

[Sports Physical Therapy]



Performance Enhancement in the Terminal Phases of Rehabilitation

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Context: There is a dearth of literature on the performance enhancement in the recovering athlete in the terminal phases of rehabilitation. There are established training methods that target strength, power, speed, endurance, and metabolic capacity that all lead to performance enhancement.

Evidence Acquisition: A PubMed search from 1980 to 2010 was undertaken for articles in English. Additional references were accrued from reference lists of research articles.

Results: Multiple options are available to improve strength, power, speed, endurance, and metabolic capacity during rehabilitation.

Conclusion: Sports clinicians have several components to address in the rehabilitation of a recovering athlete in addition to performance enhancement. Sports clinicians should focus their efforts on increasing power, a product of maximum force and speed of performance.

Keywords: performance enhancement; rehabilitation; complex training; plyometric training; heavy chain training; strength training; speed training; postactivation potentiation

The terminal phase of rehabilitation in the recovering athlete is arguably the most challenging time frame for the sports clinician. In the early phases of an athlete's recovery from an injury or a postoperative condition, an impairment-based program of pain control, minimization of swelling or effusion, and the gradual regaining of range of motion and strength allows a gradual increase in activity. Algorithm-based progressions for the upper and lower extremities ensure a stepwise progression with objective clinical landmarks.¹⁹ The 2 main challenges facing the sports clinician are designing a rehabilitation program that balances proper recovery with the high demand of return to sports and that replicates the speed and complexity of competition. The terminal phases of a rehabilitation protocol should be a hybrid of sports physical therapy and strength and conditioning.

The terminal phase of rehabilitation is defined as the time frame from when the athlete is completing an algorithm-based progression (anthropometric measures, range of motion, strength, isokinetic testing, functional tests) to when he or she is released to participate in sports.

A host of studies discuss rehabilitation functional testing and sports performance, but there is a paucity of data on performance enhancement for return to sport. This article

emphasizes important components of performance and provides examples of exercises for the terminal phases of rehabilitation to improve power and metabolic capacity.

COMMON PERFORMANCE TRAINING METHODS

There are 3 distinct schools of thought regarding which method of training results in optimal performance gains in dynamic sports such as sprinting, jumping, and throwing: traditional weight training, plyometric training, and dynamic weight training.⁶² Traditional weight training with relatively heavy loads (80% to 90% of 1 repetition maximum [RM]) for relatively few repetitions (4-8 repetitions) improves strength and can enhance power to a greater extent than light loads.^{51,52} Gains are dependent on the size theory of motor unit recruitment⁴⁸: training fast twitch motor units responsible for dynamic performance. Zatsiorsky and Kraemer proposed that maximal strength is best trained by the "conjugate method,"⁶³ comprising 3 components: first, the maximal effort method, involving resistance of at least 90% of 1 RM; second, the dynamic effort method, lifting submaximal weight at the fastest speed possible; and finally, the repetition method, lifting submaximal weight to failure.⁶³

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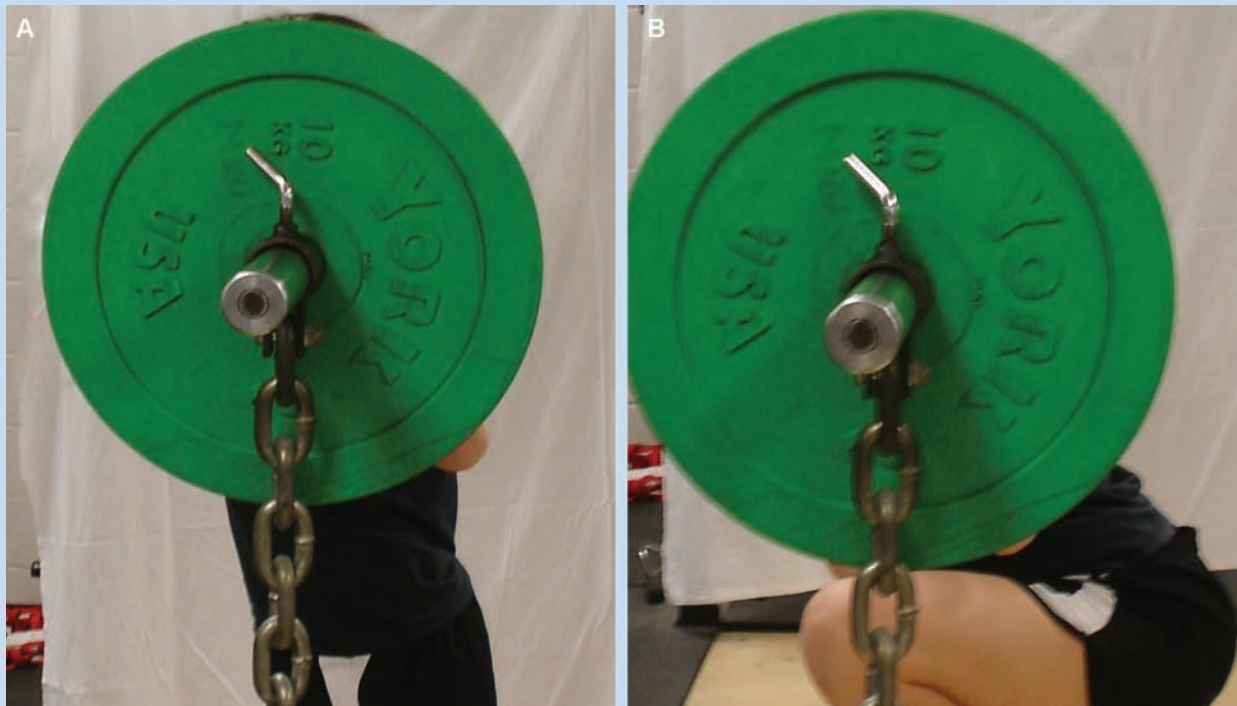


Figure 1. Heavy chain squats. The weight of the chains increases the eccentric load in the descent (A), but then concentric load increases as the athlete returns to the start position (B).

The second school of thought is to use plyometric training to improve muscular power and rate of force development, which may lead to improvements in dynamic athletic performance such as sprinting and jumping.¹¹ Additionally, plyometric training serves as a bridge between strength and power.¹¹ Finally, dynamic weight training involves relatively light loads (approximately 30% of maximum) at high speed, which results in the highest mechanical output and the greatest gains in power. A 30% 1-RM load has been recommended for the greatest mechanical power output.^{33,41,62} Baker et al⁵ found that performing jump squats at a range of 47% to 63% of 1 RM was most effective at maximizing power output.

Training for Strength

Strength is the ability of the muscle to exert force or torque at a specified velocity.³⁴ It is an essential component of all rehabilitation and performance enhancement programs, and it can vary among muscle actions.³⁵ Because all muscles function eccentrically, isometrically, and concentrically in the sagittal, frontal, and transverse planes, an integrated training program should utilize a multiplanar training approach using the entire muscle and velocity contraction spectrum.^{9,24,28}

Eccentric training produces more force than concentric training.³⁶⁻³⁸ A recent meta-analysis comparing eccentric to

concentric training found that eccentric training is more effective at increasing total and eccentric strength, as well as muscle mass, and that it is superior to concentric training for rate of force development.³⁴

Clinically, eccentric exercise can be applied by completing the concentric portion of the lift with both extremities (ie, leg press) and by using only the involved limb for the eccentric portion. Alternatively, the athlete can be assisted with the concentric portion of the lift while he or she completes the eccentric portion independently. Eccentric training is gaining support in rehabilitation, producing elevated strength in rehabilitation after an anterior cruciate ligament reconstruction.²⁵

Variable resistance training using elastic bands or heavy chains (Figure 1) has gained popularity.^{17,43,61} The training premise is twofold: (1) Load increases where the muscle has more leverage in early phases of a lift, and (2) load decreases where the muscle has little leverage in later phases of a lift.²⁶ Eccentric load increases early in the lift because the chain links are added during the descent, and it decreases as the links accumulate on the ground. Conversely, concentric load increases as chain links lift off of the floor. Both elastic band and weighted chain training increase overall maximum upper body strength in Division I football players.²⁶ Eccentric unloading may cause a rapid stretch shortening cycle and a within-repetition postactivation potentiation.⁷

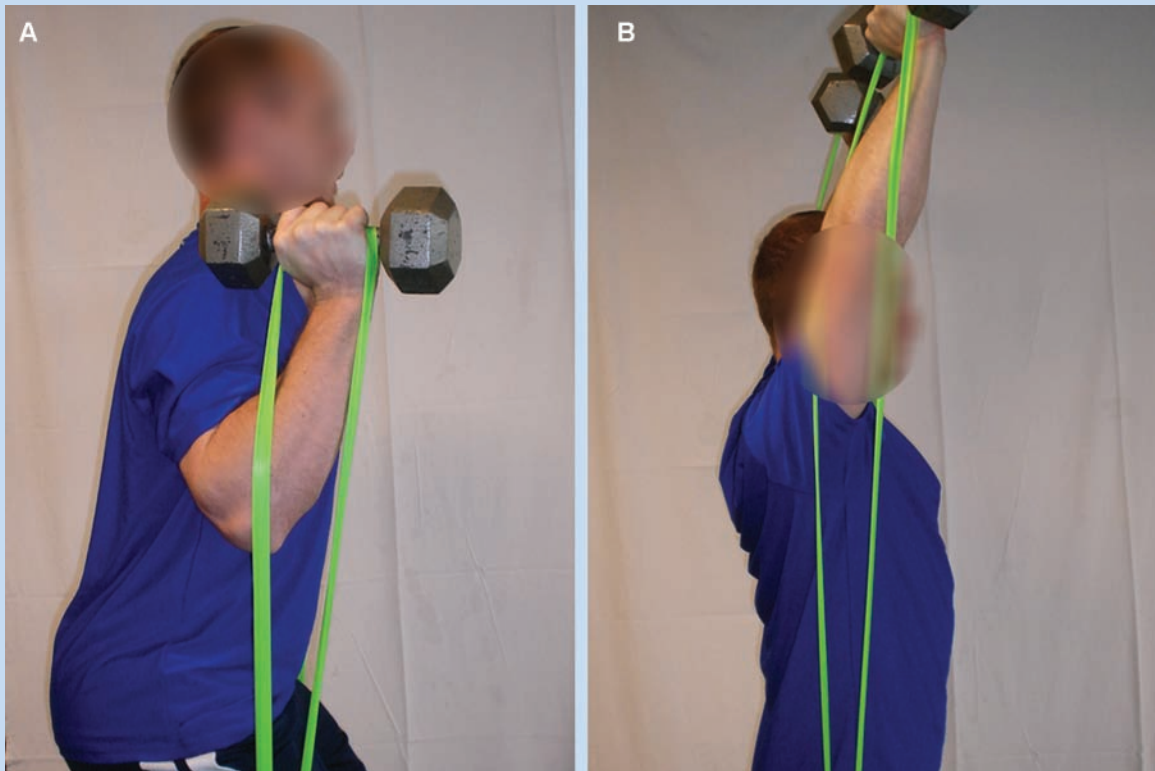


Figure 2. A, start position for dumbbell jerk/split jerk with elastic bands; B, end position for dumbbell jerk with bands.

It may not be feasible to use chains; however, tubing and exercise bands are readily available and can be attached to the ends of dumbbells while an athlete performs dumbbell bench presses, dumbbell overhead presses, dumbbell push jerks (Figure 2), split jerks (Figure 3), or barbell exercises of the same sort. Alternatively, lunges, squats, and step-ups could be performed with bands on the ends of PVC pipe or a similar device.

Training for Power

Power is work per unit of time ($\text{force} \times \text{distance}/\text{time}$) or $\text{force} \times \text{velocity}$ ($\text{distance} \times \text{time}$). Time is an essential element when training for power. Rate of force development is the rate at which strength increases.⁵⁵ It is the most important neural adaptation for the majority of athletes.¹⁵

Training programs for power require both high-force and high-quality movements. Speed of exercise performance plays a vital role in the quality of the exercise.²⁴ The 30% RM load level is superior to plyometric training and traditional weight training (80% to 90% of 1 RM) in developing dynamic athletic performance.⁶²

Complex training may be used to develop power in the athlete by alternating biomechanically similar high-load weight training with plyometric exercises, set for set, in the same workout.¹ This routine pairs a high-force activity with a high-power activity centering

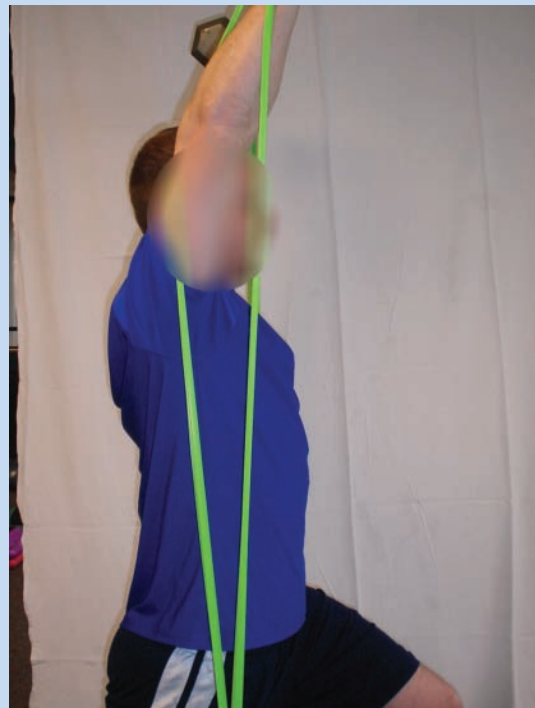


Figure 3. Dumbbell split jerk with bands: end position.

on the postactivation potentiation concept. In postactivation potentiation, the muscle force exerted is increased due to the previous contraction because the contractile history of a muscle influences the mechanical performance of subsequent muscle contractions.⁴⁷ Fatiguing muscle contractions impair muscle performance, while brief nonfatiguing contractions at high loads enhance muscle performance.⁵⁸

There are 2 proposed mechanisms of postactivation potentiation. The first is the phosphorylation of myosin regulatory light chains, which renders actin-myosin more sensitive to calcium released from the sarcoplasmic reticulum during subsequent muscle contractions.^{27,32,59,60} The second is that strength training before plyometric exercises causes increased excitation at the spinal cord, resulting in increased postsynaptic potentials and enhanced force-generating capacity.⁴⁵

There is evidence for^{18,29,39,49} and against³⁰ complex training. Repeating complex training has improved sprint performance in rugby players¹⁸ and squat jump, countermovement jump, medicine ball throw, and the Abalakov agility test in young male basketball players.⁴⁹ Matthews and others³⁹ used complex training to improve a push pass in basketball players and determined that high loads are needed to elicit a potentiation effect (85% of 1 RM). In another study utilizing complex training, college football players who performed the concentric and eccentric phases of the jump squat showed significant improvements in 1-RM squat and 1-RM power clean, emphasizing the importance of the eccentric portion of training to elicit strength and power gains.²⁹

Contrast training is another method that utilizes high and low loads in the same training session. The athlete may perform 6-repetition sets with loads between 60% and 80% of 1 RM, alternating with 6-repetition loads between 30% and 50% 1 RM at maximum speed to increase power.¹ Complex and contrast training have increased vertical jump, sprint performance, and agility in soccer players.¹ Furthermore, multijoint dynamic tests of strength (1-RM squat and 1-RM power clean) relative to body mass are closely related to countermovement jump performance.⁴⁴ Alternating heavy and light resistance in upper body complex training can be used to determine the acute effects on power output.⁴ A 5% increase in power output was seen in the group that used heavy resistance between power training sets.

Plyometric training is the most well-known form of power training. Adding complex training to the program may facilitate greater power gains. Back squats followed by countermovement jumps, depth jumps, or box jumps with rest periods between the 2 movements appear to be most beneficial with an 8- to 12-minute rest before the plyometric exercise.³⁴ Heavier loads in the strength activity require longer rest intervals. If an athlete performs plyometrics alone, full recovery between sets is encouraged to maximize power production.¹¹

Olympic weightlifting is an excellent means to develop power. These lifts maximize power production but require total body coordination, strength, and balance. There is a steep learning curve for these lifts (Figures 4-6). They can be



Figure 4. Snatch: end position.



Figure 5. Split jerk: end position.

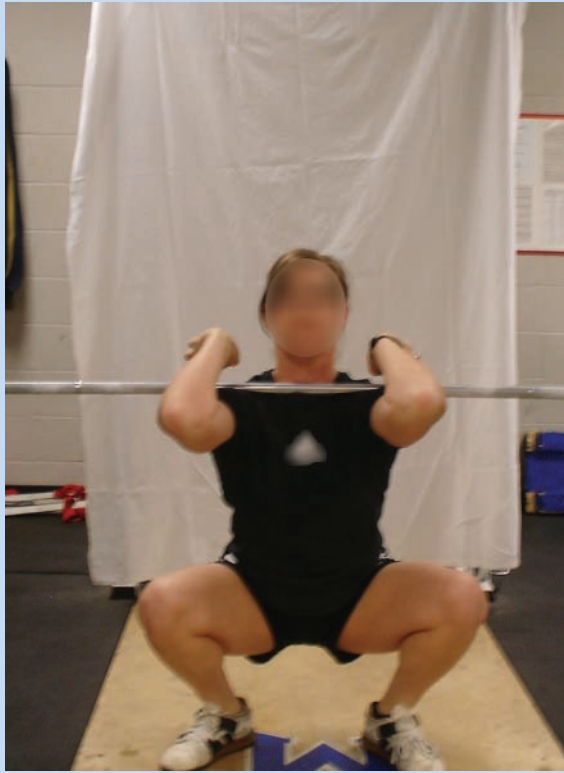


Figure 6. Clean: low catch position.

taught by breaking them down into component movements using a PVC or metal pipe or a wooden dowel. These lifts can be done with dumbbells (Figures 7 and 8), which may be more appropriate for rehabilitation. They enable the athlete to improve unilateral strength, minimize compensation by the uninvolved limb, and likely improve neuromuscular control.

Training for Speed

The 2 components of speed production are stride length and stride frequency.¹² Stride length can be improved by running uphill, bounding drills, or power skips.^{12,13} Stride frequency can be improved with fast leg drills (Figures 9-11), resisted sprints, or assisted sprints.¹³ Varied-pace sprints encourage running relaxed at high intensities and “recharging” the nervous system between maximal bouts.¹³ Resisted sprints recruit more muscle fibers and increase neural activation.¹³ Resisted sprints involve pulling a weighted sled or running with tethered resistance. Assisted sprints (harnesslike device) improve stride rate and elastic energy production.²¹ Contrary to resisted sprints, assisted sprints involve an athlete being attached to a partner who in effect “pulls” the athlete, forcing the athlete being pulled to move his or her legs faster to improve stride rate.

Intensity and training volume must be monitored when training for speed. Volume should increase gradually when training for speed, as proper technique is needed to prevent compensations or altered movement patterns. With fatigue, sprinting form is potentially sacrificed, thereby negating the positive effects of speed training. Rest periods should allow



Figure 7. Dumbbell snatch: begin (A) and end (B) positions.



Figure 8. Single-leg dumbbell snatch. Performing single-leg Olympic lifts develops strength and power as well as neuromuscular control. The athlete explodes off the contralateral leg (A) while the ipsilateral arm is elevated (B) to more closely replicate the hip and contralateral shoulder relationship, as observed in a variety of sports.



Figure 9. Toe taps. The athlete maintains the “toe up, knee up” position, taps the floor as fast as possible, and then returns to the start position. Alternatively, the athlete can switch to the contralateral leg as quickly as possible.

full recovery between sets. Speed training drills should be performed at the beginning of training sessions, before fatigue, to maximize speed production.

Training for Endurance

Endurance sports improvement is accomplished by increasing aerobic sources of energy by delaying the onset of blood lactate accumulation,⁵⁵ which is dependent on maximal oxygen consumption and the intramuscular adaptations that facilitate prolonged work.⁵⁵ To develop endurance, muscles must oxidize lactate during work and decrease dependence on glycolysis to supply energy. Endurance training eliminates the disparity between the anaerobic and aerobic abilities of muscles and lactate accumulation.⁵⁵

There are 2 types of endurance: General endurance is a base level of cardiorespiratory ability, while special endurance is related to specific activities (metabolic capacity).⁵⁵ General endurance is trained by low loads (30% of 1 RM), short rest periods (10-30 seconds), and repetitions between 20 and 150.⁵⁵ Specialized endurance training may include speed endurance: generating tension over long periods of time without a decrease in efficiency.⁵⁵ Strength endurance is developed with 25% to 50% of 1 RM, with a moderate tempo of repetition performance (60-120 repetitions per minute). Anaerobic endurance has been evaluated in elite soccer players, with and without high-intensity situational drills.⁵⁶ During the first phase, traditional sprint training was

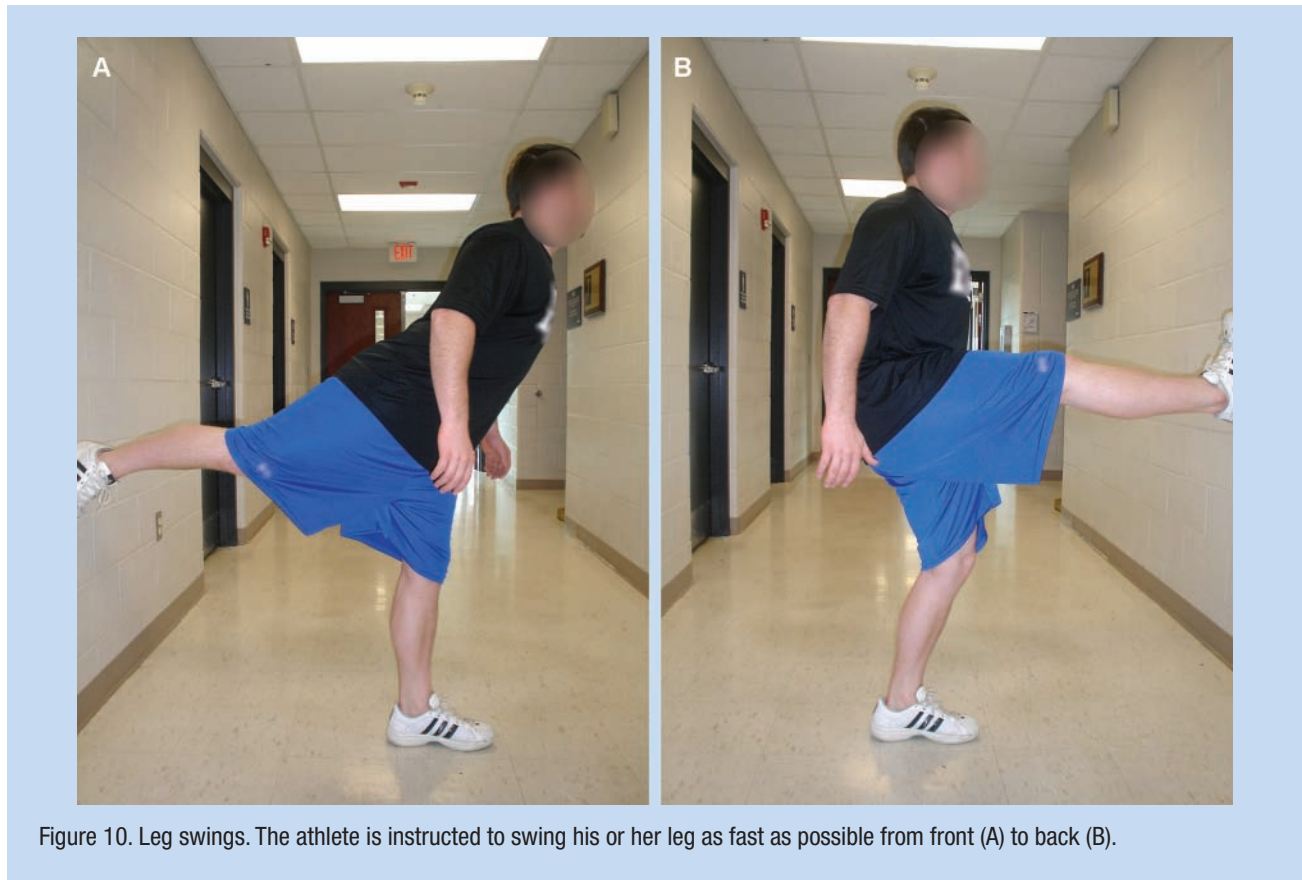


Figure 10. Leg swings. The athlete is instructed to swing his or her leg as fast as possible from front (A) to back (B).

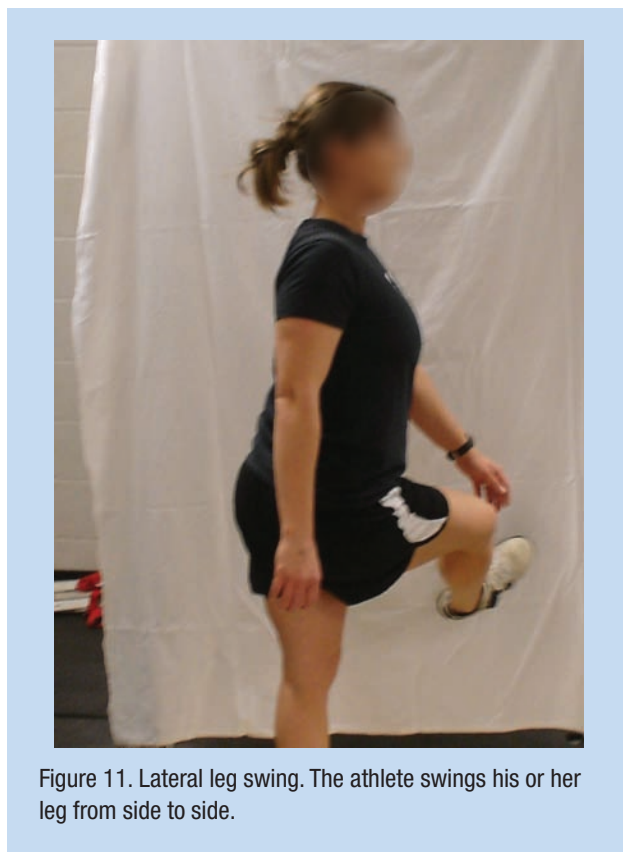


Figure 11. Lateral leg swing. The athlete swings his or her leg from side to side.

performed 2 times a week, with 15 bouts of straight-line sprinting; in the second phase, 4 × 4-minute drills at 90% to 95% of maximum heart rate, separated by 3-minute technical drills at 55% to 65% of maximum heart rate. The traditional training program in the first phase did not improve anaerobic endurance (300-yd [274.32-m] shuttle test). The second phase of training did improve endurance, demonstrating that situational, high-intensity task training is an efficient means to improve anaerobic endurance.

A mixed-intensity interval training program has also been advocated to facilitate sport-specific endurance in soccer: 30- to 90-second intervals of varying intensity over the course of 6 minutes.¹⁴ Progression involves increasing the number of 6-minute intervals.

Training for Energy System Specificity/ Metabolic Capacity

There are essentially 3 energy systems that athletes may use in sport: ATP-PC (adenosine triphosphate phosphocreatine), lactic acid, and aerobic system.⁹ The ATP-PC is used in explosive activities that require 8 to 10 seconds of maximum output: sprinting, jumping, football, and weightlifting. The lactic acid system is for events lasting around 40 seconds⁹: 200-m and 400-m runs, speed skating, and some gymnastic events. The aerobic system is for activities from 2 to 3 minutes to several hours: cross-country running and skiing. Some sports use a combination of systems, such as soccer, basketball, and volleyball.

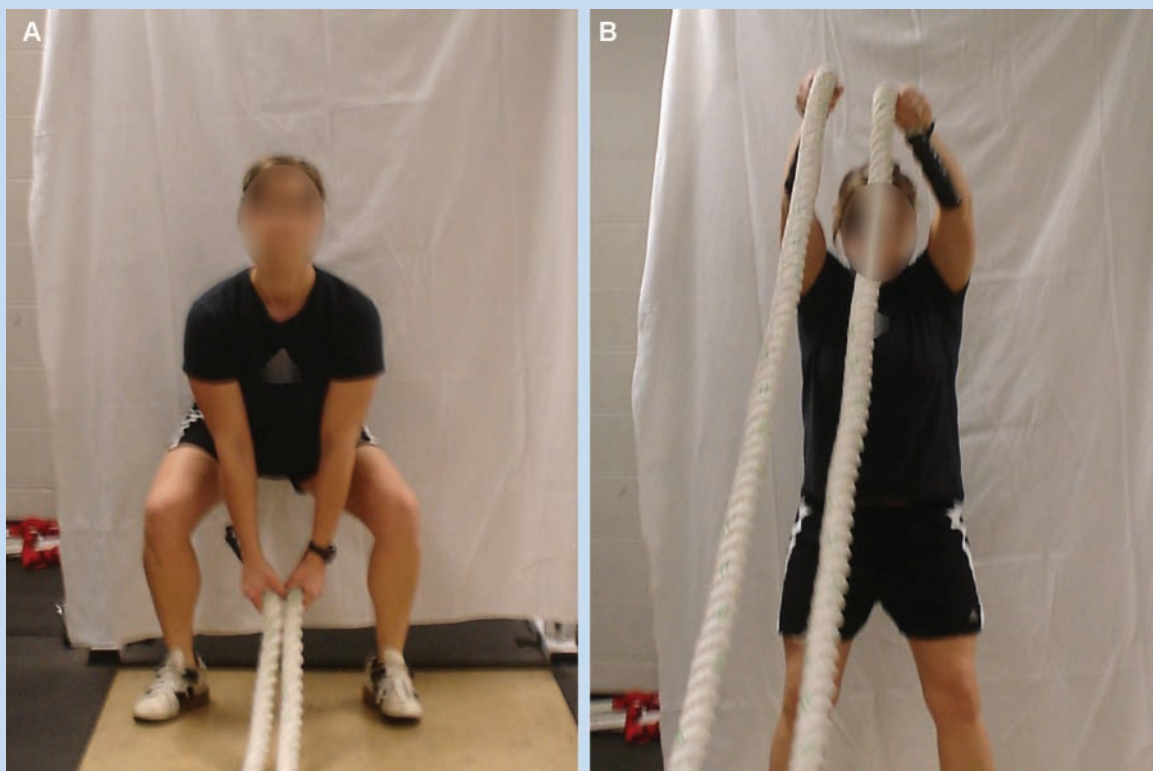


Figure 12. See-saw pattern with rope: beginning (A) and end (B).



Figure 13. Chop pattern with rope: beginning (A) and end (B).



Figure 14. Alternating-arms pattern with rope.

Exercise protocols should mimic work:rest ratios of sport. In football, for example, the average play runs 7 to 10 seconds with roughly 20 to 60 seconds of recovery.^{31,46} Therefore, high-intensity exercise with rest intervals should be part of training. Similarly, a wrestler competes in 3-minute periods of varying intensity. Progressions are made by increasing the intensity or the number of 3-minute intervals. In junior female tennis players, rally duration averages a mean of 8.2 seconds, with 17.7 seconds of rest between rallies.²³ Elite men's basketball players run at high intensity for 1.7 seconds every 21 seconds.⁴⁰ Sixty percent of basketball is low-intensity activity while 15% is high. Seventy-five percent of game time is spent with a heart rate greater than 85% of peak. Athletes can be instructed to move continuously in a given period based on sports work:rest ratios. Using heavy-duty ropes is one inexpensive method to train for increased metabolic capacity; specifically, the athlete is instructed to move the ropes in various patterns as fast as possible for a specific amount of time (Figures 12-14).

PERFORMANCE CHARACTERISTICS AND RELATIONSHIP TO ATHLETIC PERFORMANCE

The performance characteristics of high-level athletes are used to choose the training modality most likely to produce superior performance. In 46 college football players, a 36.6-m sprint

and an 18.3-m shuttle run test were predictive of performance, while height, weight, and percentage body fat were of little significance.²⁰

In prospective National Football League players, statistical significance was found between drafted and nondrafted skill players (wide receivers, cornerbacks, free safeties, strong safeties, running backs) for the 40-yd (36.6-m) dash, vertical jump, proagility shuttle, and 3-cone drill. Drafted linemen performed significantly better than nondrafted players in the 40-yd dash, 225-lb (102.1-kg) bench press, and 3-cone drill.⁵⁴

Anatomic and physiologic characteristics have been used to predict football ability,² and the only test that successfully predicts football ability is the Margaria-Kalamen power test.² At the Division IA college level, football ability correlates with vertical jump for all positions.⁵⁰

In soccer and rugby players, knee extensor torque at 240° and the initial acceleration phase (0-10 m) of a sprint correlate strongly.⁴² In elite volleyball players, sport-specific jump performance is directly related to depth jump performance, suggesting that the stretch-shortening cycle and tolerance of high stretch loads are critical.⁵³

In national and second-division rugby players, strength and maximal power are the best discriminators of elite and nonelite players, while sprinting tests do not separate the groups.⁶ Sprint momentum (body mass × 10-m sprint) is a predictor of competitive level: Heavier, faster players can repel their opponents better. Consequently, lower body strength and power should be trained while improving 10-m sprint speed.

In elite-level ice hockey players, peak anaerobic power output is important in all positions.¹⁰ Standing long jump is a predictor of hockey potential. Horizontal leg power (off-ice sprint and 3-hop jump) is the best predictor of on-ice skating performance.²²

Backward medicine ball throw is a reliable indicator of upper body power.¹⁶ Jump athletes (volleyball) score better on countermovement jump and medicine ball throws, while nonjump athletes (wrestlers) have significantly better strength scores in the 1-RM bench press and leg press.⁵⁷ Lower-limb extensor closed kinetic chain strength is related to vertical jump performance better than open kinetic chain knee extensor strength.^{3,8}

CONCLUSIONS

Performance enhancement techniques should be highly specific to the athlete's sport demands. Power production in the recovering athlete should be maximized to optimize performance. Elite athletes are more powerful and explosive than their counterparts, emphasizing the need to focus on performance training in the recovering athlete. Power relates directly to agility and speed. Height, weight, percentage body fat, and flexibility do not appear to be as important in athletic performance.

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