Review and Role of Plyometrics and Core Rehabilitation in Competitive Sport

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Abstract
Core stability and plyometric training have become common elements of training programs in competitive athletes. Core stability allows stabilization of the spine and trunk of the body in order to allow maximal translation of force to the extremities. Plyometric training is more dynamic and involves explosive-strength training. Integration of these exercises theoretically begins with core stabilization using more static exercises, allowing safe and effective transition to plyometric exercises. Both core strengthening and plyometric training have demonstrated mixed but generally positive results on injury prevention rehabilitation of certain types of injuries. Improvement in performance compared to other types of exercise is unclear at this time. This article discusses the theory and strategy behind core stability and plyometric training; reviews the literature on injury prevention, rehabilitation of injury, and performance enhancement with these modalities; and discusses the evaluation and rehabilitation of core stability.

Introduction
Core stability and core strength have been seen as an important aspect of preventing back pain since the late 1980s and 1990s. In the athletic population, especially elite athletes, core strength often was assumed to be excellent, or if found to be weak, improvements in core stability would allow these athletes to perform better or rehabilitate from injuries more effectively. However, this may not necessarily be true (28). The purpose of this article was to explain the theory behind core stability and plyometrics and explore the role of these modalities in the competitive athlete.

What is Core Strength and Stability?
It should be understood that there is no single universally accepted definition of core stability, but the concept of Kibler et al. (24) summarizes core stability as “the ability to control the position and motion of the trunk over the pelvis to allow optimum production, transfer and control of force and motion to the terminal segment in integrated kinetic chain activities.” The core of the body includes the spine, hips, pelvis, proximal lower limbs, and the abdominal region. This often is defined as a muscular box with the abdominals in the front, the paraspinals and gluteals in the back, the diaphragm as the roof, and the pelvic floor and hip girdle musculature as the bottom (2). The strength of these muscles allows the system to stabilize the spine mechanically and then distribute and deliver compressive, translational, and shear forces to and from the rest of the body (15).

Theory and Value of Plyometrics
Plyometric training is a specific type of training involving exercises in which the active muscles are stretched prior to shortening and usually requires explosive-strength training. This type of training has been reported to invoke specific neural adaptations such as increased activation of the motor units, with less muscle hypertrophy than typically observed after heavy static resistance strength training (41). Plyometric exercises can be done with or without external load. Many studies combine both heavy strength training and plyometric exercises, and some studies have shown that power and power-related skills are improved to a greater extent when combining heavy strength training and plyometrics than either modality alone (1).

Theory of Integration
In rehabilitation from injuries, athletes have received benefit from both strength exercises and plyometric training; the integration of both of these components may yield even better results (32). The overall goal in athletic rehabilitation is to return the athlete back to full participation as soon as possible. Most sporting events require supranormal
levels of conditioning and explosive application of strength, which frequently can lead to reinjury. In theory, before returning to sport, the athlete must first demonstrate competence with plyometric exercises, and before these exercises can be safely performed, they first must increase their core stability safely with static load strength training. Effective recovery from injury must begin with increased strength, progressing to safe ballistic training before returning to the sport that caused the injury.

Prevention of Injury

Deficiencies in certain aspects of core stability may predispose athletes to injuries of the back and lower extremities. Delays in trunk motor control reflex have been linked to back pain and seem to be a predisposing factor (8). In addition, athletes with deficiencies in hip abduction and external rotation have been shown to be at a higher risk of injuries of the back and lower extremities (29). More specifically, weakness in the gluteus medius, vital for hip abduction, seems to play a role in the development of patellofemoral pain in women (48). Early fatigue in core musculature also may play a role in predisposing athletes to injury, as fatigue of the abdominal muscles has been found to be a contributor to hamstring injuries (12). There also may be gender differences in whether core stability plays a role in risk of injury, as suggested by Zazulak et al. (49), who found that increased trunk displacement and decreased proprioception on testing predicted knee ligament injury for women, although these findings were not predictive in men.

Some clinicians have suggested that, in athletes, dynamic testing of core strength and plyometric ability may be more appropriate to determine who is at risk for injury, as opposed to more static core strength testing (9,36). One such screening test is the Functional Movement Screen (FMS), a series of seven movements performed by athletes, in which range of motion, stabilization, balance, and symmetry are tested and scored by an observer based on set criteria. At this point, data to support or refute the FMS as an injury predictor are limited, although one study in professional football players did find a significant correlation between lower scores and increased risk of injury (26). Other studies also have found that scores below a certain level did correspond moderately with any type of injury and strongly with serious injury in military officer candidates (35,38). Whether rehabilitating an athlete’s core stability in those with deficiencies actually decreases subsequent risk of injury, however, remains to be seen. Kiesel et al. (25) were able to note an improvement in football players’ FMS score following an off-season intervention program that focused on each player’s deficiencies on a previous FMS screening test. At this point, whether this improvement in scores will result in fewer injuries has not been evaluated yet.

Logical deduction would suggest that if, as these studies suggest, patients with core deficiencies are at increased risk of injury, then correction of these core deficiencies would help to prevent injury. At this time, current data are lacking to show a relationship between core exercise and primary prevention of injury. One intervention program combining strengthening, coordination, and core stability exercises for the pelvis in Danish soccer players failed to show a statistically significant reduction in groin injuries, although the risk of groin injury was reduced by 31% in players receiving the additional program (22). A large female youth soccer study in Norway also did not find any significant reduction in injury for the intervention group who underwent core strengthening in addition to balance, dynamic stabilization, and eccentric hamstring stretch (45).

Literature supporting the role of programs designed to improve neuromuscular control in improving biomechanics and theoretically preventing injury is more robust in female athletes, although still lacking in male athletes. There seems to be a link between improved neuromuscular control and decreased injury risk, although the specific role of plyometric training in these programs is unclear at this time. Myer et al. (32) found that a training program including plyometrics, core strengthening and balance, resistance training, and speed training did decrease knee valgus and varus torques in female athletes, although it is unclear which component of the program played the greatest role in improvement of biomechanics.

Perhaps the most impressive data regarding actual prevention of injury with plyometric and neuromuscular training come from Hewett et al. (17,18), who have shown that this type of training is beneficial in preventing anterior cruciate ligament injury in females. In addition, a meta-analysis found that several neuromuscular training programs are effective in decreasing knee injury rates (16). In males, data are very limited, although the use of plyometric training in triathletes has been shown to correct altered neuromotor control when triathletes transitioned to running from cycling, theoretically reducing risk of injury (5).

Treatment of Injuries

Much of the literature regarding the use of core stabilization and plyometric exercise in treatment of injury exists in reference to back pain. The presence of poor core stability in patients with back pain, as well as sacroiliac pain, is common (19–21,23). As Akuthota et al. (2) noted, the evidence for core stabilization exercise as treatment for back pain, however, is mixed and may not be more effective than other exercise regimens.

Patellofemoral pain also has been linked to weakness in trunk and core muscle strength, particularly in women with delays in activation of the gluteus medius (10). Two studies have shown improvement in pain symptoms of patellofemoral pain syndrome with strengthening of hip and core musculature (14,33). It also has been our clinical experience that strengthening, focusing initially on gluteus medius rehabilitation using side leg raises and side plank exercises with eventual progression to more dynamic combination of these two exercises, is effective in improving both biomechanics and pain scores in patellofemoral pain syndrome. Randomized trials are needed to determine the existence or extent of any true improvement with this intervention.

Effect on Performance

The relationship between core stability, plyometrics, and performance has not been defined clearly yet. Part of the difficulty in determining this relationship is difficulty
in establishing how to best test both core strength and performance. There are too many variables at play in most sports to link any change in performance directly to core strengthening and plyometrics, and therefore, substitute measures are used to try to determine any improvement.

Several studies have attempted to determine the relationship between core strength and sports-related athletic testing. Sharrock et al. (42) did note a correlation between core strength, as measured by a double-leg lowering test, and testing a medicine ball throw. However, no relationship was noted between core strength and the 40-yd dash, agility run, or vertical jump. Nesser et al. (34) measured core strength using the trunk flexor test, trunk extensor test, and lateral musculature test and compared performance in the bench press, squat, power clean, 20- and 40-yd sprint, shuttle run, and countermovement vertical jump in college football players. Results were inconsistent, although there were mild-to-moderate correlations between core testing and performance measurements, suggesting perhaps a potential weak relationship between core strength and performance.

Other studies have evaluated a group of athletes undergoing a core strengthening program and compared pre- and postprogram sports-specific testing measures versus those of controls. Tse et al. (46) found no correlation between a core strengthening program and the vertical jump, broad jump, shuttle run, 40-m sprint, overhead medicine ball throw, or 2,000-m maximal rowing ergometer test in college-aged rowers. Stanton et al. (44) looked specifically at Swiss ball training to improve core strength and found no improvement in treadmill VO2max, running economy, or running posture compared to controls. Sato and Mokha (40), however, did note some improvement in 5,000-m run time in the core strengthening group compared to controls.

Similar to studies in prevention, there is some question whether there is disparity in validity of static core strength testing versus dynamic testing. Okada et al. (36) found no correlation between isometric strength of the core and dynamic movements in the FMS, suggesting that strength on isometric strength of the core is not necessary to score well on more dynamic movement screening. Although there were several correlations between each of these screening tests, the authors concluded that “moderate to weak correlations identified suggest core stability and FMS are not strong predictors of performance.”

Plyometric training techniques are diverse but, as a general rule, employ fast, powerful movements with jumping and other sports-related movement. Most data have shown a positive effect of plyometric training on performance with several specific athletic movements or tests. Vertical jump height has been shown to be improved using a traditional program consisting of static flexibility, balance, strengthening, agility, and plyometric exercises in young athletes (13). Running economy also has been shown to improve with short-term plyometric training in highly trained runners (41,43). Plyometric training also has been shown to improve peak power output, squat jump, countermovement jump, and sprint velocity in soccer players during the season compared to controls (6). Improvements also have been seen in studies with swimmers and preadolescent boys (27,37). A meta-analysis of plyometric training studies also found an association between training programs and vertical jump height, although both randomized and non-randomized trials were included in the meta-analysis (30).

Not all studies have found performance-enhancing effects of plyometric training. Ronnestad et al. (39) found that plyometric training added no additional gain in professional soccer players when added to a strength training regimen. It is also not clear whether plyometric training by itself is superior to other training methods. The study of Ronnestad et al. did not include a plyometrics-only group, but the strength training-only group was noted to have gains compared to controls. Olympic weight training also has been noted to have an effect similar to that of plyometric training on vertical jump height (3). Sprint training has been reported to have training effects in athletic performance similar to or even greater than those of plyometric training (31).

How to Evaluate Core Strength and Deficiencies

Considering the wide variety of movements associated with sports, intuitively, athletes must possess sufficient strength in hip and trunk muscles to provide stability in all three planes of motion. Research demonstrates that the contribution of different muscle groups to lumbar stability depends on the direction and magnitude of trunk loading (7). The abdominals control external forces that might cause the spine to extend, laterally flex, or rotate and control excessive anterior pelvic tilt. Hip abductors and external rotators also play an important role in lower extremity alignment. They help maintain a level pelvis and prevent excessive hip adduction and internal rotation during single-limb support (29). In addition to this, biomechanical studies have shown that hip muscle activation significantly affects the ability of the quadriceps and hamstrings to generate and resist forces experienced by the entire leg during jumping (4).

Many tests have been proposed for assessment of core stability in the general population, but there is a lack of consensus on how to measure core strength (2). Athletes often have reassuring results when tested by low-exertion examinations, but the demands of their sport require significantly increased core strength and control in order to resist fatigue. The following is the protocol we use to evaluate for core strength and deficiencies. The first test, performed while the patient is standing, is observational. Without giving the patient any verbal clues, one looks at the alignment of the pelvis from the side. Ideally, the waist should be horizontal, with engagement of the trunk musculature (Fig. 1A). If the pelvis tilts forward, oftentimes, one will find weakness in the quadratus lumborum, rectus abdominis, and obliques (Fig. 1B). The single-leg squat is a functional, closed-chain test that has been shown to be a reliable test for global core stability (11). The starting position is to stand on the test leg with the hip and knee in neutral anatomical position. The athlete then moves at a self-selected pace into a squat position and then returns to the starting position (Fig. 2A). It is our belief that if core stability is present, then throughout the entire plane of motion, alignment should be maintained between the hip, knee, and ankle, without the contralateral hip dropping and the knee moving into valgus (Fig. 2B). If this is performed competently, then one moves into a progressively more difficult test: the lateral step-down (Fig. 2C). Again,
The alignment should be maintained between the hip, knee, and ankle. The last global assessment of core instability is plyometric: the hop test. This is performed on one foot at a time in a similar fashion as the single-leg squat. The athlete begins the test in a squatted position, jumps off the floor, and lands. The examiner should assess for knee alignment, height of jump, and stable, aligned soft landing.

The next assessments are done with the athlete lying on his or her side, testing both injured and uninjured sides for comparison. These tests can be used as instruction for a static strengthening program directed to the athlete before plyometric rehabilitation is begun. The side plank or bridge measures lateral core strength, particularly the quadratus lumborum (Fig. 3A). The athlete is positioned on his or her side supporting the upper body on the elbow in 0 degrees of trunk flexion with legs fully extended and feet placed one on top of the other. He or she is asked to lift his or her hips off the table, using only his or her feet and elbow for support. The examiner records how long he or she can hold this position. In our experience, this position should be held without alterations in form for 45 to 60 s to demonstrate competency. The next test, the side leg raise, measures hip abductor strength, primarily the gluteus medius (Fig. 3B). The athlete is positioned on his or her side in 0 degrees of trunk flexion with legs fully extended and feet placed one on top of the other. The upper leg is abducted completely with maximal hip external rotation to fully recruit the gluteus medius, at which point the examiner resists this motion. Subjectively, strength can be assessed as strength of 3, 4, or 5 of 5. If the athlete performs both of these tests with competence, they are combined. This combination, side plank and side raise, is more demanding, and we suggest it should be performed with competence before progressing to plyometric rehabilitation (Fig. 3C). As discussed previously, the athlete is positioned on his or her side supporting his or her upper body on his or her elbow in 0 degrees of trunk flexion with legs fully extended and feet placed one on top of the other. In this position, he or she begins to perform side raises of his or her leg, maintaining this full trunk extension. In addition to testing the muscles previously noted, the clinician now is able to assess neuromuscular coordination, hip adductor strength, and abnormal recruitment of the iliopsoas. The patient should be observed for overall stability and trunk flexion. If the abductors are weak, we believe that increased recruitment of the iliopsoas muscle is noted by forward flexion at the waist. This test is difficult for the general population to perform, but many athletes can perform at least five of

![Figure 1: Pelvic alignment examination. A. Good pelvic alignment. B. Poor pelvic alignment.](image1)

![Figure 2: Single-leg squat testing. A. Single-leg squat. Good limb alignment. B. Single-leg squat. Valgus collapse of knee. C. Single-leg side step. Good limb alignment.](image2)
these combined side plank/leg raise repetitions. Ideally, we theorize that the patient should be able to competently perform 30 of these combined raises on each side.

**Restoring Function By Addressing Core Deficiencies**

When comparing the core stability of athletes with the general population, we believe that clinicians often are reassured falsely and believe that athletes are stronger than they really are. By including the dynamic or plyometric hop test and the combined side plank/side raise, subtle strength differences may be unmasked.

Frequently, the physical therapist or the athlete will push dynamic, plyometric rehabilitation before adequate core strength is achieved, so unless the examiner can identify the weak muscular regions and intervene, the athlete often will become reinjured (47). Our recommendation is that, individually, the side plank and side raises must be performed with proper form, technique, and endurance, before the athlete is advanced to the combination exercise. The combined exercise is intense and requires coordination of the various core muscle groups on opposite sides of the body. When the athlete can perform at least three sets of 15 of this combined activity, we believe he or she will have achieved adequate core strength and stability to safely begin plyometrics. As the intensity of plyometric activity is increased without evidence of reinjury, the athlete slowly is returned to his or her sport. Plyometric activity now is intensified as his or her sport-specific demands are increased. As the athlete is allowed to return to full sports participation, core stability and strength must be maintained. A simple way of achieving this is to continue three sets of 30 of the combined side plank and side raise on each side, performed three times a week.

In our experience, the guiding principles of rehabilitation is to identify the area of weakness, obtain static muscle strength, improve neuromuscular feedback, progress to safe plyometric training, and then introduce the demands of the athletes’ specific sport. Please see the Table for a logical progression of rehabilitation from injury.

**Conclusions**

In theory, core stability and plyometric exercise are vital aspects of a training program for competitive athletes. Prior to initiation of sport-specific plyometric training, evaluation and rehabilitation of core strength should be addressed. Current data are conflicting, although there is a general consensus that each patient should be progressed individually.

**Table.**

Example of core rehabilitation and plyometric training in competitive athletes.

<table>
<thead>
<tr>
<th>General</th>
<th>Progression of rehabilitation (goals are listed)</th>
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<tr>
<td>1. Identify the weakness.</td>
<td>1. Full leg side raises: three sets of 30 on each side</td>
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<tr>
<td>2. Obtain static core strength in all regions.</td>
<td>2. Side plank/bridge: hold stable position for 45 to 60 s on each side</td>
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<td>3. Advance to plyometric training before return to sport.</td>
<td>3. Combined side plank and leg side raises: three sets of 30 on each side</td>
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<td>4. Front, side, and back single-leg hops: one set of 10 in each direction on each leg</td>
<td>4. Front, side, and back single-leg hops: one set of 10 in each direction on each leg</td>
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<tr>
<td>5. Begin introducing sport-specific activities: approximately 10% to 25% effort of sport</td>
<td>5. Begin introducing sport-specific activities: approximately 10% to 25% effort of sport</td>
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<tr>
<td>7. Scissor jumps for height: five sets of 8</td>
<td>7. Scissor jumps for height: five sets of 8</td>
</tr>
<tr>
<td>8. Progress to sport-specific activities: effort slowly increased</td>
<td>8. Progress to sport-specific activities: effort slowly increased</td>
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<tr>
<td>Maintenance</td>
<td>Maintenance</td>
</tr>
<tr>
<td>1. Full sport participation</td>
<td>1. Full sport participation</td>
</tr>
<tr>
<td>2. Continue combined side plank and side leg raises: three sets of 30 for each side, three times per week</td>
<td>2. Continue combined side plank and side leg raises: three sets of 30 for each side, three times per week</td>
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trend toward supporting the use of core stability exercises and especially dynamic plyometric training to prevent and rehabilitate certain types of injuries. At this time, it is unclear which, if any, aspects of performance are improved with core stability or plyometric programs and how these modalities may compare to other training programs. Athletes often have greater core strength than the general population, but their sport-specific demands are also much higher. To identify core instability and rehabilitate injuries successfully, the plyometric single-leg hop test and combined side plank/side raise strengthening should be considered. Further studies should focus on the role of core and plyometric exercises in sport-specific training to optimize injury prevention, injury rehabilitation, and performance.

The authors declare no conflict of interest and do not have any financial disclosures.

References


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AQ4 = Please check if "strength on isometric strength of the core" is presented correctly.

AQ5 = The term "youth" was changed to "young." Please check.

AQ6 = Please check if changes made to "Olympic weight training...those of plyometric training" reflect the intended meaning.

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AQ8 = Please check if changes made to "This combination...progressing to plyometric rehabilitation" reflect the intended meaning.

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