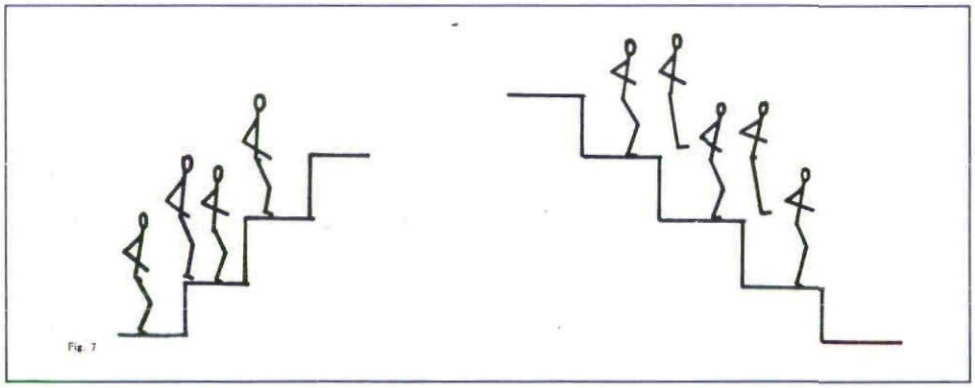
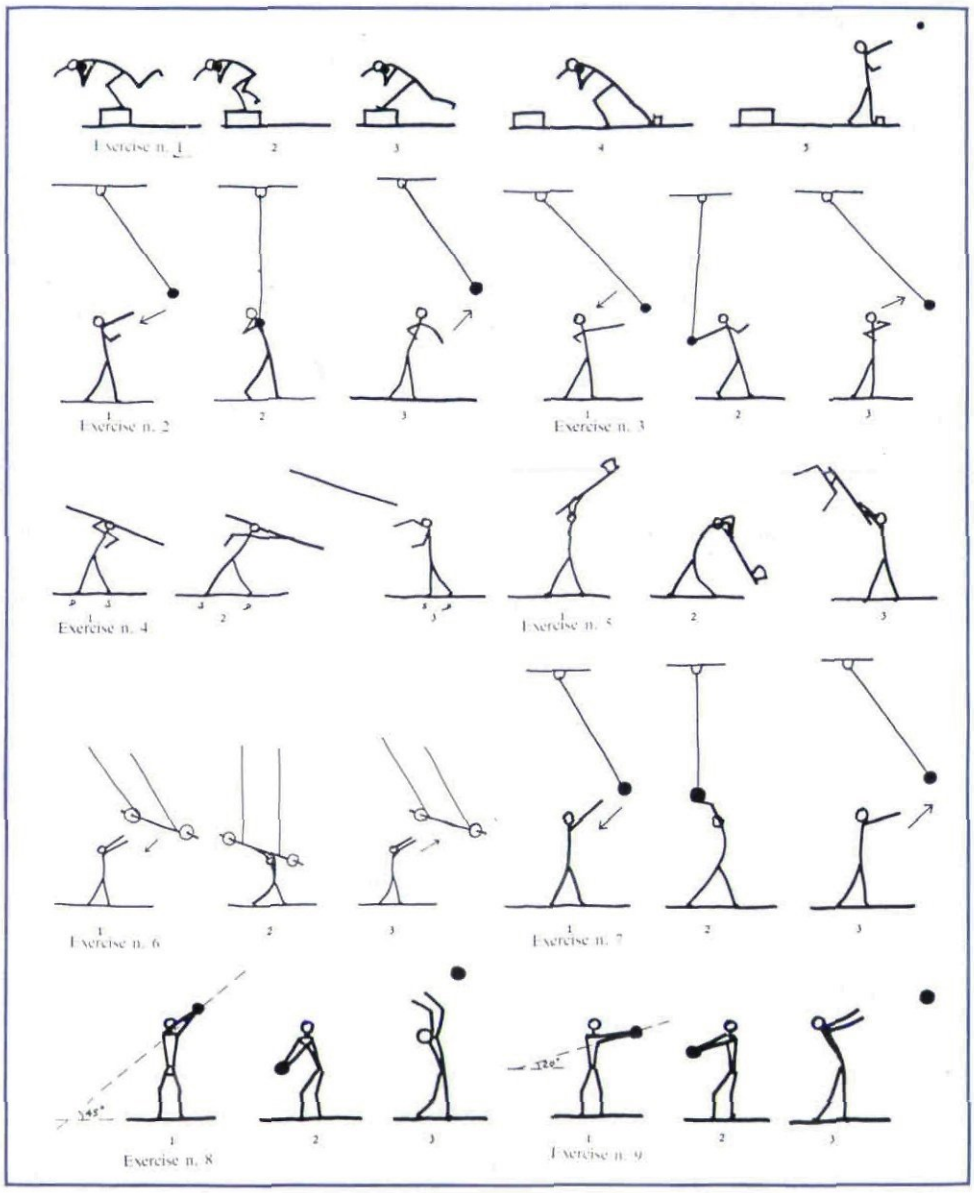


Fig. 7

— bounding run and alternate bounds (fig. 2)
— drop jumps from the optimum height (fig. 3, 3a, 3b)
— exercises increasing the difficulty of specific movements
— platforms and boards; take-offs after a run-up on a raised platform; etc. (fig. 4 and 5)
— bounds over low hurdles (fig. 6)
— step up and step down (fig. 7).

Plyometric exercises used for throwing events



Exercise n. 1 - Shot Put
Normal throwing action, including the shift, from a fixed block 30 to 40cm high. Specific for the lead leg. The implement should be covered with a soft material to avoid injuries to the neck and the shoulder.

Exercise n. 2 - Shot Put
Pushing action with the throwing arm after buffering a swinging implement, weighing between 10 and 20kg, attached to a stiff bar 5.6m in length.

Exercise n. 3 - Discus Throw
Throw from a stand after buffering a swinging implement, weighing between 8 and 15kg, attached to a stiff bar 5.6m in length.

Exercise n. 4 - Javelin Throw
Normal throwing action witt the implement starting from position 1 (right leg forward for right-handed throwers) and progressing to position 2 stretching the muscles of the chest and the shoulder.

Exercise n. 5 - Javelin Throw
Normal throwing action using an axe; the fall of the implement is buffered posteriorly by arching the back and flexing the elbows.

Exercise n. 6 - Javelin Throw
Two-arm throwing action forward over the head, using a swinging barbell weighing between 20 and 40kg; the kinetic energy is buffered by stretching the muscles of the chest and the triceps. The stiff bars should be at least 5.6m long.

Exercise n. 7 - Javelin Throw
Two-arm throwing action forward over the head, using a swinging implement, weighing between 10 ang 20kg; the kinetic energy is buffered by stretching the muscles of the upper torso, of the shoulders and the triceps. The stiff bars should be at least 5.6m long.

Exercise n. 8 - Hammer Throw
Final phase of the throw, using an implement weighing between 7 and 15kg, after buffering the kinetic energy produced by a counter movement performed with an inclination of 450°.

Exercise n. 9 - Hammer Throw
Final phase of the throw, using an implement weighing between 7 and 15kg, after buffering the kinetic energy produced by a counter movement performed with an inclination of 10°. 20°.

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