Training for Power

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Simply defined, **Power** is the capacity to **express strength** at **speed.** Power athletes **include** throwers, jumpers, sprinters and hurdlers. An additional requirement for such athletes is the need to express power in movements that demand **a specificity** of **neuro-muscular coordination.** The sequence of neuro muscular events has to be modulated in space and *time* for optimum performance.

This article is an attempt **to** *reassess* the theoretical framework that guides **training for the expression of power.** If we raise contentious issues, we would welcome the ensuing debate as a necessary prelude to re-examining the basis of our coaching programmes.

Some Theory

The types of strength development that the power **athlete** is concerned with are **elastic strength** and **absolute strength.** Similarly, such **athletes** are concerned with **maximum acceleration** or **velocity.** The specificity of strength expression that the athlete **desires,** might be sought in optimising the biomechanical Performance of the event itself, or in such partial movements or exercises that ingenuity and experience can devise.

The Contractile Components: The muscle is composed of a number of muscle cells or **fibres.** Each muscle fibre is composed in turn of a very large number of **microfibrils** made up of thick and thin filaments of the muscle proteins, actin and myosin. Training for an increase in muscle bulk (hypertrophy or increase in cross-sectional area) increases the number of constituent microfibrils through protein synthesis, but has little effect on the number of fibres or cells. The end-plates of a motor **neurone** *(nerve)* are attached to each of several muscle fibres; the group of fibres and the neurone constitute the **motor** unit Where fine movements are involved (e.g. the muscles of the eye), only a few fibres are attached to each neurone. Where gross movement is involved (contraction of a quadricep muscle), several hundred fibres are attached to, and fired by, a single neurone.

Any discussion of strength usually includes a consideration of muscle cross-sectional area and muscle **fibre** type[1]. Only two features of muscle physiology will be raised here. (a) Slow twitch fibres are well endowed with mitochondria and are capable of exerting longer contractions. Fast twitch fibres, as their name implies, are capable of more, rapid and powerful contractions. but exhaust themselves very quickly. It is a misunderstanding to believe that slow twitch fibres (type I) only contract slowly - the contractions can be quite rapid in relative terms (the contraction time for 'fast' fibres is 40-90ms, and for 'slow' fibres 90-140ms). In practice it is not so much the speed of contraction that distinguishes them, but the rate of exhaustion. (b) Secondly, it is not just the speed of muscular contraction that activates fast twitch fibres, but the intensity of effort. Fast twitch fibres (type IIB) are only brought into operation at intensities of over 70-80% maximum - i.e. when high fibre recruitment is necessary. Thus, most voluntary bodily movements utilise slow twitch fibres to protect the muscles from rapid exhaustion. That said, one must recall that intermediate fibre types exist, providing a gradient of anatomical and physiological capabilities.

Type IIB motor units are preferentially activated in fast corrective movements and reflexes. Explosive maximal contractions activate slow and fast motor units simultaneously. Present physiological dogma suggests that a motor unit is composed of a single type of muscle fibre, but that different muscle will contain different ratios of fibre types. For example, the soleus muscle of the calf is exclusively composed of slow twitch motor units. However, recent studies indicate that force-velocity relationship may vary substantially along the length of individual fibres. This suggests regional differences of myosin isoforms (the molecular basis of fibre twitch typing) along the fibre. This may allow the fibre to compensate for local differences in the, passive resistance to shortening - e.g. the distal part of a muscle undergoes a larger translation during shortening than does the proximal part.

Consider some definitions of strength and their application to the training of performance of power athletes. Maximum strength has been defined as the greatest force generated in a single maximum voluntary contraction. It does not necessarily involve either speed or endurance factors. It can be measured in the form of a maximum lift in the weights room or, for isolated muscle groups, through use of isokinetic muscle dynamometers (Cybex, Lido, KinCom). Muscle dynamometry (e.g. use of the Cybex machine to test quadricep strength in leg extension exercises at different angular velocities) readily demonstrates that at greater angular velocities (the rate of leg extension), the force that can be generated drops dramatically. These movements are made at velocities (e.g, 250 or 300º per second) considerably less than those involved in, say, straightening the take-off leg in the long jump. The relationship between maximum strength and an explosive body movement, either linear or rotational, is still unknown, but one assumes a direct relationship exists. Nevertheless, we are confining ourselves in such tests of maximum strength to concentric strength.

[1] Maughan, R.J. (1986). Muscle strength and its development - a scientific approach. In: XVI International Coaches Convention, Edinburgh.

Concentric strength is expressed when the force exerted by the athlete is sufficient to overcome the resistance or load, e.g. in lifting a weight. Gains in maximum concentric strength are most easily generated and measured in a weights room. However, the contribution of concentric strength alone to such movements such as the long jump take-off or the discus throw is both partial and unmeasurable. An eccentric muscle action[2] occurs when resisting a high load, e.g. when resisting collapse during a landing or in the controlled lowering load in the squat or bench press. Maximum eccentric strength is difficult and dangerous to measure. It is an important component in any movements involving landing on and taking off from the ground, i.e. in jumps, throws, sprints and hurdles. Although attempts to develop eccentric strength in the weights room have been made, it is best developed for the legs by forms of drop jumping, hurdle jumping, etc., where the concentration is on the height of the drop and minimising the collapse on landing. Rebound should not be an objective of such exercises. Exercises such as dropping off a box from heights up to 1 m (or more?) or hopping following a run-up, can generate forces several times body weight - much more than can be handled in the weights room Athletes must be gradually and progressively conditioned to such eccentric strength training.

Elastic strength, both in its definition and its development, is the source of much greater confusion. Lifting a weight fast is merely a fast concentric contraction. Using low weights it may not even lead to the recruitment of fast twitch fibres. With very heavy loads, the lifts are necessarily slower, but recruitment is greater. To attempt to lift weights fast is to be encouraged in most forms of weight training but not so fast that momentum prevents the muscle being exercised throughout its range of movement. With low weights the primary benefit is on co-ordination.

Yet another component of strength is involved in most athletic movements. In landing following a hop or bound, the stresses are absorbed by several elastic components of muscle, including tendons, ligaments and connective tissue. The elastic recoil of these components makes a significant contribution to the subsequent take-off. The greater resistance to collapse (collapse permits the plastic absorption of the shock forces through muscle deformation or stretching), the greater the elastic strength that can be expressed.

Unlike muscle, where the changes in fibre length (and consequent generation of force) are non-elastic, tendon is an elastic and conserved structure. All energy involved in stretching the tendon will be stored as potential energy and released as the force exerted on the tendon is allowed to decrease to zero. Thus, the tendon acts as an energy pool, which can generate high velocities of movement without imposing these high velocities on muscle fibres. As mentioned already, the potential energy stored in a tendon or other elastic structure can be released as the force is decreased. If this is done slowly, the energy will become available slowly. If this is done rapidly, the energy will be released fast. The amount of energy released per unit time is **power**[3]. To exemplify the importance of this component during the push-off in vertical counter-movement jumping (a form of depth jumping), more power is delivered by the triceps surae (ankle) tendon than by the muscle fibres of both gastrocnemius and soleus muscles[4].

Rebound exercises that concentrate on minimising the dwelling time on the ground develop elastic strength in the legs. During movements involving torsional forces, such as the winding up during the discus throw, or during rapid backward and forward movements such as those involved in withdrawing and advancing the javelin throwing arm, similar, if somewhat smaller, elastic components are involved. The more rapid the movements and transitions (e.g. Zelezny's throwing arm), the greater elastic strength expressed.

'Speed-Strength' training (Yessis, 1989) simply refers to training for explosiveness[5]. An elite sprinter typically makes contact with the ground for all of 100 milliseconds (50 milliseconds for the landing and 50 milliseconds for the push-off). This means that the sprinter has 50 milliseconds to generate maximum force to propel him forwards at speed. Similar times have been measured for the amortisation and take-off phases in the jumps. These are an order of magnitude faster than most strength exercises executed in the weights room. To develop the speed, quickness and explosiveness needed in athletic events, it is necessary to train in this manner. White fast-twitch muscle fibres must be involved. Type II-B is the fastest and most explosive, but comes into play only at intensities and speeds of close to 100% maximum. Pure strength training involving weights will involve white fibres, but usually types II-A and II-C. Thus, to develop speed-strength, either strength must bc converted to speed, or generated in a speed-type workout.

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[2] The term 'Contraction' seems inappropriate to describe the state of muscle activity when the muscle might shorten, maintain the same length, or increase in length. Cavanagh has proposed the term 'muscle action' to describe the result of skeletal muscle force development. A concentric muscle action involves shortening of the muscle, while the term eccentric identifies a lengthening action. Cavanagh, P.R. (1988) On 'muscle action' vs 'muscle contraction'. Journal of Biomechanics 27:69.

[3] Huijing, P.A. (1992). Elastic potential of muscle. In: Strength and Power in Sport, Ed. P.V.Komi, Blackwell, pp. 151-168.

[4] Bobbert, M.F., Huijing, P.A. & Ingen Schenau G.J. van (1986). An estimation of power output and work done by the human triceps surae muscle-tendon complex in jumping. Journal of Biomechanics 19: 899-906.

[5] Yessis, M (1989). Speed-strength training. Track & Field Quarterly Review, 89(4): 43-45.

Speed[6], in athletic terms, may be defined as the time taken to move the athlete's limb, body or an implement from a starting to a finishing position.

The components of speed are:

Reaction: The ability to react rapidly is neuro-muscular in basis, and is trainable. The athlete may react to an external cue (e.g. to the starting gun) or to a mental cue.

Acceleration/Power: Also a trainable component involving gross, elastic and special strength. Power involves the application of force over a distance as rapidly as possible. Thus, the range and speed of movement become important parameters.

Technique: Good technique involves the efficient conversion of force into work. Obviously, this too is a trainable component.

Speed/strength endurance: Involves the ability to maintain maximum or near maximum speed for as long as possible. It is yet another trainable component, involves the alactate/lactate energy systems, and should not be confused in training terms with endurance training for power athletes, geared towards 'training to train'.

In the early 1980s, *Dr Ralph Mann* and co-workers in the United States, and other sports scientists elsewhere, refines both the concept and the biomechanical evidence for *sprinting being a series of vertical bounds*, as the runner overcomes the force of gravity. The research suggested that the major difference between good and great sprinters or hurdlers is in the rearward angular velocity of the thigh. i.e. in the speed-strength action of the gluteal and hamstring muscle groups. The use of isokinetic dynamometers (apparatus such as the Cybex, Lido or Kin-Com, admittedly worked at far slower angular velocities than those involved in normal sprinting) suggested the need for great strength in the gluteal-hamstring muscles. This led to recommendations that the quadriceps:hamstring strength ratio should be closer to 1:1, rather than the 1.5:1 ratio usually recommended. In the longer sprints - the 400m and 400m hurdles - the hamstrings are additionally important in maintaining stride length and stride frequency by generating the tight heel-to-buttock action that is essential to the short lever forward swing-through of the thigh and subsequent foreleg extension during the swing phase of the running action.

Dr Edwin Tepper, coach for sprint/hurdles in the former GDR described the following approach for the development of 'sprinting strength' in GDR women sprinters[7].

1. Maximum strength provides a basic foundation for 'sprinting elasticity' and 'sprinting strength endurance'. There is a positive correlation between maximum strength and the capacity for cyclical acceleration.

2. Sprinting elasticity is to a high degree identical to 'special jumping capacity' (10 bounds from a run-up). It shows a very close and statistically highly significant correlation with 'acceleration' capacity.

3. Sprinting elasticity in its relationship to acceleration and locomotor speed, calls for a maximally steep rise in the 'strength-time' function of the exercise in question.

The result of this approach is a stronger orientation in training methods towards anaerobic-alactacid metabolism.

Obviously strength and neuromuscular activity predominate as factors influencing speed.

On reception of a signal, all the fibres of a motor unit contract; the 'all or none' law applies. Either the whole fibre contracts to the limit of its capacity, or, if there is no signal above the **threshold**, the fibre retains its resting length. Therefore, the force generated by a muscle is dependent on the number of motor units involved Since the brain is involved in this control of muscle activity, the selection of an appropriate number of motor units for a selected task is a learned activity. Very powerful contractions involving a high percentage of the motor units will almost certainly cause damage to the untrained muscle, and very likely to the trained muscle. Therefore, physiological inhibitions prevent near-maximal recruitment of motor units. Strength training at or near 'Maximum' increases the available neural pathways for firing motor units and damps down the protective inhibitions.

The neural impulse initiates muscle contraction by triggering biochemical reactions that cause the breakdown of the 'high energy' chemical adenosine triphosphate (ATP) to adenosine diphosphate (ADP). The energy released is used in contraction. The ATP is regenerated from ADP via creatine phosphate stored in the muscle. The levels and regeneration of ATP, therefore, determine the extent and duration of muscle contraction. Slow aerobic activity permits the generation of much more ATP, permitting repeated muscle contractions over longer periods of time.

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[6] Distance is a **scalar** quantity, which has magnitude, but no direction. Therefore, **speed**, which = distance (m)/time (sec), is also a scalar quantity. **Displacement** is a **vector** quantity, which has magnitude and direction. Therefore, **velocity**, which = displacement (m)/time (sec), is also a vector quantity. Velocity would be the more accurate term to describe the displacement of a sprinter from start to finish of a 100m race, or the rate of approach of a long jumper.
Acceleration = rate of change of velocity = $v/t = d/t^2$, where v = velocity, t = time, and d = displacement. If an object changes direction (moving at the same speed), its velocity will have changed and therefore, it is accelerating.

[7] Tepper, E. (1989). On the state of development and the training system in the GDR women's short sprints. Athletics Coach, 23(1): 8-22.

The Elastic Components: The contractile components of muscle are joined both in parallel and in series with elastic components (tendons, ligaments, etc.). The elastic component can be stretched and therefore, develops tension due to its elastic resistance to that stretch. It provides a second contribution to 'contractile force' and is effective in those activities which involve voluntary muscle contraction and elastic recoil (running, jumping, hopping, etc.).

The Myotonic Reflex: is yet another mechanism that adds to the efficiency of force expression. Muscle spindle receptors are sensitive to stretch of the muscle fibres. and their response is to stimulate a reflex contraction of the muscle. More importantly, the spindles are sensitive to the rate of change of muscle length. Thus, in drop jumping exercises, for example, it is the speed of rebound that determines the extent of reflex contraction. The Golgi tendon organs, located at the muscle-tendon junction, are sensitive to muscle tension. The protective response to tension is to inhibit the contractile mechanism, relieving the degree of stretch or contraction in the tendon and muscle. The reflex response to contract (spindles) has a lower threshold than the relaxation response (Golgi tendon organs). The net result is a reflexive, vigorous contraction of a given muscle when forcefully stretched (e.g. the take-off leg in the long jump). This net reflex is the myotonic reflex and provides a third contribution to the summated contractile force. Rebound training for elastic strength stimulates and entrains the myotonic reflex. Thus, the technical model of an activity includes a summation of contractile, elastic and myotonic reflex contractions.

Proprioception and Motor Skills: Proprioception refers to the conscious awareness of the position of a body part in space. It depends, in part, upon impulses from sense organs in and around the joints. These sensory receptors include the Golgi tendon organs muscle spindles, and still other receptors in the ligaments, synovia and skin. Impulses from these organs are synthesised in the brain cortex into a conscious picture of the position of the body or limb in space.

The learning of a motor skill is a complex and highly specific process. There is little carry-over from one, skill to another, unless they are almost identical. Thus, correction of an 'ingrained' faulty technique should be approached as teaching a completely new motor skill. A skill that has been practised sufficiently becomes memorised and capable of immediate recall - an engram. Engrams for very rapid movements (motor engrams) are stored in the motor area of the brain and involve a neural by-pass mechanism for speed. Fast movements, once underway, cannot be changed, unless they were originally programmed to be so.

Adaptation to Training: Fast contracting fibres are recruited only during rapid power movements or high intensity isometric muscle action. When they are recruited and stressed, they undergo hypertrophy very readily. Slow fibres also respond to frequent recruitment by some hypertrophy, but to a lesser extent than fast fibres[8]. In repetitive low intensity exercise (long distance running, cycling), the fast fibres may never be recruited; indeed they may undergo atrophy at the same time as the slow fibres are undergoing some increase in size. Thus, there is a selective response to the type of training.

Adaptations to training are both neuro-muscular and hypertrophic. At the start of a training programme, the increases in strength are due to improvements in inter- and intra-muscular coordination and neuronal output. Over time (2-8 weeks) the contributions from these adaptations to increasing strength decline, whereas the contribution from hypertrophy rises, the cross-over point depending on age of athlete, level of prior training and the strength programme being tested.

Drawing the Parts Together: From our minimal analysis, training an athlete for an explosive event requires attention to:

* development of adequate muscle size (hypertrophy), primarily through resistance (weight) training. The cross-sectional area of muscle is directly related to maximum strength. It should be pointed out that an increase in maximum strength is always connected with an improvement in relative strength. This is impressively demonstrated by the power performances achieved by heavy athletes (throwers) in the standing long jump or the 30m sprint. Such muscle development may be achieved through sets of 6-12 repetitions using loads of 60-75% maximum. Each set of the chosen number of repetitions must work the athlete to failure. Lifting to this principle, Carl Johnson and triple jumper, Jonathan Edwards, are satisfied with a single set of repetitions per session[9]. Throwers need additional muscle bulk for stabilisation against the linear or centripetal forces exerted against the implement.

* training the recruitment of muscle fibres and further hypertrophy through concentric and eccentric contractions involving very high loadings. Weight training might employ sets of 3-1 repetitions involving loadings of 90-100% for the development of concentric strength. Eccentric strength can be trained using depth jumping, single hops, slow bounding and hopping for distance, etc. High hurdle jumps, pausing between hurdles, stimulates concentric strength at take-off and eccentric strength during landing without collapse.

* the development of elastic strength through rebound exercises, involving elastic recoil. The term 'plyometrics' involves such a confusion of objectives and effects, that we prefer not to use it. Speed of recoil or rebound must be the primary objective for the development of elastic strength. Drop jumping should involve heights of no more than 25-40

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[8] Schmidtbleicher, D. (1992). Training for power events. In: Strength and Power in Sport. Ed. P.V.Komi, Blackwell, pp. 380-395.

[9] C. Johnson (1994). Elastic strength development. Analternative standpoint. Athletics Coach, 28(1):5-7.

cm. Raising box heights above these figures, prolongs dwelling time on the ground and changes the character of the exercise from elastic to eccentric. As mentioned earlier, measured dwelling times during sprinting or take-off for the long, high and triple jumps range between 120-200 milliseconds, providing target times for such exercises.

* reaction time may be stimulated by event-specific or non specific drills, where the concentration is on speed and technical quality of execution. Such drills might be preceded by mental rehearsal and should be terminated as soon as the quality declines. In the case of non-specific drills, the wider the range of motor skills involved. the greater the level of spin-off benefit to the execution of the event.

* acceleration of an athletes limb or body involves the application of power and, consequently, depends upon strength levels. Its application should be event-specific and biomechanically sound. Maximum acceleration or velocity in explosive events such as the jumps or throws, draw upon alactate energy sources, and require only a moderate amount of anaerobic or aerobic training. Speed endurance training for such athletes should be concerned with maintaining maximal velocities for as long as possible, the training effect being directed at ATP regeneration from, and muscle stores of creatine phosphate. Since it is impossible to separate alactate and lactate energy sources in practice, anaerobic training effects on the glycolytic system will also become evident. Since sprinting and hurdling involve repeated explosive events, an obvious necessity for anaerobic and aerobic training is evident. However, high levels of the type of training recommended for other explosive athletes is still demanded.

* special or event-specific power: is progressed through exercises that closely imitate the dynamic characteristics of the event. The explosive, reactive and ballistic nature of the event must be represented. Loads of 5-15% below or above those normally employed in competition (e.g. use of lighter or heavier implements or a weighted jacket) are appropriate. In the throws, one may attempt to gain 'carry-over' benefits, i.e. using a load less than normal for 1-2 trials, followed by a normal load followed by a heavier than normal load. Since the structure of the neuro-muscular co-ordination involved apparently does not alter within the 1 or 2 minutes between trials, the effect of the ultra-fast movements established in early trials will be carried over into subsequent ones. In sprinting using a very slight downhill gradient first, would have the same effect.

The dilemma is in constructing a programme that encompasses an adequate mix of these components in a training year in which athletes have to peak for both indoor and outdoor seasons, and often, more than once in a season. Athletes are already demonstrating the effects of increases in training volume by more frequent breakdown. Injection of power training rather abruptly before the competitive season also takes its toll. While a foundation of aerobic and anaerobic endurance and gross strength is undoubtedly necessary, how much time does one allocate to this? Are athletes spending too much time and effort in training to perform slowly? If long distance running does induce adaptations that result in atrophy of fast twitch fibres, how much speed training does one inject into the athlete's schedule to counter this? Does heavy weight-training, employing relatively slow, concentric contractions have sufficient carry-over benefits to the power athlete, whose event demands a complex admixture of concentric, eccentric and elastic strength applied at speed? We attempt to address some of these problems in the second of these back-to-back articles on power training in which we will discuss programming, training loads and intensities, specificity of training methods, complex training, and practical suggestions for the development of explosive power in different events.