STRENGTH TRAINING: STRUCTURE, PRINCIPLES, AND METHODOLOGY

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STRUCTURAL ANALYSIS OF STRENGTH QUALITIES

Maximal Strength

The maximal strength is the highest value of strength produced through maximal voluntary contractions against an insurmountable resistance. Therefore, it will determine performance in events where great resistance has to be overcome, or where great resistance must be controlled such as in the case of hammer throwing. “Controlled” referring to the fact that the muscles are required to remain in a state of isometric contractions. In sports where great acceleration of the body such as in sprinting and in events where the body is propelled from the ground (i.e. jumpers) there is a greater resistance to overcome than in events the like of middle and long distance events which only require to maintain uniform motion.

In the literature, we often see discussion on only two or three dimensions of maximal strength. Most of the time only the isometric and the concentric contractions are identified and analyzed. In some isolated cases, eccentric maximal strength is scrutinized. The concentric maximal strength is measured by the greatest load that can be moved through a range of motion. The eccentric maximal strength refers to the maximal load that can be lowered while the muscle is voluntarily lengthening. The load producing muscle lengthening maximal isometric strength is always greater (10-15%) than dynamic concentric strength, since a maximal force can only intervene if the load (limit load) and the force of contractions equilibrate each other. Concentric maximal strength scores are roughly 10 to 15% inferior to the ones of the isometric maximal strength.

Editor’s Note: Great isometric strength is required in sports where the fixation of pre-determined body position or body parts are needed (i.e. the planch and iron cross in gymnastics, knee flexion in downhill skiing). Great concentric strength is needed In most sport movements and it allows, by a shortening of the muscle, to move loads consisting of the athlete’s own body weight (i.e. high jump) or external weight (javelin throwing) or to elevate resistance (the pull phase in the snatch lift).

Eccentric maximal strength values vary from 0 to 40% above the isometric maximal strength scores (Asmussen et al 1965; Singh / Karpovich 1966; Haberkorn Butendeich 1974; Schmidtbleicher / Buhrle 1980). Isometric strength scores must be superior to concentric strength scores since great force is

necessary to overcome inertia, static work and minimal force amounts are needed for acceleration of the weight (concentric work) (see figure 3).

This brings us to consider why eccentric scores-are superior to isometric scores. There are two mechanisms which can be potentially responsible:

1. The lengthening of the muscular-tendonous system causes passive elastic strength that is added to the amount provided by the voluntary contractions.

2. The lengthening of the muscle brings about the activation of the muscle spindle reflex, therefore increasing the innervation activity that results in stronger contractions.

According to results of neurophysiological research, a maximal muscular contraction is the product of:

- Recruitment: the collective activities of all motor units accompanied by the involvement of all muscle fibers.

- Firing rate: at any given moment, all motor units are responding maximally by firing at the optimal rate determined by the innervation frequency.

Editor's Note: Great eccentric strength is required in sports where shock absorption is part of the jump (i.e. long jump, high jump, jump shot in basketball) or the pre-shot braking (i.e. handball, racquetball). It is characterized by a lengthening of the muscle which is, in effect, an eccentric contraction.

Absolute Strength

Absolute strength describes the greatest possible strength which a muscle can produce based on the magnitude of its cross section.

This is the maximal force that can be produced independent of bodyweight. Limit strength is the maximal voluntary force plus the strength reserve that can be mobilized by exogenous drugs (i.e. central nervous system stimulants) and psychological components (i.e. the dis-inhibition of such structures as the golgi-tendon apparatus).

It is also known that a normal person can only, by a voluntary contraction, exert 70% of their absolute strength potential. Therefore, the autonomic reserves are not accessed. Research has proven that by applying intense electrical stimulation on the nerve, scores increase by 30 to 40% over voluntary contractions. (Ikai et al 1967, Schmidtbleicher et al 1978).

Speed Strength

Speed strength defines the ability of the neuro-muscular system to produce the greatest possible impulse in the shortest available time span. In other words, it is

the capacity of the neuro-muscular system to overcome resistances with the greatest speed of contractions possible.

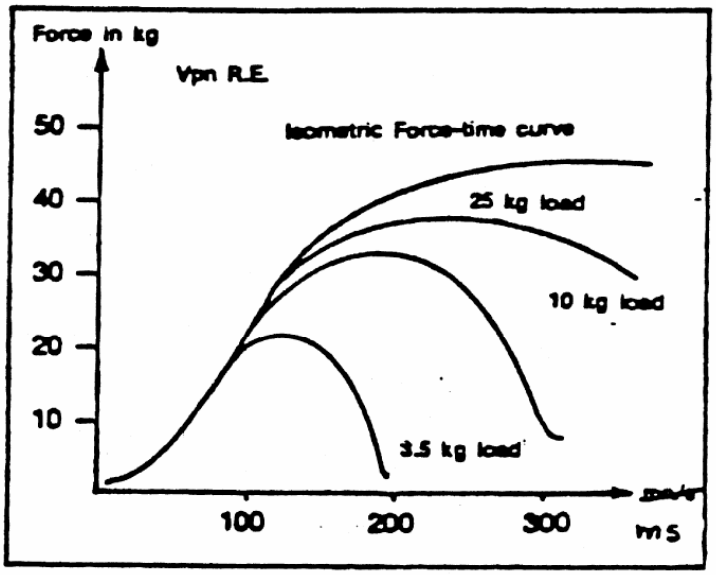

Figure 1
Force-time curves during different loading levels by isometric contraction (Bührle-Schmidtbleicher 1981, 257)

One must realize that there is a high correlation between maximal isometric strength and movement speed. An increase in strength brings about an increase in movement speed. The degree of correlation between maximal strength and movement speed increases when the load gets heavier (see figure 1). Speed strength encompasses two other strength qualities: starting strength and explosive strength.

a. **Starting Strength:** Starting strength defines the ability of the neuro-muscular system to develop from zero, the greatest possible strength in the shortest possible time. It can also be defined as the capacity to produce an increase in force at the beginning of a muscular contraction. Starting strength is essential in sports where a great initial speed is essential for optimal performance (boxing, fencing). It is based on the capacity to involve a great number of motor units at the beginning of the contractions and to develop high initial force.

b. **Explosive Strength:** Explosive strength refers to the ability of the neuro-muscular system to continue developing the already started tension-increase as fast as possible. In other words, it is the capacity to realize a vertical rise in force: the increase of force per time unit is of first order. Explosive strength depends on contraction speed of the motor units of the fast twitch fibers, the number of motor-units involved and the force of contractions of the fiber involved. If the resistance to overcome is light, starting strength predominates; if the load is increased, explosive strength is required. In cases where the load is very high, maximal strength

predominates (figure 2 illustrates the factors and components of speed-strength).

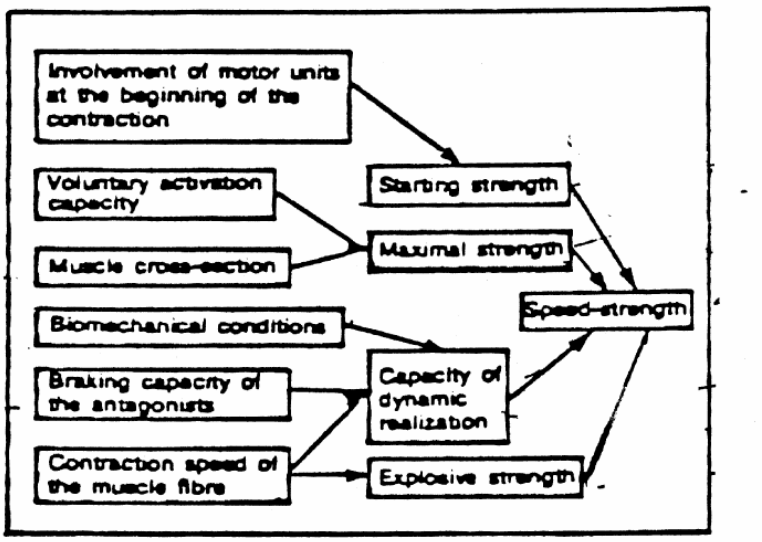

Figure 2
Factors and components of Speed-strength (Bührle-Schmidtbleicher 1981, 25)

Strength Endurance

Strength endurance defines the ability of the neuro-muscular system to produce the greatest possible performance. Strength endurance criteria's are intensity of stimulus (in % of the maximal force of contraction), the amplitude of the stimulus (sum of repetitions) and the duration of the stimulus.

A comprehensive illustration of the inter-relationship between motor strength qualities can be found in figure 3.

Overview of Strength Qualities

Maximal strength, speed strength and strength endurance are distinctly different entities and exist on a hierarchy.

- In the dimensional analytical sense, dynamic concessive positive strength, dynamic negative strength and static maximal strength are dependent from one another. To comprehend all three types of strengths, the phenomena's which can be defined and understood are: innervative behavior (voluntary activation), the muscle cross-section, and the muscle fiber type.

- Maximal strength can be considered as a basic quality which influences the speed-strength performance in concessive positive and static

contractions as well as the speed-strength performance in the stretch-shortening cycle and the stretch-endurance performance.

- Speed-strength performance can be produced by concentric movement and by isometric contractions, the components of this speed strength quality are: a) starting-strength, b) explosive strength, c) isometric maximal strength.

- The reactive movements, that is the speed-strength, is the stretch-shortening cycle which is a relatively independent motor quality. The qualitative expression of the reactive speed-strength is essentially dependent on the structure of the innervation patterns and the training state of musculo-tendonous structures in terms of their contractile and elastic qualities.

- Strength-endurance characterizes the capacity for resistance which again exhausts musculature through static or dynamic work, performed with loads which are greater than 30% of the individual maximal strength. Neural factors limit performance in short-term work (up to 30 seconds) and metabolic processes limit performance in long term work (longer than 30 seconds).

Based on the given above research findings and theoretical material, we have established a training program for a national calibre shot-putter after obtaining data from anthropometric measure motor tests, and biochemical diagnosis. A description of the tests used to measure these parameters is given below.

STRENGTH TRAINING PRINCIPLES

Progressive Load Increase

To force the proper kind of adaptation mechanism to occur, the bio-motorability must be stressed. As the neuro-muscular system adapts to the stress being imposed, greater and greater amounts of stress must be applied, for the neuro-muscular system will not continue to adapt without it. However, one should not try to increase stress in a linear fashion, but rather on a step-by-step or undulatory approach which calls for training load increases followed by a phase of unloading during which the organism regenerates itself, bringing about supercompensation.

This unloading microcycle in strength training calls for a reduction of 30-40% of the number of sets. For example, exercises performed for five sets in the loading phase are done only for three sets in the unloading phase.

Variety

Strength training programs are known to lose their efficiency after two weeks due to the relatively rapid adaptations of the neuromuscular system to the training

stress. Therefore, training programs should contain variety to avoid physiological staleness and psychological boredom.

We can distinguish long-term variation from short term variation:

- Long-term variations refer to the variations by alternations of dominant modes of loading and methods in training process of several years or in the macrocycles of high performance athletes.

- By short-term variations, we mean the alternation of loads within a unit of training cycle. Here is a fun way one can vary workouts on a short term basis:

- Variations of load magnitude: Extensive, intensive, sub-maximal, maximal, supra-maximal loads are alternated to force the muscle to respond. Be careful to respect the principle of progressive load increases.

- Variations of mode of contractions: Strength increases come about faster when different modes of muscular contractions are alternated (see figure 1) than if only one mode of work is used. Concentric, eccentric, isometric work should respectively represent 70%, 20% and 10% of the total workload.

- Variations in the speed of contractions: Strength increases are higher when different speeds of contractions are used (slow, medium, fast) than if only one speed of contractions. Slow speed training places high tension on the muscular structure since no momentum is used to displace the weight. It is very beneficial to the trophism of muscle and strength. High speed movements stimulate great neural output. Therefore, a training that solicits all muscle fibers by different tempo and modes of training can elevate overall strength.

- Variation of the exercise: Changing the nature of the exercise is another way to avoid staleness and boredom. The squat exercise can be done with the barbell on the back, the clavicles, feet narrow or wide, bar high or low, in a rack, heels elevated or flat. There is endless variations to barbell exercises. Vasilii Alexeev, World and Olympic Champion who set many world records, was known to use greatly this principle to boost his strength. Istvan Javorek, who produced many world championship and Olympic medalists while coaching the Romanian Weight Lifting Team, uses a 20 week training cycle in which no single workout is identical in nature.

S.A.I.D.: Specific Adaptations to Imposed Demands

Each physiological mechanism comprising a muscle responds to different types of training stress. Therefore, the appropriate training stress must be applied to experience the wanted effect. The S.A.I.D. principle says the training effect you receive is determined by the methodological approach taken in the workout; so, if

you seek maximal strength, you must train with the approach known to maximize strength. Neither a single set of 8-12 reps taken to muscular failure nor 4 sets of 30-40 reps will accomplish this task. The physiological mechanism of loading norm such as number of sets and reps, cadence per rep or set, speed of movement per rep, percentage of one R.M., type of exercise chosen, mode of contraction and frequency of exercise.

Effectivity

According to Soviet sports scientists Zaciorskij and Raizin, the effectivity of an exercise must be judged on the rapid growth of strength and Its transfer on the competitive exercises. We must notice that some exercises increase rapidly strength values but very little carry over the competitive exercise (i.e. parallel bar dips for shot-putting) while other exercises (such as the inclined press which also develops the triceps for shot-putting) allow to act on strength parameters that are difficulty to modify but when finally bettered , help the performance on the competitive exercise.

We can look at another example of effectivity in form of strength training for jumping. Bio-mechanical analysis has shown that the glutes, the quadriceps and the hamstrings are the major muscle groups involved in jumping. So two different training programs were compared to determine which one favored more positively jumping power. Here are the programs:

- A (Isolation Routine)
    - Nautilus hip extensions (glutes)
    - Nautilus leg extensions (quadriceps)
    - Nautilus leg curls (hamstrings)
- B (compound routine)
    - Clean pulls (glutes, quadriceps, hamstrings)
    - Back squats (glutes, quadriceps, hamstrings)

Routine B which involved only two exercises but involved all muscle groups in a fashion similar to jumping brought about the biggest increases in vertical jump. Therefore, free weight training has the greatest carry-over athletic ability.

Specificity

High effectivity and positive transfer can only be obtained by specific-strength training preceded by constructive general training.

This specific-strength is based on:

- The principle of priority development of the muscle groups specific to the discipline while taking into account the specific work angles of that event.
- The principle of dynamic accord between the training exercise and the competitive exercise.
- The principle of accord between the mode of muscular mobilization of the training exercise and the competitive exercise.
- The isolation principle in which the only muscle receiving the maximum benefit of the overload being applied will be the weakest of those acting to overcome the load. So, to insure efficient adaptation, the muscle of interest must be isolated from all others, or at least made the weak link in the chain.

PERCENTAGES OF THE CONDITIONAL TRAINING

Events	Period	S.W.	Sp.W.	G.W.
Javelin & Hammer throwing	early 60's	5-10%	20-30%	60-70%
	early 70's	50-60%	20-30%	10-20%

S.W.: special work
Sp.W.: specific work
G.W.: general work

TABLE 1: Ratio between the different types of work in throwing events over two decades.

As material by Soviet sport scientist Kusnetsov suggests, the proportion of specific-strength training has increased dramatically over the last decades (see table 1).

Specific-strength according to Pedemonte takes place in four different ways:

1. It can reflect the same technical gesture (imitative drills with barbells of dumbbells) for every sport that uses some implements (e.g. throwing implements, balls, rackets, oars, clubs, etc.)
2. A general strength drill performed with a speed or rhythm and intensity similar to those required by a specific event (e.g. Olympic lifts with a near to maximal intensity for throwers; rhythmical good-mornings with low intensity for rowers).

3. An exercise in which you are using muscular tension similar to a specific event: plyometric drills for jumpers or isometrics for wrestlers working in the basic positions used in competition.

4. Isolating the muscular groups chiefly involved in the competitive movement (e.g. Incline presses for shot-putters, step-ups for jumpers) taking care of the paths followed by the different body segments, that should be similar to those followed with the particular movement.

METHODOLOGY OF TRAINING STRENGTH QUALITIES

1. Maximal Strength Development

The amelioration of maximal strength calls for all methods characterized by a high intensity of loading and a sufficient time of loading. As mentioned before, peak strength cannot be attained through only one strength training method since the adaptation effect brings about in very little time stagnation of performance but by an optimal combination of various methods.

There is a sliding scale of maximum strength requirements for

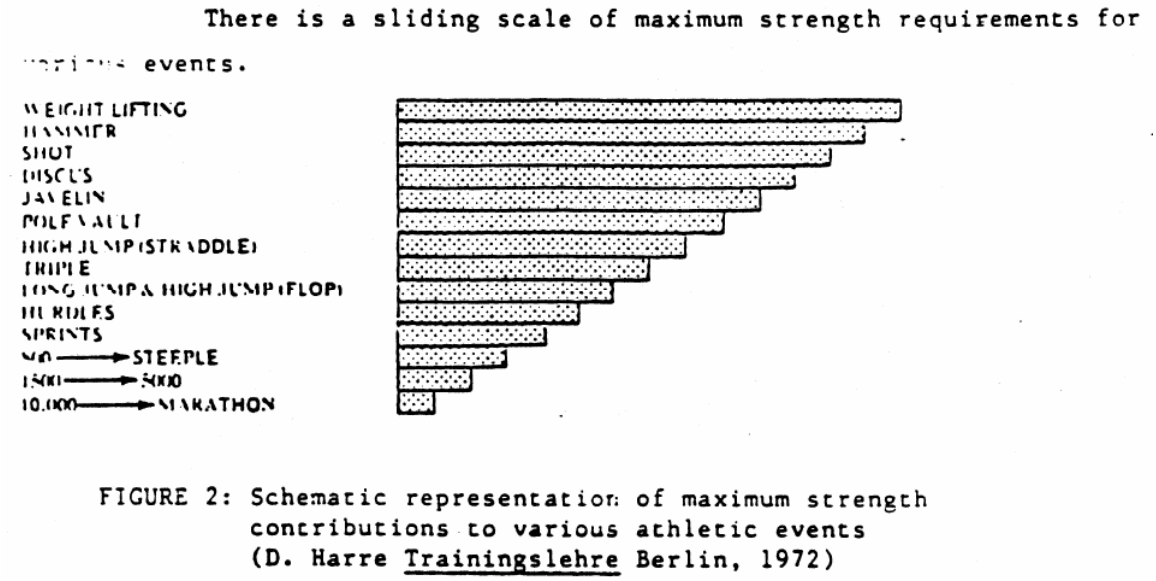

FIGURE 2: Schematic representation of maximum strength contributions to various athletic events (D. Harre Trainingslehre Berlin, 1972)

Maximal strength can be increased by methods which bring about:

a. An increase in the number and the firing frequency of fiber recruited (e.g. eccentric method).

b. The presence of appropriate enzyme concentrates in the muscle cell (e.g. bodybuilding system).

c. A dis-inhibition of the Golgi tendon organ, allowing for higher muscle tension by pushing back the defense barrier at which the muscles shut down upon application of extreme stress (e.g. plyometric training).

d. A marked decrease of the physiological components of endurance (e.g. refraining from aerobic work).

e. A learning of the neuro-motor patterns of force deployment (inter-muscular coordination).

The best strength increases in strength occur with loads allowing at the maximum 8 repetitions. Sets of 4-6 repetitions at 80-85% (up to ten sets for highly—qualitative lifters) according to strength expert C. Carl, are optimal for concentric strength training. Sets of 1 to 3 reps stress greatly the neuro-muscular system and therefore should only be used for short periods at a time (2 weeks) and by qualified athletes only.

Muscle groups that contain high proportions of ST fibers such as the soleus (88%) are better trained by repetitions of 10 or more.

Much time has been spent on finding the “magical” combination or the optimal recipe of loading norms for strength training. The following suggestions for loading norms are based on well documented research and empirical findings from both North American and European spheres of thought.

Reps

Rolf Feser, high performance coach and consultant to West German Weightlifting Federation, suggests that the privileged intensity zone of concentric strength training lies between 70 to 100% of 1 RM. Therefore, repetitions of 1 to 12 develop strength. However, snatches, cleans, jerks should be done for sets of no more than 6 reps, to prevent the deterioration of the inter-muscular coordination.

Eccentric training is usually done for 4-6 sets of 1 to 6 reps at 105-175% of 1RM. The resistance must be decelerated as much as possible, by covering the weight to a count of 6 to 8 seconds.

Isometric training is better done for 6 to 10 contractions of five to eight seconds at maximal tension. Strength increases in isometric training are very specific and occur only in the surroundings of the angle that is worked. Therefore, one should work at least 3 different distant angles in the range of motion to increase concentric strength (i.e. 45°, 90°, 135° for elbow flexion). Isometric training is useful to overcome sticking points such as the slightly above parallel position in the squat exercise.

Bulgarian and Polish coaches recommend that the first year of strength training be devoted to repetitions of eight to twenty.

Sets

The number of sets as evidence suggests is inversely proportionate to the number of reps performed. (Sets of 11 reps and more: 3 sets, sets of 8 to 10

reps: 4 sets, sets of 4 to 7 reps: 5-10 sets, sets of 1 to 3 reps: 6-10 sets). Various schemes of sets and reps have been used successfully. Here are a few:

$$\frac{(80\%,}{7}\ \frac{85\%,}{3}\ \frac{90\%)}{3}\ 3$$ Undulatory Pyramid

$$\frac{(82.5\%)}{6}\ 6,\ \frac{(90\%)}{3}\ 3$$ Paler Systems

$$\frac{(70\text{-}78\%)}{8\text{ - }12}\ 3\text{-}5,$$ Bodybuilding Systems

$$\frac{(115\%)}{6}\ 4$$ Eccentric Training

Muscles which are not usually subjected to high levels of training such as the adductors of the thigh react well to only a few sets (1 to 3). As an athlete increases his or her level of classification, more sets are needed to bring about supercompensation. Many top level strength athletes regularly perform 10 sets of an exercise.

Speed of Execution

Muscles grow faster in strength if submitted to various tempos of execution than if trained always at the same speed. Slow speed movement (3 to 10 seconds for both concentric and eccentric phases of lifting) places high tension on the neuro-muscular system due to the absence of momentum, thus favoring greatly the trophism of muscle size and strength. High speed lifting with high loads (85-100%) is another way to achieve high levels of muscle tension by recruiting a great number of fast twitch motor units.

Rest Intervals

Rest intervals in strength training should be in the order of two to eight minutes with the average being between 3 to 5 minutes. The higher the intensity worked at and the larger the muscle man involved, the longer the rest interval should be. For instance, squats at 90% should call for 5 minute rest periods.

Number of Exercises

A common mistake amongst North American strength coaches is the prescription of many exercises in a workout. Soviet weightlifting expert Vorobyev recommends 2 to 7 exercises with an average of 4 to 6 as being the ideal number of exercises; Feser recommends 30 to 35 sets per workout as a loading norm. Many athletes perform 12 to 15 exercises, bringing about excessive

fatigue. The more specialized an athlete becomes, the lower the amount of exercises he or she will perform. The current trend in strength sports is to perform 2 to 5 workouts a day lasting 40-50 minutes each. Only 1 to 2 exercises are performed per workout. For example, shot putters who want to upgrade their quadriceps strength will squat 3 times a day to force maximal supercompensation.

	SPEED-STRENGTH—Concentric/Isometric			SPEED-STRENGTH—Stretch-shortening Cycle		
	Muscle cross-section	Strength deficit	Explosive strength	Pre-activation	"Reflexivity"	Inhibition reduction
Short-term maximal contractions	x	xxx	xxx	xx		
Repetitive Submaximal Repetitions	xxx	x	x	x		
Mixed Methods	x	x	x	x		
Reactive Training Methods		xx	xx	xx	xxx	xx

x = low impact *xxx = high impact*

Table
Training effects of the introduced strength training methods in relation to specific factors and components o strength behavior.

	Near Maximal Contractions	Maximal Concentric Contractions	Maximal Isometric Contractions	Maximal Eccentric Contractions	Concentric-Eccentric Maximal Contractions
Form of work:					
Concentric	x	x			x
Isometric			x		
Eccentric				x	x
Force development:					
Explosive	x	x	x	x	x
Continuous					
Intensity Load	90 95 97 100%	100%	100%	ca. 150%	70-90%
Repetitions	3 1 1 1+1	1	2	5	6-8
Sets	1 2 3 4+5	5	5	3	3-5
Length of contraction			5-6s		
Rest Interval	3-5 min	3-5 min	3 min	3 min	5 min

Table 1
When maximal strength is sought, optimal increases in strength occur with loads permitting no more than 8 repetitions.

	Standard Method I (constant load)	Standard Method II (progressively increasing load)	Bodybuilding Method I (extensive)	Bodybuilding Method II (intensive)	Isokinetic Method	Isometric Method
Form of work:						
Concentric	x	x	x	x	x	
Isometric						x
Eccentric					x	
Force development:						
Explosive						
Continuous	x	x	x	x	x	x
Intensity Load	80%	70 80 85 90%	60-70%	85-95%	e.g. 70%	100%
Repetitions	8-10	12 10 7 5	15-20	8-5	15	10
Sets	3-5	1. 2. 3. 4.	3-5	3-5	3	3-5
Length of contraction						10-12 s
Rest Interval	3-5 min	5 min	2-3 min	3-5 min	3 min	3 min

Table 2

Editors Note: At loads of 50-75% of the maximal strength, calling for 11-30 R.M., the resulting fatigue levels cause super compensation of glycogen stores to occur, producing increases in strength endurance. If the loads are heavier (75-80%), neo-synthesis of the contractile proteins structures occurs, therefore increasing the muscle's cross-section, maximal strength, creatine phosphate content. For optimal cross-section increases, one

	Speed-strength Method	Pyramid Method
Form of work:		
Concentric	x	x
Isometric		
Eccentric		
Force development:		
Explosive	x	x
Continuous		
Intensity of Load	30-50%	80 85 90 95 100 95 85
Repetitions	7	7 5 3 2 1 3 7
Sets	5	1. 2. 3. 4. 5. 6. 7.
Length of contraction		
Rest Interval	3-5 min	3-5 min

Table 3 MIXED METHODS

Pyramid training, by its unique variability quality, can be adapted to the needs and objectives of all (circumstantial) varieties of strength training.

	Hopping Single and Double Leg	Jump Training	Depth Jumping
Form of work:			
Concentric	x	x	x
Isometric			
Eccentric	x	x	x
Force development:			
Explosive	x	x	x
Continuous			
Intensity Load:	Without Additional Load		
Repetitions	30	10	10
Sets	3	3	3-5
Length of contraction			
Rest Interval	5 min	5 min	10 min

Table 4 REACTIVE TRAINING METHODS