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# IMPROVING PERFORMANCE IN HIGH-POWER ATHLETES*

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## ABSTRACT

Coaches and athletes must consider four elements when attempting to develop performance in high-power sports: muscle hypertrophy, neuromuscular activation, stretch-shortening cycle, and skill. Performance in high-power activities, such as sprinting, jumping, and throwing are moderately related to basic measures of strength, such as the bench press and deadlift. Muscles hypertrophy when subjected to tension. The training program must be structured to maximize tension during workouts, which requires the proper combination of training and rest. High-power athletes should include presses, pulls, and squats in their programs. Neuromuscular activation training turns of larger, stronger motor units and activates them more quickly. This fitness component is best developed through plyometric and speed exercises. These training techniques transfer fairly rapidly to motor skills. Activation of the stretch-shortening cycle is central to performance in high-power sports. While elastic facilitation of movement can be developed through plyometrics, it is best made through proper execution of skills. Skill is an essential factor contributing to power formation. Skills are highly specific. Small improvements in technique can often result in large changes in power output on the playing field. This paper explores the association between muscular power and performance and reviews the research on how to train to improve muscular power expression in high-power sports.

*Key words: skill, jumping, sprinting, weight training, plyometrics*

## Introduction

High-power sports involve fast, powerful movements. They include the throwing, jumping, and sprinting events in athletics, basketball, football (soccer and American), volleyball, baseball, weight lifting, handball, and tennis. One of the distinguishing attributes of a successful high-power athlete is the ability to exert force rapidly when performing various movement skills (7). Increasing power enhances performance in high-power sports. Empirical and experimental evidence suggests that sports movements can become more powerful by increasing skill, enhancing the capacity of the neuromuscular system to exert force rapidly, and increasing the capacity of the contractile tissues in muscle to exert force.

Coaches, athletes, and researchers often assume that improvements in strength, developed through resistive or plyometric exercises, automatically result in more powerful movements in specific sports. For example, discus throwers sometimes sup-

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pose that if they increase the weight they lift in the bench press, squat, snatch, or clean, they will automatically throw the discus further. A large body of research and empirical evidence suggests otherwise.

Movement skills are highly specific. In spite of widely held beliefs of strength transferability to motor skills, research suggests that improving strength does not automatically result in more powerful movements and improved performance (28, 31, 35). Strength transfer occurs only when strength and power development programs are specific and thoroughly integrated into skill development.

### The Relationship between Strength and Performance in Selected High-Power Movements

A logical relationship exists between increased strength developed through weight training or plyometric exercises and increased power during motor performance. Much of the evidence for strength to power transfer is circumstantial. Performances in most high-power sports have increased rapidly since the widespread use of weight training that began in the 1950's. For example, the world records in the shot put and discus throw increased by over 70% between 1950 and 2001. Concurrently, strength levels (as measured by maximum weight lifts) of elite high-power athletes increased substantially. Paradoxically, many research studies have failed to establish consistently a link between increased strength developed through resistive exercise training and increased power when performing motor skills (28, 31, 35).

Strength, as measured by maximum weight lifts, is related to performance in complex and basic motor skills. Figures 1-2 show the relationship between performance in the discus throw and maximum weight lifts in elite level discus throwers (16). The subjects' best throws at the time of the study were 58-69 meters. These data were gathered during an Olympic development discus throwers camp in the United States. Bench press (r=0.61) and dead lift (r=0.55) strength, but not squat strength, were significantly related to performance in elite thro-

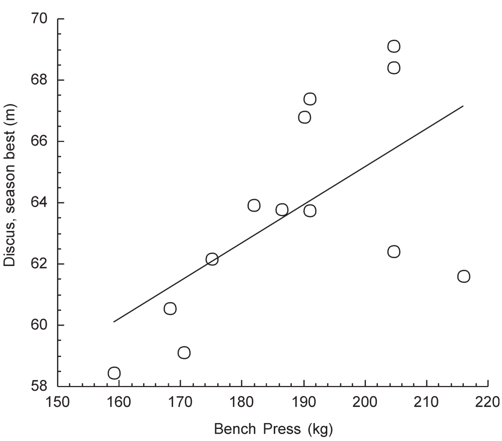


Fig. 1. *The relationship between bench press and season best discus throwing performance; r = 0.61; Discus performance (m) = 40.34 + 0.13 bench press (kg). Source: Fahey (in press)*

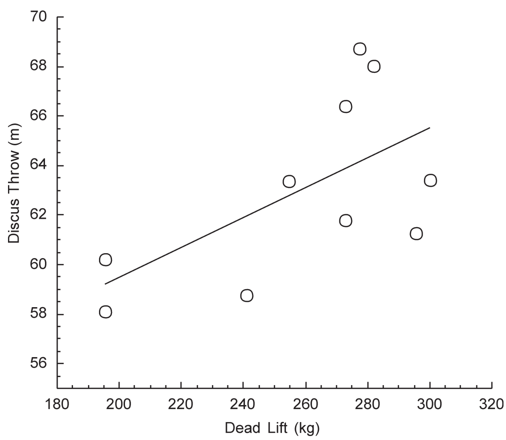


Fig. 2. *The relationship between dead lift and discus throwing performance; r= 0. 55; Discus performance (m) = 49.06 + 0.056 dead lift (kg)*

wers. The study showed that basic strength - as measured by high-tension weight lifts - is important for performance in high-power sports, such as the discus throw. These data have obvious limitations - small sample size and some heteroscedastic scatter - but, they are consistent with the relationship between strength and performance in other sports.

Similar results were found in jumpers and sprinters (unpublished data). Figure 3 shows the relationship between strength (as measured by the Cybex Lift-Taskmaster, an isokinetic device similar to the isometric leg and back dynamometer) and vertical jump performance in jumpers (high jumpers, basketball players, and volleyball players), body builders, and sedentary controls. Among jumpers there was a significant relationship between strength and vertical jump (r=0.74). Body builders showed a si-

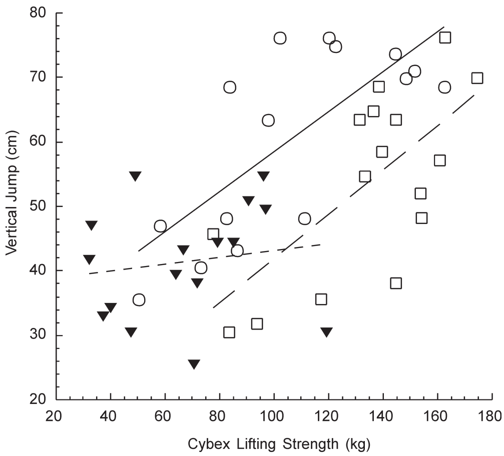


Fig. 3. *The relationship between vertical jump performance and lifting strength (Cybex Lift Taskmaster) in jumpers ○(r=0.74), bodybuilders □ (r=0.68), and control subjects ❑ (r= 0.15)*

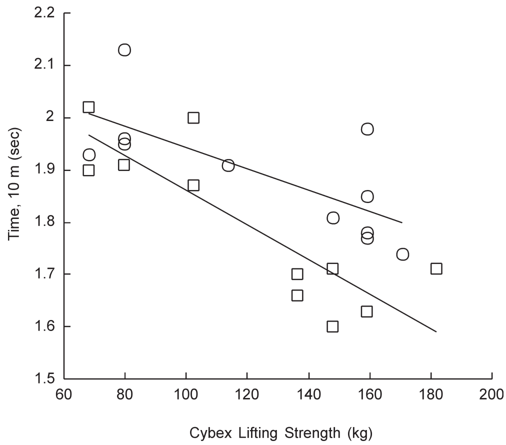


Fig. 4. *The relationship between strength and speed in sprinters □ (r=0.85) and non-sprinters ○ (r= 0.72) at 10 m of a 30 m maximum sprint*

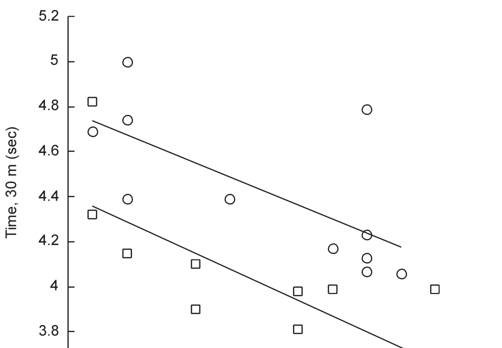


Fig. 5. *The relationship between strength and speed in sprinters □ (r=0.72) and non-sprinters ○ (r= 0.68) at 30 m of a 30 m maximum sprint*

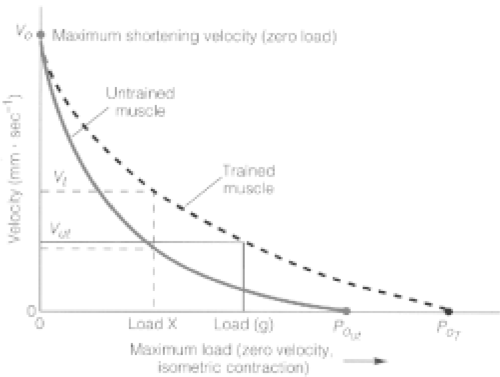


Fig. 6. *The force-velocity relationship in muscle and the effects of training. Increased muscle strength following training causes an increased shortening velocity at any percentage of maximum tension. Thus, the stronger muscle can shorten faster.*

milar relationship (r=0.68), but the y intercept of the regression was significantly lower. There was no relationship between strength and vertical jump in untrained controls (r=0.15).

Dove-Edwin (14), who studied the relationship between strength and sprint starting velocity, found a strong relationship between strength and speed, particularly over the first 10 meters (Figures 4-5). During the first 10 meters, the slope of the relationship (Speed = -0.0033 strength + 2.19, r= 0.85 vs. Speed = -0.002 strength + 2.15, r= 0.72) was greater in sprinters than non-sprinters, which suggest that strength has a relatively greater effect on starting velocity in accomplished sprinters than in athletes who are not trained sprinters. At 30 m the slopes between sprinters and non-sprinters were similar (Figure 5). These data agree with those of Young, et al. (42) who found that the single best correlate of maximum sprinting speed was the force applied at 100 ms of the sprint start.

A high relationship between strength and performance has been found in other high-power sports, including football (soccer) (40), alpine ski racing (2), wrestling (17), shot-putting (17), American football (19), basketball (4, 21, 22), rowing (26), synchronized swimming (41), gymnastics (3), rugby (29), golf (25), and tennis (37). However, this relationship is not always evident in children. No relationship between strength and performance was found in young swimmers (6), tennis players (6), or untrained subjects (10). Strength plays an important role in performance in high-power sports and serves as a basis of performance in high power sports.

**Muscle Cross Sectional Area and Power**

Muscle strength, power, and size (cross sectional area) are highly related (13, 18). Ford, et al. (18) found that in weight lifters the weight lifted varied almost exactly with height squared ($Ht^{2.16}$), suggesting that muscle mass scaled almost exactly with height cubed ($Ht^{3.16}$) and that muscle cross-sectional area was closely correlated with body height. In vivo the muscle shortens at different velocities depending on the load placed on the muscle during contraction (7). As load is increased, the velocity decreases (Figure 5). Increased muscle strength following training causes an increased shortening velocity at any percentage of maximum tension. Thus, the stronger muscle can contract faster.

The product of the force and velocity at which the muscle shortens determines the power output. A number of major factors combine to influence the power developed by skeletal muscle fibers, including the frequency of stimulation (force), the number and size of motor units and therefore, the number of crossbridges cycling in parallel (force); the position of fiber length relative to the optimal length-tension relationship (force); the position of fiber length relative to the optimal length-tension relationship (force); the length of muscle fibers and therefore, sarcomeres in series (velocity); and the myosin ATPase activity (7).

Muscle tension is the essential factor in making muscle fibers larger (9, 15, 20, 27). Muscle tension speeds the movement of amino acids into muscle cells. The faster amino acids move into the muscle, the greater the rate of protein synthesis (20). Optimal muscle hypertrophy depends on increasing the rate of amino acid transport into the cell. Any training program designed to stimulate muscle growth should attempt to insure a high intensity and duration of muscle tension.

The goal for improving this component of power development in high-power athletes is to subject the muscle to high-tension loads during training. However, this must be balanced with skill development.

It makes little sense to sacrifice technique development to develop large muscles. High-power sport training should always emphasize skill development, supplemented by exercises that develop hypertrophy, neuromuscular activation, and the stretch-shortening cycle.

**Neuromuscular Activation**

Powerful movements depend not only on muscle force, but also on the nervous system's ability to activate the muscles (33). Weight training, speed exercises, and plyometrics can cause adaptive changes in the nervous system that helps activate and coordinate muscles. This results in more power and improved performance.

Human motor units vary considerably in their force generating capacity, contraction speed, resistance to fatigue, and recruitment thresholds (32). Training can influence motor unit recruitment patterns to create coordinated, powerful movements (32, 33). Skill training, of course, is a critical part of coordinating motor unit recruitment patterns.

High-power athletes must specifically overload the neuromuscular system with plyometric and speed-building exercises to stimulate increases in power and speed of contraction. Muscle hypertrophy from resistance training is accompanied by a conversion of type IIb to type IIa muscle fibers (type IIx to IIa in humans). Caiozzo and co-workers (8) found that high-resistance training produced a rapid (i.e., after two training sessions) elevation in the fast type IIx Myosin Heavy Chain mRNA isoform and a corresponding repression of the fast type IIb MHC mRNA isoform. This slows the contractile velocity of the muscle at the level of the actin and myosin.

Doing power and speed-building exercise may attenuate the effects of heavy resistive exercise on the muscles' contractile apparatus and increase the speed that the nervous system can activate the muscles. This concept has been supported by recent studies. Delecluse and co-workers (11, 12) found that a combination of speed and resistive exercise markedly decreased sprint times, while sprinting or resistive exercise by themselves had no effect. Harridge, et al. (24) found that sprint training on a cycle ergometer did not affect maximum shortening velocity in single fibers or in the relative distribution of myosin heavy chain isoforms. Yet, the subjects improved their speed by 7% and leg muscle strength by 7-16%.

Training for power and speed sports requires the development of muscle hypertrophy to improve the force generating capacity of the muscle. However, this by itself slows the contractile speed of the myosin filaments. This must be compensated for by increasing the speed that the nervous system can "turn-on" the muscle fibers in the motor units. Fortunately, exercises that cause muscle hypertrophy also stimulate neural activation capacity to a certain extent because they shift the muscle force-velocity curve to the right (36). So, as the muscle exerts more force - with increased cross sectional area - it also moves faster.

High-power exercises, such as plyometrics and speed exercises, are more effective for enhancing neural activation than are intensely progressive overload exercises (11, 23). A critical review of the literature suggests that speed and power exercises - such as plyometrics - should be emphasized in the weeks (6-10 weeks) before competition. Progressive overload exercises that stimulate hypertrophy and changes in muscle cell contractile capacity should be a long-term training strategy. Dynamic strength is an important foundation of power. However, it must be gradually and systematically integrated with skilled movements. Training for high-power sports requires a balance between intense progressive overload and power exercises.

**Stretch-shortening Cycle**

Elastic muscle energy enhances muscle force development in a process called the stretch-shortening cycle. During sudden movements, like jumping or throwing, stretch elastic structures. The stretch represents potential energy that can enhance the force produced by muscles' contractile component. Immediately after the muscle is stretched, it actively contracts, with the recoil of the elastic elements as well as stretch receptors assisting the force development. The storage and reuse of elastic energy during the stretch-shortening cycle are influenced by fiber type and movement techniques (7).

Improved technique is the best way to increase the use of the stretch-shortening cycle in high-power sports. For example in the discus throw, coaching athletes to concentrate on lower body movements during the technique causes "separation" between the upper and lower body that increases the use of the stretch-shortening cycle. There is also considerable evidence that the stretch-shortening cycle is trainable (1, 30, 38). Training stiffens elastic tissues and enhances muscle spindle reactivity, which enhances the action of the stretch-shortening cycle in powerful movements.

**Skill**

Motor skills are highly specific (34). They involve precise motor unit recruitment patterns that are orchestrated by the nervous system. Franklin Henry, from the University of California at Berkeley, compared this process to a computer program that is stored on a disk (7). The program - imprinted on the brain - is played back as a motor reflex. Years of motor learning research has shown skills are best developed by practicing them at the same speed and in the same manner they will be used in competition (34). As discussed earlier, research on most high-power sports shows that athletes and coaches can benefit more from improvements in skill than through improvements in strength. Skill development should never be sacrificed for strength and fitness training.

**Strategies for Transferring Strength to Skill**

Weights training exercises transfer motor skills best when the neurological activation pattern of the muscles most closely resembles the skill. Closed kinetic chain exercises, such as squats or power cleans, transfer power to motor skills (e.g., jumping), better than open kinetic chain exercises, such as knee extensions or leg curls. In a closed kinetic chain exercise, movement begins at the segment freest to move and ends at the segment that is fixed. Movements typically involve several joints moving simultaneously or in sequence, much the way they do during most motor tasks. In open kinetic chain exercises, movement begins at the fixed segment and involves typically only one joint. Exercises done on many popular exercise machines are open kinetic chain, while free weight exercises, such as squats, cleans, and snatches are closed kinetic chain.

The research of Blackburn and Morrissey (5) supports the concept of neural specificity and motor performance. They found that closed kinetic chain strength (squats) showed a higher correlation with jumping performance (vertical and standing long jump performance) than open kinetic chain strength (knee, hip, and ankle extension strength). Also, Wilson and co-workers (39) demonstrated the importance of performing strength-training exercises in postures specific to the movements they are attempting to make more powerful. Their subjects were tested in a variety of motor skills and weight trained doing exercises in erect and supine postures. They found that subjects improved most in those motor skills that used the same posture used during weight training. These studies reinforce the concept that weight training exercises should be as close as possible to the target motor skill - strengthen the muscles in the specific manner you want them to improve.

**Practical Considerations for Athletes and Coaches**

A review of the literature on power development creates much confusion. Based on available research - as well as empirical observations - the following generalities are warranted.

- Strength - as measured by large muscle exercises, such as the bench press, deadlift, snatch, and clean and jerk - serves as an important base for powerful motor performance. Strength is best developed in athletes by centering the program around presses (e.g., bench press, military press, incline press), pulls (e.g., snatch, clean, high pull), and squats (e.g., squats and leg presses).
- Improved strength does readily cause more powerful movements in sport. Rather, increased strength is only valuable when it can be effectively integrated into the skill.
- Training methods that increase neuromuscular activation and the stretch-shortening cycle should be part of every program to improve performance in high-power sports. These methods include specific skill training (at full speed), plyometrics (e.g., box jumping and medicine ball), speed exercises (e.g., high knee, fast arm sprint exercise), and stretch-shortening cycle training (e.g., specific skill training - proper weight transfer and upper-lower body separation; and plyometrics).
- Speed and Plyometric exercises are more effective than high-tension weight training for power development over 8-12 weeks. Therefore, strength building strategies should be centered on years and athletic careers, while speed and plyometric training should help athletes prepare for specific competitions.
- Improving skill should be the essential component for producing more powerful movements. Never sacrifice skill development for a strength and fitness program.

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