REVIEW ARTICLE

Sports Med 2005; 35 (1): 43-53
0112-1642/05/0001-0043/$34.95/0

The Impact of Instability Resistance Training on Balance and Stability

Kenneth Anderson and *David G. Behm*

School of Human Kinetics and Recreation, Memorial University of Newfoundland, St John's, Newfoundland, Canada

Contents

Abstract

The most predominant literature regarding balance has emphasised the physiological mechanisms controlling stability. Topics range from extrinsic factors (environment) to intrinsic factors (i.e. muscle coordination, vestibular response). Balance is achieved through an interaction of central anticipatory and reflexive actions as well as the active and passive restraints imposed by the muscular system. However, less research has attempted to document the effects of balance on performance measures (i.e. force, power). Furthermore, short- and long-term adaptations to unstable environments need more substantial research. While force and other performance measures can be adversely affected by a lack of balance, the transferability of instability training to activities of daily living and sport is not precisely known. The applicability of instability and resistance training using unstable platforms or implements may have strong relevance in a rehabilitative or athletic setting. Therefore, a comprehensive review of the literature in this area may possibly be of benefit to practitioners who deal with the general population, athletes or persons debilitated by balance and/or stability disabilities.

There has been an increasing awareness of the importance and relevance of the specialised and integrated action of the muscular system in maintaining posture and optimal function of the movement system. The mechanisms of human motion have largely been studied under simplified movement conditions.[1-4] By analysing single-joint movements, such principles as force production, force or torque due to joint positions, muscle mechanics and the synchronisation of muscle activity, studies have described the basic features of human movement. In the more complex motion of bi-articular movements, findings have not precisely substantiated those results found with single-joint movements.[5] The complexity of multi-articular movements underlies the difficulty in formulating training exercises and programmes to improve performance requiring dynamic balance.

Neuromuscular mechanisms play an important role in balance not only when motionless but also during movement. The human body is not a rigid unit, as it is capable of changing shape, thereby complicating some of the simple principles of balance normally applied to inanimate objects. Moving a human body through three dimensions at differing velocities and while experiencing varying torques and forces places great demands on the strength, endurance and coordination of the system. A less than efficient neuromuscular system may not adapt well to the stresses resulting in impaired performance and injury. Trunk stability is an essential component for providing a solid base or core to exert or resist forces. It is still uncertain what type of training is most effective for improving trunk and joint stability in its roles in the prevention of injury and its contribution to balance and force output. As balance and stability have a functional role for vocational purposes, recreation, daily tasks or injury prevention and rehabilitation, it would be beneficial to identify if a particular exercise regimen and/or technique could maximise dynamic balance and the ability to exert forces while maintaining balance. As a number of neuromuscular mechanisms responsible for balance exist within the human body, we must first attempt to identify and then understand these particular mechanisms and the movement considerations involved. The objective of this paper is to review the literature concerning the need or desirability of unstable environments for training.

1. Mechanics of Posture

The apparently simple act of standing motionless is actually a continuing process of minute adjustments of body position to keep the centre of gravity over the base of support. The smaller the base, the more accurate such adjustments must be to maintain balance. It is proposed that the differential effect of postural instability on balance could be accounted for by two main mechanisms: (i) those related to the alteration of proprioceptive messages at the peripheral level; and (ii) those related to the central processing.[6]

1.1 Proprioceptive and Peripheral Control

Optimal control of balance in upright posture is an essential requirement for sport, daily activities, or for the prevention of injury. Stabilisation of postural equilibrium is achieved by continuous afferent and efferent control strategies within the sensorimotor system with feedback from somatosensory, vestibular and visual inputs.[7] For example, viscoelastic forces inherent to the ankle muscles correct perturbations to the upright posture in humans provided the ankle rotation is small.[8] For larger displacements, active contractions are required if balance is to be maintained. The literature identifies that these contractions could originate from stretch or vestibulospinal reflexes, or be a voluntary response triggered by multimodal sensory inputs.[9] It has been postulated that a confluence of trunk and upper-leg proprioceptive input establishes the basic timing of automatic, triggered balance corrections, which is then preferentially weighted by vestibular modulation in muscles that prevent falling.[10] While human postural control is shared among the vestibular, visual and somatosensory systems, the vestibular system is considered the main control system for a vertical detector.[11]

The afferent information is processed in the brainstem and cerebellum, followed by the initiation of motor commands to maintain balance. Unstable environments stress sensory and motor feedback loops resulting in increased body sway and muscle activity.[12] Standing on an unstable support calls upon higher levels of the control system and requires an essential change in the mode of utilisation of incoming proprioceptive information. This theory of postural mechanisms was investigated while standing on a rigid floor and varied amplitude 'see-saws'.[13] Electromyographic (EMG) activity of the soleus and tibialis anterior during standing on the rigid floor and on a see-saw resembled each other. However, during standing on the more unstable see-saw, the amplitude of the movement in the ankle joint was larger and a marked modulation of the EMG activity of the soleus muscle was observed. These results suggest that directionally specific torque changes in response to centre of gravity shifts provide important information for maintenance of posture.

1.2 Central Processing: Anticipatory Postural Adjustments

To achieve the primary goal of a given task, the fundamental role of the central nervous system is to coordinate the focal movement. Anticipatory postural adjustments play an important role in maintaining balance during task performance. As a result of the enhanced central drive and the corresponding augmented gamma motor neuron activity during balancing, co-contraction of the muscles involved can be implemented.[14] It is known that postural adjustments of the trunk or legs may be initiated prior to the onset of voluntary movements of the trunk or upper limb.[11] These postural adjustments appear to have the aim of minimising the equilibrium disturbances provoked by these movements.

Kornecki et al.[15] reported that when the support object was unstable, the myopotentials of all the investigated muscles preceded the instant of force application (anticipation). The stabilising muscles of the task dominated this specific neuromuscular anticipation. This may be explained by the fact the supporting structures must first be stabilised before a motor movement can be efficiently elicited. In addition, the postural adjustments in a number of different stances were measured and found that stabiliser muscles fired approximately 30ms prior to movement muscle activation.[16] The main result was that anticipatory postural adjustments were large when the lower limb flexions were performed from an initial bipedal posture (stable) and absent when they were performed from an initial unipedal posture (unstable).

Lynn and Woollacott[17] found that during quiet stance without support, EMG activity was clearly evident from the soleus, therefore, identifying the role the soleus muscle had in maintaining standing posture. In their study, measuring EMG activity of the muscles of the lower limb, they found that when the subjects were unstable, both the tibialis anterior and soleus muscle would fire before any movement would occur. However, during the same task but while under a stable condition (holding on to supports), the activity prior to the movement phase was abolished. Other results with an unstable base show the occurrence of an early inhibition of the EMG activity of the triceps surae muscles in advance of their bursting activity leading into the intended movement. Also, the occurrence of an early increase in triceps surae EMG activity before the voluntary activation of the tibialis anterior was also identified. These phenomena outline a complex pattern of activities, whereby a muscle's activity is decreased just prior to fast activation of the same muscle, or is enhanced when the only intended command is the contraction of its antagonist. Slijper and Latash[18] reported an anticipatory increase in activity of the tibialis anterior, biceps femoris, erector spinae and rectus abdominus when experiencing unstable standing. In the soleus and rectus femoris, changes in the background activity were less pronounced. In the absence of additional support (touch or grasp), arm muscles (wrist flexors/extensors, biceps, triceps) tended to show an increase in the background EMG activity. For these reasons, the authors speculate that these phenomena are anticipatory postural adjustments, and serve the purpose of minimising the subsequent postural destabilisation.

In very stable conditions, the requirements of stabilising posture under the action of transient, motion-related perturbations are alleviated. On the other hand, in very unstable conditions, anticipatory postural adjustments themselves may be viewed as sources of perturbations, which can move the centre of mass beyond the decreased area of support. This anticipatory increase in synergistic muscle activity was also documented using an inverted pendulum to induce instability of the arm.[1]

When we move, we are usually unaware of the complex neuromuscular processes that control our posture. The mechanical problem of maintaining posture is particularly challenging but with internal central processing within the cerebellum paralleled with anticipatory postural adjustments and proprioceptive feedback (vestibular, visual and somatosensory inputs), we are able to meet the constant demands for maintaining posture and balance. While instability resistance training should certainly tax the proprioceptive control of posture, it has not been established whether any positive adjustments would be mediated through anticipatory postural adjustments (central processing). There is some literature to suggest that resistance training under stable conditions can improve balance, especially in older adults.

2. Effect of Stable Resistance Training on Balance

The effect of resistance exercise on muscle strength and size has been clearly documented,[19-22] but evidence suggests that resistance training, absent of balance training, also has a positive effect on balance. It was found that strength exercises contribute to better balance and gait in women aged ≥57 years.[23] In a separate study, the mean increase in balance scores in a balance-training group was 146% and 34% in the strength-training group ($p < 0.01$).[24] A prospective, blinded, randomised trial of moderate intensity strength exercise was conducted on 132 older adults.[25] They found that gait stability improved significantly more in the resistance exercise group than in the control group. These results show that even moderate strength gains (17.6%) may benefit gait and balance, thus providing a sound basis for the encouragement of low-intensity strength training for individuals with functional limitations.

A number of studies were conducted to test if a training programme can restore balance in older individuals.[26-29] The effect of strength and endurance training on balance in older adults (aged 65–85 years) with reduced balance showed that short-term strength and endurance training had no restorative effect on balance of the study cohort.[26] Testing to determine if a strength-training programme can improve measures of balance among adults aged ≥65 years ($n = 55$) was also done.[27] At post-test, the exercisers demonstrated enhanced balance, although none of the post-test measures were significantly different from the control group. Furthermore, a randomised, controlled trial compared the effects of resistance training on static balance.[28] The strength-training group exercised three times per week using exercise machines with balance being measured on a force platform. Results indicate that double-stance measurements were unchanged after training. In single stance, the centre of displacement of the centre of pressure improved by 17%. Finally, no significant between-group differences for one-leg blind balance time suggests that strength training alone does not appear to enhance standing balance in active, community dwelling older adults.[29]

In a study of younger healthy subjects, participants were assigned to either strength- or balance-training regimens.[7] After 1 month, the training was exchanged between groups. At the first follow-up, balance training led to significant increase in the performance outcomes of the balance-training group, whereas the strength-training group did not ($p < 0.001$). However, at the second follow-up, scores of both groups were significantly increased when compared with baseline.

Motor-skill training, including balance training, increases the sensitivity of feedback pathways and shortens the onset times of the selected muscles by improving the sensitivity of the position sense of both agonistic and antagonistic muscles.[7] The muscle, as the termination of the final pathway of the sensorimotor system, particularly contributes to the maintenance of body balance. It has been documented that resistance training that increased muscular strength also increased stability and coordination.[30] Improvements in task performance were accompanied by changes in the pattern of recruitment of the muscles that were the focus of the resistance-training programme. Specifically, the trained muscles were recruited in a more consistent fashion after training. However increased strength does not guarantee improved balance. Kollmitzer et al.[7] showed that strength training actually reversed any benefit from the balance training in their study. Training of the muscles that contribute to posture may reasonably change not only muscle force output, but also the coordination of synergistic and antagonist muscle activation. Thus, depending on the specific training programme and population in question (i.e. a frail, aged individual may benefit more from the beneficial effects of increased force output for responding to perturbations), the role of resistance training on balance is unclear.

3. Stabilising Function of Muscle

Although much is known about how muscles maintain static equilibrium, little is known how they maintain dynamic balance when exerting an external force. Exerting external forces while attempting to maintain dynamic balance is tantamount to success in the majority of sports and a necessity in the activities of daily living (i.e. carrying shopping bags, babies). Exerting a force with the upper extremity upon an external object requires coordination of the neuromuscular system. This coordination would ensure the inhibition of some muscles to achieve simultaneously coupled motions to take place in other joints. Sporrong et al.[31] studied how handgrip exercises/activities increased shoulder muscle activity. Subjects were asked to perform isometric contractions against a handgrip dynamometer. In the supraspinatus and infraspinatus muscles, there was a positive correlation between the degree of the shoulder muscle activity and the intensity of handgrip exertion. This could have practical value in the rehabilitation of the hand, as not only the muscles of the hand and forearm should be rehabilitated, but also the stabiliser muscles of the shoulder as well for maximal rehabilitation of grip strength. Furthermore, muscle activity occurred simultaneously in muscles producing a movement and in antagonistic muscles of a number of different shoulder movements (i.e. flexion, extension, adduction, abduction), showing how coordination due to muscle contractions plays a significant role in stabilising the shoulder joint.[32]

This coordination leads to the extraordinary complexity of the nervous system, of which one of the most important tasks is to control the stabilisation of the joints' degrees of freedom unused in a given motor task by stimulation of antagonistic muscles. Behm et al.[33] studied agonist/antagonist relationships of the leg extensors with instability. During leg extensions, antagonistic hamstring activity increased by 29.1% ($p = 0.05$) under unstable versus stable conditions. Milner et al.[34] provided evidence from comparison of forceful flexor and extensor co-contractions that EMG was always less during maximal co-contractions than it would be as a prime mover. Slijper and Latash[18] demonstrated that during standing on an unstable board, there was a tendency for an increase in the background muscle activity, which would increase the resting stiffness or tonus of the muscle in response to the unstable platform. Adding manual support typically resulted in decreased background activity. The cost of coping with instability is an increase in co-contractions resulting in a decrease in external force. However, it can be argued that the task would not be able to be performed without this co-activation.

Thus, this stabilisation process consists of establishing active muscular constraints to minimise the degrees of freedom within a joint or series of joints and results in stabilisation of the excessive mobility of external objects. Trunk or core stabilisation is essential for maintaining static or dynamic balance and especially when attempting to exert forces upon external objects. A lack of trunk stabilisation may also be a major contributor to the back pain endemic within our society.

3.1 Local and Global Trunk Stabilisation

Functional joint stability and its effect on balance are dependent on integrated local and global muscle function.[35-37] Comerford and Mottram[36] have proposed a classification system for muscle function. They have defined and characterised vertebral muscles as local stabilisers, global stabilisers and global mobilisers. They identify that role of the local stabilisers is to maintain low force continuous activity in all positions of joint range and in all directions of joint motion. Their activity usually increases in anticipation to a load and/or movement, thus providing joint protection and support. Global stabilisers generate torque and provide control over some motions. Global mobilisers are required to have adequate length to provide full range of motion around a joint without causing overstrain elsewhere in the movement system; however, they do have a stability role under high load or strain. The normal function of the local muscle system is to provide sufficient segmental stability to the spine. The global muscle system provides general trunk stabilisation and enables the static and dynamic work necessary for daily living and sport activities.[38] The multifidus has been identified as a local stabilising muscle that acts simultaneously with the global muscles (longissimus thoracis, rectus abdominus).[35] One definition of global muscles is that they are muscles that act on the spinal column via the rib cage (i.e. erector spinae, rectus abdominus), which control the overall response, and local muscles that are attached directly to the lumbar spine.[37]

In a study of muscle recruitment patterns during asymmetric lifting in healthy individuals, it was found that the left and right internal obliques, rectus femoris and multifidus showed symmetrical co-contraction in all variants of the lifting activities.[37] In contrast, significant left/right differences were observed in the external oblique, gluteus maximus, illiocostalis lumborum pars thoracis and latissimus dorsi. These results show a symmetrical activation of the local muscles during the performance of low load, asymmetric lifting tasks, which suggest that these muscles play a stabilising role during these manoeuvres. The global muscles, however, show asymmetric patterns of activation during the same tasks, supporting their role of global stabilisers and prime movers. In addition to these findings, it was identified that the multifidus, transverse abdominus and the internal obliques act as part of the local stabilising system; whereas the longissimus thoracis, rectus abdominis and external obliques constitute a part of the global stabilising system.[35]

Arokoski et al.[35] identified that the stability of the spine was increased with either increased flexor-extensor muscle co-activation forces or increased intra-abdominal pressure. Deep local stabilising muscles, especially the multifidus and the transverse abdominus muscles, mainly contribute to stability. In the investigated exercises, the researchers found the lumbar multifidus muscle function patterns appeared to be coupled with longissimus thoracis muscles, thus the local and global back muscle function showed similar activation patterns and simultaneous function.

It has been suggested that back muscle contractions as low as 25% of maximal voluntary contraction (MVC) are able to provide maximal joint stiffness.[39] A low percentage of maximal voluntary isometric contraction from the trunk musculature thus stabilises the spine during normal movements and motor control, not just muscle strength is important to dynamic stability training.[40] Furthermore, because lumbar stabilising multifidus muscles are mainly composed of type I muscle fibres,[41] only relatively low loads (approximately 30–40% MVC) are needed to improve their effectiveness.[42] Therefore, resistance training under unstable conditions with relatively high loads may not automatically provide a suitable training environment for vertebral stability and dynamic balance. On the other hand, the integration of balance and resistance training may augment motor control while increasing muscle activation, strength and stiffness.

4. Effect of Instability Training on Trunk Musculature

It is proposed that training under unstable conditions will stress the neuromuscular system to a greater extent than traditional resistance training methods using more stable benches and floors.[12,14,43,44] Strength gains can be attributed to both increases in muscle cross-sectional area and improvements in neuromuscular coordination.[45] A number of researchers have reported that neural adaptations play a vital role in strength gains in the early portion of a resistance training programme.[45,46] In addition, it is suggested that the specific neural adaptations occurring with resistance training are not increased recruitment or activation of motor units, but an improved coordination of agonist, antagonists, synergists and stabilisers.[47,48]

With the current interest in stability training for the injured low back and home fitness equipment available to the consumer, the use of labile (moveable) surfaces to challenge the motor control system is becoming more popular. However, this could be of concern as little is known about the effects of these unstable surfaces on muscle activity.

To maximise functional performance, individuals should attempt to train in an environment that mimics their real-world situation. Often in sport and activity, the individual is not in a stationary, stable position, therefore, numerous training aids have been developed to simulate these real-world situations. One of these training aids is the 'Swiss ball'. Siff[49] found that the Swiss ball provided a wider range of movement (with an optimal starting position from a few degrees of active trunk extension), which he described as preferable to similar actions performed in most circuit training gyms. The importance of 'Swiss balls' in a rehabilitative setting has been documented in the re-education of postural muscles and to facilitate movement and postural reactions in neurologically impaired patients.[50]

Vera-Garcia et al.[51] tested the type of surface (stable or unstable) on the muscle mechanics of the abdominal wall. They indicated that performing curl-up exercises on an unstable surface increased abdominal muscle activity. EMG analysis showed the rectus abdominus muscle activity on a stable surface was 21% of the MVC and external oblique muscle activity was 5% of MVC. For the curl-up on an unstable ball, rectus abdominus activity was 35% of MVC and external oblique muscle activity was 10% of MVC. This study suggests a much higher demand on the motor control system when performing abdominal exercises on labile equipment. In addition, a stability ball training group's performance in trunk flexion and back extension improved significantly more ($p < 0.05$) than either the traditional group or the controls.[50] Possible rehabilitative benefits were suggested with the occurrence of significantly fewer recurrent sprains. Also, significantly fewer patients in a wobble-board training group had functional instability of the ankle compared with a no wobble-board training group.[44] The authors concluded that training on a wobble board was effective in reducing residual symptoms following ankle ligament trauma compared with no training.

Behm and colleagues[52] had subjects perform a variety of typical trunk strengthening exercises under stable and unstable (Swiss ball) conditions. Overall, activation of the lumbo-sacral and upper lumbar erector spinae as well as the deep abdominal stabilisers was significantly greater with the unstable condition. Thus, the very few investigations of unstable exercises on trunk muscle activation seem to concur that the introduction of instability into the activity increases the extent of muscle activation.

5. The Effects of Instability on Muscle Force and Activation

Unstable platforms or loads can lead to increased stabilisation functions at the expense of motive or force functions.[48,53] Thus, even with substantial force decrements, overall muscle activation may remain virtually unchanged. Kornecki et al.[15] found that contributions of stabilising muscles increased on average by 40% when the handle changed from stable to unstable during pushing movements They showed that the process of muscular stabilisation of the investigated joint caused, on average, 30% drops in force, velocity and power ($p < 0.01$). Instability-induced muscular stabilisation of the wrist joint caused a significant increase in the EMG contributions of the stabilising muscles and a visible drop in the contributions of the muscles that realised motor functions, which in turn bring 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 stabilising muscles. It was found that both the short and long heads of the bicep have similar functions as anterior stabilisers of the glenohumoral joint and their roles in stabilisation increase as joint stability decreases.[54] The stabilising function of scapular stabilisers while performing push-ups on miniature trampolines was also examined.[55] They found no significant difference in stabiliser EMG activity between stable and unstable conditions; however, they acknowledged the degree of stability induced by the miniature trampolines was likely to be insufficient to illicit an unstable platform.

Anderson and Behm[56] also reported no significant difference in EMG activity of the pectorals, triceps, latissimus dorsi and rectus abdominus when performing maximal isometric chest presses under stable and unstable conditions. However, maximum isometric force was decreased by 60% with the unstable base. They suggested that the decreased balance associated with resistance training on an unstable surface might force limb musculature to play a greater role in joint stability. In a further study from the same laboratory, upper lumbar, lumbosacral erector spinae, abdominal stabilisers and soleus activation were all activated to a greater extent when performing squats under unstable conditions with the same submaximal load.[57] The authors explained that the increased EMG activity of these muscles may be attributed to their greater postural and stabilisation roles with the unstable condition.

In contrast, Behm et al.[33] reported that unstable leg extensor and plantar flexor activation averaged 44.3% and 2.9% less, respectively, than during stable conditions. Unstable leg extensor force was 70.5% less than stable force while unstable plantar flexor force was 20.2% less than its respective stable force. They suggested that under conditions of great instability, as was experienced with the destabilising torque of unilateral leg extensions performed on a Swiss ball, increased stabilisation functioning of the muscles was insufficient to maintain balance resulting in decreased overall activation. In contrast, no statistical difference was found in the magnitude of forces produced in a stable versus an unstable protocol of the thumb musculature (nine separate muscles) in individuals using a modified clinical pinch meter.[58] Although force output remained constant between protocols, changes in the activation of different muscles (muscle co-ordination) were identified. For example, the flexor pollicis longus EMG was significantly greater during stable opposition pinch whereas EMG activity in the dorsal interosseus muscle was significantly greater in the unstable condition.

The literature indicates that instability affects force output in numerous ways (i.e. decreased force output, increased co-contractions, altered muscle coordination). The goal of instability resistance training would be to accommodate to an unstable environment, and thus hopefully diminish the loss of force and the extent of co-contractions.

6. Resistance Training

Resistance training can be used to induce strength, power and endurance adaptations with a myriad of exercises and equipment that will provide a spectrum of stable and unstable loads. The range of stable and unstable platforms and loads used during resistance training might also induce motor learning adaptations with the goal of improving dynamic balance and force outputs while unstable.

Several modes of training are currently available, with some of the more popular methods being the use of free-weights, weight stack machines and isokinetic devices. Each method has associated freedoms and constraints.

The advantages of free weights over machines are well documented.[59-61] The major advantages arise from the ability of free-weight exercises to mimic the movement demands of real-life sport and everyday activities from the numerous possible variations with free-weight exercises. This use of free weights is vital in the principles of exercise specificity (training in a specific manner to produce a specific outcome). In addition, free-weight lifting requires the lifter to balance and stabilise the bar/dumbbells in all movement planes. Having the individual lift dumbbells unilaterally can further augment the instability of free weights. Behm et al.[52] reported greater trunk muscle activation when dumbbell chest presses were performed unilaterally rather than bilaterally. Further advantages of free weights include a constant external resistance baseline throughout the particular movement as well as the ability for full body training. The movement of a free weight is constrained by the lifter, as opposed to a machine, which often does not require the muscles to work in the similar stabilising role.[62]

In contrast to free weights, most machines create a forced or guided one- or two-dimensional movement pattern for the user opposed to the three-dimensional movement pattern of free weights. This forced pattern does not allow as much movement freedom in movement patterns partly caused differences in people's limb lengths, bone articulations and muscle attachment sites. Rubber tubing and machines using cables that can move in three dimensions are more adaptable to individual anthropometric differences. However, cables and rubber tubing typically offer a fast-to-slow movement pattern, with greater resistance and slower speed toward the end of the movement, which contrasts with the typical slow-to-fast pattern of many sport movements.[63] Another disadvantage of machines is that they often provide resistance only at a single joint. Also, because most machines support the user, few, if any demands are required to stabilise and balance both the user and/or the load. However, machines do offer some benefits as they often ensure the correct range of motion and movement pattern, lowering the likelihood of injury, especially with individuals unfamiliar to resistance training.[64]

Free-weight exercises are generally agreed upon by the fitness community as the most advantageous method of weight training due to the positive effects of unstable training protocols on neuromuscular function.[12,14,43]

7. Conclusions

It is now evident that a large amount of resistance training information exists stemming from different equipment for varied training regimens. However, it is essential to summarise and apply this knowledge in a more functional and activity-specific model to identify if a parallel exists for the need, practicality and importance of stability training.

Through the training-induced functional increases in balance and muscle coordination that can be experienced with a stability/balance programme, it would be beneficial for fitness and health practitioners to combine balance training modalities with resistance training so their clients, especially if somatosensory impaired, can maximise the positive effects of their training time. Although force outputs are diminished under unstable conditions, the decreased balance associated with instability resistance training may force limb and trunk musculature to play a greater role in joint stability. The use of unstable platforms as a resistance training modality for strength gains can be employed to allow high muscle activation levels to be developed through an increased reliance on stabilising functions. As this high level of muscle activation can be achieved with less resistance, this training modality may have positive implications in progressive muscle and joint rehabilitation as well as sport-specific training. Since most sports involve a combination of stabilising and force producing functions (running forehand in tennis, baseball pitcher wind-up, moving slap shot in hockey and many others), instability resistance training provides similar challenges to the neuromuscular system. However, in order to induce maximum or near maximum overload forces upon the limbs, a stable platform may be necessary. It is recommended that a comprehensive, sport-specific, strength-training programme incorporate exercises under both stable and unstable conditions.

Numerous authors have attempted to make the connection in identifying the effects of strength training versus balance training on balance; however, little research has been done regarding actually performing this strength training on stable and unstable platforms and its resultant effect on balance. It is now proposed that the scientific community identify which methods and exercises offer the most benefit with reference to stability and balance while offering the highest degree of carry-over into a real-world setting.

Acknowledgements

No sources of funding were used to assist in the preparation of this review. The authors have no conflicts of interest that are directly relevant to the content of this review.

References

1. Stokes I, Gardner-Morse M. Strategies used to stabilize the elbow joint challenged by inverted pendulum loading. J Biomech 2000; 33 (6): 737-43
2. Gardner-Morse M, Stokes I, Laible J. Role of muscles in lumbar spine stability in maximum extension efforts. J Orthop Res 1995; 13 (5): 802-8
3. Milner T, Cloutier C. Compensation for mechanically unstable loading in voluntary wrist movement. Exp Brain Res 1993; 94 (3): 522-32
4. Eloranta V. Coordination of the thigh muscles in static leg extension. Electromyogr Clin Neurophysiol 1989; 29 (4): 227-33
5. Lacquaniti F, Soechting J. Responses of mono- and bi-articular muscles to load perturbations of the human arm. Exp Brain Res 1986; 65 (1): 135-44
6. Ivanenko Y, Solopova I, Levik Y, et al. The direction of postural instability affects postural reactions to ankle muscle vibration in humans. Neurosci Lett 2000; 292 (2): 103-6
7. Kollmitzer J, Ebenbichler G, Sabo A, et al. Effects of back extensor strength training versus balance training on postural control. Med Sci Sports Exerc 2000; 32 (10): 1770-6
8. Nashner L. Adapting reflexes controlling the human posture. Exp Brain Res 1976; 26 (1): 59-72
9. Allum J. Organization of stabilizing reflex responses in tibialis anterior muscles following ankle flexion perturbations of standing man. Brain Res 1983; 264 (2): 297-301
10. Allum J, Honegger F. Interactions between vestibular and proprioceptive inputs triggering and modulating human balance-correcting responses differ across muscles. Exp Brain Res 1998; 121 (4): 478-94
11. Mizuno Y, Shindo M, Kuno S, et al. Postural control responses sitting on unstable board during visual stimulation. Acta Astronaut 2001; 49 (3): 131-6
12. Nardone A, Schieppati M. Postural adjustments associated with voluntary contraction of leg muscles in standing man. Exp Brain Res 1988; 69 (3): 469-80
13. Ivanenko Y, Levik Y, Talis V, et al. Human equilibrium on unstable support: the importance of feet-support interaction. Neurosci Lett 1997; 235 (3): 109-12
14. Gantchev G, Dimitrova D. Anticipatory postural adjustments associated with arm movements during balancing on unstable support surface. Int J Psychophysiol 1996; 22 (1-2): 117-22
15. Kornecki S, Kebel A, Siemienski A. Muscular cooperation during joint stabilization, as reflected by EMG. Eur J Appl Physiol 2001; 85 (5): 453-61
16. Nouillot P, Bouisset S, Do M. Do fast voluntary movements necessitate anticipatory postural adjustments even if equilibrium is unstable? Neurosci Lett 1992; 147 (1): 1-4
17. Lin S, Woollacott M. Postural muscle responses following changing balance threats in young, stable, older, and unstable older adults. J Motor Behav 2002; 34 (1): 37-44
18. Slijper H, Latash M. The effects of instability and additional hand support on anticipatory postural adjustments in leg, trunk, and arm muscles during standing. Exp Brain Res 2000; 135 (1): 81-93
19. Hortobagyi T, DeVita P. Favorable neuromuscular and cardiovascular responses to 7 days of exercise with an eccentric overload in elderly women. J Gerontol Biol Sci Med 2000; 55 (8): B401-10
20. Durak E, Jovanovic-Peterson L, Peterson C. Randomized crossover study of the effect of resistance training on glycemic control, muscular strength, and cholesterol in type I diabetic men. Diabetes Care 1990; 13 (10): 1039-43
21. Goreham C, Green H, Ball-Burnett M, et al. High-resistance training and muscle metabolism during prolonged exercise. Am J Physiol 1999; 276 (3 pt 1): E489-96
22. Hakkinen K, Newton R, Gordon S, et al. Changes in muscle morphology, electromyographic activity, and force production characteristics during progressive strength training in young and older men. J Gerontol A Biol Sci Med Sci 1998; 53 (6): B415-23
23. Lord S, Clark R, Webster I. Physiological factors associated with falls in an elderly population. J Am Geriatr Soc 1991; 39 (12): 1194-201
24. Heitkamp H, Horstmann T, Mayer F, et al. Gain in strength and muscular balance after balance training. Int J Sports Med 2001; 22 (4): 285-90
25. Krebs D, Jettte A, Assmann S. Moderate exercise improves gait stability in disabled elders. Arch Phys Med Rehabil 1998; 79 (12): 1489-95
26. Buchner D, Cress M, de Lateur B, et al. The effect of strength and endurance training on gait, balance, fall risk, and health services use in community living older adults. J Gerontol 1997; 52 (4): M218-24
27. Topp R, Mikesky A, Wigglesworth J, et al. The effect of a 12-week dynamic resistance strength training program on gait velocity and balance of older adults. Gerontologist 1993; 33 (4): 501-6
28. Judge J, Lindsey C, Underwood M, et al. Balance improvements in older women: effects of exercise training. Phys Ther 1993; 73 (4): 254-62
29. Schlicht J, Camaione D, Owen S. Effect of intense strength training on standing balance, walking speed, and sit-to-stand performance in older adults. J Gerontol 2001; 56 (5): M281-6
30. Carroll T, Barry B, Riek S, et al. Resistance training enhances the stability of sensorimotor co-ordination. Proc R Soc Lond 2001; 268 (1464): 221-7
31. Sporrong H, Palmerud G, Herberts P. Hand grip increases shoulder muscle activity, an EMG analysis with static hand contractions in 9 subjects. Acta Orthop Scand 1996; 67 (5): 485-90
32. Kronberg M, Nemeth G, Brostrom L. Muscle activity and coordination in the normal shoulder: an electromyographic study. Clin Orthop 1990; (257): 76-85
33. Behm D, Anderson K, Curnew S. Muscle force and neuromuscular activation under stable and unstable conditions. J Strength Cond Res 2002; 16 (3): 416-22
34. Milner T, Cloutier C, Leger A, et al. Inability to activate muscles maximally during co-contraction and the effect on joint stiffness. Exp Brain Res 1995; 107 (2): 293-305
35. Arokoski J, Valta T, Airaksinen O, et al. Back and abdominal muscle function during stabilization exercises. Arch Phys Med Rehabil 2001; 82 (8): 1089-98
36. Comerford M, Mottram S. Functional stability re-training: principles and strategies for managing mechanical dysfunction. Man Ther 2001; 6 (1): 3-14
37. Kiefer A, Shirazi-Adl A, Parnianpour M. Stability of the human spine in neutral postures. Eur Spine J 1997; 6 (1): 45-53
38. Danneels L, Vanderstraeten G, Cambier D, et al. A function subdivision of hip, abdominal, and back muscles during asymmetric lifting. Spine 2001; 26 (6): E114-21
39. Cresswell A, Oddsson L, Thorstensson A. The influence of sudden perturbations on trunk muscle activity and intra-ab-

dominal pressure while standing. Exp Brain Res 1994; 98 (2): 336-41

40. Vezina M, Hubley-Kozey C. Muscle activation in therapeutic exercises to improve trunk stability. Arch Phys Med Rehabil 2000; 81 (10): 1370-9
41. Thorstensson A, Carlson H. Fiber types in human lumbar back muscles. Acta Physiol Scand 1987; 131 (2): 195-202
42. Richardson C, Jull G, Hodges P, et al. Therapeutic exercises for spinal segmental stablization in low back pain. London: Churchill Livingston, 1999
43. Sheth P, Yu B, Laskowski E, et al. Ankle disk training influences reaction times of selected muscles in a simulated ankle sprain. Am J Sports Med 1997; 25 (4): 538-43
44. Wester J, Jespersen S, Nielson K, et al. Wobble board training after partial sprains of the lateral ligaments of the ankle: a prospective random study. J Orthop Sports Phys Ther 1996; 23 (5): 332-6
45. Behm D. Neuromuscular implications and applications of resistance training. J Strength Cond Res 1995; 9 (4): 264-74
46. Sale D. Neural adaptation to resistance training. Med Sci Sports Exerc 1988; 20 (5): S135-45
47. Rutherford O, Jones D. The role of learning and coordination in strength training. Eur J Appl Occup Physiol 1986; 55 (1): 100-5
48. Kornecki S, Zschorlich V. The nature of stabilizing functions of skeletal muscles. J Biomech 1994; 27 (2): 215-25
49. Siff M. The functional mechanics of abdominal exercise. South Afr J Sports Med 1991; 6: 15-9
50. Stanforth D, Stanforth P, Hahn S, et al. A 10-week training study comparing Resistaball and traditional trunk training. J Dance Med Sci 1998; 2 (4): 134-40
51. Vera-Garcia F, Grenier S, McGill S. Abdominal muscle response during curl-ups on both stable and labile surfaces. Phys Ther 2000; 80 (6): 564-9
52. Behm DG, Leonard A, Young W, et al. Trunk muscle EMG activity with unstable and unilateral exercises. Can J Appl Physiol 2003; 28 Suppl.: S30
53. Kornecki S. Mechanism of muscular stabilization process in joints. J Biomech 1992; 25 (3): 235-45
54. Itoi E, Kuechle D, Newman S, et al. Stabilizing function of the biceps in stable and unstable shoulders. J Bone Joint Surg 1993; 75 (4): 546-50
55. Lear L, Gross M. An electromyographical ananlysis of the scapular stabilizing synergists during a push-up progression. J Orthop Sport Phys Ther 1998; 28 (3): 146-57
56. Anderson K, Behm DG. Maintenance of EMG activity and loss of force output with instability. Can J Appl Physiol 2003; 28 Suppl.: S27
57. Anderson K, Behm DG. Trunk muscle activity increases with unstable squat movements. Can J Appl Physiol 2003; 28 Suppl.: S26
58. Johanson M, Valero-Cuevas F, Hentz V. Activation patterns of the thumb muscles during stable and unstable pinch tasks. J Hand Surg [Am] 2001; 26 (4): 698-705
59. Garhammer J. Free weight equipment for the development of athletic strength and power: part I. Natl Strength Cond Assoc J 1981; 3 (6): 23-33
60. Stone M. Considerations in gaining a strength-power training effect (machines versus free weights): free weights, part II. Natl Strength Cond Assoc J 1982; 4 (4): 22-54
61. Stone M, O'Bryant H. Weight training: a scientific approach. Minneapolis (MN): Burgess International, 1987
62. Baechle T. Essentials of strength and conditioning. Champaign (IL): Human Kinetics, 1994
63. Behm D, Sale D. Velocity specificity of resistance training. Sports Med 1993; 15 (6): 374-88
64. McCaw S, Friday J. A comparison of muscle activity between a free weight and machine bench press. J Strength Cond Res 1994; 8 (4): 259-64

Correspondence and offprints: Dr *David G. Behm*, School of Human Kinetics and Recreation, Memorial University of Newfoundland, St John's, Newfoundland A1C 5S7, Canada.
E-mail: dbehm@mun.ca