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Core Training: Stabilizing the Confusion

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summary

Confusion exists regarding what the core musculature is, how it is evaluated, how it is trained, and how it is applied to functional performance. The core musculature is divided into 2 systems, local (stabilization) and global (movement), with distinction between core-strength, core-stability, and functional exercises.

Recently, an infomercial promised its audience that the advertised piece of exercise equipment would give anyone an "attractive core." There are unfortunate, and at times humorous, misconceptions associated with core muscle training and the idea of someone having an attractive transversus abdominis or attractive multifidus muscle. To the trained eye, it was apparent that these advertisers were referring to the potential chiseled appearance of the rectus abdominis and perhaps external obliques, but similar to many misperceptions, these individuals did not have a complete understanding of what the core truly is. At times, the same confusion is noted in the exercise physiology, fitness, and strength and conditioning professions. The confusion runs from the specific anatomy of the core with regard to defining what it truly is, to whether particular exercises are designed to enhance core strength or core stability, to the definition of core exercise, to its separation from functional exercise, and finally to the effects of core training on performance outcomes. Many times this confusion is as simple as pure semantics and/or differences in terminology, but in any case, the confusion does more to divide the misunderstood topic than it does to combine research areas and training strategies. Using available research, this article attempts to educate the readership on an extremely popular, but controversial, topic. In hopes of eliminating much of the confusion associated with the core musculature, the specific intent of this article is to provide an idea of where current core research resides, thereby enabling direction for future scientific research and application in the strength and conditioning fields.

Core Strength Versus Core Stability

It is wise to begin this section by describing a general foundational overview of the core, and then discuss the differences between core strength and core stability. The "core musculature" can be defined generally as the 29 pairs of muscles that support the lumbo-pelvic-hip complex in order to stabilize the spine, pelvis, and kinetic chain during functional movements (26). The core is also commonly referred to as the "powerhouse" or the foundation of all limb movement (1). These muscles are theorized to create this foundation for movement through muscle contraction that provides direct support and increased intra-abdominal pressure to the inherently unstable spine (10, 25, 33, 61). To ensure stability of the spine in order to produce force and to prevent injury, trunk muscles must have sufficient strength, endurance, and recruitment patterns (10).

"Strength," in reference to this article, can be defined as the ability of a muscle to exert or withstand force. Active control of spine stability, in this case, is achieved through the regulation of this force in the surrounding muscles (16). When instability is present, there is a failure to maintain correct vertebral alignment, or, in other words, a failure in the musculature to apply enough force to stabilize the spine. So, "stability" describes the ability of the body to control the whole range of motion of a joint so there is no major deformity, neurological deficit, or incapacitating pain (51, 53). In general, the goal of the core musculature is to stabilize the spine during functional demands, because the body wants to maximize this stability (1, 16). This level of stability and kinematic response of the trunk is determined by the mechanical stability level of the spine and the reflex response of the trunk muscles prior to force being applied to the body (16). Limb movement provides exertional force onto the spine, where the magnitude of reactive forces is proportional to the inertia of the limb (35, 37), whereas coactivation of the agonistic and antagonistic trunk muscles work to stiffen the lumbar spine to increase its stability (16). There is a concern, which is discussed later, that too much strength or force from core musculature actually can cause greater instability if it is not directed correctly. Also, there is evidence to support that endurance is the more important training variable when it comes to the core musculature (46, 47).

With a general understanding of the goal of the core musculature to stabilize the spine against forces, one can begin to separate the confusion between the terms "core stability" and "core strength," despite the limited research. When the term "core stability" is used, reference is being made to the stability of the spine, not the stability of the muscles themselves. Within the research, there has been no reference to enhancing the stability of a muscle, but rather its ability to contract. When the term "core strength" is used, reference is being made to the ability of the musculature to stabilize the spine through contractile forces and intra-abdominal pressure. Cholewicki and colleagues confirm that "active control of spine stability is achieved through the regulation of force in the surrounding muscles. Therefore, coactivation of agonistic and antagonistic trunk muscles stiffens the lumbar spine and increases its stability" (16, p. 1380). Increases in muscle activation potentially lead to greater spinal stability. In the same vein, confusion also may arise as to whether a given exercise is a core-strength or a core-stability exercise. Core exercises do not aim to increase the stability of the musculature, but rather aim to enhance the muscles' ability to stabilize the spine, particularly the lumbar spine. The confusion between core strength and core stability may be clarified further with a proper understanding of the anatomy of the core musculature.

Table 1
Muscle Characteristics

Local	Global
Deeply placed	Superficial
Aponeurotic	Fusiform
Slow-twitch nature	Fast-twitch nature
Active in endurance activities	Active in power activities
Selectively weaken	Preferential recruitment
Poor recruitment, may be inhibited	Shorten and tighten
Activated at low resistance levels (30–40% maximal voluntary contraction)	Activated at higher resistance levels (above 40% maximal voluntary contraction)
Lengthen	

Anatomy of the Core Musculature: Local and Global Systems

Leonardo da Vinci first described the concept of muscle grouping around the spine. He suggested that the central muscles of the neck stabilized the spinal segments, whereas the more lateral muscles acted as guide ropes supporting the vertebrae (18). Bergmark first classified the muscles acting on the lumbosacral spine as either "local" or "global" (9). Scientific modifications have been made to these initial classifications (1, 51). The local and global muscles can be categorized according to the varying characteristics between them (Table 1). The local musculature (Table 2) includes the transversus abdominis (TrA), multifidus, internal oblique, medial fibers of external oblique, the quadratus lumborum, diaphragm, and pelvic floor muscles (61, 64). These muscles have shorter muscle lengths, attach directly to the vertebrae, and are primarily responsible to generate sufficient force for segmental stability of the spine (10, 26, 61). Recent research has promoted the TrA and multifidi as the primary stabilizers of the spine (26, 50, 51). The TrA is the deepest of the abdominal muscles, originating at the iliac crest, inguinal ligament, and thoracic and lumbar spinous processes via the thoracolumbar fascia, then attaching anteriorly at the linea alba (49, 61). When contracted, it is able to increase tension of the thoracolumbar fascia and increase intra-abdominal pressure, which increases spinal stiffness in order to resist forces acting on the lumbar spine (26, 52, 61). The multifidi attach from the vertebral arches to the spinous processes spanning from sacral to cervical spine. Each muscle spans 1–3 vertebral levels, thus providing the largest contribution to intersegmental stability (61). Because of their short moment arms, the multifidi are not involved with gross movement (1). The TrA and multifidi have been found to activate prior to limb movement in an attempt to stabilize the spine for that movement (33–38). The TrA

Table 2
Core Musculature

Local muscles (stabilization system)		Global muscles (movement system)
Primary	**Secondary**	
Transversus abdominis	Internal oblique	Rectus abdominis
Multifidi	Medial fibers of external oblique	Lateral fibers of external oblique
	Quadratus lumborum	Psoas major
	Diaphragm	Erector spinae
	Pelvic floor muscles	Iliocostalis (thoracic portion)
	Iliocostalis and lognissimus (lumbar portions)	

has been shown to activate up to 100 milliseconds before the activation of limb musculature during limb reaction time tests (30). The TrA, specifically, is activated regardless of direction of limb movement (26, 33–36, 38). This activation promotes spinal stability no matter the direction and begins to confirm the primary stabilizing function of the TrA.

Due to the lone stabilization functions of the TrA and multifidi, the local system can be divided into primary and secondary stabilizers (Table 2). The primary stabilizers are the TrA and multifidi, because they do not create movement of the spine. The internal oblique, the medial fibers of the external oblique, and the quadratus lumborum function primarily to stabilize the spine, but also function secondarily to move the spine (51).

The muscles primarily in charge of producing movement and torque of the spine are the global muscles (Table 2). Global muscles (sometimes categorized as “slings”) possess long levers and large moment arms, making them capable of producing high outputs of torque, with emphasis on speed, power, and larger arcs of multiplanar movement, while countering external loads for transfer to the local musculature (26, 61). These muscles include the rectus abdominis, lateral fibers of the external oblique, psoas major, and the erector spinae. Traditional exercises such as the sit-up have focused on enhancing the capacity of this global musculature. It is thought that exercises that produce gross movement of the spine, such as the sit-up, emphasize the global system and not the local system. These exercises emphasize the global systems, not isolate the global systems, because both systems theoretically work in synergism (17). With reference to fiber typing, the local system comprises mainly type I fibers, whereas the global system mainly consists of type II fibers (57, 61). It should be noted here that there are other, less researched muscles not labeled in the classification of local and global musculatures, and these classifications may vary with new and much needed discoveries from research investigations. With the lack of current research in this area and most investigations using populations with variations of low back pain, it is difficult to make assumptions regarding the application of the core musculature to the strength and conditioning populations. Nonetheless, these assumptions are made.

Application of the Core Musculature

Core and lumbo-pelvic-hip stabilization research began by investigating individuals with low back pain, chronic low back pain, spondylolysis, and spondylolisthesis (22, 23, 34, 51, 52, 57, 59, 64, 66). It has been shown that in individuals with low back pain and lumbar instability, local stabilizing muscles, including the TrA, are affected preferentially, resulting in inefficient muscular stabilization of the spine (33–37, 52). Although in in vivo porcine studies, Hodges and colleagues have shown the TrA to increase intra-abdominal pressure, thus reducing lumbar intervertebral displacement and increasing lumbar stiffness (33). Despite the lack of in vivo TrA research in humans, other research has been able to create a strong theory of its importance, along with the other local muscles, in stabilizing the spine (1, 9, 16, 22, 27, 33–38, 43). The core musculature becomes especially important as the application of forces onto the spine during events of life and sport challenges the musculature’s ability to stabilize and protect the spine.

As previously stated, the spine is inherently unstable. The ligamentous spine (stripped of muscle) will fail or buckle under compression loads of as little as 2 kg or 20 N (10, 46). Level walking can produce up to 140 N of compression force to each side of the spine with each step (20). Holding an 80-lb object in front of the body while standing in neutral posture will produce large compression forces of 2,000 N at the lower lumbar levels (24). Compression was found to be 3,230 N for straight-leg sit-ups and 3,410 N for bent-knee sit-ups, whereas shear forces were 260 and 300 N, respectively (47). Rowing has been shown to produce peak spinal compression forces on the spine of 6,066 N for men and 5,031 N for women (3). Football blocking has been shown to produce average compression forces, anteroposterior shear forces, and lateral shear forces of 8,679 ± 1,965 N; 3,304 ± 116 N; and 1,709 ± 411 N, respectively (28). Half-squat exercises with barbell loads in the range of 0.8–1.6 times body weight applied variant spinal compressive loads between 6 and 10 times body weight (13). In other words, a 200-lb athlete lifting a barbell loaded to 320 lbs during a half-squat would be applying 2,000 lbs or almost 8,900 N of compressive force onto the lumbar spine. Cholewicki, McGill, and Norman showed that the average compressive loads on the L4-L5 joint of powerlifters were estimated to be up to 17,192 N (15). Extreme lifting also has been shown to produce loads on the lumbar spine of up to 36,400 N (29).

These types of compressive loads at the lumbar spine, from life and sport, exceed those loads determined during fatigue studies to cause pathologic changes in both the lumbar disk and the pars interarticularis, which contribute to conditions such as spondylolysis (28). Spine compression and lateral shear forces also have been shown to increase as the lift origin becomes more asymmetric, with one-hand lifting changing the compression and shear profiles significantly (44). This knowledge is valuable, because much of life and sport requires not only extreme loading of the spinal musculature, but also varying angles, positions, and speeds. This understanding of the multiplanar forces that life and sport place on the spine and the injury that could ensue have prompted individuals to seek methods to train the strength or stabilizing capacity, endurance, and neuromuscular reactive properties of the core musculature. It has been suggested that focus should move past strength alone to understand the speed with which the muscles contract in reaction to a force (51). It also has been suggested that an individual who demonstrates strong performance on a strength test of force may not necessarily display an equally strong performance on a test of endurance (43). The individual's history and the specificity of training should dictate the outcomes of assessment tools and subsequent training emphasis. As with other muscular assessment, measures of the core should include various performance measures of force, endurance, and power. This area, among many others, is one of needed future research.

Assessing the Core Musculature

There is limited research on the assessment of core musculature, which adds to some of the confusion associated with this topic. Clinically, core activation has been measured with ultrasound, magnetic resonance, and electromyography (3, 33–38, 50, 54, 64). One of the limitations in the clinical diagnosis of lumbar instability revolves around the difficulty to accurately detect abnormal or excessive intersegmental motion, with conventional radiologic testing often reported as being insensitive and unreliable (52). There could be possible advancements in these areas, but current research with the core musculature is lacking, to the authors' knowledge. Progress has been made toward simpler assessments of the core musculature, with growing knowledge of abdominal hollowing aiding this progress. Abdominal hollowing is specifically the cocontraction of the local system, especially the TrA, multifidi, internal oblique, diaphragm, and pelvic floor musculature, while an individual isometrically contracts and draws in the abdominal wall or navel without movement of the spine or pelvis (5, 19, 22, 52, 56, 57, 59, 60, 63). This drawing-in maneuver is designed to emphasize the deep local muscle activity, because there is minimal activation of the more superficial global muscles, such as the rectus abdominis (51). It has been shown that abdominal hollowing, rather than the sit-up movement, activates a cocontraction mechanism of the TrA, multifidus, and internal obliques, rather than the rectus abdominis and external obliques, with increased activation of the TrA when lumbopelvic motion is limited (56, 59, 63). Abdominal hollowing also has been shown to increase the cross-sectional area of the TrA (19). The research of abdominal hollowing provides important feedback as to the design of future core assessment programs by illustrating that many exercises that may be performed as core exercises do not preferentially activate the local stabilization system of the core, but rather emphasize the global musculature. A growing number of researchers, however, have concerns that abdominal hollowing during exercise can actually cause injury and should not be advocated. The newer suggestion for athletes appears to be the abdominal bracing technique. This growing controversy is discussed in more detail in the next section.

This focus on activating the stabilization system of the core is thought to carry into future prescription for athletes as well. As it is, the most commonly utilized assessments and training are done in the supine or prone position. They are designed to assess or to train the stabilizing system with minimal activation of the movement system, but a question arises when athletes do not typically require spinal stabilization in a supine or prone position. Athletes and other individuals must be concerned with spinal stability, including abdominal hollowing, with the effects such as gravity, external forces, and momentum. To the authors' knowledge, there is no current, valid test for the core musculature in a plane or position other than supine and prone, along with limited research in quantifying the activation of both stability and global systems in the athlete. Assuming the law of specificity applies to the core musculature as well, it may be beneficial for future research to assess and to quantify the activation of the stabilization system in positions more specific to a given sport, function, or action.

Posterior pelvic tilting also has been advocated to cause cocontraction of the local stabilization musculature. Nevertheless, it is not suggested at times due to the increased activation of the rectus abdominis and speculation of negative preload effects on the lumbar spine that

Table 3
Sahrmann Core Stability Test

Level 1	Begin in supine, crook-lying position while abdominal hollowing Slowly raise 1 leg to 100° of hip flexion with comfortable knee flexion Opposite leg brought up to same position*
Level 2	From hip-flexed position, slowly lower 1 leg until heel contacts ground Slide out leg to fully extend the knee Return to starting flexed position
Level 3	From hip-flexed position, slowly lower 1 leg until heel is 12 cm above ground Slide out leg to fully extend the knee Return to starting flexed position
Level 4	From hip-flexed position, slowly lower both legs until heel contacts ground Slide out legs to fully extend the knees Return to starting flexed position
Level 5	From hip-flexed position, slowly lower both legs until heels 12 cm above ground Slide out legs to fully extend the knees Return to starting flexed position

* Subsequent levels begin in this hip-flexed position.

often cause low back pain (22). For the pelvic tilt to be performed, the individual contracts the lower abdominal muscles to rotate the pelvis posteriorly, so that the lumbar spine flattens out. A common posture is hyperlordotic, which tilts the pelvis anteriorly or forward and is associated with the imbalanced lengthening of the abdominal muscles and gluteals combined with shortening of the hip flexors that may lead to lack of accurate segmental control (51).

Researchers investigating simpler forms of core strength (its ability to stabilize) and endurance assessments have utilized these findings supporting the cocontraction effects of abdominal hollowing on the local stabilization musculature. Abdominal hollowing, especially in the supine position, has been shown to increase the activity of the TrA (8, 63). In response to this notion, researchers have begun to utilize an inflatable biofeedback transducer placed under the lumbar spine in this supine position. TrA activation decreases as lumbopelvic movement increases, and thus stability of the spine can then be measured indirectly through changes in the pressure applied to the transducer (63). A common test utilizing this biofeedback transducer, as well as increased spine stabilization demands with lumbopelvic motion, is a modified Sahrmann lower abdominal assessment (1, 62).

The Sahrmann assessment protocol is illustrated in Table 3 and begins in the supine crook-lying position. Strength, endurance, and stability at the lumbar spine with the varying protocols, including the Sahrmann scale, are assessed using an inflatable pressure tranducer or cuff, such as the Stabilizer (Chattanooga Pacific Pty. Ltd., Brisbane, Australia) (61). With the Sahrmann core stability test, the transducer is placed under the individual's lumbar spine while he or she is lying supine in a hook-lying position. The transducer then is inflated to 40 mm Hg, while the individual activates the stabilizing musculature via the abdominal hollowing technique. Abdominal hollowing, if performed correctly, will result in either no change in pressure or a slight decrease from the initial 40 mm Hg (22). There are 5 levels in the Sahrmann test. In order to advance to a new level, the lumbar spine position must be maintained, as indicated by a change of no more than 10 mm Hg in pressure on the analog dial of the pressure biofeedback unit (62). Pelvic tilt with its flattening of the lumbar spine onto the cuff will increase the pressure reading. This pelvic tilting will increase the pressure transducer to a point where it does not move, thus indicating that the lumbar spine has maintained stability (61). The Sahrmann protocol could possibly be used as a scientifically based protocol that indirectly tests the ability of the core musculature to stabilize the spine with and without motion of the lumbopelvic complex. This protocol may provide an easier means for future research to pre- and posttest the effects of training on the core musculature. Nevertheless, there is important research needed to validate the effectiveness of this assessment in varying populations, as well as research investigating muscle activation and its application to performance.

Quantifying the Core and Other Concerns

Research has begun to further quantify the muscles that contribute to stability under spinal load, expanding on the few studies that have been done in this area (39, 40, 41). In other words, these researchers seek to determine how much muscular stiffness is necessary for stability (11, 14, 47), typically by placing a numeric value to activity, compression, and resultant stability. Activation patterns are measured while certain exercises are performed at different spinal loads, and these patterns are quantified using advanced biomechanical models

(45). Extensive discussion of these biomechanical models is out of the scope of this article, but the growing area of research has brought valuable information to the strength and conditioning profession in regard to abdominal exercise prescription.

As stated previously, much research has proposed the TrA as a major contributor to spinal stability and has suggested abdominal hollowing or "drawing-in" as a way to activate the TrA with minimal activation of the rectus abdominis and other global muscles. Abdominal hollowing has been shown to increase the thickness of the TrA (19) and promotes greater sacroiliac joint stability (59). Because most of this research, however, has been performed with patients with low back pain, questions have arisen regarding its application to a healthy individual or advanced athlete. Many scientists now suggest that a more suitable method of stabilizing the spine may be abdominal bracing, due to its ability to cocontract more abdominal muscles, instead of one muscle, such as the TrA, being activated for stability (40). Vera-Garcia and colleagues showed that coactivation of all trunk abdominal muscles (abdominal bracing) increased the stability of the spine and reduced lumbar displacement after loading. All the torso muscles appear to play an important role in securing spinal stability and must work together to accomplish this stability. Many of these same scientists disagree with abdominal hollowing and the attempt to singularly activate the TrA and multifidus before dynamic, athletic movements. Hollowing or drawing-in may decrease activation of many muscles that are normally active during dynamic movements, thus preventing the natural abdominal cocontraction of all musculature.

Not only has the interpretation of the scientific literature caused confusion of proper abdominal activation technique (abdominal hollowing, drawing-in, or abdominal bracing), but these terms have been misconstrued. There are many popular fitness facilities, to remain unnamed, that teach the drawing-in maneuver to their trainers for subsequent prescription to clients. They use the term "draw-in" to describe the inward movement of the abdomen with abdominal contraction, similar to the feeling when all air is expelled forcefully. The activation of the TrA will create a pull inward against the abdominal viscera, thus being a strong muscle of exhalation and expulsion (32). By forcefully expiring all of one's air, the activation of the TrA is thought to be optimal and the client can experience the proper sensation of the tight abdominals during the drawing-in maneuver. In this case, the sensation of abdominal activation may simulate that of abdominal bracing. Richardson and Jull (58) originally described drawing-in by asking patients to "gently draw in the abdominal wall especially in the lower abdominal area." Abdominal hollowing or drawing-in has been defined further as the isometric contraction of the abdominal wall without movement of the spine or pelvis (22) or as placing emphasis on anterolateral abdominal muscle activity over the rectus abdominis by drawing the navel up and in toward the spine (2). The draw-in maneuver is described differently than the abdominal bracing technique, in which more of the external obliques are activated (58). Abdominal bracing has been described more specifically as coactivation of all the abdominals (2, 65) or as lateral flaring of the abdominal wall (42, 63). The drawing-in or abdominal hollowing maneuver may be better suited for static exercises that focus on training the local system, but may be a poor suggestion for activating abdominals during performance tasks where the global system must be active. Conversely, abdominal bracing is not appropriate if the aim of the exercise is to preferentially activate the TrA or the internal obliques (63). It seems that hollowing is being suggested currently for greater TrA activity in a supine position with low back pain patients, whereas abdominal bracing may be more suitable for more dynamic movements and external loading. It has been noted previously that future research will need to investigate whether or not these types of static exercises translate to multiplanar, dynamic situations.

Not only has controversy arisen over what type of abdominal activation is optimal for spinal stability, but research has begun to examine the potentially harmful effects of too much stability, in addition to those of too little stability. Sufficient stability of the lumbar spine can be achieved for a neutral spine in most people with modest levels of coactivation of the abdominal wall (47). This "sufficient stability" would be the minimal level to assure spinal stability without imposing unnecessary loads on the muscles and associated tissues (65). Because it appears that endurance may be more important than strength and should be trained before strength, training may be better focused toward re-educating faulty motor control systems (46, 47) rather than toward stabilization system strength, which may cause inappropriate force to the spine.

Currently, there seems to be no such thing as an ideal set of exercises for all individuals, but there are general suggestions for exercises that emphasize trunk stabilization in a neutral spine, while also emphasizing mobility at the hips and knees (4, 6, 47). Based on his quantifying research, McGill (46) has suggested the proper order of exercises to be the cat stretch exercise, anterior abdominals and curl-ups with hands under the spine to help maintain a neutral spine, lateral musculature activation with side bridges, and finally, extensor exercises like the bird dog (4-point kneeling, opposite arm, opposite leg raise) exercises. McGill has made further suggestions that the ideal exercise would challenge the muscle while imposing minimum spine loads with a neutral posture and elements of whole body stabilization (47, 48). Caution should be used when implementing whole body stabilization as a pure core

Figure 1. Dying bug.

Figure 2. Marching.

Figure 3. Prone bridge.

exercise, because scientific observations have not correlated balancing while standing on an unstable surface to training spinal stabilizers (12). Future research should begin to examine the spinal stabilizers during these popular exercises and to quantify loads on the spine during real-time, real-life activities. How do the loads presented in quantification studies compare with the exercises and performance tasks of athletes? This research would fall in line with suggestions of utilizing core exercises while standing, because specificity would suggest such exercises to mimic the demands of life and sport. Implementation of core applications and/or advanced abdominal exercises and being infused into fitness and sport performance protocols more rapidly than valid research is being conducted. Quantification of the core appears to be a valid area of future research for the strength and conditioning or fitness professional to stay up-to-date and to utilize in future prescriptions.

Training the Core Musculature

The main purposes of basic core strength training (training the local system) is to increase stability and to gain coordination and timing of the deep abdominal wall musculature, as well as to reduce and prevent injury (26, 66). Most of the research done on the application of the core musculature has focused on limited bouts in order to examine activation only. There has been an enormous media frenzy that advocates the ability of core training to enhance performance; unfortunately, there is limited research to support these claims. Hagins and associates showed that a 4-week lumbar stabilization exercise program improved the ability to perform progressively difficult lumbar stabilization exercises (30). Six weeks of Swiss ball training specifically designed for core activation improved the ability of the core musculature to stabilize the spine significantly, while also improving core endurance (62). Because the spine is mechanically unstable, stiffness may be decreased at one joint accompanied by muscles and a motor control system that is "unfit." This combination results in inappropriate muscle activation sequences when performing even relatively simple tasks (46). Core training seeks to coordinate the kinetic chain (muscular, skeletal, and nervous systems) to enhance the synergism and function of the core musculature. Panjabi (53) created a convenient model for the core musculature, categorizing the interaction of the spine into 3 systems: passive, active, and neural. The passive system consists of the vertebrae, intervertebral discs, zygapophyseal joints, and ligaments. The active system consists of the muscles and tendons surrounding and acting upon the spinal column, including both local and global muscles. The neural system describes the central nervous system (CNS) and accompanying nerves that direct efferent and afferent control over the active system to provide dynamic stability during movement. These systems work interdependently, so that one is able to make up or compensate for deficits in another (53).

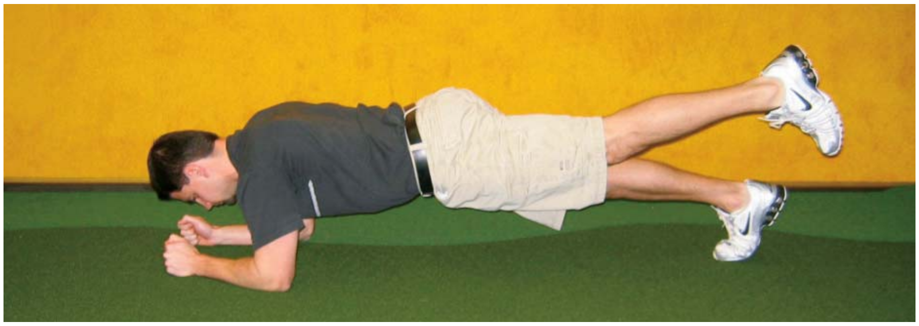

Figure 4. Prone bridge—hip extension.

Figure 5. Side bridge.

Active System: Local and Global Musculature

The progression of training in the core musculature typically and currently works from the inside out. Training focuses on optimizing the function of the local system before emphasizing movements that utilize the global system. Functional progression is the most important aspect of the core-strengthening program, which includes performance goals, a thorough history of functional activities, varied assessments, and training in all 3 planes of motion (1, 43). As previously mentioned, the local or stabilizing system consists of mainly type I tonic musculature. The type I fibers of the local stabilization system tend to weaken by sagging (51). Specificity, then, would require local system exercises that involve little to no motion through the spine and pelvis for the local, stabilizing muscles. Examples of these local system exercises are shown in Figures 1–7. The local system is activated with low resistances and slow movements that prolong the low-intensity isometric contraction of these specific stabilizing muscles (51, 61). Because most isolation exercises of the local musculature, including the TrA, are in nonfunctional positions, exercise training may need to shift to more functional positions and activities. The global system, consisting of more type II fibers that create movement of the spine, may be emphasized through exercises that involve more dynamic eccentric and concentric movement of the spine through a full range of motion. Examples of these global system exercises are

Figure 6. Side bridge abduction.

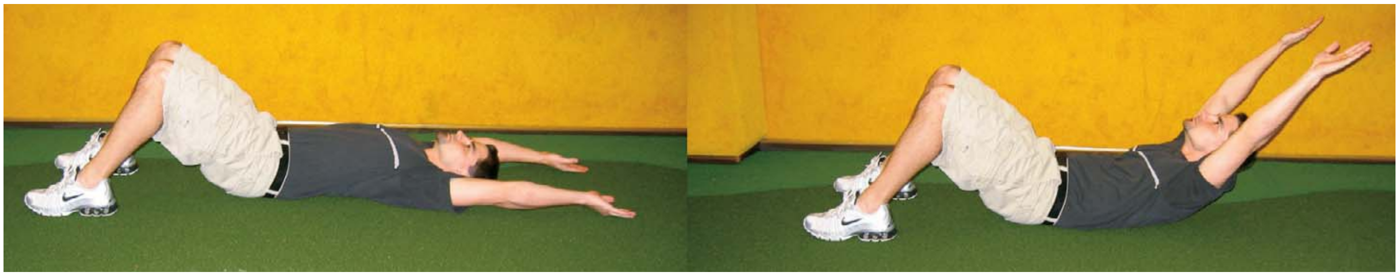

Figure 7. Long lever crunch.

Figure 8. T rotation.

Figure 9. Twist on ball.

Figure 10. Cable wood chop.

Figure 11. Cable reverse wood chop.

seen in Figures 8–14. The activity of global muscles, which tend to shorten or tighten, will differ from that of the sagging local system (51). Rapid movement and higher resistances also will recruit these global muscles, especially the rectus abdominis (51). These types of exercises not only emphasize the global system, but also create an environment for the local system to begin to stabilize the spine in varying, multiplanar movements. Training the core for an emphasis in strength would include high load, low repetition tasks, while endurance enhancement requires longer, less demanding exercises (46). Beyond our knowledge of basic muscle physiology and adaptation, there is little research on the specific types of core exercises to be used and their effects on the ability of the musculature to stabilize the spine in varying planes of motion. With the limited research in this area, specificity to the individual's history and goals, along with progression, should not be overlooked.

Neural System

The stability of the lumbar spine is not dependent solely on the basic morphology of the passive and active systems, but also the correct functioning of the neuromuscular system (52). The patterns of recruitment and relative onset times between muscles are modulated by the CNS, ensuring optimal movement control, muscle performance of the core, and control of reactive forces produced by the limb movements (10, 35). Training and exercise can lead to great increases in maximal dynamic strength through neural adaptations in all musculature, so the neuromuscular system then can specifically compensate and improve dynam-

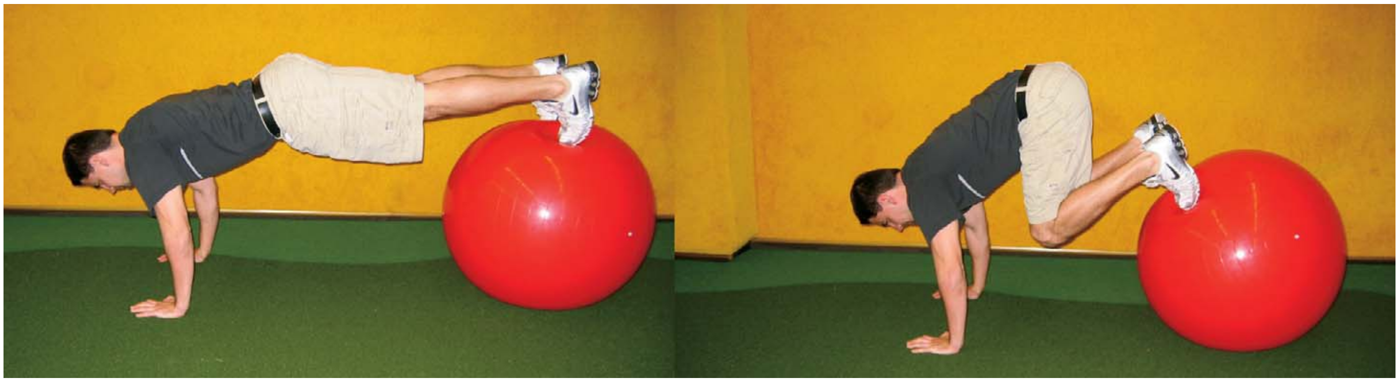

Figure 12. Skier crunch.

Figure 13. Overhead press functional progression.

Figure 14. Two arm/single arm chest press functional progression.

ic stability of the spine (31, 51). More focus may be directed toward coordination and timely muscle activation of the deeper local system to enhance spine stability, rather than just toward improving strength and range of motion (17, 26). There are no current guidelines to accomplish these adaptations, emphasizing another important area for future research. The reflex response of the stabilizing musculature to applied or produced force combines with the mechanical stability level to determine the kinematic response of the trunk (16). It also seems that some unexpected loading scenarios onto the trunk may be too fast and/or with too high of a magnitude for the reflex response to control intersegmental displacement effectively and safely (16). In these scenarios, it may be more important to consider that it is not the strength of the stabilizing musculature, but the speed with which the muscles contract in reaction to the forces that are capable of displacing the spine (51). Potvin and O'Brien showed that trunk muscle cocontraction increased firing during lateral bend contractions as the agonist trunk muscles fatigued (55). The investigators proposed that the fatigue produced by the exertions compromised neural coordination and that the increased cocontraction served to maintain stability of the spine. As with other forms of training, the neural component, as well as optimal gains in musculature adaptation, should be considered for future research.

It also should be noted here that much emphasis has been placed on the ability of the TrA and multifidi (core stabilization system) to activate prior to the limbs and global system muscles in order to stabilize the spine against gross movement patterns. Despite this emphasis, these differing musculatures may not work in isolation, but may work together to stabilize and move the spine. The TrA has been shown to activate independently of other core musculature to decrease activation during lumbopelvic movement (38, 63). So, other musculature will activate to work together for stable spine maintenance in dynamic multiplanar movements. Beneficial progression in exercises for enhancing spinal stability, then, may involve the entire spinal musculature and its motor control under various loading conditions (17).

Until research begins to shed light upon optimal progression during core training, progression may be programmed according to the known frequency, intensity, time, and type (FITT) principle that commonly is used in select training protocols. As with most training protocols, the FITT principle is utilized and manipulated to meet specific needs of the individual. This manipulation would seemingly be no different in core training practices. Common sense with knowledge of general neuromuscular adaptations can be used to manipulate these select variables, though always considering the safety of the individual first. Frequency can be adjusted, as with any other muscle being trained, to emphasize overload, recovery, and specificity. Intensity can be progressed in exercises training the local and global musculatures by simply increasing the instability of the environment, foot positioning, and lift progression (Table 4, Figures 13 and 14) or by increasing resistance by wearing a weight vest during exercises. Time or duration of exercises tends to fluctuate, depending upon the particular exercise used. The local musculature exercises that require little to no movement typically require durations of 30–45 seconds, utilizing assumptions based on their type I fiber composition and stabilization duties. At the point where holding an exercise for 45 seconds is no longer challenging, progressions can be made with intensity, thus decreasing the ability to hold the exercise for a given duration. As the individual adapts to the training progression, adjustments again can be made through any of the other previously noted variables. Research examining the alteration and progression of all training variables with the core is at its genesis and is of great importance to the advancement of the literature in this area. Movement or global system exercises may utilize numbered repetitions, which will be adjusted and progressed according to the specific needs of the individual. Again, the type of exercises selected fall under the principle of specificity, always considering the exercise history, current level of fitness, and performance goals of the person involved in the individually designed training protocol.

Table 4
Functional Training Progressions

Stance	Lifts
1. 2 feet at hip or shoulder width	1. Both arms at the same time
2. Staggered stance	2. Alternating
3. Single-leg	3. Single-arm
4. Repeat 1–3 on stability device	4. Repeat 1–3 with rotation

Further, as core training progresses, consideration always should be placed on synergistic relationships within the human body, including the ability of the 2 systems of the core musculature to work together (17). Local and global musculatures work together to create dynamically stable and functionally efficient multiplanar movements of the spinal column. Argument could be made that because, ideally, both systems work together, training should begin to utilize this relationship and progress from there to maximize its functional transition to a specific outcome or function. Even as progression aims to challenge the core musculature in environments similar to those of competition or of life, it may be wise to begin slowly, using the specificity and FITT principles. In addition, it is commonly agreed that most individuals overtrain the global musculature before optimal development of the local system has been accomplished. Overtraining of the global musculature before sufficiently training the local musculature is thought to create a situation where force is being produced by the global muscles that cannot be controlled and handled by the local musculature. Anecdotally, this situation has been exemplified as a fast sports car with a poor braking system. The car and its associated engine designed to reach high speeds represents the overtrained global system, whereas the poor braking system represents the undertrained local system. Even though the sports car can reach accelerated velocities, the brakes are unable to properly slow it down, and thus a crash occurs. In real life, the subsequent crash refers to maladaptive movement of the body and eventual injury to the spine. Despite the effectiveness of such analogies, however, there is a lack of research to confirm the theories behind the interaction of the different systems of the core musculature. As with all forms of training, progression and specificity of the core musculature must be considered, and future research must seek to determine specific training's effect on performance to accomplish safe and optimal performance outcomes.

Functional Training

With the distinctions made between training specifically for local and global systems and having established the importance of proper, specific progression, one final area that is often confused and misunderstood will be addressed. Specifically, some confusion with core training arises with the mislabeling of certain exercises as "core exercises." The general definition of the word "core", as can be found in an ordinary dictionary, is "the central or most important part of something." For instance, many weight training protocols have a set of core exercises, such as the squat. In this case, core describes the central, fundamental, or basic lifts that are needed to build upon in that particular area of training. In this example, core does not mean that the lifts are specifically training the local and global musculature of the lumbar spine (our definition of core). This distinction must be made, because certain central or fundamental exercises, such as the squat, are labeled as core exercises. The squat will require the activation of the core musculature, both local and global systems, to ensure proper spinal stability during the movement. However, the same can be said of very simple tasks as well, such as bending over to pick up a small object (46). Picking up a small object is not considered a core exercise, even though the core musculature is activated. So, because the core musculature is used in any movement that requires segmental stabilization and protection of the spine, confusion may arise if we are not careful in using the label of "core exercise."

This distinction must be made, especially with the rush of stability training equipment that is flooding the market. Confusion occurs because certain devices and exercise protocols are advertised to train the core musculature. When performing exercises on unstable surfaces, the core musculature will be challenged, but the intent of the exercise is to train the neuromuscular system by progressively challenging balance, stability of the limbs, coordination, precision, skill acquisition, and proprioception (7, 26, 62). These exercises also may be considered functional exercises when they are specific to the demands of an individual's sport or activity. The exercise does not have to be on an unstable surface, a Swiss ball, or any other piece of stability equipment to be considered functional. On the one hand, for example, a controlled seated machine rowing exercise would be functional for a rower, because it is more specific to the athlete's goals and the seated environment of competition. On the other hand, unstable environments pose very functionally based (task- and goal-specific) exercises for athletes and nonathletes alike, because most sports and even activities of daily living require force production and acceptance in multiplanar, dynamically unstable environments. For instance, a functional training mentality may promote an offensive lineman to train at times with a standing cable chest press on a single leg, because many times offensive linemen are required to exert upper-body force on an opponent during a game while in a single-leg environment. This type of exercise, like the squat, is not considered a core exercise specifically designed to train the local and global musculature of the spine. It is a functional, sport-specific performance enhancement exercise that is individualized to the athlete. The core must be utilized in this movement, but the intent is to create an environment to train the neuromuscular system to stabilize dynamically, to produce force proprioceptively, and to manage force exerted on the global movement system, which will minimize the force transferred onto the local stabilization system and the spine. In current theory, once the stability of the inner and global core musculatures have been examined and have been trained, then a progressive protocol may be added to develop the enhanced capabilities of the limb musculature in sport-specific training. Again, consideration may need to be made as to whether or not this approach is the best in utilizing spinal stabilization in sport-specific environments. In addition, future research should examine the effectiveness of placing the individual in an environment that is overly unstable, such as standing on a wobble-board. Questions concerned with the amount of force production loss, the amount of neuromuscular stimulation, and its transfer from these extremely unstable environments to performance should be answered by future research in these areas.

A commonly seen progression in functional lift and stance progressions is shown in Table 4, with examples in Figures 13 and 14. Progression is required, because as the instability of the lift or environment increases, so do the demands placed upon the stabilization musculature (2, 21). These functional progressions seek to gradually place individuals in functional environments and platforms that will be required of them during life or sport. Advances in the stance and lift progressions can be utilized in conjunction during training. For example, the most stable dumbbell overhead press exercise would be with 2 feet at hip or shoulder width while pressing both arms at the same time. The most unstable format of the same exercise would be a single-leg, contralateral, single-arm press with rotation. The importance of training in these environments can be seen, because there is a decrease in force production as the environment becomes more unstable (3). Given that production and maintenance of force decreases with increasingly unstable environments, such as the offensive lineman blocking in a single-leg or staggered stance while applying force with a single arm, it may seem practical and optimal to progressively train the individual's ability to produce and maintain force in these naturalistic or functional environments. With the progressive nature of functional training and its common confusion with core training, careful attention may be needed in the labeling of exercises to ensure the dissemination of terminology and future research in these areas.

Future Research

With a growing understanding of specific labeling needs and the function of the core musculature, research should begin to examine the effect of varying training programs on core strength, core endurance, and neuromuscular adaptations. Furthermore, researchers could begin to examine core training's functional application to specific performance variables or how specific core-exercise training can be applied to performance or sport-specific training. Limited research has been conducted in this area. Stanton, Reaburn, and Humphries compared core-training effects on running economy (62). After 6 weeks of Swiss ball training, despite significantly improving core musculature strength and endurance, subjects did not demonstrate any significant changes in running economy. The authors do note that these results may be applicable only to the specific population that was used for this study (male athletes, 15.5 ± 1.4 years of age). In addition, despite participants getting stronger and scoring higher on the Sahrmann test with no improvement in running economy, one may question the effectiveness of uniplanar core training on multiplanar performance. With the lack of research regarding the application of core training on performance, further studies should examine specific and varied training protocols' effects on performance. Future research also should continue to validate core assessment techniques, with consideration of the specificity of the individual's history, goals, training, and prescription. Core assessment and training also should be investigated with athletic and normal populations for standardization and application, in addition to low back pain populations, with emphasis on continued validation of protocols utilizing inflatable biofeedback transducers to measure core strength and endurance. It is hoped that with a more informed understanding of the research behind the core, professionals can eliminate confusion over its definition, varied terminology, and functional progressive applications, and will be able to coordinate future research endeavors. The main conclusion with the core and its application to the strength and conditioning disciplines is that research is limited. ♦

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