Journal of Strength and Conditioning Research, 2006, 20(3), 716–722
© 2006 National Strength & Conditioning Association

Brief Review

THE ROLE OF INSTABILITY WITH RESISTANCE TRAINING

DAVID G. BEHM[1] AND KENNETH G. ANDERSON[2]

[1]*School of Human Kinetics and Recreation, Memorial University of Newfoundland, St. John's, Newfoundland, Canada;* [2]*School of Human Kinetics, University of British Columbia, Vancouver, British Columbia, Canada.*

ABSTRACT. Behm, D.G., and K.G. Anderson. The role of instability with resistance training. *J. Strength Cond. Res. 20(3):716–722. 2006.*—There are many instances in daily life and sport in which force must be exerted when an individual performing the task is in an unstable condition. Instability can decrease the externally-measured force output of a muscle while maintaining high muscle activation. The high muscle activation of limbs and trunk when unstable can be attributed to the increased stabilization functions. The increased stress associated with instability has been postulated to promote greater neuromuscular adaptations, such as decreased cocontractions, improved coordination, and confidence in performing a skill. In addition, high muscle activation with less stress on joints and muscles could also be beneficial for general musculoskeletal health and rehabilitation. However, the lower force output may be detrimental to absolute strength gains when resistance training. Furthermore, other studies have reported increased cocontractions with unstable training. The positive effects of instability resistance training on sports performance have yet to be quantified. The examination of the literature suggests that when implementing a resistance training program for musculoskeletal health or rehabilitation, both stable and unstable exercises should be included to ensure an emphasis on both higher force (stable) and balance (unstable) stressors to the neuromuscular system.

KEY WORDS. balance, strength, muscle activation, cocontractions, trunk muscles

INTRODUCTION

Resistance training involving balls, platforms, and other devices to induce varying degrees of instability has recently enjoyed a surge in popularity. Balls have been used by entertainers and circus performers for many years. It is unclear when they first began to be used as a training and rehabilitation tool, but physical therapists have been using "Physio Balls" since before World War II. With the upsurge of interest in neuromuscular training generated by researchers such as Sherrington (43, 44), physical therapists began to integrate the use of balls into therapy. Physical therapists, especially the Germans and Swiss (consequently, the term "Swiss balls") were especially active in using balls for sports training and therapy. More recently, the rehabilitation literature has reported the successful application of balance training to reduce the incidence of ankle sprains in a group of volleyball players (53). This decrease in ankle injury incidence may be related to the improved discrimination of ankle inversion movements found with wobble board training (55). Similarly, the use of Tai Chi has been reported to improve knee joint proprioception (51) and functional balance (17) in elderly individuals. The combination of resistance training and balance stressors may be an efficient means of improving balance and strength.

Proponents of instability resistance training deduce that the greater instability of the unstable platform and human body interface will stress the neuromuscular system to a greater extent than traditional resistance training methods using more stable benches and floors. Stress, according to Selye's (42) adaptation curve, is essential in forcing the body to adapt to new stimuli. The advantage of an unstable training environment would be based on the importance of neuromuscular adaptations with increases in strength. Strength gains can be attributed to both increases in muscle cross-sectional area and improvements in neuromuscular coordination (6). It has been reported that neural adaptations play the most important role in strength gains in the early stages of a resistance training program (6). Rutherford and Jones (39) suggested that the specific neural adaptation occurring with training was not increased recruitment or activation of motor units but an improved coordination of agonist, antagonists, synergists, and stabilizers. Thus, the inherently greater instability of an unstable platform and body interface should challenge the neuromuscular system to a greater extent than under stable conditions, possibly enhancing strength gains attributed to neural adaptations. Base or platform instability can be induced by sitting, lying, kneeling, or standing on balls (i.e., Swiss balls or Physio Balls), "Dyna-Discs" (rubberized inflated discs), wobble and rocker boards, foam rollers, low-density mats, and other similar devices. Instability can also be produced with unstable loads, such as partially filled containers of water or sand, and flexible tubing. Similarly, some authors advise the use of free weights over machines for improved training results (49), because the balance and control of free weights force the individual to stress and coordinate more synergist, stabilizing, and antagonist muscle groups. The rationale underlying destabilizing training environments would lead one to conclude that unstable environments should provide a more varied and effective training stimulus. On the other hand, there are a variety of disadvantages associated with instability resistance training that may outweigh the advantages, which will be discussed later in the review.

Resistance training is not only practiced by competitive athletes, but also pursued for general health and rehabilitation. This brief review will attempt to provide information regarding some of the effects of instability resistance training on force output, trunk and limb muscle activation, cocontractions, coordination, and other factors and the application of instability training to sport, health, and rehabilitation.

TRAINING SPECIFICITY

According to the concept of training specificity (6), because not all forces are produced under stable conditions (i.e., shooting a puck while balancing on a single skate blade in hockey, performing a routine on a balance beam in gymnastics, changing direction rapidly by pivoting on 1 foot on uneven natural turf in football, soccer, field hockey, or other sports), then training must attempt to closely mimic the demands of the sport or occupation. For instance, Behm et al. (8) showed significant correlations ($p < 0.005$) between hockey skating performance and static balance tests, with the highest correlation between balance and the skating ability of hockey players under the age of 19 years ($r = 0.65$). In addition, college baseball pitchers with weaker vestibular input are reported to have higher levels of pitching errors (30).

Whereas most sports involve dynamic balance, instability resistance training is typically performed under fairly stationary conditions. Whether possible improvements in static balance or stability will transfer effectively to dynamic stability is still debatable. Shimada et al. (45) reported that walking (dynamic) balance did not correlate with standing (static) balance. Nonetheless, a number of papers have shown feedforward (37) or proactive adjustments (28) with prior experience or knowledge of forthcoming perturbations resulting in a lower occurrence of balance disruptions. Except in these studies, the training and testing involved the same perturbations, whereas with typical static instability devices such as Swiss balls, BOSU ("both sides up") domes, wobble boards, and Dyna-Discs, the training dynamics do not specifically match the athletic performance. Thus, it is debatable whether instability resistance training may enhance sport performance. Willardson (56) states that "the optimal method to promote increases in balance, proprioception and core stability for any given sport is to practice the skill itself on the same surface on which the skill is performed in competition." Unfortunately, this is not always possible, for example, for some outdoor sports (i.e., football, baseball) during the winter season in northern climates or sports that utilize ice surfaces when the arenas are closed in the warmer seasons. Thus, alternative challenges to the athlete's balance may be necessary.

Moreover, there is some evidence in the literature that may illustrate other positive adaptations associated with the effect of instability resistance training on musculoskeletal health. These adaptations, which include trunk strengthening, changes in muscle function, limb strength gains, and cocontractions, are discussed in the following sections.

TRUNK STRENGTHENING WITH INSTABILITY RESISTANCE EXERCISES

Improvements in core stability (torso or trunk strength) have been postulated in the popular media to be enhanced with instability training. Nevertheless, conflicting findings are evident in the literature when balls are used to enhance trunk or abdominal musculature. Siff (46) found that the wider range of movement that is available with the use of a ball (with an optimal starting position from a few degrees of active trunk extension) is preferable to similar actions performed in most circuit training gyms. Cosio-Lima et al. (14) illustrated greater gains in torso balance and trunk electromyographic (EMG) activity after 5 weeks of Physio Ball training compared to traditional floor exercises. In contrast, Stanforth et al. (48) stated that training with the "Resistaball" was comparable to traditional floor work for training the back and abdominal muscles. Further evidence supporting the hypothesis of improved core or trunk strength has only recently begun to emerge in the literature.

The strengthening of trunk or core stabilizing muscles is an important consideration for activities of daily living (ADL), sports performance, and the rehabilitation of low back pain (LBP). A strong and stable trunk (core) provides a solid foundation for the torques generated by the limbs. However, increased back strength is not necessarily associated with the prevention of LBP. Some studies have reported no advantage of trunk strengthening (33) or lumbar muscularity (41) in the prevention of LBP. Yet, increased back strength may provide some protection from LBP when greater forces are needed for the task (11). It has also been proposed that the spine may become unstable because of weak trunk stabilizer muscles (47). However, a lack of back muscle endurance is strongly associated with LBP (36). Overall, there is general agreement that resistance exercise is beneficial in the rehabilitation of LBP (1).

A commonly-prescribed adaptation to trunk strengthening rehabilitation exercises is the use of unstable surfaces. Swiss balls or Physio Balls are often advocated to promote proper posture while seated in order to prevent LBP (35). It has been proposed that the demands of an unstable surface will cause an increase in muscle activation in order to complete the exercise in a controlled manner (19). Behm et al. (9) illustrated that instability with trunk strengthening exercises increased the activation of the lower abdominal muscles. In the same study, shoulder and chest presses were performed with stable and unstable bases. Although there was no effect of instability on the shoulder press, the unstable chest press had either significantly greater or tendencies towards greater activation of the upper lumbar erector spinae, lumbosacral erector spinae, and lower abdominal muscles. Trunk stabilizer activation during a chest press with an unstable base exceeded activation with a stable base by 37–54% (9). Increased trunk muscle activation can also be achieved whether the instability is derived from the platform or the limbs when performing bench presses (18) or push-ups (21). Increased trunk stabilizer activation with an unstable base concurs with the findings of Arokoski et al. (5) and Vera-Garcia et al. (52). Unfortunately, Arokoski et al. (5) applied an unstable base to only 2 of the 15 exercises they employed. In addition, the majority of the activities they chose created greater stress on back rather than abdominal musculature. Vera-Garcia et al. (52) examined only curl-ups and found increased abdominal muscle activity with labile surfaces. Anderson and Behm (4) had subjects perform squats under differing degrees of stability. The higher degrees of instability resulted in approximately 20–30% greater activation of trunk stabilizing muscles. However, the submaximal resistance (maximum resistance was 60% of body mass) was moved at a relatively slow pace (1 second down, 1 second transition, 1 second up) and thus the recruitment patterns would differ considerably from high-power sports such as football, rugby, hockey, and others. Therefore, based on these findings, unstable platforms or resistance may be used during specific trunk strengthening exercises or in conjunction with limb strengthening activities to augment activation of the trunk musculature.

The instability-induced greater trunk activations in the aforementioned studies were never compared to the greater loads that can be accommodated with stable training. For example, it is not known whether trunk activation levels are higher when performing a 3, 5, or 10 repetition maximum (RM) squat or deadlift, as compared to the lower loads exerted with unstable squats or deadlifts or with unstable calisthenic-style trunk-strengthening activities. In order to complete a 3–5RM squat or deadlift, considerable activation of the trunk is necessary to protect the vertebrae. Conversely, most members of the population who are primarily concerned with musculoskeletal health or rehabilitation would not be interested in attempting such high-load, intense exercises. Whereas competitive athletes may be able to highly activate their trunks with high-load, relatively stable resistance exercises, individuals more interested in health and rehabilitation can achieve higher trunk activation with lower loads using unstable conditions.

Trunk Strengthening With Unilateral Exercises

Further modifications in addition to instability platforms may be instituted with limb resistance training exercises to stress the trunk musculature. Traditional resistance training exercises are more often bilateral using either a barbell or a pair of dumbbells. Conversely, numerous ADL and sport actions are unilateral (31). Examples of unilateral sport actions would include most racquet sports and throwing actions. Accordingly, for some ADL and sports, unilateral exercises may be more beneficial than bilateral actions by adhering to the concept of training specificity (40). Unilateral resistance exercises may also have the additional bonus of stimulating the trunk stabilizers to a greater extent. Rather than implementing an unstable base, unilateral resisted actions would provide a disruptive moment arm (torque) to the body, providing another type of unstable condition. Recently, Behm et al. (9) reported greater trunk activation with unilateral shoulder and chest press actions. Unilateral dumbbell presses exhibited greater activation of the lumbosacral and upper lumbar erector spinae with both shoulder and chest presses. However, lower abdominal muscle activation was only significantly greater with the unilateral dumbbell chest press. 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 moment arm of the unilateral movements. Therefore, in order to more highly activate the trunk stabilizers while training the upper limbs, only 1 dumbbell should be handled during the action. The advantage of this activity is that high resistive forces can still be applied while providing a greater challenge to trunk muscle activation.

Effect of Instability on Muscle Functions

Typically, the ability to exert force or power is depressed under conditions of instability. Behm et al. (7) found decreases in force output of approximately 70% and 20% when performing leg extensions and plantar flexor contractions, respectively, while seated on an unstable ball. Similarly, Kornecki and Zschorlich (25) observed 20–40% decreases when exerting muscular power against an unstable pendulumlike device. When comparing stable and unstable chest presses, Anderson and Behm (3) showed that isometric chest press forces were depressed by 60% under unstable conditions, although muscle EMG activity was not significantly altered. During the chest press, there was no significant difference between unstable and stable conditions in the EMG activity of the pectoralis major, anterior deltoid, triceps brachii, latissimus dorsi, or rectus abdominus. The similar extent of muscle activation accompanied by decreased force with instability suggested that the motive forces of the muscles (their ability to apply external force) were transferred into greater stabilizing forces. Thus, although externally-measured forces are impaired by instability, muscle activation can be maintained or increased because of the increased reliance on stabilization functions. In another study from our laboratory, muscle activation measured by the interpolated twitch technique was recorded with single- and double-leg extensions and squats (10). The highest activation levels were found with the squats and lowest with the single-leg extensions. The contractions of multiple lower-body muscle groups during the squats may have enhanced quadriceps activation. In addition, greater levels of activation may have been necessary to cope with the stabilization necessary for bilateral and multi-articular contractions (squats). These findings would benefit musculoskeletal rehabilitation because high muscle activation can be maintained while using lower-intensity resistance. The use of heavy weights under stable conditions to activate high-threshold motor units increases the chance of injuring the recovering muscle tissue. Current research in our laboratory is exploring whether longer term instability resistance training can modify the extent of stabilization functions in order to improve motive forces.

Furthermore, coordination, force, and performance could be hampered under unstable conditions by an increase in the stiffness of the joints performing the action. Carpenter et al. (13) indicated that a stiffening strategy was adopted when individuals were presented with a threat of instability. Similarly, Adkin et al. (2) reported that when subjects received a postural threat (fear of falling), the magnitude and rate of voluntary movements were reduced. In addition, participants reported increased anxiety and arousal as well as decreased confidence. Thus, one might argue that a program that could improve stability or balance could subsequently improve force output, coordination, and confidence, all factors that are intricately involved in successful athletic performance. An improvement in these same factors would benefit elderly individuals who might otherwise remain housebound in the winter because of a lack of confidence in their balance and strength.

However, new movement patterns, and especially movement patterns 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 (56). Furthermore, the specific practice of a sport 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 (34). Gymnasts are reported to be more efficient at integrating and reweighting proprioceptive inputs (54). Because some sports may provide a balance training impetus, the possibility of a limited transfer of instability resistance training effects may not be significant in active sport participants.

EFFECT OF INSTABILITY RESISTANCE TRAINING ON LIMB STRENGTH GAINS

Behm et al. (7) reported that force output of leg extensors was only 29.5% of a stable maximum voluntary contraction (MVC) whereas unstable plantar flexors were 79.8% of a stable MVC when performing an open kinetic chain exercise (limb contracts with the trunk stationary or in this case seated) with either an unstable (Swiss ball) or stable (chair) seat. As previously reported, Anderson and Behm (3) found force deficits of approximately 60% when performing an isometric chest press action with an unstable base (Swiss ball). On the one hand, these deficits might promote the essential point of instability training: that because forces have been demonstrated to be lower with unstable conditions, training in that environment is of utmost necessity to ensure action-specific strength adaptations. Conversely, overload tension on the muscle is essential for fostering strength training adaptations (6, 50). A number of authors have stated that training programs to promote general and maximal strength need repetitions that provide a resistance intensity in the range of 40–120% of 1RM or MVC (26, 49, 50). A very unstable environment, as provided with the leg extension protocol, would not provide sufficient overload resistance (29.5%) to promote quadriceps strength adaptations. Whereas the plantar-flexors protocol also had significantly less force than the stable condition, the higher intensity of the contraction could still supply an overload stress (79.8% of stable MVC) on the muscle with a limited number of contractions.

On the other hand, closed kinetic chain exercises (distal portion of limb is stationary while trunk is in motion) have shown greater degrees of limb activation. Soleus EMG activity was approximately 30–40% greater when squats were performed on an unstable platform (4). Quadriceps activity was only 5–15% greater with the unstable squat (4). Because the soleus may have more postural responsibilities than the quadriceps, it would be logical to expect greater soleus activity when unstable. Kornecki et al. (24) found that contributions of stabilizing muscles increased on average by 40% when the handle changed from stable to unstable during pushing movements. They showed that the process of muscular stabilization of the investigated joint caused, on average, 30% drops in force, velocity, and power. Instability-induced muscular stabilization of the wrist joint caused a significant increase in the EMG contributions of the stabilizing muscles and a visible drop in the contributions of the muscles that realized motor functions, which in turn brought about a significant loss of maximum force, velocity, and power produced against an external object.

A number of other authors have examined the function of limb stabilizing muscles. It was found that the short and long heads of the biceps have similar functions as anterior stabilizers of the glenohumeral joint, and their roles in stabilization increases as joint stability decreases (22). The stabilizing function of scapular stabilizers while performing push-ups on miniature trampolines was also examined (27). The researchers found no significant difference in stabilizer EMG activity between stable and unstable conditions; however, they acknowledged that the degree of stability induced by the miniature trampolines was likely insufficient to elicit an unstable platform.

If the goal of the individual is to build limb muscle strength, not all training should be performed under very unstable conditions. Particularly, unstable open kinetic chain exercises for the lower limbs should not be emphasized in favor of more action-specific closed kinetic chain activities such as squats and lunges. A combination of unstable and stable resistance training should provide a melding of balance and strength improvements especially for the general population.

EFFECT OF INSTABILITY RESISTANCE TRAINING ON COCONTRACTIONS

In the same Behm et al. (7) study previously mentioned, the unstable plantar flexors and leg extensor 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. Similarly, subjects who had to counteract a predictable unstable upper limb force during 2 blocks of 144 trials each increased their accuracy by increasing muscle cocontractions (32). Engelhorn (16) also reported increased antagonist activity as subjects mastered a learned task (29). Antagonist activity has been reported to be greater when uncertainty exists in the required task (15, 29). Increased antagonist activity may also be present to increase joint stiffness (23) to promote stability (20). Whereas increased antagonist activity could be utilized to improve motor control and balance, it would also contribute to a greater decrement in force with the unstable conditions by providing greater resistance to the intended motion. Continued training, though, can result in lower coactivation levels in certain types of work (38). Carolan and Cafarelli (12) demonstrated a decrease in coactivation associated with a resistance training program of the leg extensors. The use of instability resistance training to improve balance and stability and decrease movement uncertainty might be hypothesized to decrease cocontractions, which in terms of energy conservation would improve movement efficiency.

PRACTICAL APPLICATIONS

Unstable conditions can lead to decreases in the force output of the limb and increases in antagonist activity. Greater degrees of instability exacerbate these changes. In light of these findings, the use of instability resistance devices as a resistance training modality for peripheral or limb strength gains should be employed when the degree of instability is light to moderate, allowing an overload force or resistance to be developed. For example, if an individual is in a position in which he or she cannot stay upright (attempting to stand or perform a squat maneuver on a Swiss ball or Physio Ball), the amount of resistance that can be applied to the muscle will be diminished because the focus is on balance (extreme instability). On the other hand, performing contractions while seated on a ball with 1 or 2 feet on the floor (moderate to light instability) requires less focus to maintain balance, and hence more concentration and resources can be applied to moving greater resistance. However, although the resistive challenge to a limb under very unstable condi-

TABLE 1. A 2-week resistance training program involving a combination of stable and unstable resistance exercises. The acronym "BOSU" pertains to the phrase "both sides up" and refers to a dome-shaped instability device. Dyna-Discs are smaller inflated discs placed under each foot. Swiss balls are large balls with typical diameters of 55–75 cm.*

Strength Microcycle 1 Exercise	Strength Microcycle 2 Exercise
Shoulder flexion (scissors) on BOSU	Upright rowing
DB chest press on Swiss ball	Bench press
Bent-over rowing on BOSU	Seated rowing
Biceps curls on Dyna-Discs	Preacher curls
Front lunges (stable)	Squat on BOSU
Side lunges (stable)	

* DB = dumbbell.

tions may be less than necessary to develop strength adaptations, torso musculature may be under greater stress. With unstable conditions, a relatively small resistive torque on the distal portion of a limb can result in substantial motive torque by the torso. Perhaps the greatest contribution of instability training may be to improve core stability rather than limb strength. In addition, the preliminary purpose of the instability need not be significant strength gains, but an attempt to improve balance, stability and proprioceptive capabilities.

Overall, the trunk stabilizer muscles are more highly activated by unstable than by stable exercises. In addition, resistance exercises using a single arm (unilateral) will also cause greater activation of the contralateral side trunk stabilizers. Therefore, it is recommended that for strengthening or increasing the endurance of the trunk stabilizers, the exercise should involve a destabilizing component. The lack of stability may originate from the base or platform upon which the exercise is performed (i.e., ball or wobble board) or by placing body segments or resistance outside the base of support of the body (i.e., unilateral dumbbell resisted movements). However, it must be recognized that when an individual is attempting to exert forces under unstable conditions, the maximum forces achieved under stable conditions are not possible because of the greater muscle stabilization functions. Furthermore, the number of RMs would also need to be adjusted to compensate for the unstable platform. Thus, it is recommended that, when an instability resistance training program is instituted, exercises be performed under stable conditions as well to ensure higher tensions on the muscles. This combination of stable and unstable exercises for similar muscle groups could be organized within a single training session or alternated over weekly sessions. Table 1 provides an example of a 2-week program alternating stable and unstable exercises.

Finally, the benefits of instability resistance training may be more pronounced for those individuals pursuing primarily health and rehabilitation benefits and not participating in challenging athletic activities or training with free weights involving high loads (Table 2). It is not known at this time whether instability resistance training provides greater benefits to active athletes for balance, trunk muscle activation, and coordination when implemented in conjunction with a traditional resistance

TABLE 2. This table provides a general description of the benefits of specific instability resistance and balance training effects on training for rehabilitation, general musculoskeletal health and sports performance.

Instability resistance and balance training effects	Rehabilitation	Musculoskeletal health	Sports performance
↑ trunk activation when compared to similar intensity stable activities	*	*	*
↑ limb muscle activation when compared to similar intensity stable closed kinetic chain exercises (i.e., squats)	* ↓ loads used to prevent injury	*	† Near-maximal or maximal activation can be achieved with high loads
↓ limb muscle activation when compared to similar stable open kinetic chain conditions	‡	‡	‡
↑ cocontractions with acute exposure to instability	* ↑ cocontractions increase joint protection	†	† Unknown whether chronic instability training will reduce cocontractions
↑ agonist stabilization functions	* ↑ agonist stabilization may increase joint protection	†	‡ Unknown whether chronic instability training will transfer agonist stabilizer to motive functions
↓ force and power output	‡	‡	‡
↑ static balance	† Limited or unknown application to dynamic balance	†	† Specific sport practice may provide sufficient dynamic balance training effect
Action specificity	?	?	?

* Significant benefit.
† Minimal benefit.
‡ No benefit.

TABLE 3. Instability resistance training literature.

What are some of the questions that remain unanswered?

1. Can static instability training contribute to greater dynamic balance?
2. Will static instability resistance training provide greater forces or power during unstable dynamic conditions than traditional resistance training (i.e., alter stabilizing to motive functions)?
3. Because of the instability-induced decrease in force output, should balance training be performed independently of resistance training?
4. Can the levels of trunk activation achieved with unstable exercises be equaled or increased with the greater resistance possible with stable resistance training (i.e., squats and deadlifts)?
5. Can instability resistance training reduce the extent of cocontractions?
6. For exercise prescription purposes, is it possible to generally quantify the differences in muscle activation intensity or force loss with unstable correlates of stable exercises?
7. Can training on unstable platforms improve performance in activities that receive stability perturbations from other sources (i.e., external forces such as encountered in football and rugby?

training program. There are many questions still to be answered regarding this area of training (see Table 3).

REFERENCES

1. Abenhaim, L., M. Rossignol, J.P. Valat, M. Nordin, B. Avouac, F. Blotman, J. Charlot, L. Dreiser, E. Legrand, S. Rozenberg, and P. Vautravers. The role of activity in the therapeutic management of back pain. Report of the International Paris Task Force on Pain. *Spine* 25:1S–33S. 2000.
2. Adkin, A.L., J.S. Frank, M.G. Carpenter, and G.W. Peysar. Fear of falling modifies anticipatory postural control. *Exp. Brain Res.* 143:160–170. 2002.
3. Anderson, K., and D.G. Behm. Maintenance of EMG activity and loss of force output with instability. *J. Strength Cond. Res.* 18:637–640. 2004.
4. Anderson, K., and D.G. Behm. Trunk muscle activity increases with unstable squat movements. *Can. J. Appl. Physiol.* 30: 33–45. 2005.
5. Arokoski, J.P., T. Valta, O. Airaksinen, and M. Kankaanpaa. Back and abdominal muscle function during stabilization exercises. *Arch. Phys. Med. Rehabil.* 82:1089–1098. 2001.
6. Behm, D.G. Neuromuscular implications and applications of resistance training. *J. Strength Cond. Res.* 9:264–274. 1995.
7. Behm, D.G., K. Anderson, and R.S. Curnew. Muscle force and activation under stable and unstable conditions. *J. Strength Cond. Res.* 16:416–422. 2002.
8. Behm, D.G., D. Button, K. Power, K. Anderson, and M. Connors. Relationship between hockey skating speed and selected performance measures. *J. Strength Cond. Res.* 19:326–331. 2005.
9. Behm, D.G., A. Leonard, W. Young, A. Bonsey, and S. MacKinnon. Trunk muscle EMG activity with unstable and unilateral exercises. *J. Strength Cond. Res.* 19:193–201. 2005.
10. Behm, D.G., K.E. Power, and E.J. Drinkwater. Muscle activation is enhanced with multi- and uni-articular bilateral versus unilateral contractions. *Can. J. Appl. Physiol.* 28:38–52. 2003.
11. Cady, L.D., D.P. Bischoff, and E.R. O'Connell. Strength and fitness and subsequent back injuries in fire fighters. *J. Occup. Med.* 21:269–272. 1979.
12. Carolan, B., and E. Cafarelli. Adaptations in coactivation after isometric resistance training. *J. Appl. Physiol.* 73:911–917. 1992.
13. Carpenter, M.G., J.G. Frank, C.P. Silcher, and G.W. Peysar. The influence of postural threat on the control of upright stance. *Exp. Brain. Res.* 138:210–218. 2001.
14. Cosio-Lima, L.M., K.L. Reynolds, C. Winter, V. Paolone, and M.T. Jones. Effects of physioball and conventional floor exercises on early phase adaptations in back and abdominal core stability and balance in women. *J. Strength Cond. Res.* 17: 721–725. 2003.
15. De Luca, C.J., and B. Mambrito. Voluntary control of motor units in human antagonist muscles: Coactivation and reciprocal activation. *J. Neurophysiol.* 58:525–542. 1987.
16. Engelhorn, R. Agonist and antagonist muscle EMG activity pattern changes with skill acquisition. *Res. Q. Exerc. Sport* 54: 315–323. 1983.
17. Fuzhong, L., P. Harmer, K.J. Fisher, and E. McAuley. Tai chi: Improving functional balance and predicting subsequent falls in older persons. *Med. Sci. Sports Exerc.* 36:2046–2052. 2004.
18. Gaetz, M., J. Norwood, and G. Anderson. EMG activity of trunk stabilizers during stable/unstable bench press. *Can. J. Appl. Physiol.* 29:S48. 2004.
19. Grenier, S.G., F.J. Vera-Garcia, and S.M. McGill. Abdominal response during curl-ups on both stable and labile surfaces. *Phys. Ther.* 86:564–569. 2000.
20. Hogan, N. Adaptive control of mechanical impedance by coactivation of antagonist muscles. *Int. Electrical Eng. J.* 29:681–690. 1984.
21. Holtzmann, M., M. Gaetz, and G. Anderson. EMG activity of trunk stabilizers during stable and unstable push-ups. *Can. J. Appl. Physiol.* 29:S55. 2004.
22. Itoi, E., D. Kuechle, S. Newman, B. Morrey, and K. An. Stabilizing function of the biceps in stable and unstable shoulders. *J. Bone Joint Surg.* 75:546–550. 1993.
23. Karst, G.M., and Z. Hasan. Antagonist muscle activity during human forearm movements under varying kinematic and loading conditions. *Exp. Brain Res.* 67:391–401. 1987.
24. Kornecki, S., A. Kebel, and A. Siemienski. Muscular cooperation during joint stabilization, as reflected by EMG. *Eur. J. Appl. Physiol.* 85:453–461. 2001.
25. Kornecki, S., and V. Zschorlich. The nature of stabilizing functions of skeletal muscles. *J. Biomech.* 27:215–225. 1994.
26. Kraemer, W.J., and S.J. Fleck. Resistance training: Exercise prescription (Part 4 of 4). *Physician Sports Med.* 16:69–81. 1988.
27. Lear, L.J., and M.T. Gross. An electromyographical analysis of the scapular stabilizing synergists during a push-up progression. *J. Sports Phys. Ther.* 28:148–149. 1998.
28. Marigold, D.S., and A.E. Patla. Strategies for dynamic stability during locomotion on a slippery surface: Effects of prior experience and knowledge. *J. Neurophysiol.* 88:339–353. 2002.
29. Marsden, C.D., J.A. Obeso, and J.C. Rothwell. The function of the antagonist muscle during fast limb movements in man. *J. Physiol.* 335:1–13. 1983.
30. Marsh, D.W., L.A. Richard, L.A. Williams, and K.J. Lynch. The relationship between balance and pitching error in college baseball pitchers. *J. Strength Cond. Res.* 18:441–446. 2004.
31. McCurdy, K., and C. Conner. Unilateral support resistance training incorporating the hip and knee. *Strength Cond. J.* 25: 45–51. 2003.
32. Milner, T.E. Accuracy of internal dynamics models in limb movements depends on stability. *Exp. Brain Res.* 159:172–184. 2004.
33. Nadler, S.F., G.A. Malanga, L.A. Bartoli, J.H. Feinberg, M. Prybicen, and M. Deprince. Hip muscle imbalance and low back pain in athletes: Influence of core strengthening. *Med. Sci. Sports Exerc.* 34:9–16. 2002.
34. Nagy, E., K. Toth, G. Janositz, G. Kovacs, A. Feher-Kiss, L. Angyan, and G. Horvath. Postural control in athletes participating in an ironman triathlon. *Eur. J. Appl. Physiol.* 92: 407–413. 2004.
35. Norris, C.M. *Back Stability.* Windsor, Canada: Human Kinetics Publ., 2000. pp. 123–138.

36. NOURBAKHSH, M.R., AND A.M. ARAB. Relationship between mechanical factors and incidence of low back pain. *J. Orthop. Sports Phys. Ther.* 32:447–460. 2002.
37. PAVOL, M.J., AND Y-C. PAI. Feedforward adaptatons are used to compensate for a potential loss of balance. *Exp. Brain Res.* 145:528–538. 2002.
38. PERSON, R.S. EMG study of co-ordination of activity of human antagonist muscles in the proces of developing motor habits. *J. Vysceit Nerveun Dejat* 8:17–27. 1958.
39. RUTHERFORD, O.M., AND D.A. JONES. The role of learning and coordination in strength training. *Eur. J. Appl. Physiol.* 55:100–105. 1986.
40. SALE, D. Neural adaptation to resistance training. *Med. Sci. Sports Exerc.* 20:135–145. 1988.
41. SAVAGE, R.A., R. MILLERCHIP, G.H. WHITEHOUSE, AND R.H.T. EDWARDS. Lumbar muscularity and its relationship with age, occupation and low back pain. *Eur. J. Appl. Physiol.* 63:265–268. 1991.
42. SELYE, H. *The Stress of Life.* New York: McGraw Hill Publ., 1956. pp. 12–38.
43. SHERRINGTON, C.S. Flexion-reflex of the limb, crossed extension reflex stepping and standing. *J. Physiol.* 40:28–121. 1910.
44. SHERRINGTON, C.S. Remarks on some aspects of reflex inhibition. *Proc. R. Soc. Lond.* 97:519–519. 1925.
45. SHIMADA, H., S. OBUCHI, N. KAMIDE, Y. SHIBA, M. OKAMOTO, AND S. KAKURAI. Relationship with dynamic balance function during standing and walking. *Am. J. Phys. Med. Rehabil.* 82: 511–516. 2003.
46. SIFF, M.C. The functional mechanics of abdominal exercise. *S. Afr. J. Sports Med.* 6:15–19. 1991.
47. SOUZA, G.M., L.L. BAKER, AND C.M. POWERS. Electromyographic activity of selected trunk muscles during dynamic spine stabilization exercises. *Arch. Phys. Med. Rehabil.* 82: 1551–1557. 2001.
48. STANFORTH, D., P.R. STANFORTH, S.R. HAHN, AND A. PHILLIPS. A 10 week training study comparing resistaball and traditional trunk training. *J. Dance Med. Sci.* 2:134–140. 1998.
49. STONE, M.H., S.S. PLISK, M.E. STONE, B.K. SCHILLING, H.S. O'BRYANT, AND K.C. PIERCE. Athletic performance development: Volume load-1 set vs. multiple sets, training velocity and training variation. *Strength Cond. J.* 20:22–31. 1998.
50. TAN, B. Manipulating resistance training program variables to optimize maximum strength in men: A review. *J. Strength Cond. Res.* 13:289–304. 1999.
51. TSANG, W., AND C. HUI-CHAN. Effects of tai chi on joint proprioception and stability limits in elderly subjects. *Med. Sci. Sports Exerc.* 35:1962–1971. 2003.
52. VERA-GARCIA, F.J., S.G. GRENIER, AND S.M. MCGILL. Abdominal muscle response during curl-ups on both stable and labile surfaces. *Phys. Ther.* 80:564–569. 2002.
53. VERHAGEN, E.A., M. VAN TULDER, A.J. VAN DER BEEK, L.M. BOUTER, AND W. VAN MECHELEN. An economic evaluation of a proprioceptive balance board training programme for the prevention of ankle sprains in volleyball. *Br. J. Sports Med.* 39: 111–115. 2005.
54. VUILLERME, N., N. TEASDALE, AND V. NOUGIER. The effect of expertise in gymnastics on proprioceptive sensory integration in human subjects. *Neurosci. Lett.* 311:73–76. 2001.
55. WADDINGTON, G., H. SEWARD, T. WRIGLEY, N. LACEY, AND R. ADAMS. Comparing wobble board and jump-landing training effects on knee and ankle movement discrimination. *J. Sci. Med. Sport* 3:449–459. 2000.
56. WILLARDSON, J.M. The effectiveness of resistance exercises performed on unstable equipment. *Strength Cond. J.* 26:70–74. 2004.

Address correspondence to David Behm, Ph.D., dbehm@mun.ca.