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Brief Review

CORE STABILITY TRAINING: APPLICATIONS TO SPORTS CONDITIONING PROGRAMS

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ABSTRACT. Willardson, J.M. Core stability training: Applications to sports conditioning programs. *J. Strength Cond. Res. 21(3):979–985. 2007.*—In recent years, fitness practitioners have increasingly recommended core stability exercises in sports conditioning programs. Greater core stability may benefit sports performance by providing a foundation for greater force production in the upper and lower extremities. Traditional resistance exercises have been modified to emphasize core stability. Such modifications have included performing exercises on unstable rather than stable surfaces, performing exercises while standing rather than seated, performing exercises with free weights rather than machines, and performing exercises unilaterally rather than bilaterally. Despite the popularity of core stability training, relatively little scientific research has been conducted to demonstrate the benefits for healthy athletes. Therefore, the purpose of this review was to critically examine core stability training and other issues related to this topic to determine useful applications for sports conditioning programs. Based on the current literature, prescription of core stability exercises should vary based on the phase of training and the health status of the athlete. During preseason and in-season mesocycles, free weight exercises performed while standing on a stable surface are recommended for increases in core strength and power. Free weight exercises performed in this manner are specific to the core stability requirements of sports-related skills due to moderate levels of instability and high levels of force production. Conversely, during postseason and off-season mesocycles, Swiss ball exercises involving isometric muscle actions, small loads, and long tension times are recommended for increases in core endurance. Furthermore, balance board and stability disc exercises, performed in conjunction with plyometric exercises, are recommended to improve proprioceptive and reactive capabilities, which may reduce the likelihood of lower extremity injuries.

KEY WORDS. strength, muscular endurance, muscle activation, balance, sports performance, injury prevention and rehabilitation

INTRODUCTION

In recent years, fitness professionals have increasingly emphasized core stability exercises in sports conditioning programs (9, 12, 18, 23, 38, 42). In the past, these types of exercises were performed only by individuals with low back problems in physical therapy clinics (27). However, core stability exercises are now commonly performed by healthy individuals in fitness and sports conditioning centers. This shift to commercial settings may have emanated from exercises popularized by the San Francisco Spine Institute when the concept of the neutral spine was stressed in their 1989 manual titled *Dynamic Lumbar Stabilization Program* (37).

During the last decade, the roles of a physical therapist, personal trainer, and strength and conditioning coach have increasingly merged. For example, personal trainers and strength and conditioning coaches now receive catalogs advertising equipment specifically designed for core stability training. Seminars and workshops offered at national conferences have spread information concerning the proper use and proposed benefits of such training. A few individuals in the fitness industry have especially capitalized on the promotion of such equipment and training strategies (9, 12, 18, 38, 42).

Although research from the rehabilitation literature has demonstrated the effectiveness of core stability exercises for reducing the likelihood of lower back and lower extremity injuries (10, 17, 28–30, 34, 43), relatively little research has directly examined the performance benefits for healthy athletes (39, 40). Certain individuals have promoted core stability exercises for sports conditioning with little scientific evidence to support their claims (9, 12, 18, 38, 42). The concept of core stability and how this characteristic can be trained to augment sports performance has been interpreted differently among practitioners. Furthermore, what distinguishes core stability exercises from other traditional resistance exercises has never been clearly defined. Therefore, the purpose of this review will be to critically examine the concept of core stability training and other issues related to this topic to determine useful applications for sports conditioning programs.

CONCEPT OF CORE STABILITY

The term *core* has been used to refer to the trunk or more specifically the lumbopelvic region of the body (8, 27, 28, 32, 33, 37). The stability of the lumbopelvic region is crucial to provide a foundation for movement of the upper and lower extremities, to support loads, and to protect the spinal cord and nerve roots (32). Panjabi (33) defined core stability as "the capacity of the stabilizing system to maintain the intervertebral neutral zones within physiological limits" (p. 394). The stabilizing system has been divided into 3 distinct subsystems: the passive subsystem, the active muscle subsystem, and the neural subsystem (32).

The passive subsystem consists of the spinal ligaments and facet articulations between adjacent vertebrae. The passive subsystem allows the lumbar spine to support a limited load (approximately 10 kg) that is far less than body mass. Therefore, the active muscle subsystem is necessary to allow support of body mass plus additional loads associated with resistance exercises and dynamic activities (27, 28, 32).

Bergmark (8) divided the active muscle subsystem into "global" and "local" groups, based on their primary roles in stabilizing the core. The global group consists of the large, superficial muscles that transfer force between the thoracic cage and pelvis and act to increase intra-abdominal pressure (e.g., rectus abdominis, internal and external oblique abdominis, transversis abdominis, erector spinae, lateral portion quadratus lumborum). Conversely, the local group consists of the small, deep muscles that control intersegmental motion between adjacent

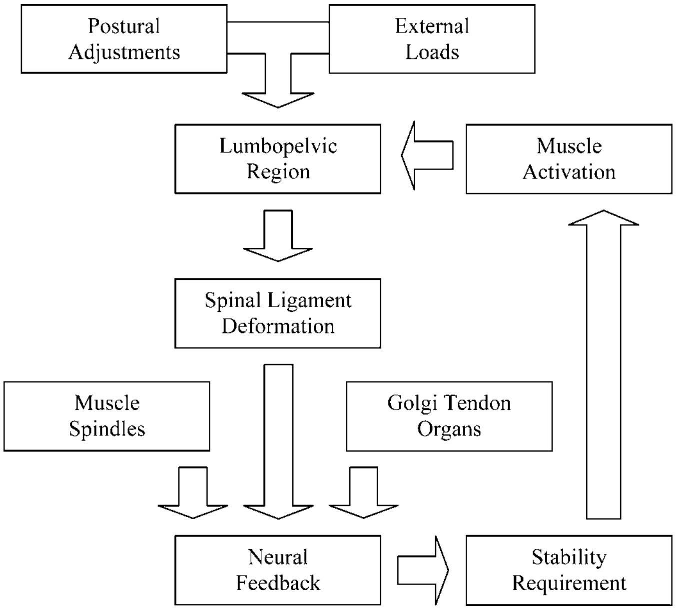

FIGURE 1. Model of core stability.

vertebrae (e.g., multifidus, rotatores, interspinal, intertransverse). The core muscles can be likened to guy wires, with tension being controlled by the neural subsystem. As tension increases within these muscles, compressive forces increase between the lumbar vertebrae; this stiffens the lumbar spine to enhance stability (27, 28, 32).

The neural subsystem has the complex task of continuously monitoring and adjusting muscle forces based on feedback provided by muscles spindles, Golgi tendon organs, and spinal ligaments (Figure 1). The requirements for stability can change instantaneously, based on postural adjustments or external loads accepted by the body. The neural subsystem must work concomitantly to ensure sufficient stability but also allow for desired joint movements to occur (27, 28, 32).

A key muscle that works with the neural subsystem to ensure sufficient stability is the transversis abdominis. Cresswell and Thorstensson (16) demonstrated that this muscle functioned primarily to increase intra-abdominal pressure, which reduced the compressive load on the lumbar spine. Other studies have demonstrated that the transversis abdominis was the first muscle activated during unexpected and self-loading of the trunk (15) and during upper and lower extremity movements, regardless of the direction of movement (21, 22).

Hodges and Richardson (22) proposed a feed-forward mechanism associated with function of the transversis abdominis. The neural subsystem utilizes feedback from previous movement patterns to coordinate and preactivate this muscle in preparation for postural adjustments or the acceptance of external loads. In another study, Hodges and Richardson (20) demonstrated delayed activation of the transversis abdominis in subjects with low back pain, suggestive of neural control deficits.

Some practitioners mistakenly believe that the smaller local muscles are involved primarily with core stability, whereas the larger global muscles are involved primarily with force production (9, 12, 18, 23, 38, 42). This mistaken belief has prompted ineffective training strategies designed to train the local and global muscle groups separately in nonfunctional positions. For example, the abdominal draw-in maneuver, typically performed in the quadruped or supine body position, has been widely promoted to train the stabilizing function of the transversis abdominis (9, 23, 42). Although this muscle is a key stabilizer of the lumber spine, several other core muscles, both local and global, work together to achieve spinal stability during movement tasks (3, 13, 16, 24) (Table 1). For example, local muscles, such as the multifidus and rotators, contain high densities of muscle spindles. Therefore, these muscles function as kinesiological monitors that provide the neural subsystem with proprioceptive feedback to facilitate coactivation of the global muscles to meet stability requirements (31).

McGill (28) stated, "The relative contributions of each muscle continually changes throughout a task, such that discussion of the most important stabilizing muscle is restricted to a transient instant in time" (p. 355). Core stability is a dynamic concept that continually changes to meet postural adjustments or external loads accepted by the body. This suggests that to increase core stability, exercises must be performed that simulate the movement patterns of a given sport.

From a sports performance perspective, greater core stability provides a foundation for greater force production in the upper and lower extremities (26, 39, 44, 48). Athletes who perform throwing-type motions could particularly benefit. For example, greater core stability could allow a baseball pitcher to impart greater acceleration to a baseball, as force is transferred from the ground, up through the lower extremities, across the trunk, and out to the throwing arm. However, several questions remain as to what types of resistance exercises best train core stability in healthy athletes. Therefore, the remainder of this review will address some of the most hotly debated topics relevant to core stability training.

STABLE VS. UNSTABLE SURFACES

Several practitioners have suggested that Swiss ball exercises are most effective for training core stability (9, 12, 18, 38, 42). Research has demonstrated higher core muscle activity when resistance exercises were performed on a Swiss ball vs. a stable surface (2, 6, 41). Behm and associates (6) examined muscle activation in the core musculature during 6 common trunk exercises, as well as during bilateral and unilateral dumbbell shoulder press and chest press exercises, performed on a Swiss ball vs. a stable floor or bench. Core muscle activity was examined in the upper lumbar erector spinae, the lumbosacral erector spinae, and the lower-abdominal muscle regions.

Behm and associates (6) demonstrated that performing trunk exercises on a Swiss ball resulted in significantly greater activation of the lower abdominal region. The highest activity of lower abdominal region was recorded for the side bridge exercise. For the shoulder press exercise, core muscle activity was not significantly different between the Swiss ball and stable bench conditions. For the chest press exercise, performing repetitions on a Swiss ball resulted in significantly greater activity in the upper lumbar erector spinae and lumbosacral erector spinae regions.

In addition, performing the shoulder press and chest press exercises unilaterally, whether on a Swiss ball or stable bench, invoked significantly greater activation of the core musculature. Based on these results, Behm and colleagues (6) concluded that exercises prescribed for strengthening or increasing the endurance of the core stabilizers for activities of daily living, sports performance, or rehabilitation should involve a destabilizing component. The lack of stability may originate from the base or platform on which the exercise is performed (e.g., Swiss ball) or by placing limbs or resistance outside the base of support of the body (e.g., unilateral dumbbell resisted movements).

A similar study by Vera-Garcia et al. (41) evaluated muscle activity in the upper and lower regions of the rectus abdominis during curl-ups performed on a stable bench or Swiss ball. The stable bench condition resulted in the lowest amplitude of abdominal muscle activity with 21% of maximal voluntary contraction (MVC). Conversely, the Swiss ball condition resulted in the highest amplitude with 50% MVC.

Vera-Garcia and others (41) concluded "the muscle activity levels demonstrated on the Swiss ball suggested a much higher demand on the motor system and appeared to constitute sufficient stimuli to increase both the strength and endurance properties of muscle" (p. 569). However, a problem of this conclusion is that the level of muscle activation may not indicate the potential for force production. When performing resistance exercises on a Swiss ball, force production capability in the upper and lower extremities is significantly reduced; this may limit the potential of these exercises to benefit sports performance.

Behm and associates (5) examined isometric muscle force and activation of the leg extensor (LE) and plantar flexor (PF) muscle groups when actions were performed on a stable bench vs. a Swiss ball. Isometric force output was reported to be 70.5% (LE) and 20.2% (PF) less when actions were performed on a Swiss ball. Muscle activation followed the same pattern with 44.3% (LE) and 2.9% (PF) less activation when actions were performed on a Swiss ball. In a related study, Anderson and Behm (2) demonstrated that maximal isometric force output of the pectoralis major decreased 60% when the chest press exercise was performed on a Swiss ball vs. a stable bench.

Because core stability is required for successful execution of sports skills, a functionally based program should include resistance exercises that involve a destabilizing component. However, very few sports skills require the degree of instability inherent with Swiss ball exercises. Therefore, a more specific approach might be to perform free weight exercises while standing on a stable surface. Free weight exercises performed in this manner involve moderate levels of instability and high levels of force production (1, 4, 19, 26, 36, 44–46, 48). This approach allows for the simultaneous development of core stability and upper and lower extremity strength, which might be more transferable to sports performance.

McGill (28) stated, "Any exercise that channels motor patterns to ensure a stable spine, through repetition, constitutes a core stability exercise" (p. 356). Therefore, traditional resistance exercises can be considered core stability exercises if modified for that purpose. For example, exercises can be performed while standing rather than seated, with free weights rather than machines, and unilaterally rather than bilaterally (26, 44–46, 48). The bottom line is that healthy athletes who already perform traditional resistance exercises, such as the deadlift, squat, power clean, push-press, and Russian-style rotation, are likely receiving sufficient core stability training without the need for Swiss ball exercises.

BALANCE TRAINING

Balance exercises can be considered a type of core stability training in that these exercises activate the core musculature. Sudden perturbations applied to the body during competition can potentially move the center of gravity outside the base of support. To avoid losing balance and falling, postural adjustments are made to move the center of gravity back inside the base of support. These postural adjustments require activation of the core musculature to stabilize the lumbar spine. Because sports skills are often times performed off balance, greater core stability provides a foundation for greater force production in the upper and lower extremities (14, 35, 39, 47).

Balance is specific for every skill and is improved through repetition of static postures or dynamic movements. Sensory input (vision, vestibular system, proprioception) processed in the cerebral cortex allows for improvements in balance to occur through refinements in neural programming (35). Previous research demonstrated that performance of exercises on unstable equipment (e.g., Swiss ball and BOSU balance trainer) significantly improved static balance and postural control measures (14, 39, 47). Although functionally impaired individuals in rehabilitation settings may benefit from such improvements, the benefits for healthy athletes on performance measures has not been determined.

Behm and colleagues (7) examined the relationship between ice hockey skating speed and the ability to balance on a wobble board. Because ice hockey is played on a highly unstable surface, the authors hypothesized that a high correlation would occur between these measures. However, for the most skilled players, hockey skating speed was not significantly related to wobble board balance ($r = -0.28$). These results indicate that performing balance exercises on a wobble board, which requires a high level of static balance, may not transfer to hockey skating speed, which requires a high level of dynamic balance. The optimal approach to improve balance for healthy athletes might be through practice of relevant skills and movements on the same surface on which those skills and movements are performed during competition.

CORE STABILITY TRAINING AND SPORTS PERFORMANCE

Despite the wide-spread promotion of Swiss ball exercises as being sports specific (9, 12, 18, 38, 42), few studies have actually examined the effectiveness of such exercises on performance measures. Stanton et al. (40) examined the effect of a Swiss ball training program on core stability, $\dot{V}O_2$max, and running economy. Subjects were randomly divided into a Swiss ball group or a control group. Both groups continued to perform their normal physical training, which consisted of skills training and run-based conditioning.

Stanton and others (40) demonstrated significant differences favoring the Swiss ball group for core stability, evaluated with the Swiss ball prone core stability test. However, nonsignificant differences were demonstrated between groups for $\dot{V}O_2$max and running economy. The authors concluded, "the selection of resistance exercises that recruit the core musculature in the manner required for running may have elicited specific adaptation, leading to enhanced run performance, such as exercises performed in a unilateral, single-leg support, standing position, with the arms held in a manner similar to running" (p. 527). Stanton and colleagues (40) demonstrated that improvements in core stability were skill specific. Thus, performing resistance exercises on a Swiss ball improved core stability when evaluated with the Swiss ball prone

TABLE 1. Core muscle involvement and movement tasks.

Authors	Purpose	Methods	Movements	Muscles	Summary of results
Arokoski and colleagues	Evaluate activity of thoracic and lumbar paraspinal and abdominal muscles in different therapeutic exercises	10 healthy men EMG data from 3 consecutive repetitions averaged for each exercise	Prone 1. BHE (floor) 2. RBHE (floor) 3. LB (table) 4. UHE (hips off edge of table) 5. BHE (hips off edge of table) Supine 6. HB 7. HB with unilateral KE 8. HB with feet on SB Seated 9. TV with alt DB SF 10. TF 30° with alt DB SF Standing 11. TV with alt DBSF 12. TF 30° with alt DBSF 13. TV with alt DBSF on WB 14. TV with ISE 15. TV with ISF 16. TV with ISA	RA EO LT MF	Highest muscle activity (exercise number; % MVC ± SD) RA (14; 42.1 ± 25.4) EO (14; 37.2 ± 21.0) LT (15; 82.3 ± 37.2) MF (5; 62.1 ± 37.1) MF function coupled with LT function, thus local and global muscles demonstrated similar activity patters and simultaneous function Standing exercises with upper extremity isometric muscle actions generally elicited higher core activity vs. exercises in other positions
Cholewicki and Van Vliet	Compare relative contribution of various trunk muscles to lumbar spine stability	8 healthy men EMG data used in biomechanical model Percent decrease in SI due to removing muscle group indicated contribution of that muscle group to lumbar spine stability	Seated isometric exertions (target force levels 20, 40, and 60% MVC) 1. TF 2. TE 3. LTF 4. TR Standing isometric lifts (target force levels 0, 20, 40, and 60% body mass) 5.TVL 6. TF 45° holding weight	RA EO IO LD IC LT LES MF PS QL	Contribution of different trunk muscles to lumbar spine stability depended on direction and magnitude of load No single muscle group contributed more than 30% to SI Removal of LES caused largest reduction in SI
Cresswell and Thorstensson	Investigate relationship between IAP and force during lifting and lowering at different velocities and EMG activity of abdominal and trunk extensor muscles	7 healthy men Lifting and lowering performed on isokinetic dynamometer capable of measuring force during concentric and eccentric muscle actions IAP measured within gastric ventricle by way of micro-tip pressure transducer Intramuscular and EMG data used to evaluate muscle activity	Romanian-style deadlift performed with maximal effort at 0.12, 0.24, 0.48, 0.72, and 0.96 ms^{-1}	TR IO EO RA	At every velocity IAP higher while lifting vs. lowering. Conversely, at every velocity maximal force higher while lowering vs. lifting Correlations between muscle activity and IAP TR ($r = 0.97$) IO ($r = 0.95$) EO ($r = 0.64$) RA ($r = -0.05$) Due to horizontal fiber alignment, activation of TR ideal for increasing IAP without adding to spinal compressive force that occurs with activation of other muscles, which run parallel (RA) or partially parallel (EO or IO) to spine

TABLE 1. Continued.

Authors	Purpose	Methods	Movements	Muscles	Summary of results
Kavcic and colleagues	Compare relative contribution of various trunk muscles to lumbar spine stability	10 healthy men EMG data used in biomechanical model Percent decrease in SI due to removing muscle group indicated contribution of that muscle group to lumbar spine stability	Supine 1. TC 2. HB 3. HB with unilateral KE Side 4. RSB Seated 5. On SB 6. On stool Quadruped 7. With RHE 8. With LSF and RHE	RA IO EO LD IC LT MES MF	No single muscle when manipulated from 0 to 100% MVC created unstable spine Those muscles antagonistic to dominant moment of task most effective at increasing lumbar spine stability Motor patterns should be trained that involve contribution of many potentially important lumbar spine stabilizers

* EMG = electromyography; IAP = intra-abdominal pressure; SI = stability index; BHE = bilateral hip extension; RBHE = resisted bilateral hip extension; LB = lifting buttocks; UHE = unilateral hip extension; HB = hip bridge; KE = knee extension; SB = Swiss ball; TV = trunk vertical; TF = trunk flexion; DBSF = dumbbell shoulder joint flexion; WB = wobble board; ISE = isometric shoulder joint extension; ISF = isometric shoulder joint flexion; ISA = isometric shoulder joint adduction; TE = trunk extension; LTF = lateral trunk flexion; TR = trunk rotation; TVL = trunk vertical load; TC = trunk curl; RSB = right side bridge; RHE = right hip extension; LAF = left shoulder joint flexion; RA = rectus abdominis; EO = external oblique abdominis; LT = longissimus thoracis; MF = multifidus; IO = internal oblique abdominis; LD = latissimus dorsi; IC = iliocostalis; LES = lumbar erector spinae; PS = psoas; QL = quadratus lumborum; TR = transversis abdominis; MVC = maximal voluntary contraction.

core stability test but did not improve core stability when evaluated with the running performance measures.

Stanton and colleagues (40) concluded, "While a wealth of anecdotal evidence supports the use of Swiss ball training to enhance physical performance, this has not been substantiated by valid scientific investigation" (p. 526). Typically, Swiss ball exercises are characterized by isometric muscle actions, small loads, and long tension times, conducive to the development of core endurance (11, 14). However, the development of core strength and power might be more important for improvements to occur in sports-related performance measures (1, 4, 19, 26, 36, 44–46, 48).

There is no guarantee that improvements in core strength and power will transfer to improvements in sports performance. Although a 100% transfer is impossible to achieve, resistance exercises should be chosen that closely simulate the demands of a sport (36). When selecting resistance exercises to develop sports-specific core stability, the use of a Swiss ball may reduce specificity. Because the majority of sports are ground based, resistance exercises designed to improve sports-specific core stability should be prescribed likewise for the highest possible transfer to occur (44–46, 48).

Two practitioners have recommended Swiss ball exercises for such sports as swimming, in which there is no base of support (12, 18). Swimming is different from other ground-based sports in that the core becomes the reference point for all movement. Greater core stability could be particularly beneficial for swimmers to allow efficient transfer of force between the trunk and the upper and lower extremities to propel the body through the water. Swiss ball exercises performed in the prone position, with the feet not in contact with the ground, appear to be specific to the core stability requirements of swimming.

Scibek and colleagues (39) examined the effect of a Swiss ball training program on dry-land performance measures and swim performance in collegiate swimmers. Subjects were randomly divided into a Swiss ball group or a control group and evaluated before and after 6 weeks on the following dry-land performance measures: hamstring flexibility, vertical jump, forward and backwards medicine ball throw, and postural control. Swim performance was evaluated with timed 100-yard trials.

The authors demonstrated significant differences favoring the Swiss ball group for the forward medicine ball throw and postural control measures. However, nonsignificant differences were demonstrated between groups for the vertical jump, backwards medicine ball throw, and hamstring flexibility measures. Despite improvements on 2 dry-land performance measures, swim time did not improve for the treatment group. These results indicate that Swiss ball training might not be specific to the core stability requirements of swimming.

The specificity of a resistance exercise relative to a sport is determined by several characteristics; one of which is core stability requirements. Free weight exercises performed while standing on a stable surface might be more transferable to sports performance (1, 4, 19, 26, 36, 44–46, 48). Traditional resistance exercises, such as the deadlift, squat, power clean, push-press, and Russian-style rotation, can be modified further to place greater emphasis on core stability (48). For example, the squat and dead-lift can be performed with dumbbells while supported on a single leg (26), and the power clean and push-press can be performed with dumbbells unilaterally (6). Trunk rotation exercises can also be performed with cables or medicine balls to simultaneously develop sports-specific core stability and upper body power (1, 4, 19, 44).

INJURY PREVENTION AND REHABILITATION

Although core strength and power appear to be more important for improvements in sports-related performance measures (e.g., vertical jump, speed, agility), core endurance appears be more important for injury prevention and rehabilitation (27, 28). McGill (27) argued that the development of core endurance should take precedence over the development of core strength for preventing and rehabilitating low back injuries. In agreement with this perspective, Arokoski and others (3) stated "because lumbar stabilizing multifidus muscles are mainly composed of type I fibers, only relatively low loads are needed to improve their performance" (p. 1,096). Core stabilization–type exercises have also been advocated in the prevention and rehabilitation of lower extremity injuries (10, 17, 29, 30, 34, 43).

The core of the body provides a foundation upon which the muscles of the lower extremities produce or resist force. Several of the muscles acting on the knee joint originate within the lumbopelvic region. Therefore, lack of conditioning in the core musculature may result in faulty landing mechanics with increased valgus type forces acting on the knee joint, which can lead to anterior cruciate ligament (ACL) injuries (29).

Research has demonstrated the effectiveness of exercises performed on unstable equipment (e.g., balance boards, stability discs) for reducing the likelihood of ACL injuries (10, 17, 29, 30, 34, 43). These types of exercises may increase the sensitivity of muscle spindles, resulting in a higher state of readiness to respond to perturbing forces applied to a joint. Exposing a joint to potentially destabilizing forces during training may be a necessary stimulus to encourage the development of effective neuromuscular compensatory patterns (29).

Paterno and others (34) demonstrated improvements in single limb postural control in women athletes after a 6-week training program that included balance exercises (performed on a BOSU balance trainer), plyometrics, dynamic movement training, and resistance exercises. Wedderkopp and colleagues (43) demonstrated that a dynamic warm-up followed by ankle disc exercises reduced the likelihood of lower extremity injuries in women team handball players. The control group had a 6 times higher risk of injury vs. the treatment group. Myklebust and associates (30) demonstrated that plyometrics and balance exercises (performed on a floor, mat, and wobble board) significantly reduced the risk of ACL injuries in elite women team handball players. A common limitation of these studies was that several types of exercises were used in the training programs. Therefore, the independent effect of exercises performed on unstable equipment was difficult to determine.

However, other studies that were strictly controlled also demonstrated the effectiveness of exercises performed on unstable equipment (10, 17). Caraffa and others (10) reported significantly fewer ACL injuries in semiprofessional and amateur soccer players who performed wobble board exercises in addition to their standard training program. During 3 seasons, a total of 10 arthroscopically verified ACL injuries occurred in the wobble board group vs. 70 in the control group.

Fitzgerald, Axe, and Snyder-Mackler (17) evaluated the effectiveness of a perturbation training program as an adjunct to a standard rehabilitation program on ACL rehabilitation. Subjects were divided into "standard" and "perturbation" groups. The perturbation group performed balance exercises of increasing difficulty and unpredictability on a Balance Master, tiltboard, and roller board. Unsuccessful rehabilitation was defined as an occurrence of the knee giving way or reduction in status from being a candidate for rehabilitation to being at high risk for reinjury. Based on this definition, subjects in the perturbation group were 5 times more likely to successfully return to vigorous sports activities.

When prescribing core stability exercises, the concept of specificity should have foremost importance. Not all Swiss ball and balance board exercises are specific or beneficial, as several practitioners have suggested (9, 12, 18, 38, 42). However, these types of exercises have their place, particularly during postseason and off-season mesocycles or for the purpose of injury prevention and rehabilitation. Based on the current literature, free weight exercises performed while standing on a stable surface should be the primary training modality to develop core stability and enhance sports performance in healthy athletes (1, 4, 19, 36, 44–46, 48).

PRACTICAL APPLICATIONS

Increasing core stability should be an important priority for all sports conditioning programs. Sports skills are often performed in unstable body positions (e.g., running forehand in tennis, baseball pitcher delivery, shooting a puck in hockey), which necessitates the prescription of resistance exercises designed to train core stability. Traditional resistance exercises can be modified to emphasize core stability. Such modifications might include performing exercises on unstable rather than stable surfaces (41), performing exercises while standing rather than seated (3), performing exercises with free weights rather than machines (19, 36, 48), and performing exercises unilaterally rather than bilaterally (6, 26).

Prescription of core stability exercises should vary based on the phase of training and the health status of the athlete. During preseason and in-season mesocycles, increases in core strength and power should be the primary focus. Because the majority of sports skills are ground based, with moderate degrees of instability, resistance exercises should be prescribed likewise for the highest possible transfer to occur (1, 4, 19, 36, 44–46, 48). Traditional resistance exercises, such as the squat, deadlift, power clean, and push-press, can be performed unilaterally to emphasize core stability (6). Furthermore, resistance exercises that involve a rotational component can be performed with cables or medicine balls to simultaneously develop sports-specific core stability and upper body power (1, 4).

Conversely, during postseason and off-season mesocycles, increases in core endurance should be the primary focus. Resistance exercises performed on a Swiss ball involving isometric muscle actions, small loads, and long tension times are effective for this purpose (11, 14). Furthermore, the performance of exercises on balance boards and stability discs can reduce the likelihood of lower extremity injuries due to increased sensitivity of muscle spindles and greater postural control (39, 47).

RECOMMENDATIONS FOR FUTURE RESEARCH

The majority of research demonstrating the effectiveness of core stability training has been conducted on untrained individuals or unhealthy athletes in rehabilitation settings (11, 14, 17, 20, 47). The core stability exercises prescribed for these populations have typically involved isometric muscle actions, small loads, and long tension times, which may not develop the core stability necessary to benefit sports performance in healthy athletes. A new paradigm is necessary among personal trainers and strength and conditioning coaches in the types of exercises prescribed for healthy athletes.

Future research focusing on the effects of traditional resistance exercises (e.g., deadlift, squat, power clean, push-press, and Russian-style rotation) on core stability would help create this new paradigm. Currently, there is no test battery to evaluate core stability in healthy athletes. Previously, core stability was evaluated in relatively nonfunctional quadruped, prone, or supine body positions (25). Therefore, future research should seek to establish a core stability test battery that involves dynamic muscle actions while supporting relatively large loads in a standing position, consistent with the core stability requirements of sports participation.

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