REVIEW / SYNTHÈSE

The use of instability to train the core musculature

David G. Behm, Eric J. Drinkwater, Jeffrey M. Willardson, and Patrick M. Cowley

Abstract: Training of the trunk or core muscles for enhanced health, rehabilitation, and athletic performance has received renewed emphasis. Instability resistance exercises have become a popular means of training the core and improving balance. Whether instability resistance training is as, more, or less effective than traditional ground-based resistance training is not fully resolved. The purpose of this review is to address the effectiveness of instability resistance training for athletic, nonathletic, and rehabilitation conditioning. The anatomical core is defined as the axial skeleton and all soft tissues with a proximal attachment on the axial skeleton. Spinal stability is an interaction of passive and active muscle and neural subsystems. Training programs must prepare athletes for a wide variety of postures and external forces, and should include exercises with a destabilizing component. While unstable devices have been shown to be effective in decreasing the incidence of low back pain and increasing the sensory efficiency of soft tissues, they are not recommended as the primary exercises for hypertrophy, absolute strength, or power, especially in trained athletes. For athletes, ground-based free-weight exercises with moderate levels of instability should form the foundation of exercises to train the core musculature. Instability resistance exercises can play an important role in periodization and rehabilitation, and as alternative exercises for the recreationally active individual with less interest or access to ground-based free-weight exercises. Based on the relatively high proportion of type I fibers, the core musculature might respond well to multiple sets with high repetitions (e.g., >15 per set); however, a particular sport may necessitate fewer repetitions.

Key words: trunk muscles, back, abdominals, resistance training, strength training, balance.

Résumé : L’entraînement des muscles du tronc, les muscles profonds, à des fins d’amélioration de la santé, de réadaptation et de performance sportive suscite un nouvel intérêt. Les exercices de déstabilisation sont de plus en plus utilisés pour l’entraînement des muscles profonds et l’amélioration de l’équilibre. On ne sait pourtant pas si les exercices de déstabilisation sont plus ou moins efficaces que les exercices de force traditionnels exécutés au sol. Cet article-synthèse s’intéresse à l’efficacité des exercices de déstabilisation sur la mise en forme dans des conditions sportives, récréatives et de réadaptation. On définit le centre anatomique comme étant le squelette axial et l’ensemble des tissus mous dont l’attache proximale est sur le squelette axial. La stabilité vertébrale résulte de l’interaction des forces musculaires, actives et passives, et des sous-systèmes nerveux. Les programmes d’entraînement préparant les athlètes à composer avec diverses postures et des forces externes doivent comporter des exercices présentant une composante de déstabilisation. Bien que les appareils de déstabilisation soient efficaces pour diminuer l’incidence des lombalgies et pour améliorer la sensibilité des tissus mous, ils ne sont pas recommandés pour la réalisation des exercices de base conçus pour favoriser l’hypertrophie, l’augmentation de la force absolue et de la puissance notamment chez les athlètes entraînés. Pour l’entraînement des muscles profonds chez les athlètes, on devrait privilégier les exercices de force réalisés au sol avec des poids libres et présentant un degré modéré d’instabilité. Les exercices de déstabilisation peuvent jouer un rôle important dans la périodisation de l’entraînement, la réadaptation et comme exercices alternatifs pour les individus physiquement actifs moins intéressés ou n’ayant pas accès au plateau d’exercices avec poids libres. Du fait que les muscles profonds sont constitués d’une forte proportion relative de fibres de type I, ils devraient bien répondre à des séries multiples de plusieurs répétitions (soit plus de 15 par série); dans certains sports, il est concevable de diminuer le nombre de répétitions.

Mots-clés : muscles du tronc, dos, abdominaux, entraînement avec charge, entraînement à la force, équilibre.

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D.G. Behm.[1] School of Human Kinetics and Recreation, Memorial University of Newfoundland, St. John’s, NL A1C 5S7, Canada.
E.J. Drinkwater. School of Human Movement Studies, Charles Sturt University, Panorama Avenue, Bathurst, 2795, NSW, Australia.
J.M. Willardson. Kinesiology and Sports Studies Department, Eastern Illinois University, Charleston, IL 61920, USA.
P.M. Cowley. Department of Exercise Science, Syracuse University, Syracuse, NY 13207, USA.

[1] Corresponding author (e-mail: dbehm@mun.ca).

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Introduction

The term "core" has been commonly discussed in the popular media and professional journals for the past decade or more. However, the precise definition of core is tenuous, with multiple meanings, depending on the interpretation of the literature (Willson et al. 2005). Previously, Willson et al. (2005) defined the core as the lumbo-pelvic hip complex, consisting of the lumbar spine, pelvis, and hip joints, and the active and passive tissues that produce or restrict motion of these segments. Although this definition may be most appropriate from a rehabilitation perspective, the application to athletic conditioning requires a more expansive definition that considers the transfer of forces and momentum to the appendicular skeleton. Thus, for this literature review, the anatomical core will be defined as the axial skeleton (which includes the pelvic girdle and shoulder girdles) and all soft tissues (i.e., articular and fibro-cartilage, ligaments, tendons, muscles, and fascia) with a proximal attachment originating on the axial skeleton, regardless of whether the soft tissue terminates on the axial or appendicular skeleton (upper and lower extremities). These soft tissues can act to generate motion (concentric action) or resist motion (eccentric and isometric actions).

According to the principle of training specificity (Behm 1995; Behm and Sale 1993), and since motion for physical tasks, such as sports skills, fitness activities, occupational tasks, and activities of daily living, occur on relatively unstable surfaces (e.g., skiing, snowboarding), training must attempt to closely address the demands of the sport. Whereas most activities require dynamic balance, resistance training for the core musculature using unstable devices, such as physioballs and low-density foam cushions, typically require static balance (Behm et al. 2005*a*; Shimada et al. 2003). Willardson (2004) stated that "the optimal method to promote increases in balance, proprioception and spinal stability for any given sport is to practice the skill itself on the same surface on which the skill is performed in competition." In a similar vein, Schmidtbleicher (1992) stated that intermuscular coordination can only be developed by practicing the movement for which coordination is sought. Unfortunately, this is not always possible, as is the case for outdoor activities (e.g., football, baseball) during the winter season in colder climates or activities that utilize ice surfaces when the arenas are closed during the warmer seasons. Second, alternative challenges that provide a progressive overload to stimulate balance improvements may be necessary. Considering the variety of published results using instability devices, a clear synthesis of the literature is needed to establish the training specificity and effectiveness of instability resistance training for the core musculature.

Not all training that targets the core musculature involves unstable devices. Ground-based training routines can be very dynamic and ballistic in nature, utilizing body mass and nontraditional external objects (e.g., truck tires). The action of pulling or pushing a sled may effectively address the actions in a rugby scrum, whereas lifting large truck tires can address the angle and summation of forces involved with the blocking technique of an offensive lineman in North American football. However, the effectiveness of such training programs has yet to be quantified in peer-reviewed scientific articles. Still, similar dynamic and ballistic movements can be achieved using Olympic lifts and variations of such lifts.

The use of static balance exercises performed while supported on unstable devices might be viewed as a preliminary training step in improving balance and the strength and endurance of the core musculature, prior to the implementation of dynamic and ballistic resistance exercises, such as Olympic lifts. However, there is extensive controversy in both the popular media and the scientific literature concerning the effectiveness of instability devices, compared with ground-based free-weight exercises, for training the core musculature.

There are many instability devices available for athletic and fitness conditioning, as well as for exercises to rehabilitate the lower back. Perhaps the best known instability device is the "Swiss", "physio", or, as it is known in Germany, the "pezzi" gymnastic ball. The Swiss or physioball is an air-pressurized ball that can be purchased in a variety of diameters. Another common device is the hemispherical physioball with an inflated dome side and a hard rubber flat side (e.g., BOSU). Other devices include inflatable discs, wobble or balance boards, foam tubes, and high- and low-density foam platforms. Suspended chains and ropes can be used to decrease stability while performing exercises such as push-ups and pull-ups. Natural surfaces (e.g., sand) can also be used as instability bases, providing a greater challenge to balance and force production under unstable conditions. Many of these devices have been used previously in rehabilitation settings to increase activation of the core musculature for lower back health, and are now widely used for athletic purposes as well.

Historically, resistance training involving balls, platforms, and other unstable devices and surfaces are used to induce varying degrees of instability, and hence greater stabilizing functions in the core musculature. Unstable devices (e.g., wobble boards, Swiss or physioballs) promote postural disequilibrium or imbalance, as postural sway may project the centre of mass beyond the device's area of support. Unstable devices also promote postural disequilibrium, as the surface distorts (e.g., low-density foam cushion, sand) readily in response to the reaction forces associated with changes in the centre of pressure. It is unclear when these devices began to be used as training and rehabilitation tools, but physical therapists were using physioballs prior to World War II.

With the upsurge of interest in neuromuscular training (Sherrington 1910, 1925), physical therapists began to integrate Swiss or physioballs into therapy. Physical therapists (consequently, the term physioballs) were among the first to use physioballs for training and therapy. Spinal stability reemerged as an area of emphasis in the rehabilitation literature in the 1980s and 1990s, with authors such as Bergmark (1989), McGill and colleagues (McGill 1988, 1991*a*, 1991*b*, 1992*a*, 1992*b*, 1996; McGill and Hoodless 1990; McGill and Norman 1985, 1986, 1987, 1988; McGill et al. 1999*b*), Hides et al. (1994), and Hodges and Richardson (1997*a*, 1997*b*, 1999) examining spinal stability analysis, anticipatory postural adjustments, and other concepts related to spinal stability (generally defined as the ability of the spinal stabilizing system to resist perturbations). Recently, Reeves and colleagues (2007) explained that training the core musculature improves the robustness of the stabilizing system, thus providing a buffer of protection against spinal injuries.

Specific training practices aimed at targeting the spinal stabilizing muscles are an important consideration for physical tasks and the rehabilitation of low back pain (Abenhaim et al. 2000). For example, a stable trunk provides a solid foundation for the torques generated by the limbs when shovelling snow, lifting boxes, or hitting a tennis ball. Increased strength of the low back musculature is not necessarily associated with the prevention of low back pain (Nadler et al. 2000, 2001, 2002), but it may provide some protection when greater forces are needed during the performance of athletic skills or certain occupational tasks (Cady et al. 1979; Cairns et al. 2006; Caldwell et al. 2003; Hides et al. 2010).

Conversely, decreased muscular endurance of the low back musculature is strongly associated with low back pain (McGill 2001; Nourbakhsh and Arab 2002). Therefore, training methods for the core musculature might be structured differently, based on the health status and training goals of the athlete and nonathlete. Various recommendations have been presented in the popular media (Boyle 2004; Chek 1999; Gambetta 1999; Santana 2001; Verstegen and Williams 2004) and professional journals (Gamble 2007; Kolber and Beekhuizen 2007; Willardson 2004) on training the core musculature. Current training methods, in some respects, are based on historical methods of targeting this area of the body.

Training the core musculature need not involve only specialized unstable devices. Early resistance training methods (during the first half of the 20th century) primarily involved free weights, such as dumbbells and barbells, which provided destabilizing torques while allowing 3-dimensional freedom of movement. Prior to that, physical education classes were primarily based on gymnastics training, which emphasized the core musculature. Even more historically dated is the use of medicine type balls by the Ancient Greeks. However, in the 1950s and 1960s, weight stack machines were popularized by companies such as Universal. Later, in the 1970s and 1980s, companies such as Nautilus continued to popularize weight stack machines over free weights for athletes and fitness enthusiasts. Notwithstanding the popularity, simplicity of use, and safety advantages, the machine's stability and limited range of movement minimized the need for stabilizing functions by the user.

In the late 1990s and into the early 21st century, the use of free weights resurged in popularity, because of the variety of exercises that can be performed and the potentially greater training adaptations that might be gained in the core musculature. Some authors have advised the use of free weights over machines for improved transfer of training (Baechle et al. 2008; Garhammer 1981; Kraemer and Fleck 1988; Schmidtbleicher 1992; Stone et al. 1998; Willardson 2007; Yessis 2003), since the balance and control of free weights requires the individual to stress and coordinate muscle groups in synergistic, stabilizing, and antagonistic roles. Whether instability devices used to train the core musculature are a necessary adjunct to a ground-based training program is a highly contested question that needs a comprehensive review and evaluation.

Proponents of using unstable devices have hypothesized that the greater instability elicited may stress the neuromuscular system to a greater extent than ground-based training methods (Boyle 2004; Chek 1999; Gambetta 1999; Santana 2001; Verstegen and Williams 2004). The rationale suggests that destabilizing training environments may enhance neuromuscular adaptations and training specificity, while providing a more varied and effective training stimulus. However, there are a variety of disadvantages associated with unstable devices that may outweigh the advantages that will be discussed later in this review. Therefore, this literature review will attempt to provide a quantitative assessment of the advantages and disadvantages of training the core musculature using instability devices. This review will begin by providing a foundation of knowledge by examining the anatomy, physiology, and biomechanics of the core musculature. From this foundation, the acute effects of instability devices and exercises on kinetics, kinematics, and core and limb muscle activation will be reviewed. Based on these studies, the review will then provide practical recommendations involving the evaluation, assessment, prescription, programming, effectiveness, and application of instability and ground-based free-weight exercises for the spectrum of fitness enthusiasts (from recreational fitness to professional athletes). Because the rehabilitation literature is very extensive in this area, this literature review will focus on training the core musculature for healthy and athletic populations.

Physiology and biomechanics of the core

Anatomical aspects

Portions of the axial and appendicular skeletons are included in the definition of the core. The axial skeleton consists of the skull, sternum, ribcage, vertebral column, pelvic girdle, and shoulder girdle; the appendicular skeleton consists of the upper and lower extremities. The ribcage and vertebral column are collectively referred to as the trunk; the shoulder girdles connect the upper extremities to the trunk, and the pelvic girdle connects the lower extremities to the trunk.

The spine is the most mobile in the cervical and lumbar regions because of changes in the orientation of the facet joints at the cervico-thoracic (C7-T1) and thoraco-lumbar (T12-L1) junctions (Boyle et al. 1996; Masharawi et al. 2004; Oxland et al. 1992). Possible movements of the vertebral column include flexion and extension, which refers to movements in the sagittal plane; lateral flexion and reduction, which refers to movements in the frontal plane; and axial rotation, which refers to movements in the transverse plane.

When considering motion at the facet joints, movement that is approximately 1°–2° in each plane is possible without passive resistance from the vertebral ligaments and intervertebral discs (Panjabi 1992*a*, 1992*b*; Panjabi et al. 1976; Stokes and Frymoyer 1987). This unresisted motion is termed the neutral zone. Movement beyond the neutral zone requires the involvement of different stabilizing mechanisms to preserve spinal stability. Panjabi (1992*a*) divided the stabilizing system into 3 distinct subsystems: the passive subsystem, the active muscle subsystem, and the neural subsystem. These subsystems work together to stabilize the vertebral column. Chronic low back problems may occur when one of the subsystems becomes deficient, which places greater compensatory stress on the other subsystems (McGill 2001).

Passive subsystem

The passive subsystem consists of the vertebral ligaments, intervertebral discs, and facet joints between adjacent vertebrae. The passive subsystem is particularly important toward the end points in the neutral zone, at which point the vertebral ligaments tighten and develop reactive tension to resist motion. The vertebral ligaments are equipped with proprioceptors that relay sensory feedback to the central nervous system regarding position and movement of the vertebral column (Holm et al. 2002; Kang et al. 2002; Panjabi 1992*a*). This sensory feedback is crucial to stimulate specific neural recruitment patterns of the core musculature to meet task demands.

When considered independently, the passive subsystem has limited potential to stabilize the vertebral column. For example, in vitro experiments have demonstrated that the osteoligamentous lumbar spine buckles under compressive loading of approximately 90 N (9.2 kg) (Panjabi 1992*a*). The mass of the body in a standing position exceeds this level of support, and compressive forces have been estimated to exceed 10 000 N during dynamic lifting tasks (Cholewicki et al. 1991). The ability to withstand these large forces is dependent on additional stabilization provided by the active muscle subsystem.

Active muscle subsystem

Tension development within the abdominal and paraspinal muscles increases the stiffness of the spine to enhance stability. The core muscles can be divided into different groups, based on specific stabilizing functions (Bergmark 1989; Gibbons and Comerford 2001). The local axial skeleton stabilizers include the small, deep muscles (e.g., multifidus, rotatores, interspinalis, intertransversalis) that provide intersegmental stiffness between adjacent vertebrae. Other local axial skeleton stabilizers include the transversus abdominis, internal oblique abdominis, quadratus lumborum, diaphragm, and the levator ani (i.e., 6 pelvic floor muscles). The transversus abdominis, diaphragm, and levator ani are particularly important for increasing intra-abdominal pressure (i.e., pressure within the abdominal cavity), which may reduce compressive forces between the lumbar vertebrae (Cresswell and Thorstensson 1994; Kibler et al. 2006; Willardson 2007). The global axial skeleton stabilizers include the large, superficial muscles (e.g., rectus abdominis, external oblique abdominis, erector spinae group) that provide multisegmental stiffness over a greater range and act as prime movers during dynamic activities.

Other core muscles might be considered to be axial-appendicular transfer muscles that connect the trunk (i.e., axial skeleton) to the upper and lower extremities (i.e., appendicular skeleton) via the pelvic girdle and shoulder girdle, respectively. These muscles function in transferring torques and angular momentum during the performance of integrated kinetic chain activities, such as throwing or kicking (Cresswell and Thorstensson 1994; Kibler et al. 2006; Willardson 2007). Examples of such muscles that connect the trunk to the lower extremities include the hip flexors (e.g., rectus femoris, sartorius, iliacus, and psoas major and minor), hip extensors (e.g., gluteus maximus, semimembranosus, semitendinosus, and long head of the biceps femoris), hip adductors (e.g., adductor magnus, adductor brevis, adductor longus, gracilis, and pectineus), and hip abductors (e.g., tensor fascia latae, gluteus medius, and gluteus minimus). Examples of axial-appendicular transfer muscles that connect the trunk to the upper extremities include the scapular stabilizers (e.g., pectoralis minor, serratus anterior, rhomboids, trapezius, levator scapulae) and muscles that act on the shoulder joint (e.g., latissimus dorsi, pectoralis major, coracobrachialis, deltoid, teres major, rotator cuff).

Active neural subsystem

The active neural subsystem controls the recruitment of the core musculature via feed-forward and feedback mechanisms. Feed-forward mechanisms are preplanned motor programs, whereas feedback mechanisms are utilized to fine tune motor programs as skills are performed with greater efficiency over time. During performance of motor skills, anticipatory postural adjustments (e.g., feed-forward mechanisms) take place immediately prior to or simultaneous with movement to maintain wholebody stability (Bouisset et al. 2000*a*, 2000*b*; Nouillot et al. 1992, et al. 2000). The transversus abdominis muscle was shown to be the first core muscle activated during arm and leg raising tasks (Hodges and Richardson 1997*a,* 1997*b*). Therefore, anticipatory feed-forward activation of the core musculature is required in preparation for movement.

Proprioceptors embedded within the intervertebral discs, vertebral ligaments, and facet joint capsules provide sensory feedback regarding position and movement of the vertebral column (Holm et al. 2002; Kang et al. 2002; Panjabi 1992*a*). This sensory feedback is crucial to stimulate specific neural recruitment patterns of the core musculature to meet task demands. Sensory feedback from muscle spindles is also utilized to meet spinal stability requirements. Specifically, the smaller deep vertebral muscles (e.g., multifidus) have the greatest spindle density, as opposed to the larger superficial vertebral muscles (e.g., erector spinae group) (Amonoo-Kuofi 1982, 1983; Nitz and Peck 1986).

The smaller deep muscles are less effective in stiffening the spine; thus, their primary role is in providing sensory feedback that facilitates coactivation of the larger superficial muscles. At any given activation level of the smaller deep muscles, there is an upper limit to the possible activation level of the larger superficial muscles, beyond which the spine buckles (Willson et al. 2005). In summary, spinal stability represents the combined interaction of the passive, active, and neural subsystems. The specific neural recruitment patterns of the core musculature can change instantaneously, depending on postural adjustments or external forces applied to the body. Therefore, training programs must be structured so that athletes are prepared for the wide variety of postures and external forces encountered during sports participation. This is best accomplished through performance of a wide variety of exercises that encompass all planes of movement.

Biomechanics of spinal stability

The core might be thought of as the kinetic link that facilitates the transfer of torques and angular momentum between the lower and upper extremities during the performance of sports skills, occupational skills, fitness activities, and activities of daily living. For example, during a baseball pitch, torques and angular momentum are transferred sequentially from the lower extremities and then across the pelvic girdle, trunk, dominant shoulder girdle, and dominant upper extremity. Weakness in the core musculature may interrupt the transfer of torques and angular momentum, resulting in a slower pitching velocity. In this case, the muscles that act on the shoulder joint may attempt to compensate with greater torque production, which, over time, may result in overuse injuries. Therefore, training strategies must ensure that there are no weak links in the kinetic chain, particularly in the core musculature, which connects the lower extremities to the upper extremities.

The stability of the vertebral column, and thus the effective transfer of torques and angular momentum through the kinetic chain, is dependent on sequential activation patterns in the core musculature. No single muscle can be considered the primary stabilizer, and the appropriate combination and intensity of muscle activation is dependent on factors such as posture, external forces, movement velocity, and fatigue. Additionally, as task conditions change, feedback from sensory organs can change the combination and intensity of muscle activation that allows for the optimal combination of spinal stability and mobility (Holm et al. 2002; Kang et al. 2002; Panjabi 1992*a*).

The core muscles with the largest moment arms, and thus most capable of stabilizing the vertebral column, include the erector spinae, quadratus lumborum, and the rectus abdominis. The parallel alignment of these muscles allows for the generation of large compressive forces, which stiffens the spinal column (Bogduk et al. 1992; McGill 1996; Santaguida and McGill 1995). In addition to active muscle force, intra-abdominal pressure may contribute to spinal stability (Cholewicki et al. 2002*b*, 1999*a,* 1999*b*). The internal and external obliques and transversus abdominis contribute greatly to generating intra-abdominal pressure. The role of these muscles in stiffening the spine via intra-abdominal pressure has been emphasized through instruction of the abdominal hollowing maneuver (Richardson and Jull 1995). During this maneuver, the abdominal wall is pulled posteriorly toward the spine.

However, abdominal hollowing resulted in 32% less stability than abdominal bracing, which is the typical method to generate intra-abdominal pressure (Grenier and McGill 2007). Drawing in the abdominal wall during abdominal hollowing reduces the moment arm for the internal and external obliques and rectus abdominis, thus reducing their potential to stabilize the vertebral column. Conversely, the generation of intra-abdominal pressure through co-contraction of all major abdominal muscles (abdominal bracing) appears to better stabilize the spine (Grenier and McGill 2007).

In summary, spinal stability is dependent on the appropriate combination and intensity of muscle activation and the generation of intra-abdominal pressure. No single muscle or structure can be singled out as being most important. The appropriate combination and intensity of muscle activation is dependent on the task demands (e.g., posture, external forces). Abdominal bracing appears to be more effective than abdominal hollowing to stabilize the spine. Therefore, when coaching athletes regarding proper lifting mechanics, abdominal bracing should be emphasized through co-contraction of the abdominal muscles.

Core muscle activation

Multijoint vs. isolated training

Multijoint exercises, such as Olympic lifts, are often advocated for their emphasis on coordination, motor learning, and stability. The increased stress of postural adjustments with Olympic lifts, and variations of such lifts, might benefit motoneuron activation by the inclusion of greater vestibulospinal and reticulospinal tract input. Hence, for increased sports performance and core muscle activation, it would seem more beneficial to de-emphasize machine-based resistance exercises and emphasize ground-based free-weight exercises. In addition, some researchers and professionals advocate even greater degrees of instability in conjunction with multijoint exercises to further improve coordination and stability.

Acute effects of instability on core muscle activation

It has been proposed that the demands of lifting while supported on an unstable surface will cause an increase in core muscle activation to maintain control during performance of a given exercise (Vera-Garcia et al. 2000). A number of authors have demonstrated that performing exercises to emphasize the core musculature while supported on unstable surfaces increases core muscle activation, as opposed to performing the same exercises under stable conditions (Anderson and Behm 2004; Arjmand and Shirazi-Adl 2005; Vera-Garcia et al. 2007). Increased core muscle activation can be achieved whether the instability is derived from the platform or from the limbs when performing chest presses (Gaetz et al. 2004) or push-ups (Holtzmann et al. 2004). Increased abdominal muscle activity and increased perceived exertion were reported when performing push-ups and when performing squats (Marshall and Murphy 2006*a*) and chest presses (Marshall and Murphy 2006*b*), respectively, on a physioball. Anderson and Behm (2005) had subjects perform squats on a Smith machine (bar guided by rails), and perform regular Olympic squats on a stable floor and on inflatable discs. They reported that higher degrees of instability (inflatable discs > Olympic squat > Smith machine) when performing a squat resulted in approximately 20%–30% greater activation of the spinal stabilizing muscles. However, Freeman et al. (2006) reported that ballistic dynamic push-ups required greater muscle activation and spinal loading than the modest increases in spinal loading when push-ups were performed on labile (basketball) balls. Therefore, instability devices may provide a less intense limb exercise but still provide high core muscle activation.

Other modifications, in addition to unstable surfaces, may be instituted with limb resistance training exercises to emphasize the core musculature. Traditional resistance exercises are more often bilateral, using either a barbell or a pair of dumbbells. Conversely, numerous activities of daily living, occupational tasks, and sport actions are unilateral (e.g., racquet sports, baseball) (McCurdy and Conner 2003), and thus unilateral exercises may be more beneficial when they adhere to the principle of training specificity (Sale

1988). Behm et al. (2003) reported greater upper lumbar and lumbosacral erector spinae activation during the unilateral shoulder press and greater lower abdominal stabilizer activity during the unilateral chest press. Rather than implementing an unstable base, unilateral resisted actions provide a disruptive moment arm (torque) to the body, thus providing another type of unstable condition.

The instability-induced greater core muscle activation in the aforementioned studies was not compared with the greater loads that can typically be accommodated during ground-based free-weight training (see Acute effects of instability on exercise kinematics and kinetics section). Hamlyn et al. (2007) demonstrated that squats and dead lifts (80% of 1 repetition maximum (1RM)) produced greater activation of the erector spinae muscles (34%–70%) than unstable callisthenic exercises. In a similar study, Nuzzo et al. (2008) found greater longissimus and multifidus activation for stable dead lift and squat exercises than for unstable callisthenic exercises. Willardson et al. (2009) reported significantly higher muscle activity for the rectus abdominis during the overhead press and transversus abdominis–internal oblique abdominis during the overhead press and biceps curl when lifting with 75% of 1RM on stable ground than when lifting with 50% of 1RM on a hemispherical physioball. Conversely, there were no significant differences in muscle activity for the external oblique abdominis and erector spinae for the squat, dead lift, overhead press, and biceps curl when lifting with 75% of 1RM on stable ground or with 50% of 1RM on a hemispherical physioball. Overall, Willardson et al. (2009) did not demonstrate any advantage in utilizing a hemispherical physioball for training the core musculature.

Whereas competitive athletes may be able to achieve greater core muscle activation with higher load ground-based free-weight exercises, individuals more interested in health and rehabilitation may choose to achieve greater core muscle activation with lower loads while supported on unstable surfaces. Notwithstanding that fact, moderately unstable devices may not provide a significant training stimulus for highly trained individuals. Wahl and Behm (2008) found that the use of moderately unstable devices (i.e., rubber disc, hemispherical physioball) did not provide as great a stability challenge as the physioball or wobble board in highly resistance-trained individuals. Since these individuals may have possessed enhanced stability from the performance of ground-based free-weight exercises, a greater degree of instability may be necessary for further adaptations. Hence, the training needs and adaptations of experienced and inexperienced individuals suggest that their training programs should differ.

Prolonged physioball training in sedentary individuals may improve spinal stability. Carter et al. (2006) had previously sedentary individuals train on physioballs twice a week for 10 weeks. Following training, the subjects scored significantly better on a static back endurance and side bridge test. However, the control group used in this study remained sedentary; it was not compared with a traditional training group. Cosio-Lima et al. (2003) illustrated greater gains in torso balance and trunk electromyography activity after 5 weeks of physioball training than after traditional floor exercises. Hence, it is not known if traditional resistance training techniques could have provided similar or better results.

Acute effects of instability on limb muscle activation

Exercises performed on unstable surfaces can not only increase core muscle activation, they can also increase limb muscle activation and co-contractions. Triceps and deltoid muscle activity were increased when push-ups and chest presses (60% of 1RM) were performed under unstable conditions, as opposed to stable conditions (Marshall and Murphy 2006*a*, 2006*b*). The soleus (30%–40%) and quadriceps (5%–15%) experienced greater activation during unstable squats (Anderson and Behm 2005). Both the short and long heads of the biceps can contribute as anterior stabilizers of the glenohumeral joint, and their roles in stabilization increases as joint stability decreases (Itoi et al. 1993). There is typically also a decrease in force output in conjunction with the high limb muscle activation, emphasizing the switch from muscle mobilizing to stabilizing functions (Anderson and Behm 2004).

Co-contractile activity may increase when training on unstable support surfaces. Behm et al. (2002*b*) reported that resisted plantar flexion and leg extension muscle actions performed under unstable conditions experienced 30.7% and 40.2% greater antagonist activity than the stable conditions, respectively. The role of the antagonist, in this case, may have been attempting to control the position of the limb when producing force. Antagonist activity has been reported to be greater when uncertainty exists in the required task (De Luca and Mambrito 1987; Marsden et al. 1983). Increased antagonist activity may also be present to increase joint stiffness (Karst and Hasan 1987) to promote stability (Hogan 1984).

While increased antagonist activity could be utilized to improve motor control, balance (Engelhorn 1983), and mechanical impedance (opposition to a disruptive force) (Hogan 1984), it would also contribute to a greater decrement in force during unstable conditions by providing greater resistance to the intended motion. However, continued training may result in lower coactivation levels during lifting activities (Carolan and Cafarelli 1992; Person 1958). More research is needed to determine if the use of unstable surfaces to improve balance and stability and decrease movement uncertainty might decrease co-contractions, which, in terms of energy conservation, may improve movement efficiency.

Acute effects of instability on exercise kinematics and kinetics

There are both positive and negative reports on the effects of unstable surface training on the kinetics and kinematics of training movements. Negative effects include the depression of force or power under conditions of instability. For example, the use of a physioball resulted in decreased force output during leg extension (↓70%) (Behm et al. 2002*b*), plantar flexion (↓20%) (Behm et al. 2002*b*), and isometric chest press (↓60%) (Anderson and Behm 2004). During the isometric chest press, there was no significant difference between the unstable and stable conditions for the limb and chest muscles activity. The similar extent of muscle activation accompanied by decreased force with instability suggested that the dynamic motive forces of the muscles (the ability to apply external force) were transferred into greater stabilizing functions (greater emphasis on isometric contractions) (Anderson and Behm 2004). Similarly, Kornecki and Zschorlich (1994) demonstrated 20%–40% decreases in muscular power when utilizing an unstable pendulum-like device during pushing movements. Kornecki and colleagues (2001) also found that muscle contributions to stability increased, on average, by 40% when a handle was changed from stable to unstable during pushing movements. While isometric force production appears to be reduced, 1RM isokinetic barbell bench-press strength on the physioball, compared with a stable flat bench, was reported to be preserved (Cowley et al. 2007; Goodman et al. 2008). Koshida et al. (2008) suggested that the statistically significant yet small decrements in force, power, and velocity (6%–10%) with a dynamic bench press performed on a Swiss ball may not compromise the training effect. However, because Koshida and colleagues (2008) implemented a 50% of 1RM resistance, the possible beneficial training effects may be more applicable to power and endurance than to maximal and hypertrophic strength training. The aforementioned studies indicate that the type of contraction performed affects force-generating capacity on unstable platforms.

Furthermore, force, power, and performance can be limited during instability exercise by an increase in the stiffness of the joints performing the action. Carpenter et al. (2001) indicated that a stiffening strategy was adopted when individuals were presented with a threat of instability. This type of stiffening strategy can adversely affect the magnitude and rate of voluntary movements (Adkin et al. 2002). Additionally, new movement patterns, especially those performed when unstable, are generally learned at a low velocity, whereas most sports are conducted at high velocities, resulting in a contradiction of training specificity (Behm 1995; Behm and Sale 1993). Kornecki and Zschorlich (1994) demonstrated that the process of muscular stabilization of the joint caused ~30% drops in force, velocity, and power when the handle changed from stable to unstable during pushing movements. Drinkwater et al. (2007) had participants perform squats with varying resistance on a stable floor, foam pads, or a hemispherical physioball. There were significant instability-induced decrements in peak concentric power, force, peak eccentric power, velocity, and squat depth. The deficits were generally greater as the resistance increased. Similarly, McBride et al. (2006) reported reductions in peak force, rate of force development, and agonist muscle activity when performing squats on a rubber disc vs. a stable force platform. These findings suggest that squats performed under increasingly unstable conditions may not provide an optimal environment for strength and power training.

Sport-specific practice may be sufficient to ameliorate factors associated with stability. For example, triathletes have been reported to be more stable and less dependent on vision for postural control than controls (Nagy et al. 2004). Gymnasts were reported to be more efficient at integrating and responding to proprioceptive inputs (Vuillerme et al. 2001). Conversely, an impaired response to proprioceptive inputs was evident with national level skiers, who performed more poorly than their regional level counterparts when tested for postural control on a force platform without their ski boots on (Noé and Paillard 2005). The authors speculated that the inferior performance of the national level skiers could be a long term effect of wearing ski boots, which restricts range of motion, lending further support to the training specificity model. Wahl and Behm (2008) illustrated that highly resistance-trained individuals did not experience significantly greater muscle activation with exercises performed on moderately unstable devices. Moreover, while younger hockey players demonstrate a significant correlation between static balance and skating speed, more experienced hockey players do not, suggesting sport-specific practice is an ample stimulus for stability training adaptation (Behm et al. 2005*b*).

Practical applications

Evaluation of core performance

While clinicians and researchers in sports medicine agree the core musculature contributes to sports-specific tasks, the precise methods of training and evaluation have yet to be firmly established. Training and evaluation methods, per se, should be specific to the demands imposed by sport, occupational tasks, fitness activities, and activities of daily living. This makes evaluation of core stability a paramount issue for clinicians and researchers alike, as few current assessments test athletes in functional positions. In the same vein, understanding the role of the core musculature during physical tasks is essential for optimal training programs.

Assessing the individual

Current evaluation methods include structural and (or) performance assessments, which may or may not involve recording the voluntary surface electromyogram from the core musculature. Clinicians often use structural assessments for patients presenting with pain or recovering from an injury. For example, in the clinical examination of patients with low back pain, assessments of range of motion and spinal stability, followed by radiological examination, are standard. Unfortunately, the repeatability, sensitivity, and specificity of these assessments are not infallible. Clinicians fail to repeatedly diagnose lumbar spine instability using manual assessments of trunk range of motion and intervertebral segmental motion (Binkley et al. 1995; Hicks et al. 2003). Moreover, such manual assessments may not reflect segmental spine movement in vivo (Landel et al. 2008). While magnetic resonance imaging is an important diagnostic tool for identifying anatomical correlates of low back pain, it sometimes fails to differentiate between those with spine abnormalities and low back pain from those without low back pain (Iwai et al. 2004; Okada et al. 2007). Structural assessments are commonly used to diagnose injury, so their usefulness in assessing healthy athletes is limited.

Performance assessments of the core musculature are routine in sports medicine because of their value in assessing injury and tracking preoperative and postoperative rehabilitation progress, and because of their prognostic value of injury risk (Flory et al. 1993; Ireland et al. 2003; Nadler et al. 2000, 2001). The majority of current tests assess the strength or endurance of the core musculature. Isometric and isokinetic dynamometers are used to assess strength, whereas endurance tests, which are exclusively performed isometrically, are performed to task failure (Flory et al. 1993; McGill et al. 1999*a*). Isometric endurance tests include the Biering-Sørensen test of lumbar extension (Biering-Sørensen 1984) and the flexor and side bridge endurance tests (McGill 2001). Isoinertial tests, such as the field test of trunk flexor endurance, have also been promoted (Baechle et al. 2008). New field tests of core stability that correlate with traditional measures have been proposed, like the front abdominal power test of Cowley and Swensen (2008). This test, along with selected anthropometric data, can be used to estimate isokinetic trunk strength (Cowley et al. 2009).

Still, characterizing core stability using a single test is unlikely to capture the pivotal role these muscles play during physical task. Indeed, poor correlation between tests of isokinetic trunk strength and isometric trunk endurance suggests these tests measure different aspects of core function (Latikka et al. 1995; Nesser et al. 2008). In addition, the external validity of these tests to physical tasks is ambiguous. While some authors have shown that measures of core stability and sports performance are related (Nesser et al. 2008; Sato and Mokha 2009), others have not (Schibek et al. 2001; Stanton et al. 2004; Tse et al. 2005). Thus, there is a need for new robust tests that assess multiple aspects of core function and correlate well to physical tasks.

Other instrumented tests used to assess neuromuscular control of the core, like trunk repositioning and load release tasks, have been described (Reeves et al. 2006; Silfies et al. 2007). The trunk repositioning tasks require an individual to actively or passively move back to a neutral spine position following a predefined displacement. Load release tasks require an individual to perform an isometric trunk contraction at a predefined intensity against an external load, which is subsequently released, and the displacement of the trunk is quantified. The voluntary surface electromyography can be recorded from the core musculature to examine the on–off activation of muscles after release. Athletes with recent lower back injury exhibit altered recruitment of the core musculature following load release (Cholewicki et al. 2002*a*). In addition, repositioning error and the magnitude of trunk displacement during load release is predictive of lower extremity injury in female, but not male, athletes (Zazulak et al. 2007*a*, 2007*b*). While these tests certainly hold prognostic value of injury risk, their relation to sports performance variables in healthy athletes is unknown.

To date, while there are many reliable tests to assess core function, the validity of these tests has yet to be justified experimentally. The most common tests of core function include isometric and isokinetic measures of strength and isometric tests of endurance. These tests have been shown to be reliable in a number of subject populations, and are relatively easy to administer (reviewed in Willson et al. 2005). No single test of core stability can be applied to the entire population, and tests should be chosen based on the demands of the given physical task. There is also a need for new valid tests of core stability that assess multiple aspects of function and correlate well to physical tasks.

Assessing core demands during sport

The synergistic relationship between the muscles of the core and limbs are documented for a variety of sports-specific tasks, such as overhead throwing in baseball, forehand and backhand strokes in tennis, cycling, and various lifting tasks (Abt et al. 2007; Aguinaldo et al. 2007; Brown and Abani 1985; Cholewicki and VanVliet 2002; Ellenbecker and Roetert 2004; Stodden et al. 2001; Thelen et al. 1996). These studies highlight the role the core musculature plays in the transfer of torques and momentum throughout the kinetic chain during sports performance. Deficiencies in any part of the kinetic chain could lead to suboptimal performance or injury. For example, fatiguing the core prior to maximal cycling exercise alters lower extremity kinematics, which may increase the likelihood of injury (Abt et al. 2007). This underscores the importance of all parts of the kinetic chain being considered in the development of training programs, in comparison to training the core musculature in isolation, where the pattern and magnitude of muscle activation is likely different than that during physical tasks. Thus, factors such as posture, external forces, movement velocity, and fatigue must be considered.

Many studies have proposed that optimal core stability is vital for injury prevention, inasmuch as poor core stability predicts injury. Poor core stability, which is typically defined as muscle weakness in a specific group of core muscles (e.g., hip abduction), is predictive of anterior cruciate ligament injury, patellofemoral pain, iliotibial band syndrome, low back pain, and improper landing kinematics (i.e., knee valgus) (Fredericson et al. 2000; Ireland et al. 2003; Jacobs et al. 2007; Leetun et al. 2004; Nadler et al. 2000, 2001; Pollard et al. 2007). While these studies support the adoption of core training programs for injury prevention, they do not suggest that such training programs will improve physical tasks. Such training programs have been largely unsuccessful in preventing injury or improving strength and sport-specific performance (Nadler et al. 2002; Steffen et al. 2008*a*, 2008*b*).

Thus, when assessing the role of the core musculature during sports tasks, it is important to consider the demands at all joints and muscles in the kinetic chain, including those distal and proximal to the core. It's unlikely that a single joint or muscle acting in isolation will contribute to performance decrements or injury risk.

Specificity in exercise programming for the core

Resistance exercises designed to address spinal stability should be prescribed based on the spinal stabilization demands of a given sport and the transfer of forces and energy between the trunk and extremities. The spinal stabilization demands of resistance exercises can be altered through modifications in the base of support (e.g., from a stable surface to an unstable device), posture (e.g., from a seated to a standing posture), the type of equipment used (e.g., from using machines to using free weights), how the exercise is performed (e.g., from a bilateral to a unilateral technique or stance) (Behm et al. 2002*a*, 2003; McCurdy and Conner 2003; McCurdy et al. 2005; Willardson 2007), or the addition of extra resistance. Improvements in the ability to stabilize the spine may occur naturally in conjunction with the development of other characteristics (e.g., balance) if athletes or nonathletes receive instruction regarding proper pelvic positioning and abdominal bracing prior to performing certain lifts (e.g., back squats, dead lifts, Olympic lifts, and lifts that involve trunk rotation).

Fitness training programs designed by strength and conditioning coaches and personal trainers commonly include a series of exercises designed to emphasize the core musculature. These exercises may require both dynamic (trunk flexion, extension, lateral flexion, and axial rotation) and isometric muscle actions (supine, side or prone bridging), and are commonly performed while supported on an unstable device (e.g., physioball, low-density foam cushion, wobble board). Although the core musculature is trained during ground-based free-weight lifts (e.g., back squats, dead lifts, Olympic lifts, and lifts that involve trunk rotation) (Hamlyn et al. 2007), the decision to include specific isolation exercises for this area of the body may depend on the phase of training and the specific needs of the individual.

Neural and muscular adaptations that result from performance of resistance exercises are typically expressed through increases in power, absolute strength, or muscular endurance (Bagnall et al. 1984). Development of each of these muscular characteristics can potentially contribute to increased spinal stability if incorporated through the specific practice of relevant physical tasks. However, training the core musculature must be appropriately periodized, rather than it being a permanent fixture in the program or, alternatively, a training afterthought. As with any other component of fitness, specific training of the core muscles should be emphasized to varying extents during all phases of a complete program.

Unstable devices

Because spinal stability is required for efficient execution of physical tasks, a comprehensive program should include resistance exercises that involve a destabilizing component. Many trainers and coaches will advise their clients and athletes that resistance exercises performed on unstable devices train the agonists of the lift and increase activation of the core musculature. For example, performing a dumbbell chest press while bridged on a physioball simultaneously trains the prime movers for this lift (e.g., pectoralis major, anterior portion of the deltoid, and triceps brachii) and increases activation of the core musculature (e.g., erector spinae, gluteus maximus, hamstrings group). However, the force (Anderson and Behm 2004; Behm et al. 2002*b*; Drake et al. 2006; Santana et al. 2007) and power output for the agonists of the lift (Drinkwater et al. 2007) might be reduced to less than 70% of what might be generated under stable conditions. Currently, few studies have demonstrated significant performance improvements in trained athletes consequent to interventions that emphasized resistance exercises performed on unstable devices (Cressey et al. 2007; Schibek et al. 2001; Stanton et al. 2004). Furthermore, most studies have involved untrained or recreationally active individuals (Butcher et al. 2007; Cosio-Lima et al. 2003; Cowley et al. 2007; Kean et al. 2006; Thompson et al. 2007; Yaggie and Campbell 2006). The few studies that have demonstrated significant performance improvements using resistance exercises performed on unstable devices are summarized in Table 1.

Differences in outcomes between trained athletes and untrained or recreationally active individuals might be accounted for by the principle of diminishing returns. Trained athletes may need a greater adaptive stimulus in terms of force production, movement velocity, and rate of force production than what can ultimately be provided when resistance exercises are performed on unstable devices, because of the need for a higher volume and intensity to stimulate adaptations (Baechle et al. 2008; Kraemer et al. 2002). Since the majority of sports are ground-based, resistance exercises designed to address spinal stability should be prescribed likewise (Cressey et al. 2007; Willardson 2007). Ground-based free-weight lifts are characterized by moderate levels of instability that allow for the simultaneous development of upper and lower extremity strength, thereby addressing all links in the kinetic chain.

From a rehabilitation standpoint, the utilization of unstable devices has been shown to be effective in decreasing the incidence of low back pain and increasing the sensory efficiency of soft tissues that stabilize the knee and ankle joints (Caraffa et al. 1996; Carter et al. 2006; Kolber and Beekhuizen 2007; Vera-Garcia et al. 2007; Verhagen et al. 2004). Such training may promote agonist–antagonist co-contractions with shorter latency periods that allow for rapid stiffening and protection of joint complexes. However, increased antagonist activity may also contribute negatively to strength and power development by opposing the intended direction of motion (Drinkwater et al. 2007). This may partially help explain why isolated training for core musculature may be useful in rehabilitation programs but less consistently effective in sports conditioning programs.

The use of unstable devices may provide the greatest benefits in rehabilitation-type settings to restore normal function of the core musculature among injured athletes or in commercial-type settings to maintain or increase the function of the core musculature in untrained or recreationally active individuals. Therefore, performing conventional resistance exercises while supported on unstable devices can be a component of a periodized program when the absolute intensity utilized is less than 70% 1RM (e.g., during localized muscular endurance phases). Also, unstable devices should not be utilized when hypertrophy, absolute strength, or power is the primary training goal, as force generation, power output and movement velocity are impaired and may be insufficient to stimulate the desired adaptations. If unstable devices are to be used during these phases, they should be for supplementary training only (e.g., active rest days). Additionally, trainers and coaches must remain observant for errors in the trainee's technique that may result from instability (Drinkwater et al. 2007).

Bilateral vs. unilateral exercises

Another method of inducing activation of the core musculature is to perform unilateral movements (e.g., unilateral dumbbell shoulder press); as 1 shoulder acts, the contralateral core musculature must also act to maintain an upright posture. It is common for individuals to train with 2 alternately moving dumbbells. However, the mass of the contralateral dumbbell would provide a counterbalance, diminishing the destabilizing torque of the unilateral movement. Therefore, a better strategy to stimulate the spinal stabilizers while training the upper limbs would be to use 1 dumbbell during the action (Behm et al. 2003; Santana et al. 2007). The effect of unilateral contractions on the activation and force output of the agonists for an exercise is not entirely clear. Bilateral muscle actions that have been shown

Table 1. Research involving trained and untrained subjects using unstable devices and the associated performance adaptations.

References	Sample	Mode	Results
Butcher et al. (2007)	Untrained athletes	Trunk stability group vs. control group.*	Trunk stability group had significantly greater vertical jump take-off velocity vs. control group.
Cosio-Lima et al. (2003)	Untrained sedentary individuals	Physioball group vs. control group.†	Physioball group had significantly greater timed unilateral stance balance vs. control group.
Cowley et al. (2007)	Untrained young women	Resistance training on physioball group vs. stable flat bench group.	Both groups had significantly increased 1RM strength and endurance on physioball and flat bench. Both groups had significantly increased distance on front abdominal power test.
Cressey et al. (2007)	Trained collegiate soccer players	Unstable group vs. stable group.† Both groups performed the same training program, except the unstable group performed supplemental exercises on an unstable device. Unstable group performed the squat, dead lift, lunge, single-leg squat, and single-leg balance on inflatable discs.	Stable group had significantly greater power bounce drop jump and countermovement jump vs. stable group. Stable group had significantly greater improvement in 40-yard sprint time and a trend toward greater improvement in 10-yard sprint time vs. unstable group. Both groups had significant improvement in T-agility time.
Kean et al. (2006)	Untrained recreationally active individuals	Wobble board group vs. control group.*	Wobble board group had significantly greater countermovement jump height and rectus femoris activity on jump landing tests vs. control group.
Sato and Mokha (2009)	Trained runners	Core training group vs. control group.* Core training group performed, on a physioball, abdominal crunch, back extension, supine opposite arm–leg raise, hip raise, and Russian twist for 2 or 3 sets, 10 to 15 repetitions, 4 sessions per week.	No significant differences between groups in vertical ground reaction force and horizontal ground reaction force during running stride. Core training group had greater mean improvement in Star Excursion Balance Test and 5000-m run time.
Schibek et al. (2001)	Trained collegiate swimmers	Physioball group vs. control group.*	Physioball group had significantly greater scores with forward medicine ball throw and postural control vs. control group. No significant differences between groups vertical jump, backwards medicine ball throw, hamstring flexibility, 100-yard swim time.
Stanton et al. (2004)	Trained secondary-school basketball and football players	Physioball group vs. control group.*	No significant differences between groups $\dot{V}O_{2\,\max}$, velocity at $\dot{V}O_{2\,\max}$, running economy, running posture.
Thompson et al. (2007)	Untrained recreationally active golfers	Trunk stability group (performed exercises on physioball) vs. control group.*	Trunk stability group had significantly greater club head speed vs. control group.
Yaggie and Campbell (2006)	Untrained recreationally active individuals	Hemispherical physioball group vs. control group.*	Hemispherical physioball group had significant improvement in shuttle run time.

Note: 1 yard = 0.914 m. 1RM, 1 repetition maximum; $\dot{V}O_{2\,\max}$, maximal oxygen uptake

*The control groups maintained current activity levels and performed no specific core exercises.

†The control groups maintained current activity levels and performed the same core exercises on a stable floor.

to impair force output in some but not all movement patterns are termed bilateral deficit (Häkkinen et al. 1995; Jakobi and Chilibeck 2001); they have also been shown to increase voluntary activation of agonist muscle groups (Behm et al. 2002*a*; Santana et al. 2007), termed bilateral facilitation. It has been theorized that trained individuals might be prone to bilateral facilitation, while untrained individuals might be prone to bilateral deficit (Behm et al. 2003; Howard and Enoka 1991). Unilateral contractions can also stimulate neural activity in the contralateral but inactive limb, referred to as cross education (Kannus et al. 1992). Therefore, because of the apparent bilateral facilitation in trained individuals, unilateral exercises should not be considered force building exercises in trained individuals; these exercises might be more effective for strength development in untrained or injured individuals.

Machines vs. free-weight exercises

The general consensus in the comparison of free-weight exercises to machine-based training is that there are advantages and disadvantages to each mode (Häkkinen et al. 1995). It is anecdotally accepted that there is greater activation of muscles that function as stabilizers during free-weight training than during fixed-form (i.e., machine) training (Haff 2000). Evidence partially refuting this contention was provided by Anderson and Behm (2005), who found no significant differences in the activity of the abdominal stabilizers during the free-weight squat or the Smith-machine squat. However, this study also found that the activity of the back stabilizers was 30% lower during the Smith-machine squat than during the free-weight squat.

Since machine-based resistance exercises provide the greatest stability, thereby allowing maximal force to be exerted by the targeted muscle group, a case could be made that the nature of machine-based resistance exercises for targeting specific muscle groups makes such fixed-form training a valuable tool in training the force-generating capacity of the targeted muscles. However, in an applied setting (e.g., sports conditioning), muscles rarely function in such an isolated manner. The added specificity of ground-based free-weight lifts to real-world activities likely outweighs the potential increase in isolated muscle activity when transitioning from free-weight to fixed-form training (Anderson and Behm 2005).

Studies such as Bobbert and Van Soest (1994) and Morriss et al. (2001) have demonstrated that strength increases attributed to machine training may not only be negligible, they might evenbe detrimental to muscle activation during athletic movement. However, adding further instability by transitioning from ground-based free-weight training to free-weight training while supported on an unstable device may not add further specificity; this has been shown to result in greater decrements in force and power output (Drinkwater et al. 2007). Therefore, while ground-based free-weight lifts might be the best combination of specificity and instability, adding further instability by utilizing free weights while supported on unstable devices may not be beneficial during training phases that focus on absolute strength and power development. Ground-based free-weight lifts provide sufficient instability for sport-specific adaptation; further extremes of instability are likely detrimental to resistance training activities.

Isolation exercises for the core musculature

There are 3 commonly accepted approaches for training the core musculature: closed chain exercises while supported on stable surfaces; closed chain exercises while supported on unstable surfaces; and open chain isolation exercises while supported on either stable or unstable surfaces. Each of these approaches may incorporate additional resistance (e.g., free weights, resistance bands, cables). Isolation exercises typically consist of isometric or dynamic muscle actions designed to emphasize specific core muscles with little integration of the upper and lower extremities. Examples of such exercises include trunk flexion to emphasize the rectus abdominis, trunk rotation to emphasize the external and internal oblique abdominis, and abdominal hollowing to emphasize the transversus abdominis. Isolation exercises are commonly observed in the popular media because they are regarded as easy to teach and learn, and sensing the targeted muscle group working might be motivating to the participant.

Isolation exercises can be effective for increasing trunk muscle activation (Cosio-Lima et al. 2003), which may lead to improvements in spinal stability and reduce injury rates (Moffroid et al. 1993) when applied through the specific practice of the relevant sports skills (Butcher et al. 2007; Kean et al. 2006). However, at the present time, there is little evidence to suggest that isolation exercises are more effective than ground-based free-weight lifts (e.g., back squats, dead lifts, Olympic lifts, and lifts that involve trunk rotation) for eliciting performance improvements (Hamlyn et al. 2007). Also, the characteristics that distinguish exercises for spinal stability from other forms of resistance exercise have never been made clear (Willardson 2007). One of the greatest ongoing debates concerning isolation exercises for the core musculature is whether such exercises are actually necessary, considering that most physical tasks involve movement of either the upper or lower extremities and activation of, at least, the transverse abdominis (Hodges and Richardson 1997*a*, 1999), which, in conjunction with other muscles, serves to stabilize the spine (Cholewicki and VanVliet 2002).

Ground-based free-weight lifts, such as those that require “muscular stabilization of posture while performing the lifting movement” (Baechle et al. 2008, p. 400) (e.g., back squats, dead lifts, Olympic lifts, and lifts that involve trunk rotation), appear to provide similar or greater activation of the core musculature as isolation exercises (Hamlyn et al. 2007). The added advantage of training the core musculature with ground-based free-weight lifts rather than with isolation exercises is the greater specificity to sports skills. As with most other muscle groups, the core musculature rarely functions in isolation (Cholewicki and VanVliet 2002; McGill et al. 2003), so a person must learn to coordinate activation of the core musculature, either for stability or mobility, with the muscles of the upper and lower extremities; isolation exercises for the core musculature do not train this coordination (Kawasaki et al. 2005). Therefore, ground-based free-weight lifts should form the foundation of training the core musculature; isolation exercises for the core musculature might be most useful for localized muscular endurance development or for aesthetic-related goals (e.g., bodybuilding).

Exercise position

Isolation exercises for the core musculature are typically taught in a series of progressions (Akuthota et al. 2008), with the rationale that a trainee must be taught to activate their transversus abdominis and multifidus through abdominal hollowing or drawing in; trainees typically learn this technique from a stable position before moving into less stable positions. Usual progressions involve moving from a fully supported supine or prone position to a quadruped, seated, and finally standing position (Akuthota et al. 2008). Further activation of the core muscles is then elicited by performing dynamic movements and isolation exercises in progressively less stable positions, such as while supported on an unstable device (e.g., physioball) (Sternlicht et al. 2007).

Given that, in patients with chronic low back pain, there is known dysfunction of the transverse abdominis (Hodges and Richardson 1999) and atrophy of the multifidus (Hides et al. 1994), the drawing in technique may provide some useful rehabilitative purpose. However, the need for teaching abdominal hollowing may be unnecessary in healthy athletes. It has also been demonstrated that abdominal bracing (i.e., the maximal voluntary activation of all abdominal muscles in unison) is more effective for lumbar stability and easier to learn (Grenier and McGill 2007; Stanton and Kawchuk 2008; Van Wingerden et al. 1993). While isolation exercises for the core musculature might be effective in rehabilitating low back injuries (Akuthota et al. 2008), the specificity of these types of exercises to physical tasks is limited, even when performed dynamically. While some of these exercises can be coordinated with hip extension, with the intent of becoming specific to running and jumping (e.g., supine bridging with the feet supported on a physioball), these exercises rarely, if ever, are trained with sufficient force and velocity to positively improve strength and power (Vezina and Hubley-Kozey 2000).

Volume, intensity, and frequency

Isolation exercises for the core musculature are particularly well suited for high-volume training that emphasizes localized muscular endurance development. Because these exercises often utilize only body mass, with or without additional unstable stimuli, the force output is low, allowing for many repetitions per set (Drinkwater et al. 2007; Vezina and Hubley-Kozey 2000). Indeed, some popular media reports on high-profile entertainers have described routines that consist of several hundred repetitions (Lee and Little 1998).

The inherent characteristics of the core musculature may determine the volume necessary to elicit adaptations. For example, aerobic-type muscle fibers (i.e., type I) comprise the majority (>80%) of the erector spinae (Mannion et al. 1997), multifidus, and longissimus thoracis (Thorstensson and Carlson 1987) muscles in healthy males and females. The combination of exercises with low force requirements and core muscles with high fatigue resistance may necessitate a high volume to induce sufficient fatigue for a training effect. High volume, even with relatively low force, will gradually increase muscle fibre recruitment by inducing fatigue of the lower-threshold motor units, thereby recruiting higher-threshold motor units (Sale 1987). The absolute strength, power, and hypertrophic potential of these muscles might be limited by the relatively low proportion of type II fibers in the erector spinae (35%) (Mannion et al. 1997), multifidus (38%), and longissimus thoracis (44%) (Thorstensson and Carlson 1987). Therefore, based on the relatively high proportion of type I fibers, the core musculature might respond particularly well to multiple sets that involve many repetitions (e.g., >15 per set). However, the characteristics of a given physical task may necessitate repetition ranges that emphasize strength and power development (e.g., <6 per set).

There is little reason to believe that the core muscles respond to the training stimuli differently than any other muscles, so trained individuals would be expected to need greater intensity than untrained individuals. To accomplish an increased intensity, an individual may, for example, perform flexion movements of the hip while hanging from a pull-up bar, thus increasing the demand on the abdominal muscles to maintain a posterior pelvic tilt. This strategy might be more effective in developing strength than in performing a high volume of isolated trunk flexion movements (e.g., abdominal crunches). Since intensity is inversely related to volume, as higher-intensity movements are incorporated, the number of exercises per training session and the frequency of training sessions per week might need adjustment accordingly. There is a need for more research to determine if a specific dose–response relationship exists for this area of the body, and if training variables should be structured differently for the core musculature. Based on the current body of knowledge, the recommendations cited in other resources regarding strength, power, and localized muscular endurance development are applicable to the core musculature (Baechle et al. 2008; Kraemer et al. 2002).

Conclusions

In this review, the core has been defined as the axial skeleton, pelvic girdle and shoulder girdle, and all soft tissues with a proximal attachment originating on the axial skeleton, regardless of whether the soft tissue terminates on the axial or appendicular skeleton. This group of muscles plays an essential role in generating and resisting motion and in providing protection against spinal injuries. Performing resistance exercises while supported on unstable devices is quite popular today; this type of training has been utilized for decades based on the premise that greater instability will stress the neuromuscular system to a greater extent than similar activities performed on stable surfaces. Greater activation of core muscles has been reported when similar exercises were performed while supported on an unstable surface, as opposed to a stable surface. However, performing resistance exercises on unstable devices can also inhibit force, power, velocity, and range of motion.

Elite athletes represent a very small segment of the population, and the training methods employed to maximize performance might be different from the training methods employed to improve general health and functionality. Elite athletes push their bodies to the limits of their inherent potential; this requires significantly higher volumes and intensities of training to achieve maximal performance. Therefore, the training methods that might be practiced in rehabilitation-type settings to restore function of the core musculature for daily activities are often different from the training methods practiced in strength and conditioning-type settings to maximize function of the core musculature for sports performance. In both rehabilitation and general fitness conditioning settings, the utilization of unstable devices has been shown to be effective in decreasing the incidence of low back pain and increasing the sensory efficiency of soft tissues that stabilize the knee and ankle joints. Such training may promote agonist–antagonist co-contractions with shorter latency periods, which allows for rapid stiffening and protection of joint complexes. Training programs must be structured so that athletes, nonathletes, and workers are prepared for the wide variety of postures and external forces encountered during physical tasks. This is best accomplished through performance of a wide variety of exercises that encompass all planes of movement.

For athletes and nonathletes at all levels, ground-based free-weight lifts should form the foundation of exercises to train the core musculature. Such closed chain lifts are characterized by moderate levels of instability that allow for the simultaneous development of upper and lower extremity strength, thereby addressing all links in the kinetic chain. However, there is a role for resistance exercises performed on unstable devices, either as supplemental exercises during low force phases (<70% 1RM) or during training phases that emphasize localized muscular endurance development. Because of the inherent characteristics of many of the core muscles, a high-volume approach might be necessary to induce fatigue in the preferentially recruited type I fibers, thus enabling the recruitment of higher-threshold type II fibers. Ground-based free-weight lifts, such as squats, dead lifts, Olympic lifts, and lifts that involve trunk rotation, provide moderate instability with higher loads, and have been shown to activate the core musculature to a greater extent than calisthenic-type exercises, whether performed on stable or unstable surfaces. Hence, individuals interested in training for high performance should emphasize ground-based free-weight lifts, and institute unstable devices and surfaces into a periodized training program when a lower load is planned or in rehabilitation settings and general fitness conditioning when supplementary isolation exercises might be necessary.

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