The Role of Instability Rehabilitative Resistance Training for the Core Musculature

David G. Behm, PhD,1 Eric J. Drinkwater, PhD,2 Jeffrey M. Willardson, PhD,3 and Patrick M. Cowley, PhD4

1School of Human Kinetics and Recreation, Memorial University of Newfoundland, St John’s, Newfoundland, Canada; 2School of Human Movement Studies, Charles Sturt University, New South Wales, Australia; 3Department of Kinesiology and Sports Studies, Eastern Illinois University, Charleston, Illinois; and 4Department of Exercise Science, Syracuse University, Syracuse, New York

SUMMARY

NEUROMUSCULAR TRAINING OF THE SPINAL STABILIZING MUSCULATURE IS RELEVANT FOR LOWER BACK PAIN PREVENTION AND TREATMENT. INSTABILITY RESISTANCE EXERCISES PROMOTE COCONTRACTIONS, INCREASING JOINT STABILITY. OF GREATEST IMPORTANCE TO JOINT STABILITY IS NOT NECESSARILY STRENGTH OR ENDURANCE BUT MOTOR CONTROL. DYNAMIC PROVOCATIVE CALISTHENIC EXERCISES MAY IMPROVE CORE STABILIZING FUNCTIONS. HIGHER CORE MUSCLE ACTIVATION IS POSSIBLE WITH STABLE GROUND-BASED EXERCISES. PERFORMING RESISTANCE EXERCISES ON UNSTABLE SURFACES MAY HAVE BENEFITS IN JOINT INJURY PREVENTION AND IMPROVING BALANCE; HOWEVER, STRENGTH GAINS COULD BE COMPROMISED. HIGHER LEVELS OF DYNAMIC STABILIZATION MAY BE RECOMMENDED WITH REHABILITATION BUT SHOULD ONLY BE ONE COMPONENT OF A PERIODIZED PLAN.

INTRODUCTION

A major emphasis of research over the past decade is the introduction of various modes of instability in resistance training and the application as a training modality for athletes as well as health and fitness enthusiasts, although its use as a rehabilitative tool has received less attention. Historically, physical therapists were using balls before World War II (consequently, the term physioballs). German and Swiss (consequently, the term Swiss balls) physical therapists were especially active in using balls for sports training and therapy. These applications have continued to the present day. For example, the Canadian Society for Exercise Physiology position stand (13) on the use of instability to train the core musculature states the following: “Individuals who are involved with rehabilitation, health-related fitness pursuits or cannot access or are less interested in the training stresses associated with ground based free weight lifts, can also receive beneficial resistance training adaptations with instability devices and exercises to achieve functional health benefits.” Instability exercises and devices have been defined as promoting postural disequilibrium or imbalance as postural sway projects the center of mass beyond the device’s area of support or in other cases, reaction forces can change the center of pressure because of surface distortions (e.g., low-density foam cushion, sand) (14).

Research has indicated that introducing greater levels of instability or dynamic lumbar stabilization during resistance training tends to decrease force output albeit with high muscle activation (14); this might not be considered optimal for athletic conditioning (13) but could be more relevant for rehabilitation purposes. The progressive introduction of greater instability during resistance exercises might have application in the prevention and treatment of common ailments, such as low back pain (LBP), and limb and joint injuries (25,34).

Specific training practices aimed at targeting the stabilizing action of the spinal muscles are an important consideration in the rehabilitation of LBP (1). For example, a strong trunk

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provides a solid foundation for the torques generated by the limbs when performing daily and athletic activities. Increased strength of the low back musculature is not necessarily associated with the prevention of LBP (78–80). However, it may provide some protection when greater forces are needed during performance of athletic skills or certain occupational tasks (19–21). Conversely, decreased muscular endurance of the low back musculature (77,81) and impaired coordination (3,46,49) is strongly associated with LBP. Furthermore, the coordinated activation of the core musculature is critical to ensure sufficient spinal stability at different time points throughout a movement task. A recent study by Hubley-Kozey et al. (54) demonstrated variations in activation sequences among muscles of the abdominal wall during a supine bilateral leg raising task. Greater consistency in the muscle activation sequence was noted among individuals who were better able to control lumbar-pelvic motion (lordosis versus anterior pelvic tilt monitored with reflexive tape on the iliac crest by video camera), especially during phases of the task in which the hips and knees were extended, creating greater resistive torque.

The purpose of this review is to examine the instability resistance training literature to determine the appropriateness and role of this training modality as a rehabilitation tool. The bulk of the literature has investigated the acute and chronic responses to instability training with healthy uninjured individuals. It is our objective to evaluate and translate these findings for the purposes of injury prevention and rehabilitation. With these objectives in mind, this review article will begin by defining core muscle stability; illustrate few studies that have examined prevention of injuries using instability; examine the effects of instability on core and limb muscle activation, motor control, force, and power; and then based on this literature, provide clinical recommendations.

DEFINITION OF CORE MUSCLE STABILITY

Many published articles espouse the advantage of progressively increasing the level of instability for resistance exercises that involve the core musculature (7,11,14,15). Willson et al. (106) 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 appropriate from a rehabilitation perspective, Behm et al. (14) provided a more expansive definition such that the anatomical core was defined as the axial skeleton 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 (upper and lower extremities). These soft tissues can act to generate motion (concentric action) or resist motion (eccentric and isometric actions). This broader definition illustrates the potential interconnection between the stabilizing capacity of the core musculature and injuries that may occur distally in the extremities. The prevention of LBP and, in some cases, limb and joint injuries can be based on the ability of the core muscles to stabilize the vertebral system (1,25).

Panjabi (83,84) divided the stabilizing system into 3 distinct subsystems: the passive subsystem, the active muscle subsystem, and the active neural subsystem. The passive subsystem consists of the vertebral ligaments, thoracolumbar fascia, intervertebral discs, and facet joints. Although the vertebral ligaments are equipped with proprioceptors that relay sensory feedback to the central nervous system (52,59,83), the passive subsystem has limited potential to stabilize the vertebral column. In vitro experiments have demonstrated that the osteoligamentous lumbar spine buckled under compressive loading of approximately 90 N (i.e., 9.2 kg) (83), whereas the mass of the body in a standing position exceeds 10,000 N during dynamic lifting tasks (27). The ability to withstand these large forces is dependent on additional stabilization provided by the active muscle subsystem.

Tension development within the active muscle system is provided by the abdominal (e.g., transversus abdominis, internal obliques) and paraspinal (e.g., multifidus) muscles, which increase the stiffness of the spine to enhance stability. These muscles function in transferring torques and angular momentum during the performance of integrated kinetic chain activities involving the limbs, such as throwing or kicking (31,64,104). The active neural subsystem controls the recruitment of the core musculature via feed-forward and feedback mechanisms. Feed-forward mechanisms are pre-planned motor programs in preparation for movement, whereas feedback mechanisms are used to fine tune motor programs as skills are performed with greater efficiency over time. The goal of instability exercises is to place demands on both the spinal feedforward and feedback systems to reprogram them for healthy functioning.

PREVENTION OF INJURIES TO THE EXTREMITIES

Impaired neuromuscular control of the core muscles and/or core muscle weakness can predispose individuals not only to low back injuries but also to lower extremity injuries (37,55,57,68,79,80,86). These associations support the adoption of core muscle training programs for injury prevention. The rehabilitation literature has reported the successful application of balance training to reduce the incidence of ankle sprains in a group of volleyball players (101). This decrease in ankle injury incidence may be related to the improved discrimination of ankle inversion movements found with wobble board training (102). Similarly, the use of tai chi has been reported to improve knee joint proprioception (97) and functional balance (39) in elderly individuals. The utilization of unstable devices has been shown to be effective in decreasing the incidence of LBP and increasing...
the sensory efficiency of soft tissues that stabilize the knee and ankle joints (22,25,100). The combination of resistance training and balance stressors may be an efficient means of improving balance and strength that is important for preventing sports-related injuries and recuperating individuals who cannot withstand heavier loads or high resistance.

**INSTABILITY EFFECTS ON CORE MUSCLE ACTIVATION**

Reeves et al. (88) explained that training the core musculature improves the robustness of the stabilizing system, potentially protecting against low back injuries. A recent study by Durall et al. (34) indicated that there were no new incidences of LBP reported in college gymnasts who participated in a 10-week core muscle training program that incorporated progressive manual loading of the side bridge and prone back extension exercises in addition to their normal trunk flexion exercises. As described in the previous section, training the core musculature can also help prevent joint injuries distally in the upper and lower extremities. It has been proposed that the demands of lifting while supported on an unstable surface will elicit an increase in core muscle activation to maintain postural equilibrium during performance of a given exercise (43). Thus, exercises that can improve the coordination (3,6,18,22) and extent (25,29) of core muscle activation potentially enhance the prevention and rehabilitation of LBP and accompanying extremity injuries.

However, it must be remembered that spinal stabilization strategies are task specific; thus, the ideal approach in rehabilitation and athletic training settings is to incorporate a variety of exercises that require different muscle activation sequences. Keogh et al. (62) examined whether endurance performance for common trunk stability exercises (trunk flexion, side bridge, and prone bridge) could distinguish differences in strength for a dumbbell shoulder press on a stable bench versus a Swiss ball. Subjects were divided into groups based on the ratio of strength on the Swiss ball relative to the stable bench; those with higher ratios exhibited similar dumbbell shoulder press strength on each surface. Surprisingly, the findings indicated that there was little relationship between performance on the trunk stability exercises and the percentage strength on the Swiss ball relative to the stable bench. The authors concluded that core stability exhibits relatively high levels of task specificity and that performance in common core stabilizing drills may not enhance performance in more dynamic multi-joint activities.

A greater extent of core muscle activation has been demonstrated when performing exercises while supported on unstable surfaces versus performing the same exercises under stable conditions (5,8,100). Increased core muscle activation can be achieved whether the instability is derived from a platform (e.g., inflatable discs or balls) or an unstable apparatus moved by the limbs (e.g., chains, partially filled jugs of water). For example, performing chest presses (40) while lying on an unstable ball or push-ups with hands placed on a ball result in an increased core activation (53) compared with a stable bench or floor, respectively. Increased abdominal muscle activity was reported when performing push-ups, squats (72), and chest presses (74), respectively, on a physioball compared with the stable ground or bench. Anderson and Behm (7) had subjects perform squats on a Smith machine (bar guided by rails), on a stable floor, and on inflatable discs. They reported that higher degrees of instability (inflatable discs > squat > Smith machine) when performing a squat resulted in approximately 20-30% greater activation of the spinal stabilizing muscles (upper and lower erector spinae). Instability devices may provide lower loading for the extremities, yet elicit higher core muscle activation (14).

Conversely, Freeman et al. (38) reported that ballistic dynamic push-ups required greater muscle activation of core muscles and spinal loading (shear forces on vertebral column) as compared with the modest increases in spinal loading when push-ups were performed on basketballs. Recent studies by Kohler et al. (65) and Uribe et al. (99) reported little differences in core or limb muscle activation for resistance exercises performed on unstable surfaces as compared with stable surfaces. Kohler et al. (65) assessed the activation of several muscles (i.e., medial deltoid, triceps brachii, rectus abdominis, external oblique abdominis, upper erector spinae) during performance of a barbell shoulder press on a stable bench or a Swiss ball with a 10 repetition maximum (RM) load (relative to each surface). The results indicated that for the medial deltoid and triceps brachii, the shoulder press performed on a bench elicited 4.2% and 14.3% greater activation, respectively, than when performed on a Swiss ball. For the rectus abdominis and external oblique abdominis, the shoulder press performed on a bench elicited 21.2% and 18.7% greater activation, respectively, than when performed on a Swiss ball. Conversely, for the upper erector spinae, the barbell shoulder press on a Swiss ball elicited 15.6% greater activity than when performed on a bench.

Similarly, Uribe et al. (99) assessed the activation of the pectoralis major, anterior deltoid, and rectus abdominis during performance of a dumbbell chest press and shoulder press on a bench or Swiss ball with 80% of a 1RM load (relative to a stable surface). The results indicated no significant differences between surfaces for the muscles assessed during both exercises. For chest press and shoulder press exercises, the Swiss ball does not appear to sufficiently challenge the maintenance of postural equilibrium to significantly alter core or limb muscle activity from when these exercises are performed on a stable bench.

However, a potential disadvantage of performing resistance exercises on unstable surfaces is that ultimately the
external loading might be limited relative to ground-based free weight training. Marshall and Desai (73) stated, “When compared with relatively basic to teach and perform resistance exercises such as shoulder extensions, squats, and deadlifts, the use of a Swiss ball seems redundant. Additionally, the benefit of conventional resistance training is that increasing the external load will increase the activity of muscle groups of interest, while allowing for periodization and progression of the training dose over time, whereas a Swiss ball based program appears to require more complex and difficult movements for ongoing progression” (pp. 1543–1544).

Furthermore, both Hamlyn et al. (44) and Nuzzo et al. (82) demonstrated that squats and deadlifts produced greater activation of the erector spinae muscles versus unstable calisthenic exercises such as the superman exercise and side bridge. The amount of external resistance that can safely be lifted and controlled on an unstable surface (i.e., hemispherical physioball) is ultimately limited relative to a ground-based condition. Willardson et al. (105) 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 versus 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, deadlift, overhead press, and biceps curl when lifting with 75% of 1RM on stable ground or with 50% of 1RM on a hemispherical physioball. The intent of this experiment was to determine whether the unstable surface would compensate for less resistance relative to the ground-based condition with greater resistance; instability did not in this case. A ground-based condition with equal resistance (50% 1RM) for the control condition resulted in greater activity of the transversus abdominis/internal obliques (although not significant) versus the unstable condition. This result further indicates that the unstable surface was not necessary. Overall, Willardson et al. (105) did not demonstrate any advantage in using a hemispherical physioball for training the core musculature.

The clinical significance of these findings is that although competitive athletes with performance-based goals may be able to achieve greater core muscle activation with higher-load ground-based free weight exercises, physical therapists and individuals training for health and rehabilitation may choose to achieve high core muscle activation with lower loads while supported on unstable surfaces or using relatively unstable implements. Typically, individuals with LBP experience impairments in the coordination or motor control of core musculature (18,46,49). Although certain ground-based free weight exercises, such as squat and deadlifts, can provide greater core muscle activation, they also necessitate higher levels of intermuscle coordination. If intermuscle coordination is impaired with chronic LBP, a healthy alternative may be the high activation that can be achieved with lower-resistance unstable exercises that involve bracing (i.e., cocontraction) of the abdominal musculature. Jorgensen et al. (58) demonstrated moderate to high activation levels (i.e., 60–80% maximal voluntary contraction) of the rectus abdominis, external oblique abdominis, erector spinae, and trapezius in untrained women who performed progressively more difficult versions of the supine bridge, quadruped, side bridge, and prone plank. These findings suggest that for untrained individuals, the utilization of body mass and manipulation of resistive torque via postural adjustments can sufficiently load the core musculature to increase strength and localize muscular endurance.

Long-term instability training in sedentary individuals may improve spinal stability. Carter et al. (25) had previously sedentary individuals train on physioballs twice a week for 10 weeks. After training, these subjects scored significantly better on a static back endurance and side bridge test as compared with controls. However, the control group used in this study remained sedentary rather than being compared with traditional training. Cosio-Lima et al. (29) illustrated greater gains in torso balance and trunk electromyographic (EMG) activity after 5 weeks of physioball training compared with traditional floor exercises in women. Untrained individuals involved in 7 (63) or 8 weeks (94) of either traditional stable or instability resistance training found no differences in force, static balance, or functional performance between the groups. However, all measures improved over time for both the unstable and stable trained groups. In the study by Sparkes and Behm (94), there was a trend ($P = 0.08$) for the unstable group to increase unstable forces to a greater extent. Hence, traditional resistance training techniques provided similar results in these 2 studies.

**INSTABILITY EFFECTS ON LIMB MUSCLE ACTIVATION**

Exercises performed on unstable surfaces can increase not only core muscle activation but also limb muscle activation and cocontractions. Triceps and deltoid muscle activity were increased when push-ups and chest presses (60% of 1RM) were performed under unstable (push-ups on a ball; chest press lying on a ball) versus stable conditions (72,74). Both the short and long heads of the biceps can function as anterior stabilizers of the glenohumeral joint and their roles in stabilization increases as joint stability decreases (56). There is typically also a decrease in force output in conjunction with the high limb muscle activation (14), emphasizing the switch from muscle mobilizing to stabilizing functions (5).

Generally, cocontractile activity increases when training on unstable support surfaces (12). The role of the antagonist in this case may have been 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 (32,71). Increased antagonist activity may also be present to increase joint stiffness (61) and hence stability (51). Furthermore, cocontractions are prevalent for joint protection (9). This role for joint protection was reported as early as 1965 (17) and is essential in protecting the joints from excessive forces (10,98).

Although increased antagonist activity could be used for protection, to improve motor control, balance (35), and mechanical impedance (opposition to a disruptive force) (51), 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 (23). More research is needed to determine if the use of unstable surfaces to improve balance and stability and decrease movement uncertainty might decrease cocontractions, which in terms of energy conservation may improve movement efficiency.

It should be noted that the instability-induced higher muscle activation and cocontractions while exerting lower force, which could be an advantage for rehabilitating injuries such as sprains and strains, might not be as appropriate for some other conditions such as arthritis. Based on the assumption of linear or near-linear force-EMG relations (4), the high muscle activation should produce similar amounts of internal force production. In conjunction with instability-induced greater cocontractions, internal muscle and joint tension may remain high, which could lead to pain with an arthritic joint. Furthermore, as the arthritic joint may be stiff or hypomobile, greater stability is likely not to be recommended. Hence, caution should be used if recommending this type of training in a rehabilitation setting because internal muscle tension may remain high. This is an area for future research.

**INSTABILITY EFFECTS ON MOTOR CONTROL**

Appropriate coordination or motor control of the core muscles may be as or more important than the extent of muscle activation. Akuthota and Nadler (3) stated that motor relearning may be more important than strengthening in patients with LBP. There are many studies that report motor control deficits of the core muscles in patients with LBP (18,46,49,89). Deep trunk stabilizers, such as the transversus abdominis and multifidus, respond with anticipatory postural adjustments (APAs) to movements of the upper or lower limbs (31,45–50). In healthy individuals, the activation of stabilizing muscles precedes the instant of force application when unstable (66,93). Individuals with LBP tend to display delays or disruptions in this protective APA. These delays can occur in other muscles as well. For example, the rectus abdominis and erector spinae were delayed during rapid shoulder (46) and hip (49) flexion in a group of subjects with chronic LBP compared with those in the healthy controls. A delayed reflex response of trunk muscles is reported to be a risk factor for low back injuries in athletes (107). Other motor control difficulties can also arise with LBP. Radebold et al. (87) found that the antagonist muscle group was delayed in contracting, whereas the agonist was delayed in relaxing during quick trunk flexion and extension in a group of subjects with chronic LBP. Chronic LBP has also been associated with early or over recruitment of certain stabilizing muscles. Ferguson et al. (36) found that the erector spinae contracted earlier and longer during lifting tasks in a group of subjects with chronic LBP compared with that in healthy controls. Thus, exercises that can reprogram appropriate anticipatory and concomitant postural adjustments would be important for the prevention and rehabilitation of LBP. These responses would include an appropriate anticipatory response by dorsal (e.g., multifidus, erector spinae) and ventral (e.g., transversus abdominis, internal obliques) trunk stabilizing muscles but also include the appropriate motor coordination to deactivate these muscles upon completion of the movement.

The anticipatory contraction to presstitute joints before movement is not unique to the spine and has been shown in peripheral joints as well (28). The contraction of the upper trapezius, biceps, and rotator cuff of the shoulder (28) has been shown to anticipate movement in healthy subjects. Therefore, instability training of the upper body may help to improve stability of the shoulder joint.

Anderson and Behm (6) commented that resistance training in general can not only increase muscular strength but also improve the coordination of synergistic and antagonist muscle activity, leading to improved stability. Training on unstable surfaces has been reported to promote APAs (41). Repeated exposures to unstable surfaces allow for modification and knowledge of the surface resulting in proactive (70) or feed-forward (85) adjustments. Joint stability exercises, balance training, and perturbation training can significantly improve neuromuscular control (22). Furthermore, the sensitivity of afferent feedback pathways can be improved with balance and motor skill training (18), resulting in quicker onset times of stabilizing muscles (6). For example, a back extensor rehabilitation training program of 2-week duration reduced reaction times in patients with LBP to a similar time as healthy controls (103). Instability training may promote agonist-antagonist cocontractions with shorter latency periods that allow for rapid stiffening and protection of joint complexes (14). However, increased antagonist activity may also contribute negatively to strength and power development by opposing the intended direction of motion (33). Drinkwater et al. (33) found decreases in power, velocity, and range of motion when performing a squat under unstable versus stable conditions. 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 (13,14,104). Thus, it seems apparent that instability resistance training and balance training in a rehabilitation program can improve the extent of core muscle activation and the coordination or motor control of the core stabilizers. Traditional resistance training can accomplish the same muscle activation goals but may necessitate the use of greater resistances.

EFFECTS OF INSTABILITY ON FORCE AND POWER

Whereas the reported impairments of force and power under conditions of instability may limit athletic strength, power, and hypertrophy training (13), it may be more advantageous with rehabilitation exercises. Instability-induced decreases in force output have been documented during leg extension (70%) (12), plantar flexion (120%) (12), and isometric chest press (160%) (5). However, during the isometric chest press, there was no significant difference for the limb and chest muscles' activity between the unstable versus stable conditions. The similar extent of muscle activation accompanied by decreased force with instability suggested that the muscles' ability to apply external force was transferred into greater stabilizing functions (greater emphasis on isometric contractions) (5). Using unstable implements, muscular force and power decreased 20–40% (66,67). Although isometric force production appears to be reduced, maximal dynamic barbell bench press strength on the physioball compared with a stable flat bench is not affected (30,42). Thus, there seems to be some evidence that dynamic resistance training, which usually does not involve maximal contractions, does not experience the same extent of force decrement as maximal isometric contractions. Hence, it may be possible during rehabilitation to use lower resistances while still ensuring relatively high muscle activation around the recuperating joint or limb.

A stiffening strategy, which may be adopted when individuals are presented with a threat of instability (24), can adversely affect the magnitude and rate of voluntary movements (2). Kornecki and Zschorlich (67) demonstrated that muscular stabilization of the joint caused approximately 30% decrement in force, velocity, and power during unstable pushing movements compared with stable. Performing squats under unstable conditions resulted in decreased force, power, range of motion, rate of force development, and velocity (33,75). Although this motor control characteristic would not be optimal for developing maximal strength and power in athletes (13), the slower and more deliberate movements when unstable would be more similar to the rate of movement typically used in the earlier stages of rehabilitation (95).

CLINICAL APPLICATIONS

The use of unstable devices may provide benefits in rehabilitation type settings to restore normal function of the core musculature among injured individuals. Resistance exercises performed on unstable devices train the agonists and increases 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). First, the lower force (5,12,92) and power output for the agonists (33) in association with relatively high muscle activation may decrease the resistive torques experienced by the soft tissues but still provides activation of a large spectrum of the muscle fibers. Second, the instability-induced lower resistance may facilitate a greater emphasis on endurance work (14) during the rehabilitation process. Further 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) (76), and thus, unilateral exercises may be more beneficial because they adhere to the principle of training specificity (91). Behm et al. (15) 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 would provide a disruptive torque to the body, thus providing another type of unstable condition. Therefore, an effective strategy to stimulate the spinal stabilizers while training the upper limbs would be to use one dumbbell during the action (16,92).

Unilateral contractions can also stimulate neural activity in the contralateral but inactive limb, referred to as cross education (60). Therefore, by training the contralateral healthy limb, the injured limb may maintain greater strength, while also stimulating activation of the core muscles.

For back health, it is unnecessary to load the vertebrae with excessive loads as maximum stiffness of a vertebral joint can be achieved with contractions as low as 25% of maximal voluntary contraction (31). Furthermore, the efficiency of the multifidus, a deep stabilizer, can be improved with training loads of 30–40% of maximal voluntary contraction (26). Thus, lower loads with higher repetitions should theoretically provide sufficient training stresses for the prevention or rehabilitation of low back problems. Furthermore, the inherent characteristics of the core musculature may determine the volume necessary to elicit adaptations. For example, aerobic-type muscle fibers (type I) comprise the majority (>80%) of the erector spinae (69), multifidus, and longissimus thoracis (96) muscles in healthy men and women. 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 the muscle fiber recruitment by inducing fatigue of the lower threshold motor units, thereby recruiting higher threshold motor units (90). Because muscle activation tends to be higher when the same exercises are performed under unstable conditions (6,7,11,12–15), the volume of repetitions should be lower when back-specific exercises are performed under unstable versus stable conditions. Therefore, based on the relatively high proportion of type I fibers, the core musculature might respond particularly well to multiple sets that involve high repetitions (e.g., >15 per set) (13).

CONCLUSIONS
Considering the potential benefits of coactivation in joint injury prevention and treatment and in balance, there are implications for instability training in rehabilitation. However, the routine use of instability resistance training may have a consequence of reduced force output because of the resistive forces from coactivation. For example, a barbell squat load that an athlete perceives as maximal on an unstable platform likely decreases well below the 85% 1RM recommendation for strength development on a stable platform. Therefore, a therapist in a rehabilitation setting may routinely recommend instability training because high-load lifting is usually avoided but high muscle activation and coordination are maintained.

David G. Behm is an associate director of the Graduate Studies and Research with the School of Human Kinetics and Recreation at the Memorial University of Newfoundland.

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