MUSCLE AND FORCE CHARACTERISTICS IN STABLE AND UNSTABLE EXERCISE PROTOCOLS

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Muscle and Force Characteristics in Stable and Unstable Exercise Protocols

By

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"Obstacles are those frightful things you see, when you take your eyes off your goal"
-- Henry Ford

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List of Abbreviations

1RM - One Repetition Maximum
APA - Anticipatory Postural Adjustments
AS - Abdominal Stabilizers
BF - Biceps Femoris
BVL - Bi-lateral Vestibular Loss
CNS - Central Nervous System
DT - Deltoid
EMG - Electromyography
ES - Erector Spinae
Hz - Hertz
IAP - Intra-Abdominal Pressure
LE - Leg Extension
LT - Latissimus Dorsi
mS- Millisecond
MT - Multifidus
mV - Millivolts
MVC - Maximal Voluntary Contraction
MVIC - Maximal Voluntary Isometric Contraction
N - Newton
PF - Plantar Flexion
PM - Pectoralis Major
RA - Rectus Abdominus
RF - Rectus Femoris
RMS - Root Mean Square
SD - Standard Deviation
SEC - Seconds
SEM - Standard Error Measure
SOL - Soleus
TA - Tibialis Anterior
TRI - Tricep
VL - Vastus Lateralis

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Co-authorship Statement

This thesis was prepared under the supervision of Dr. David Behm (School of Human Kinetics and Recreation). Dr. Behm played a vital role in my personal motivation, topic development, proof reading and editing, and technical support. I was personally responsible for subject recruitment, data collection, data analysis, and final write-up of two of the enclosed research articles "*Maintenance of EMG Activity and Loss of Force Output With Instability*" and "*Trunk Muscle Activity Increases with Unstable Squat Movements*". The third research article included (see Appendix) entitled "*Muscle Force and Activation Under Stable and Unstable Conditions*" was a collaborative effort between Dr. David Behm, myself, and Mr. Steve Curnew. My role as second author included the subject recruitment, data acquisition, data analysis, and write-up for the plantar flexor protocol. As this article has already been published, I felt it should be included as an Appendix as opposed to within the body of this manuscript.

Chapter 1 Introduction

Background of Study

Stability and balance ball training is one of the fastest growing resistance training methods in the training arena today and continues to grow in popularity. Proponents of these pieces of equipment postulate that the greater instability of the ground-human interface will stress the neuromuscular system to a greater extent than traditional resistance training methods using stable benches and floors.

Strength gains can be attributed to both increases in cross-sectional area and improvements in neuromuscular co-ordination (Behm, 1995). Research has reported that neural adaptations play the most important role in strength gains in the early portion of a resistance-training program (Behm, 1995; Sale, 1988). Rutherford and Jones (1986) suggested that the specific neural muscular adaptation occurring with training was due to improved co-ordination of the agonist, antagonists, synergists, and stabilizers.

Thus, the inherently greater instability of a balance implement and body interface would challenge the neuromuscular system to a greater extent, possibly enhancing strength gains attributed to neural adaptations, in turn, possibly improving athletic performance.

Purpose of Study

The challenge of stability is encountered frequently in activities demanding static postures as well as in many skills and tasks involving movement. Static and dynamic stability are important aspects of both slow and fast locomotion. Wagner and Blickhan (1999) define stability as a measure that quantifies the system's ability to return to its prescribed path or condition after a disturbance. This ability to return to homeostasis after a disturbance or altered path is vital to success to today's highly competitive athlete.

It is well known (Kreighbaum & Barthels, 1996) that the position of the center of gravity, as well as, the geometrical configuration of body segments, is accurately controlled relative to the feet and to the direction of gravity. There are different strategies for equilibrium maintenance during standing on a rigid floor, on a narrow or soft support surface, on a movable support, during locomotion, and even while skating. Investigations of standing on a movable support in the past have been extensive, but often used single joint and isometric movements (Allum, 1983; Ebig et al., 1997; Henry et al., 1998). This research investigated the performance of dynamic resistance movements on a movable support and the effect of varied resistance on the musculature under varied conditions of stability. It is therefore the purpose of this study to identify muscle activation during both stable and unstable movements.

Significance of Study

A recent focus in the research of resistance training has been on exercises that restore or develop dynamic stability to the trunk as spinal instability has been linked to the development of low back dysfunction (Granata and Marras, 2000). Dynamic instability of the spine has been associated with insufficient strength and endurance of the trunk stabilizing muscles and inappropriate recruitment of the trunk and abdominal muscles (Vezina et al, 2000). It was Nemessuri (1968) who first identified that muscles had both stabilizing and motor functions. Therefore, dynamic stability exercises should improve the muscular responsiveness needed to stabilize the spine against perturbations associated with movements and activities of daily living. Dynamic stability exercises, such as the use of balance boards and stability balls, should also emphasize proper sequencing of muscle activation, co-activating synergistic muscles, and restoring muscle strength and endurance to key trunk stabilizers.

In many traditional rehabilitation programs, the major muscles of interest have been the primary movers. Successful and immediate rehabilitation must not only include exercise for the primary movers but for the articulation synergists as well. Interventions to improve muscle weakness, minor balance deficits, and bone mineral density may reduce injurious falls. By gaining a better understanding of balance mechanisms, interventions that are effective in improving balance can be designed. Furthermore, as many actions that are performed in daily life and during sport seldom exist under strict stable environments, exercises that may simulate this multi-dimensional positioning may benefit sport and/or daily life performance.

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Chapter 2 Review of Literature

Introduction

Throughout the last two decades there has been an increasing awareness of the importance and relevance of the specialized and integrated action of the muscular system in maintaining stability and optimal function of the movement system. The mechanism of human motion has largely been studied under simplified movement conditions (Stokes & Gardner-Morse, 1999; Gardner-Morse et al. 1995; Milner & Cloutier, 1993; Eloranta, 1989). By analyzing single-joint movements such principles as force production, force or torque due to joint positions, muscle mechanics and the synchronization 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 (Lacquaniti & Soechting, 1986).

Neuromuscular mechanisms play an important role in body balance not only when motionless but during movement as well. As a number of these mechanisms exist within the human body, we must first attempt to identify and then understand these particular mechanisms and the movement considerations involved. 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. 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 maximize benefits to mechanisms of balance. The objective of this paper is to review the literature concerning the need or desirability of unstable environments for training.

Mechanics of Stability

The apparently simple act of standing motionless is actually a continuing process of minute adjustments of body position to keep the center of gravity over the base of support. The smaller the base, the more accurate such adjustments must be to maintain stability. Ivanenko et al. (2000) proposed that the differential effect of postural instability could be accounted for by two main mechanisms: those related to the alteration of proprioceptive messages at the peripheral level; and those related to the central processing and supraspinal modulation of local reflexes.

Proprioceptive and Peripheral Control

Optimal control of balance and postural stability in upright posture are essential requirements for high level sport, daily activities, or for the prevention of injury. According to Kollmitzer et al. (2000), stabilization of postural equilibrium is achieved by continuous afferent and efferent control strategies within the sensorimotor system with feedback from somatosensory, vestibular, and visual inputs. The afferent information is processed in the brainstem and cerebellum, followed by the initiation of motor commands. When any of these sensory motor feedback loops are suppressed or defective, body sway increases, and muscle activity increases accordingly to maintain balance (Nardone, 1988). In response to forward body sway, the associated postural muscles on the posterior side of the body are activated sequentially in an ascending pattern from the leg, to the thigh to the trunk. The muscles on the anterior side of the body are activated in the same sequence in response to backward sway (Lin and Woollacott, 2002). The force enhancement due to coordinated concentric and eccentric contractions could help to drive the system back to the prescribed path. This action would correspond to a very fast internal feedback loop and would facilitate neuronal control (Wagner and Blickhan, 1999). Loeb has coined the term "preflex" for such a "zero-delay", intrinsic response of a neuromuscular system and perturbation (Brown and Loeb, 1999).

Motor skill 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 (Kollmitzer et al. 2000). The muscle, as the termination of the final pathway of the sensorimotor system, particularly contributes to the maintenance of body balance. Muscle performance depends on the training status of a muscle and varies between individuals as well as between muscles within an individual (Johnson et al. 1973). Training of the muscles that contribute to posture and stability may reasonably change not only muscle performance, but its respective central control mechanisms as well.

According to Nashner (1976) perturbations to the upright posture in humans are corrected by viscoelastic forces inherent to the ankle muscles provided the ankle rotation is small. For larger displacements, active contractions are required if stability is to be maintained. Allum (1983), insists these contractions could originate from stretch or vestibulospinal reflexes, or be a voluntary response triggered by multimodal sensory inputs. Mizuno et al. (2001), indicates that human postural control is shared among the vestibular, visual and somatosensory systems with the vestibular system considered as the main control system for a vertical detector.

Interactions between proprioceptive and vestibular inputs contributing to the generation of balance corrections may vary across muscles depending on the availability of sensory information at centers initiating and modulating muscle synergies. Information that is not available from one sensory system may be obtained by switching to another (Horak et al. 1994). However, Allum and Sheppard (1999) state that this switching to other inputs only occurs for later stabilizing action, once the primary motor command to correct the imbalance has been issued. It has been postulated by Allum and Honegger (1998), 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. They suggested that trunk inputs provide an ideal candidate for triggering balance corrections as these would still be present when vestibular, ankle and knee inputs are absent.

In summary, with reference to peripheral control of balance and stabilization, the CNS has the flexibility to choose between visual, vestibular and somatosensory inputs in modulating muscle activity.

Central Control

The previous section discussed the role of proprioceptive feedback in stabilization and balance maintenance, however, central processing occurring in the brain also plays a vital role in these phenomena. It is well documented (Enoka, 2002; Van Wynsberghe, 1995) that the cerebellum is the main processing center for skeletal movement and receives information from the spinal cord and cerebral cortex, enabling it to accurately control motor performance. However, the role of the cerebellum in motor control and its effect on balance is beyond the scope of this report, therefore, I will focus on the intended movements at the muscle level in response to central processing.

According to Loram et al. (2001) reduction in standing sway depends on the following processes: (1) registering quickly and accurately when position has changed, and velocity and acceleration have increased; (2) judging joint torque impulses accurately to arrest the motion and to return to balance; and (3) accurately maintaining the joint torque close to that required for balance.

Carpenter et al. (2001) specifically examined the effects of vestibular loss in labyrinthectomized cats on balance correcting, and stabilizing reactions in postural leg and trunk muscles. They found the amplitude of balance correcting responses in leg muscles was severely reduced in felines with bilateral peripheral vestibular loss (BVL). Furthermore, Inglis and MacPherson (1995) observed significant differences in muscle activation amplitude but not in timing or the pattern of postural muscle responses with BVL. These studies therefore demonstrate the importance of the vestibular system in balance and stability control.

Di Fabio et al. (1990) suggest that sensory feedback provides information for direct and timely modifications to functional balance reactions that is not at a conscious level. They further state that both centrally triggered and sensory modulated output models may contribute to understanding balance mechanisms. Centrally triggered postural responses are produced once a threshold level of sensory feedback is provided as the adequate stimulus. In summary, it is proposed that a mix of centrally triggered and peripheral-afferent driven patterns produce a compensatory response.

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 movment. Anticipatory postural adjustments play an important role in maintaining body stability during task performance. As a result of the enhanced central drive and the corresponding augmented gamma motorneuron activity during balancing, the stretch reflex mechanism and the co-contraction of the muscles involved can be implemented (Gantchev & Dimitrova, 1996). 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 (Nardone and Schieppati, 1988). These postural adjustments appear to have the aim of minimizing the equilibrium disturbances provoked by these movements.

Kornecki (2001) states that when the support object was unstable the myopotentials of all the investigated muscles preceded the instant of force application (anticipation). The stabilizing muscles of the task dominated this specific neuromuscular anticipation. This may be explained by the fact the supporting structures must first be stabilized before a motor movement can be efficiently elicited. These findings are supported by Nouillot et al. (1992) who measured postural adjustments in a number of different stances and found that stabilizer muscles fired approximately 30 msec prior to movement muscle activation.

During quiet stance without support, EMG activity was clearly evident from the soleus in results put forth by Nardone and Schieppati (1988) 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 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 EMG activity in the triceps surae 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. For these reasons, the authors speculate that these phenomena are anticipatory postural adjustments, and serve the purpose of minimizing the subsequent postural destabilization.

Visual Feedback

Loram et al. (2001) states that when subjects are standing still, visual feedback enabled vertical sway displacement to be reduced more than without visual feedback, therefore identifying the importance of visual feedback in maintaining balance. Shumway-Cook & Woollacott, (2000) also suggest the importance of visual and/or auditory cues in maintaining stability. However, the availability of visual feedback makes no significant difference to ankle impedence which may suggest that visual feedback aids in the vestibular control of stability as opposed to direct muscle responses.

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 visual feedback, we are able to meet the constant demands for maintaining posture and balance.

Stabilizing Function of Muscle

Although much is known about how muscles maintain static equilibrium, little is known how they maintain stability. Exerting a force with the upper extremity upon an external object requires coordination of the neuromuscular system; this would ensure the inhibition of some joints to achieve simultaneously coupled motions to take place in other joints. This leads to the extraordinary complexity of the nervous system, of which one of the most important tasks is to control the stabilization of the joints' degrees of freedom unused in a given motor task by stimulation of antagonistic muscles. Thus, this stabilization process consists of establishing active muscular constraints to minimize the degrees of freedom within a joint or series of joints and in stabilization of the excessive mobility of external objects.

<u>Postural Muscle Contraction</u>

Wagner and Blickhan (1999) demonstrated that muscles are sufficient to stabilize articular-skeletal systems. Even more importantly, this effect strongly depends on the design of the musculoskeletal system (i.e. the geometry of the joint and the linkage system, the geometry of the muscle, and its intrinsic properties). Stability can be passively provided only if these properties are closely integrated to each other.

Two components are necessary for successful stabilization of vertical posture; adequate perception of a reference point with respect to which posture should be stabilized and the timely generation of appropriate muscle torques that restore balance in response to spontaneous body sway or perturbations. During quiet standing, no urgent corrections are typically required and postural muscles are strong enough to comfortably deal with small body deviations described as postural sway. Therefore, stabilization of the projection of the center of mass may depend more on adequate perception of a reference point.

Slijper and Latash (2000) identified two problems regarding the maintenance of vertical posture. The first is related to balancing the body so that the projection of its center of mass does not move beyond the small area of support. The second problem relates to the effect of external forces, torques, and changes in body geometry that occurs during voluntary movements.

In very stable conditions, the requirements of stabilizing posture under the action of transient, motion-related perturbations are alleviated. On the other hand, in very unstable conditions, anticipatory postural adjustments (APA's) themselves may be viewed as sources of perturbations which can move the center of mass beyond the decreased area of support. Slijper and Latash (2000) found that there was an anticipatory increase in activity of the tibialis anterior (TA), biceps femoris (BF), erector spinae (ES) and rectus abdominus (RA) when experiencing unstable standing. In the soleus (SOL) and rectus femoris (RF), 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. This anticipatory increase in synergistic muscle activity was also documented by Stokes and Gardner-Morse (2000) using an inverted pendulum to induce instability of the arm.

Slijper and Latash (2000) found that when subjects were standing on an unstable platform, the amplitude of the EMG bursts in the leg and trunk muscles decreased. The effects of additional manual support could be seen during stable standing, but were particularly pronounced during standing on the unstable board. During standing on the unstable board, there was a tendency for an increase in the background muscle activity; this tendency was higher for frontal than for sagittal instability. Adding manual support typically resulted in decreased background activity. However, most of these changes were small and not statistically significant. but significant changes of magnitude (30-50%) were found only in the RF and the BF. Muscle activity was compared between the dorsal (SOL, BF, ES) and ventral (TA, RF, RA) muscle groups. The summed activity of both dorsal and ventral muscles changed significantly, however, the difference between groups did not show a significant change. When subjects stood on the unstable surface or without additional support, there was typically an early anticipatory increase in the activity of the dorsal side of the body (ES, BF, SOL) associated with a backward shift of the center of mass.

Nardone and Schieppati (1988) manipulated a platform under the feet of subjects and measured the EMG activity of the leg. When the platform was displaced backward, thrusting the body forward, a gastrocnemius and hamstring contraction was initiated to maintain erect stable posture. This helps to show that both automatic and associated postural adjustments always precede focal movement.

Muscle Stiffness

It is purported that muscle stiffness increases with activation; therefore co-activation of agonistic and antagonistic muscles can be used to increase joint stability (Stokes and Gardner-Morse 2000; Milner et al. 1995; and Milner and Cloutier 1993). Milner and Cloutier (1993) illustrated this point as they identified muscle stiffness and viscosity increased with joint torque. Using an upper limb model, McIntyre et al. (1996) showed that human subjects must increase the stiffness at a joint in order to maintain limb stability in the presence of applied external forces.

Muscle stabilization is the sum of two processes. The first one would consist of an evident, although mild, increase of the tissue's stiffness, functionally connected with the joint under stabilization (Loram et al. 2001; Grilner, 1972). The other process, completing the phenomenon of muscular stabilization in joints would consist, in turn, of controlling and inhibiting the effect of the central nervous system on the muscles responsible for controlling the body segment (Kornecki, 1992).

The role of multi-articulate muscles has also been investigated. McIntyre et al. (1996), found the level of torque at one joint can affect the stiffness required at another. With multi-joint muscles present, each muscle's stiffness needs be a function only of its own force output in order to maintain overall limb stability. McIntyre et al. (1996) also reported that multi-joint muscles are shown to provide mechanical couplings which are necessary for the maintenance of stability. Crisco and Panjabi (1991) identified the more muscles that span a joint, the greater the potential for restoring the equilibrium position of that joint. By utilizing these muscles, the neuro-muscular-skeletal system can control a global property of the system with a passive local strategy.

It has been suggested by Cresswell et al. (1994) that back muscle contractions as low as 25% of MVC (maximal voluntary contraction) are able to provide maximal joint stiffness. Furthermore, because lumbar stabilizing multifidus muscles are mainly composed of type I muscle fibers (Thorstensson and Carlson, 1987) only relatively low loads (approximately 30-40% MVC) are needed to improve their effectiveness (Richardson et al. 1999).

Co-Contractions

Nemessuri (1968) first identified that muscles had both stabilizing and motor functions. These stabilizing functions are achieved by activating antagonistic muscle groups, which is tantamount to stiffening those joint degrees of freedom that are not engaged in the motor act. This process of muscular stabilization has also been alluded to by a number of authors (Aruin et al. 1998; Cadoret and Smith 1996; Flanagan and Wing 1997, Gottlieb et al. 1992; Smith et al. 1997; and Wing et al. 1997). The currently used optimization criteria does not predict the simultaneous contraction of antagonistic muscles to stiffen a joint, but only to counterbalance a torque component produced by a multifunctional and/or multiarticular muscle (Siemienski, 1992). The degree of antagonist co-contraction increases in proportion to the degree of mechanical instability inherent in the task (Milner et al. 1995).

Kornecki et al. (2001) states the global contributions of stabilizing muscles increased on average by 40% when the handle changed from stable to unstable during pushing movements. He showed that the process of muscular stabilization of the investigated joint caused, on average, 30% drops in force, velocity, and power ($p<0.01$).

Coerced muscle 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 bring about a significant loss of maximum force, velocity and power produced against an external object.

Many authors have examined the function of limb stabilizing muscles. Itoi (1993) concluded that both the short and long heads of the bicep have similar functions as anterior stabilizers of the glenohumoral joint and their roles in stabilization increases as joint stability decreases. Lear and Gross (1998) looked at the stabilizing function of scapular stabilizers while performing push-ups on miniature trampolines. They found no significant difference in stabilizer EMG activity between stable and unstable conditions, however, they acknowledged the degree of stability induced by the miniature trampolines was likely insufficient to illicit an unstable platform. Kornecki et al. (2001) showed the contributions of wrist stabilizers were dependent upon the state of equilibrium of the external object. This indicates a wrist stabilizing function of these groups of muscles, with their activities increasing when the external object became unstable. Results by Lear and Gross (1998) support the research that increased tension at a joint results in increased activity of the stabilizer muscles at and around that particular joint.

Results from Loram et al. (2001) revealed that ankle impedance and muscle co-contraction were not significantly changed when the sway amplitude was decreased, implying no change in ankle stiffness. It is clear from their EMG recordings that, as a result of the trial conditions, there was no significant change in the mean activation level of the tibialis anterior. This implied that co-contraction of the muscles about the ankle joint was not a factor in bringing about changes in sway amplitude.

Sporrong et al. (1996) studied how handgrip exercises/activities increased shoulder muscle activity. Subjects were asked to perform isometric contractions against a handgrip dynamometer. In the supra- 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 stabilizer muscles of the shoulder as well for maximal rehabilitation of grip strength.

Muscle activity and coordination of healthy shoulders were studied by Kronberg et al. (1990). Results showed muscle activity occurred simultaneously in muscles producing the movement and in antagonistic muscles of a number of different shoulder movements (ie. flexion, extension, adduction, abduction), showing how coordination due to muscle contractions plays a significant role in stabilizing the shoulder joint.

Research has also been conducted looking at the stabilization through co-contraction in the lower limbs. Behm et al. (2002) looked at agonist/antagonist relationships in stable and unstable movements (leg extension-LE and plantar flexion-PF). During leg extensions, antagonistic hamstring activity increased by 29.1% ($p = 0.05$) under unstable versus stable conditions. The antagonist tibialis anterior during plantar flexion showed an increase of 30.3% in EMG activity during the unstable PF, however, these results were not statistically significant.

Through the review of experimental studies using electromyography and/or muscle force measurements, it is now clear the central nervous system uses unique strategies (postural muscle contraction, muscle co-contraction, and muscle stiffness) to generate muscle force patterns necessary to perform a given movement or task.

Spinal Stability

A fundamental property of the postural control system is the ability to gate appropriate sensory information so as to avoid undesirable responses triggered by an external or internal cause. Numerous factors affect the stabilization of the human spinal column including the co-contractions of muscles, development of intra-thoracic pressure as well as characteristics of the muscles involved.

Muscle Co-contractions

Empirical measures have demonstrated significant muscle activity in the trunk flexor muscles during extension or lifting tasks (Zetterberg et al. 1987). Co-contractions may add protection against low back disorders by improving spinal stability (Cholewicki, 1997). However, this trunk co-contraction also contributes to spinal load which has been cited as a risk factor for low back disorders (Norman et al. 1998). According to Granata et al. (2000), vertebral tissue failure may be resisted at compressive loads up to 12000 N, with national standards advising against spinal compression in excess of 6400 N. However, failure of the unsupported spine can occur as a result of mechanical instability at compressive loads less than 100 N. By recruiting antagonistic co-contraction of the trunk muscles, spinal stability can be improved, allowing the structure to withstand extreme compressive loads safely (Gardner-Morse et al. 1995). However, spinal load also increases with antagonistic co-contraction during lifting exertions. This study demonstrated that trunk flexors co-contract simultaneously with the extensors during lifting tasks. Granata and Marras, (1995), found this co-contraction significantly increases spinal load, accounting for 26%-45% of the total compressive load while

Gardner-Morse and Stokes (1998), reported the level of co-activation measured in electromyography (EMG) studies increased compressive load on the spine during extension efforts by 16-19%. However, it should be identified that both authors recognized model limitations in these predictors.

Recognizing the relationship between stability and low back disorders, it may be hypothesized that antagonistic co-contraction can reduce the risk of low back injury by increasing spinal stability. In an experiment by Granata et al. (2000) both stability and spinal load increased with antagonistic co-contraction but a comparison between the margin of stability demonstrated the increase in stability was significantly greater than the concomitant increase in spinal load. Hughes et al. (1995) calculated the increase in spinal compression resulting from abdominal muscle co-activation could be as much as 5.52 times as much as the force increase in the abdominal muscles. Cholewicki et al. (1997) examined the co-activation of trunk flexor and extensor muscles at a neutral spine posture. He found the average antagonistic flexor-extensor muscle co-activation levels around the neutral spine posture was 1.7% ± 0.8% of maximum voluntary contraction for no external load trials and 2.9% ± 1.4% of maximum voluntary contraction for trials with added 32 kg mass to the torso. Hence the overall effect of co-contraction served to reduce risk in terms of spinal load versus stability. Therefore, for co-contraction to be considered beneficial, the maximum stable load must increase more than the applied load.

Bergmark (1989) introduced the idea that muscle stiffness, which increases with activation, must exceed a critical value to prevent spinal buckling. Crisco and Panjabi (1991) found that in the case of decreased intervertebral stiffness, as is the case with spinal ligamentous injury, an increase in muscular stiffness maintained spinal stability.

Because muscle stiffness increases with activation, Garner-Morse and Stokes (1998) hypothesized that the neuromuscular control system sets the muscle activation and co-activation to ensure lumbar stability. This would reduce the need for active neuromuscular control system responses and their inherent time delays.

The increased spinal load associated with antagonistic co-contraction challenges the stability of the spinal structure (ie. added load requires a greater stabilizing effort). For co-contraction to be considered beneficial, biomechanical stability must increase more than spinal load. Otherwise, it may be possible for co-contraction to generate spinal loads that cannot be stabilized. It remains to be demonstrated whether increased stability at the cost of increased spinal load is beneficial (Granata et al. 2000).

Local and Global Stabilization

Functional stability is dependent on integrated local and global muscle function (Arokoski 2001; Comerford and Mottram 2001; Kiefer 1997). Comerford and Mottram (2001) have proposed a classification system for muscle function. They have defined and characterized muscles as local stabilizers, global stabilizers, and global mobilizers. They identify the local stabilizers' role 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 stabilizers generate torque and provide control over some motions. Global mobilizers 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 stabilization and enables the static and dynamic work necessary for daily living and sport activities (Daneels et al. 2001). Arokoski (2001) identifies the multifidus as a local stabilizing muscle which acts simultaneously with the global muscles (longissimus thoracis, rectus abdominus). Kiefer (1997) defines global muscles that act on the spinal column through the rib cage (ie. erector spinae, rectus abdominus), which control the overall response, and local muscles that are attached directly to the lumbar spine.

In an experimental study of muscle recruitment patterns during asymmetric lifting in healthy individuals, Daneels et al. (2001) found the left and right internal obliques, rectus femoris, and multifidus showed symmetrical co-contraction in all variants of the lifting activities. 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 stabilizing role during these maneuvers. The global muscles however, show asymmetric patterns of activation during the same tasks, supporting their role of global stabilizers and prime movers. These findings are supported by Arkoski et al. (2001) who identified the multifidus, transverse abdominus, and the internal obliques as part of the local stabilizing system; whereas the longissimus thoracis, rectus abdominis, and external obliques constitute a part of the global stabilizing system.

Arokoski et al. (2001) sought to assess how load increments increased the abdominal and paraspinal muscle activities. Arokoski found the stability of the spine was increased with either increased antagonistic flexor-extensor muscle co-activation forces or increased intra-abdominal pressure. Deep local stabilizing muscles, especially the multifidus and the transverse abdominus muscles, mainly contribute to stability. In the investigated exercises, Arokoski 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. Arokoski also reports that erector spinae and multifidus have greater activity during trunk holding (76-79% of MVC) than in leg holding (66-68% of MVC).

In modern anatomical texts, the multifidus muscles are referred to as the stabilizers of the vertebral column (Martini, 2001). Bogduk and Twomey (1987), have suggested that the role of the deep muscles, including the multifidus, is to prevent consequential motion produced by the more superficial muscles as they move the thoracic cage and pelvis. Snijders et al. (1995) also documented the importance of the transverse abdominis in active stability and showed activity of this muscle is consistently related to intra-abdominal pressure whereas the obliques were not as important in increasing and/or maintaining intra-abdominal pressure. Unfortunately, Crisco and Panjabi (1991) stated there was no scientific evidence for any of these statements.

The standing or sitting neutral posture is a body position sustained in the workplace and throughout daily activities for prolonged periods of time. Kiefer et al. (1997) investigated the mechanisms affecting spinal alignment in this neutral setting and found activation of the local muscle system considerably increased the sagittal movement of the pelvic level, thereby altering the spinal curvatures as this pelvic rotation appeared to stabilize the spinal column further. In contrast to the strategy for stabilization of upper and lower extremity joints with the presence of high co-activations, the absence of muscle co-activation in the trunk upright posture indicates that a more efficient control strategy is used for the stabilization of the spine. Kiefer et al. (1997) noted that volunteers with asymptomatic spines found relatively low levels of superficial muscle EMG activity while an erect posture was maintained. They found activity in the local muscle system to be 5 times higher than those in the global system. The actions of the muscles and pelvic rotation are postulated to be coordinated by a neural controller or feedback parameter. The results suggest that pelvic rotation, muscle activation, and the off-center placement of the line of gravity are exploited to stabilize the passive spinal system in neutral postures.

A low percentage of maximal voluntary isometric contraction (MVIC) from the trunk musculature stabilizes the spine during normal movements, and motor control, not just muscle strength, is important to dynamic stability training (Vezina & Hubley-Kozey, 2000).

Intra-abdominal Pressure

Experiments with whole cadavers by Tesh (1987) showed how the abdominal muscles might act to improve stability of the vertebral column *in vivo*. In the case of the sagittal plane, the main conclusion is that both increasing intra-abdominal pressure and increased tension in the thoracolumbar fascia are almost equally effective although intra-abdominal pressure is more diffuse in its point of application and fascial tension is more locally effective. These cadaver experiments also identified the importance of the thoracolumbar fascia in the coronal plane as it contributes up to 40% of the total bending moment required to support the lumbar spine in extreme lateral bending.

The transverse abdominus muscle has, due to its mediolateral fiber orientation, long been purported to be a primary activator of increased intra-abdominal pressure (IAP) (Bartelink, 1957). This conclusion was reached in a more recent investigation where IAP was high during maximal isometric extension of the trunk, despite little or no activity from the external oblique, internal oblique or rectus abdominus (Creswell and Thorstensson, 1989). During voluntary expulsive maneuvers with a closed glottis, De Troyer et al. (1990) reported that subjects showed large amounts of activity in the transverse abdominus with simultaneous activity in both the rectus abdominus and the external oblique (internal oblique was not investigated). Cresswell et al. (1992) found the transverse abdominus, and to a lesser extent internal oblique, are the muscles of the ventrolateral abdominal wall that appeared most consistently to govern the development of IAP. They also state the transverse abdominus muscle appears to contribute toward twisting torques and stabilization, and seems to play the most significant role in intra-abdominal pressure production during isometric trunk loading. Gardner-Morse and Stokes (1998) found that even small levels of co-activation (40%) of the obliques produced increased stability. According to their analysis, the external obliques provided the greatest gains in stability, but at a cost of an increased rate in muscle fatigue.

Claims, many unsubstantiated, indicate some exercises are more beneficial than others for recruiting the trunk musculature in a manner that would improve trunk stability. Abdominal hollowing exercises examined by Vezina & Hubley-Kozey (2000) did not recruit the abdominal muscles to adequate levels for strengthening in their healthy sample, however, all five (5) muscle sites were active, forming the basis of a stabilizing exercise approach. These low activation amplitudes for the abdominal hollowing exercise show the minimal strengthening potential associated with this maneuver.

It must be stated that as IAP is highly regulated by the muscles of the trunk and abdomen, any pathology or injury to this musculature can negatively affect spinal stabilization.

Muscle Morphology and Stabilization

Peck et al. (1984) in studies examining numerous human joints and the spinal musculature of dogs, found that small muscles running parallel to large muscles have a significantly higher muscle spindle density than the larger muscles. They hypothesized the major function of these smaller muscles was proprioceptive, requiring the larger muscles to control the spanned joint(s) mechanically. Their results show that the inter-segmental muscular architecture, consisting of muscles that originated from adjacent vertebrae, required the highest muscular stiffness for stability. As the number of vertebrae spanned by the multi-segmental muscles increased, so did the efficiency of stabilization. During the cohort, the muscles that originated from the pelvis, an architecture that permitted the largest possible number of vertebrae to be spanned for each muscle, the result was a 90% increase in the efficiency of stabilization. Crisco and Panjabi (1991) identified the more muscles that span a joint, the greater the potential for restoring the equilibrium position of that joint. The author also states the stiffness of all materials decreases with increasing length as muscular stiffness is inversely proportional to muscle length.

The effect of muscle position and orientations was also studied by Peck et al. (1984). It was found that as the lateral position of a muscle's origin or insertion increased, so did its stabilizing efficiency. These findings are simply due to the increase in the effective moment arm of the muscle about the joints. Peck et al's model found the deep intervertebral muscles were the least efficient at laterally stabilizing the spine. The model also demonstrated the efficiency of the multisegmental muscles increased with the number of vertebrae spanned, and that the most efficient architecture consisted of muscles that attached to the pelvis, spanning the maximum number of vertebrae.

Much of the processing that occurs in the central nervous system (CNS) is based on the premise the body is under a stable situation. If unstable, these higher centers may no longer provide accurate accommodation strategies to deal with the lack of stability. Therefore, this brief overview of current theories (spinal muscle co-contraction, intra-abdominal pressure, and muscle morphology) of postural control was necessary as extremity (limb) functioning is somehow related to the stability and position of the core (trunk).

Instability and Force Output

Joint instability and muscle weakness or imbalance can result in both the reduction and misdirection of force. Numerous authors have documented a decrease in force output in response to instability. Kornecki et al. (2001) noted that coerced 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 create movement, which in turn brings about a significant loss of maximum force, velocity and power. Kornecki showed that the process of muscular stabilization of the investigated joint caused, on average a 30% drop in force, velocity and power ($p < 0.01$) about these joints. Kornecki (1992) also confirmed that the process of muscular stabilization reduced a significant percentage (24%) of the potential force output.

Behm et al. (2002) examined force output and muscle coordination of the (LE) and (PF) under stable and unstable conditions. Their results showed the ability to exert force under stable conditions significantly exceeded force output under the unstable conditions for both muscle groups tested (LE and PF). Unstable LE force was 70.5% less than stable force while unstable PF force was 20.2% less than its respective stable force. Furthermore, unstable LE and PF activation averaged 44.3% and 2.9% less respectively, than during stable conditions.

It was evident from comparison of forceful flexor and extensor co-contractions in a study by Milner et al. (1995) that EMG was always less during maximal co-contraction than it would be as a prime mover. Along with net joint force output declining with muscle co-activation, the metabolic cost of performing the actual activity increases due to elevated activation levels (Milner and Cloutier, 1993). However, one can argue that the task would not be able to be performed without this co-activation.

In contrast, Johanson et al. (2001) found no statistical difference 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. Although force output remained constant between groups, 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, co-contractions, recruitment patterns). Therefore, if people can accommodate to an unstable environment, it may be possible to regulate the loss of force and the extent of agonist and antagonistic muscles working against themselves.

Resistance Training

Resistance training has become a popular physical activity in today's society while offering many physical, mental and social benefits. Instability can be induced with resistance training and can than be compared to muscle function under stable conditions.

<u>Equipment</u>

Strength training is an integral part of many people's daily activity. 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 in free weights over machines have been compiled in articles by Garhammer (1981) and Stone (1982) with an additional summary available in Stone and O'Bryant (1987). 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 stabilize the bar/dumbells in all movement planes. Further advantages of free weights include a constant 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 stabilizing role (Baechle, 1994).

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 caused in part by 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 (Behm et al. 1993). 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 stabilize 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 (McCaw et al. 1994).

To maximize functional performance, individuals should attempt to train in an environment which 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". The effectiveness of Swiss Ball training has been demonstrated with abdominal training. Siff (1991) found that the wider range of movement (with an optimal starting position from a few degrees of active trunk extension) is preferable to similar actions performed in most circuit training gyms. Stanforth et al. (1998) identified the importance of "Swiss Balls" in a rehabilitative setting to re-educate postural muscles and to facilitate movement and postural reactions in neurologically impaired patients. However, there has not been any evidence other than anecdotal to demonstrate the overall effectiveness of Swiss Ball training.

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 (Gantchev, 1996; Ivanenko, 1997; Sheth, 1997). Therefore, the question remains if the inherently greater instability of a supproting surface and/or body interface would challenge the neuromuscular system to a greater extent, enhancing strength gains through neural adaptations.

Unstable Training

It is proposed that the training under unstable conditions will stress the neuromuscular system to a greater extent than traditional resistance training methods using more stable benches and floors (Gantchev, 1996 Ivanenko, 1997; Sheth, 1997; Wester et al., 1996). The advantage of an unstable training environment would reflect the importance of neuromuscular adaptations on increases in strength. Strength gains can be attributed to both increases in muscle cross-sectional area and improvements in neuromuscular co-ordination (Behm, 1995). A number of researchers, including Behm

(1995) and Sale (1988) have reported that neural adaptations play a vital role in strength gains in the early portion of a resistance training program. Rutherford and Jones (1986) suggested that the specific neural adaptation occurring with training was not increased recruitment or activation of motor units, but an improved co-ordination of agonist, antagonists, synergists and stabilizers. Korneki (1994) clearly revealed that when an object becomes unstable, it necessitates muscle-stabilizing functions in the human motor system. The author also states that due to the stabilizing function of the prime movers, a considerable drop in the mean power results. Despite these principles, none of the studies reviewed have investigated both training and physiologic adaptations in the human motor system in both a stable and unstable environment.

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 underneath the subject, 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.

Vera-Garcia et al. (2000) tested the type of surface (stable or unstable) on the muscle mechanics of the abdominal wall. Results 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. Stanforth et al. (1998)

found the stability ball training group's performance in trunk flexion improved significantly more ($p < 0.05$) than either the traditional group or the controls. Similar findings were found with back extension. Wester et al. (1996) found significantly fewer recurrent sprains, and significantly fewer patients in a wobble-board training group that had functional instability of the ankle compared with a no wobble-board training group. The authors concluded that training on a wobble board was effective in reducing residual symptoms following ankle ligament trauma compared to no training.

Standing on an unstable support calls upon higher levels of the control system and requires an essential change in the mode of utilization of incoming proprioceptive information. Ivanenko et al. (1997) investigated postural mechanisms while standing on a rigid floor and varied amplitude "seesaws". EMG activity of the soleus and tibialis anterior during standing on the rigid floor and on a seesaw resembled each other. There was a moderate level of soleus activity whereas the tibialis anterior was almost inactive in most cases. However, during standing on the more unstable seesaw, 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. This lower limb muscle activation may be explained by the forward body displacement being accompanied by a compensatory plantar flexion in the ankle joint, therefore, correcting the center of gravity. These results suggest that directionally specific torque changes in response to center of gravity shifts provide important information for maintenance of posture.

It is now evident that a large amount of resistance training information exists stemming from different equipment for varied training regimens. However, it is central to summarize 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.

Resistance Exercise and Stability

The human neuromuscular system possesses the remarkable ability to adapt with increases in strength and hypertrophy after as little as just 7 days (Hortobagyi, 2001). For example, progressive resistance exercise will result in greater maximal contractile strength (Behm, 1995). Programs for resistance exercise and strength gains vary as much as the individuals participating in resistance training. As much as the type of exercises varies, the time-lines of the training program itself also vary.

The effect of resistance exercise on muscle strength and size has been clearly documented (Durak et al., 1990; Goreham et al., 1999; Hakkinen et al 1998; and Hortobagyi et al., 2000), but evidence also suggests that resistance training, absent of balance training, also has a positive effect on balance. Lord et al. (1991) found that strength exercises contribute to better balance and gait in women age 57 and older. Heitkamp et al. (2001) found that for the one-leg stand, the mean increase in a balance training group was 146% and 34% in the strength training group ($p<0.01$). A prospective, blinded, randomized trial of moderate intensity strength exercise was conducted on 132 older adults by Krebs et al. (1998). They found that gait stability improved significantly ($p < 0.05$) 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.

Studies conducted to test if a training program can restore balance in older individuals include Buchner et al. (1997) who tested the effect of strength and endurance training on balance in older adults (aged 65-85 years) with reduced balance. Results show that short-term strength and endurance training had no restorative effect on balance of the study cohort. Topp et al. (1993) tested whether a strength training program can improve measures of balance among adults age 65 and older (n = 55). At post-test the exercisers demonstrated enhanced balance, although none of the post-test measures was significantly different from the control group. A randomized control trial by Judge et al. (1993) compared the effects of resistance training on static balance. The strength training group exercised three times per week using exercise machines with balance being obtained on a force platform. Results indicate that double-stance measurements were unchanged after training. In single stance, the center of displacement of the center of pressure improved by 17%. Schlicht et al. (2001) found no significant between-group differences for 1-leg blind balance time suggesting strength training alone does not appear to enhance standing balance in active, community dwelling older adults.

In a study by Kollmitzer et al. (2000) twenty-six young healthy subjects were assigned to either strength training or balance training regimens. After one 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.

Any discussion on the effects of resistance training on stability is incomplete without particular reference to muscle coordination. Carroll et al. (2001) clearly demonstrated that resistance training that increased muscular strength also increased stability and co-ordination. Improvements in task performance were accompanied by changes in the pattern of recruitment of the muscles that were the focus of the resistance training program. Specifically, the trained muscles were recruited in a more consistent fashion after training. These finding suggest that resistance training is associated with changes in the nature of the neurophysiological constraints underlying the control of voluntary movement.

Through these functional increases in balance and muscle coordination that can be experienced with a stability/balance program, it would be beneficial for fitness and health practitioners to combine these types of training modalities with resistance training so their clients, especially if somatosensory impaired, can maximize the positive effects of their training time.

Summary

Maintaining a desired posture following threats to balance depends upon the ability of the central nervous system (CNS) to generate organized postural muscle responses. The literature reviewed has identified that force output often decreases when one is unstable and that unstable training can improve our balance, stability and coordination. We have also identified a number of neuromuscular phenomena which exist to aid in the maintenance of stability and posture.

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.

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Chapter 3

Maintenance of EMG Activity and Loss of Force Output With Instability

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Abstract

Swiss Balls used as a platform for training provide an unstable environment for force production. The objective of this study was to measure differences in force output and electromyographic activity of the pectoralis major, anterior deltoid, triceps, latissimus dorsi, and rectus abdominus, for isometric and dynamic contractions under stable and unstable conditions. Ten healthy male subjects performed a chest press while supported on a bench or a ball. Unstable isometric maximum force output was 59.6% less in comparison when under stable conditions. However, there was no significant differences in overall EMG activity between the stable and unstable protocol. Contraction type differences in EMG activity were detected, with generally greater activity during concentric than eccentric or isometric contractions. The pectoralis major ($p<0.006$), deltoid ($p<0.007$) and latissimus dorsi ($p=0.07$) had greater EMG activity during the concentric phase of the lifts compared to the eccentric phase. Resistance training on an unstable surface may force limb musculature to play a greater role in joint stability at the expense of force production.

Keywords: electromyography, isometric, dynamic, resistance training, swiss ball, instability.

Introduction

There has been a lack of research examining the use of unstable platforms and their effects on force and muscle activation of the upper body musculature. The use of unstable training environments has been purported in the popular literature to enhance sports specific training effects through increased activation of stabilzers and core muscles. Korneki (1994) clearly revealed that when a person becomes unstable, it necessitates muscle-stabilizing functions. The effectiveness of Swiss ball training has been demonstrated with abdominal training. Siff (1991) found that the wider range of movement (with an optimal starting position from a few degrees of active trunk extension, as is the case on the Swiss ball) is preferable to similar actions performed in most circuit training gyms. Vera-Garcia (2000) identified higher electromyographic (EMG) activity when performing a sit-up on an unstable surface compared to a flat surface. Conversely, Behm et al. (2002) examined isometric contractions of the quadriceps and plantar flexors and reported significant decreases in force and muscle activation with the unstable platforms. They suggested that moderate but not extreme instability may allow for overload stress to be placed on the lower limb musculature. There has not been any evidence, other than anecdotal, to demonstrate the overall effectiveness of Swiss Ball training. Furthermore, there have not been any studies examining the effect of unstable platforms on upper body muscle limb force and activation.

Instability may arise not only from the base or platform but also from the implements utilized. The use of free weights with training has been advocated as more beneficial than machines partially due to their inherent instability. The major advantages of free weights would be derived from the ability of free-weight exercises to mimic the movement demands of real life sport, and activities of daily living (Garhammer 1981, Stone 1982, Stone and O'Bryant 1987, McCaw 1994). This use of free weight is fundamental in the principles of exercise specificity (training in a specific manner to produce a specific outcome). Furthermore, free weights permit three-dimensional movement and do not hinder the individual athlete's movement pattern (Baechle, 1994). Thus, instability can be incurred through both stable and unstable bases (platforms) and forms of resistance. However, there have been no studies that have included free weights to investigate the effect of stability of both the platform and the resistance modality on muscle performance.

The objective of this investigation was to compare muscular activation patterns under stable and unstable conditions with both isometric and dynamic resistance movement patterns. Based on previous research, it was hypothesized that while EMG activity would be greater with dynamic rather than isometric contractions (Grabiner and Owings, 2002; Cresswell and Thorstensson, 1994), and EMG activity would be lower during the unstable movement compared to the stable movement (Behm et al. 2002).

Materials and Methods

Subjects

Ten healthy male subjects with mean age, weight, height and years lifting experience (26.2 ± 6.0 yrs, 87.3 ± 12.2 kg, 177.3 ± 6 cm, and 7.9 ± 4.4 yrs) from Memorial University of Newfoundland participated in the study. All subjects performed both stable and unstable protocols under randomized conditions. All subjects were fully informed of the procedures and signed a consent form prior to experimentation.

Memorial University of Newfoundland Human Investigation Committee approved the study.

Measurement and Instrumentation

Electromyography- Electromyographic signals were measured from five locations; sternal origin of the pectoralis major, mid-belly of the anterior deltoid, and the long head of triceps, latissimus dorsi (lateral of scapula), and rectus abdominus (one-inch lateral of umbilicus). All surface electrodes were placed on the right side of each subject. EMG location sites were identified, shaved, sanded (to remove dead epithelial cells), and cleansed with rubbing alcohol to decrease resistance and achieve maximal adhesion of the electrode. The EMG signal was collected at 2000 Hz, amplified (1000X), filtered (10-1000 Hz) and smoothed (10 samples). The maximum amplitude of the root mean square (RMS) of the EMG signal was evaluated with the Acqknowledge software program (Acqknowledge III, Biopac Systems Inc., Holliston, MA).

Force- Modified handgrips were connected to a force transducer (Omega, BLH Electronics, Universal 3SB load cell) securely fastened to the floor beneath the lifting platform. Signals were amplified (Biopac Systems MEC 100 amplifier Holliston, MA) and monitored on a computer screen (Daytek computer monitor) after being directed through an analog-digital converter (Biopac Systems Inc., DA 100: analog-digital converter MP100WSW; Holliston, MA). All data were recorded on a Sona Phoenix computer at a sampling rate of 2000Hz and analyzed with Acqknowledge software program.

Protocol

Platform

The stable condition was achieved by having each subject assume a supine position on an exercise bench. Feet were flat on the floor about shoulder width apart and knees flexed to 90 degrees. Head, shoulders, and buttocks rested on the bench, with a normal arch in the lumbar spine.

An unstable position was adopted by taking a supine position on a Thera-Band™ Exercise Ball (Akron, Ohio), Subjects stabilized their body by positioning their feet, shoulder width apart on the floor. Shoulders rested on the ball while buttocks and head were not supported. All testing was performed in a single session.

Resistance

For the stable and unstable isometric protocols, each subject performed a number of practice attempts to familiarize themselves with the movement. A set of modified hand grips were strapped to a bar connected to a Wheatstone bridge configuration strain gauge (Omega Engineering Inc., LCCA 250, Don Mills, Ontario) securely attached to a platform on the floor. The upper-arm was positioned parallel to the ground with elbows pointed directly out to the side. A 90° angle was formed at the elbow resulting in the forearm pointing up toward the ceiling. The maximal voluntary contraction (MVC) was then established under both stable and unstable conditions (Figure 3.1). Submaximal (75% of MVC) contractions were also performed for comparison.

Figure 3.1. Chest Press Methods: a) Stable, b) Unstable

For the dynamic protocol, subjects were first tested to establish their one repetition maximum (1RM) chest press with dumbbells under stable conditions. Dumbbells were held with a pronated grip, with hands slightly wider than shoulder-width apart and elbows pointed out to the sides and flexed at 90°. Subjects inhaled as the weight was lowered at a slow to moderate rate of speed and exhaled during the up phase to relieve intra-thoracic pressure. Subjects were controlled for speed (2 sec-down, 2 sec-up) via a digital time display at close visual range on a computer monitor. Subjects continued the upward movement until their arms were extended. Once the 1RM was established, dumbbells equal to 75% 1RM were used for the experiment. Dumbbells using 100% 1RM were not used in the experiment since the resistance could not be safely controlled under unstable conditions. Subjects performed two repetitions on the stable bench as well as the unstable ball with the 75% 1RM dumbbells. Measurements obtained from the 75% of 1 RM were then compared to 75% MVC with stable and unstable conditions. It should be noted that sufficient recovery time of 2-3 minutes (Weir, 1994) was given between both isometric and dynamic repetitions allowing the muscles to recover from the previous lift.

Statistical Analysis

One-and two-way ANOVAs with repeated measures were used. The one-way ANOVA compared maximal isometric contractions (MVICs) between stable and unstable conditions. Dependent variables included force and EMG activity. The two levels identified with the two-way ANOVA were stability of platform (factors: stable and unstable) and stability of resistance (factors: 75% isometric MVC and 75% of dynamic 1 RM). The dependent variable was EMG activity of the muscles tested. Maximal dynamic contractions (1 RM) could not be performed with unstable conditions and thus could not be compared with a 1 RM under stable conditions. Differences were considered significant at a $p \leq 0.05$ level. If significant differences were detected, a Bonferroni (Dunn's) procedure was utilized to identify group differences. Descriptive statistics include means and standard deviations (SD).

Results

Maximal Voluntary Contraction: The ability to exert isometric MVC force under stable conditions significantly exceeded force output under unstable conditions ($p<0.01$). Unstable chest press force was 59.6% less than stable chest press force. (Figure 3.2).

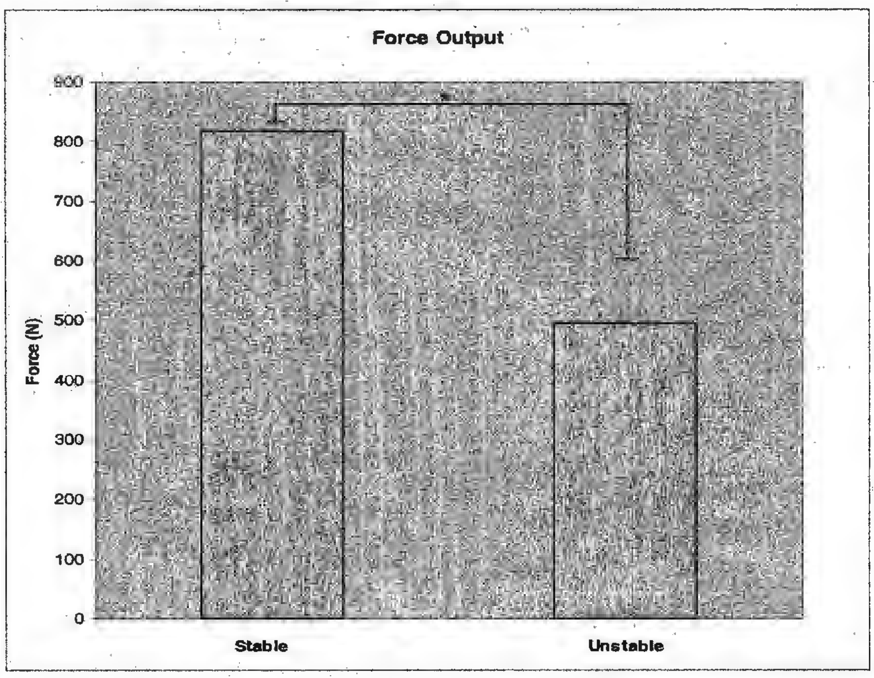

Figure 3.2. Mean MVIC force between stable and unstable protocols where the asterisk (*) signifies $p<0.01$.

EMG Activity: There was no significant evidence of changes in the extent of muscle activation as measured by EMG within the same muscle between the stable and unstable MVC. Similarly, there were no differences between stable and unstable EMG for both the submaximal isometric and dynamic protocols. However, there was significant evidence for contraction type effect. EMG activity during concentric contractions of the pectoralis major was 22.1% and 19.9% greater than eccentric and isometric contractions respectively ($p=0.006$). The deltoid exhibited 38.3% greater concentric EMG activity than eccentric ($p=0.007$). Deltoid isometric EMG activity was not significantly different from the other two types of contractions. There were no significant differences among the different types of triceps contractions.

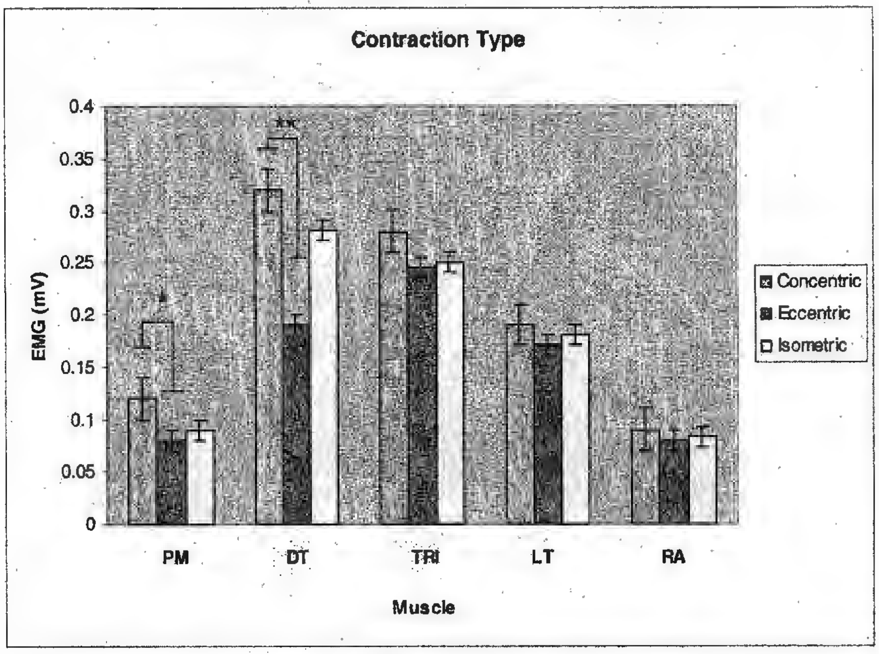

Figure 3.3. Mean (±SD) EMG (mV) between concentric, eccentric and isometric contractions of muscles tested (pectoralis major-PM, deltoid-DT, tricep-TRI, latissimus dorsi-LT, and rectus abdominus-RA). Significant differences are identified by (*) $p<0.006$ and (**) $p<0.007$.

Discussion

Limb muscles may be forced to aid in joint stability when performing unstable movements. With this added effort being directed to joint stability, total force output may decrease (Behm et al, 2002). The proponents of training under unstable conditions with a "Swiss" Ball claim that the instability provides a greater stress to the overall musculature. Stress, according to Selye's (1956) adaptation curve is essential in forcing the body to adapt to new stimuli. Periodization models by Bompa (1990) emphasize the importance of altering volumes, intensities, mode or type of exercises in order to provide novel stimuli to the neuromuscular system. Furthermore, according to the concept of training specificity (see review: Behm, 1995) because not all forces are produced under stable conditions (i.e. mogul skiing, shooting a puck in hockey), then training must attempt to closely mimic the demands of that particular sport. Finally, some authors (Stone et al., 1998; McCaw, 1994) advance the use of free weights over machines for improved training results since the balance and control of free weights forces the individual to stress and co-ordinate more synergist, stabilizing, and antagonist muscle groups. It has been hypothesized that performing exercises on unstable platforms further stresses synergistic and stabilizing muscles.

In the present study, maximal isometric force output with the unstable chest press condition was significantly lower (59.6%) than in the stable condition. This finding supports Korneki (1994) who identified that a percentage of force output was diverted to joint stabilization. Similarly, Behm et al. (2002) identified decreases in the isometric force output of the quadriceps and plantar flexors when performed under unstable conditions. Since EMG activity was not inhibited while unstable, a muscle group may be activated to the same extent as with stable conditions with lower force outputs or less resistance. Therefore, it is possible the muscle is maintaining EMG activity levels through a combination of force production and stabilizing functions. A possible benefit of unstable resistance training would be the ability to achieve high muscle activation (via movement and stabilizing functions) with lower resultant joint torques from the reduced loads, resulting in less stress on the articular system. Furthermore, the need for greater stabilizing responsibilities of the limb musculature may mimic more closely the typical requirements of daily activities or sport. Conversely, Johanson et al. (2001) found no statistical difference in the magnitude of thumb tip forces produced in a stable versus an unstable protocol of the thumb musculature. These findings may be explained by the changes in the activation of different muscles (muscle co-ordination) identified in their study.

Increases in EMG activity of muscles controlling joints while unstable or perturbed have been reported by a number of authors (Ivanenko et al., 1997; Gantchev and Dimitrova, 1996). Unfortunately, as forces were not measured in these studies, no correlation to force output was presented. This discrepancy might be attributed to the muscles examined. Lear and Gross (1998) looked at the stabilizing function of scapular stabilizers while performing push-ups on miniature trampolines. They found no significant difference in stabilizer EMG activity between stable and unstable cohorts, however, they acknowledged the degree of stability induced by the miniature trampolines was likely insufficient to be considered an unstable platform. In the present study, muscles that were considered to be prime movers rather than stabilizers were evaluated. Their response to instability may differ from primarily stabilizing muscles, some of which may not have been measured with this study.

Decreases in muscle activation, as estimated using the interpolated twitch technique and integrated EMG, have been reported (Behm et al. 2002) for actions under unstable conditions. While both the present study and the study by Behm et al. (2002) found significant decreases in MVC force, the latter study showed a decrease in EMG activity. The experimental design may explain these findings. Behm et al. (2002) had subjects perform unilateral knee extension and plantar flexion contractions while seated. As only one leg was tested, the unilateral limb forces would generate disruptive moments or torques upon the stability of the body. Thus to maintain balance, the activation and force output of the lower limb would need to be decreased. The bilateral contractions of the upper limbs in the present study would not generate similar disruptive moments, as both limbs are involved in the movement, if the resistance could be maintained directly above the torso. Indeed, greater forces and activation might even improve stability by distorting the roundness of the ball and providing a more horizontal stable platform.

Contraction type differences in EMG activity were detected, with generally greater activity during concentric than eccentric or isometric contractions. The pectoralis major ($p<0.006$), and deltoid ($p<0.007$) had greater EMG activity during the concentric phase of the lifts compared to the eccentric phase, which is consistent with a number of authors (Grabiner and Owings 2002, Kellis and Baltzopoulos 1998, Creswell and Thorstensson 1994).

Conclusion

Bilateral contractions of the upper body under unstable conditions can lead to decreases in force output with no significant change in EMG activity levels of muscle prime movers. In light of these findings, the use of "Swiss" balls as a resistance training modality for strength gains can be employed to allow an overload force or resistance to be developed as well as increased reliance on stabilizing functions. As this overload stress can be achieved with less resistance, this training modality may have positive implications in progressive muscle and joint rehabilitation.

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Chapter 4

Trunk Muscle Activity Increases With

Unstable Squat Movements

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Abstract

The objective of this study was to determine differences in electromyographic activity of the soleus (SOL), vastus lateralis (VL), biceps femoris (BF), abdominal stabilizers (AS), erector spinae (ES) and multifidus (MT) while performing squats of varied stability and resistance (own body mass, 29.5 kg, 60% body mass). Stability was altered by performing the squat movement on a Smith machine, a free squat, and while standing on two balance discs. Fourteen male subjects performed the movements. Activity of the SOL, AS, MT, and ES was highest while performing the unstable squat and lowest with the Smith machine protocol ($p<0.05$). Increased EMG activity of these muscles may be attributed to their postural and spinal stabilization role. Furthermore, EMG activity was higher during concentric contractions compared to eccentric contractions. Performing squats on unstable surfaces may permit a training adaptation of the core muscles responsible in supporting the spinal column (ie. erector spinae) as well as the muscles most responsible for maintaining posture (ie. soleus).

Keywords: electromyography, concentric, eccentric, resistance training, stabilizers

Introduction

It is purported that greater instability of the human-surface interface will stress the neuromuscular system to a greater extent than traditional resistance training methods using more stable benches and floors. However, it is important to identify to what extent instability will influence the acute response of muscle. 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 co-ordination (Behm, 1995). A number of researchers have reported that neural adaptations play the most important role in strength gains in the early portion of a resistance training program (Behm, 1995; Sale, 1988). Rutherford and Jones (1986), suggested that the specific neural adaptation occurring with training was not increased recruitment or activation of motor units but an improved co-ordination of agonist, antagonist, synergists and stabilizers. Thus, the inherently greater instability of the body-surface interface would challenge the neuromuscular system to a greater extent, possibly enhancing strength gains attributed to neural adaptations.

There are few studies to our knowledge examining the effect of unstable resistance training movements on muscle activation and force. Vera-Garcia (2000) identified higher electromyographic (EMG) activity when performing a sit-up on an unstable surface compared to a flat surface. Siff (1991) found that the wider range of movement with Swiss balls is preferable to similar actions performed in most circuit training gyms. Behm et al. (2002) reported that the statistical decreases in quadriceps and plantar flexor force and activation with unstable conditions were dependent upon the degree of instability. This research suggested that strength training adaptations of the limbs were possible if the degree of instability is moderate as opposed to severe. Perhaps the importance of instability training is not only the unique stress placed upon the limb musculature but its impact on trunk musculature responses. Thus the objective of this study was to examine the effect of differing levels of instability on trunk and limb muscle activation during a closed kinetic chain activity (squat). It was therefore, hypothesized, that as stability decreased, trunk muscle activity would increase.

Materials and Methods

Subjects

Fourteen male (n = 14) physically active subjects (25.2 ± 6.2 yrs, 175.3 ± 6.5 cm, 82.6 ± 9.7 kg) from Memorial University of Newfoundland participated in the study. All subjects had previous resistance training experience (mean = 7.8 yrs ± 6.4). All subjects read and signed a consent form prior to experimentation. Memorial University of Newfoundland Human Investigation Committee approved the study.

Measurement and Instrumentation

EMG was measured during all protocols of varied stability and resistance. Surface EMG signals were measured from six muscle groups: mid-belly of vastus lateralis (VL), mid-belly of biceps femoris (BF), mid-line of soleus (SOL), erector spinae (ES) at T12-L1, multifidus (MT) at L5, and abdominal stabilizers (AS), positioned superior to the inguinal ligament and medial to the anterior superior iliac spine. As McGill et al. (1996) reported that surface electrodes could represent the activation profiles of deep abdominal muscles over a broad variety of tasks and Ng et al. (1998) identified possible contamination of EMG signals from more than one muscle (internal obliques and transverse abdominus), the term abdominal stabilizers will be used to refer to the EMG measured at this position. EMG location sites were identified, shaved, sanded (to remove dead epithelial cells), and cleansed with rubbing alcohol to reduce resistance and achieve maximal adhesion of the electrode (Kendall® Medi-trace 100 series, Chikopee, MA). To maximize EMG sensitivity, the electrodes were aligned parallel to muscle fiber orientation rather than in a perpendicular position (Ng et al. 1998). EMG signals were then amplified (1000x), filtered (10-1000 Hz) and smoothed (10 samples) (Biopac Systems MEC 100 amplifier, Santa Barbara, Ca.), and stored on computer after being directed through an analog-digital converter (Biopac MP100). All data were recorded at a sampling rate of 2000Hz and analyzed with a software program (Acqknowledge 3.7.2., Biopac Systems, Santa Barbara, Ca.). The maximum amplitude of the root mean square (RMS) of the EMG signal was evaluated over the duration of the concentric and eccentric contractions of the squat.

Protocol

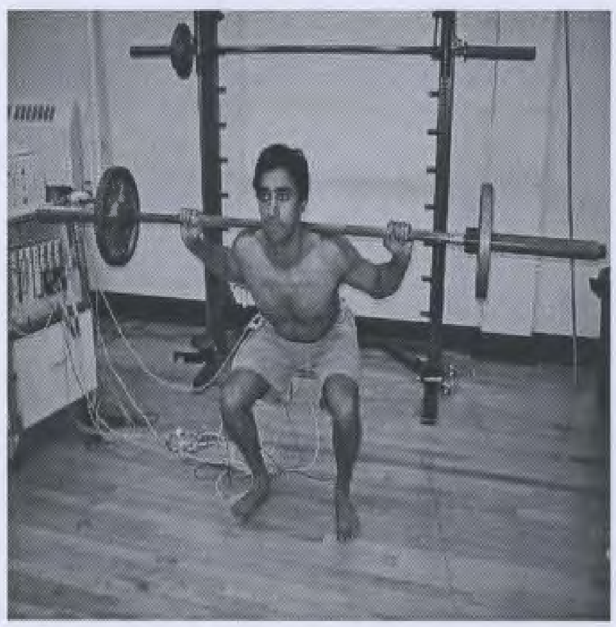
Prior to experimental data collection, subjects were given a two-week orientation session where subjects performed both stable and unstable squats (on balance discs) using only body mass for 3 sets of 10 repetitions on six different occasions. Immediately prior to data collection, a 5-minute warm-up was performed on a cycle ergometer. All testing was performed in a single session.

The squat was performed under three levels of stability: relatively unstable, relatively stable, and very stable. (Table 4.1). The relatively unstable squat was performed with a Balance Disc under each foot, relatively stable used a regular squat (standard Olympic bar on shoulders behind head) and very stable squat was performed with a Smith machine (bar sliding on rails). (Figures 4.1a, 4.1b, and 4.1c).

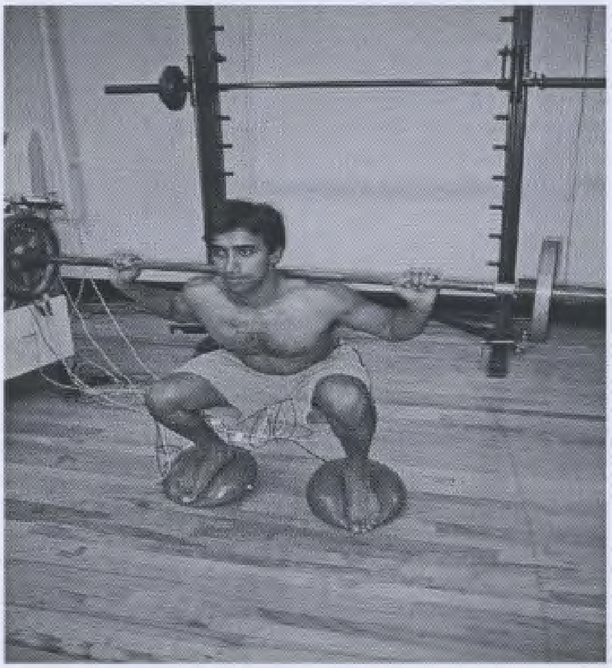
Table 4.1. Stability Spectrum

Least Stable →		Most Stable
Balance Disc Squat	Free Squat	Smith Machine Squat

a)



b)



c)

Figure 4.1. Squat methods: a) Smith, b) Free, c) Unstable.

Each movement had contractions of three intensities: no external resistance (body mass), 29.5 kg (weight of Smith machine bar), and 60% of body mass (standardized resistance which permitted the subjects to complete the movement on the balance discs safely) (Table 4.2). For safety reasons, maximal loads were not used. Subjects were instructed to maintain a 1-second down-phase, 1-second transition phase, and 1-second up-phase cadence for the squat movement. Subjects were permitted to perform a practice repetition immediately prior to testing with each type of squat to familiarize themselves with the balance, resistance and timing. Typically only 1-2 repetitions were performed with data acquired and analyzed from the repetition adhering most closely to the time constraints (1-s down, 1-s up). The order of stability condition and intensity were randomly assigned with two minutes rest given between repetitions to prevent a fatigue effect.

Table 4.2. Resistance Spectrum

Least Resistance ⟶		Most Resistance
Body Mass	29.5 kg (65 lbs)	60% of Body Mass

Subjects stood with feet placed approximately shoulder width apart with toes pointed straight ahead. The barbell was held behind the neck, across the shoulders and resting on the upper trapezius muscle. The grip was a little wider than shoulder width. Breath was held during the down-phase of the lift and air was expired during the up-phase of the lift. Subjects were instructed to maintain heel contact with the floor. Escamilla (2001) reported peak quadriceps EMG activity occurring at approximately 80-90° of knee flexion. Quadriceps activity remained fairly constant beyond 80-90° of knee flexion, hence descending beyond 90° flexion (parallel squat), may not enhance quadriceps development (Escamilla 2001). Therefore, subjects were instructed to begin the up-phase once the upper leg was at a position parallel to the ground (90° knee flexion).

Statistical Analysis

A 3-way ANOVA (3x3x2) repeated measures were used (GB-STAT for MS Windows, Version 7.0. Silver Springs, MD.) The three levels identified were squat method (Smith machine, free squat, unstable), resistance (body mass, 29.5 kg, 60% body mass) and contraction type (eccentric-down, concentric-up). Upon review of collected data, the AS appeared to become highly active during the transition from eccentric-concentric phases and the temporal data were analyzed with a repeated measures 1-way ANOVA. Differences were considered significant at a $p < 0.05$ levels. If significant differences were detected, a Bonferroni (Dunn's) procedure was utilized to identify group differences. Data were reported as means ± SEM.

Results

Extent of Stability

Trunk Muscles

The EMG activity of the AS during the Smith and free squat were 29.6% ($p<0.01$) and 18.6% ($p<0.05$), respectively, less than during the unstable squat while differences between the Smith and free squat were not significant. EMG activity of the MT was 22.9% ($p<0.05$) and 20% ($p<0.05$) lower in the free and Smith squat, respectively, compared to the unstable squat, however, no significant differences between the Smith and free squat were identified. The ES experienced a 33.8% ($p<0.01$) decrease in the Smith compared to unstable squat and a 22.9% ($p<0.05$) decrease in the free compared to unstable squat. (Figure 4.2). There was also a 29% ($p<0.05$) decrease in activity of the ES during the Smith compared to free squat.

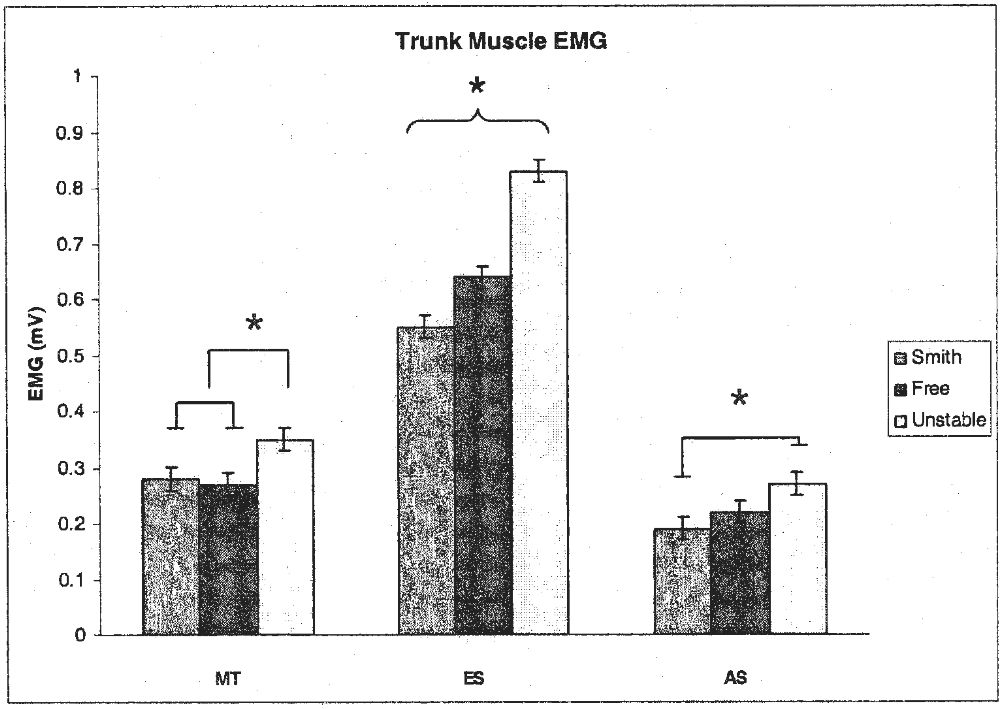


Figure 4.2. Mean (±SEM) of trunk muscle EMG (MT, AS, ES) over three squat movements. Muscle group and squat technique are labeled on the x-axis with root mean squared (RMS) EMG (mV) on the y-axis. Asterisks (*) identify significant differences at ($p < 0.05$).

Limb Muscles

EMG of the SOL during the Smith and free squats were 73.1% and 58.5% less than during the unstable squat respectively ($p<0.0001$). Muscle activity of the VL was 4.8% ($p<0.05$) lower in the unstable compared to the Smith squat while the VL activity during the free squat was 14.3% ($p<0.01$) lower than the Smith squat. There were no significant BF differences between the three squat protocols (Figure 4.3).

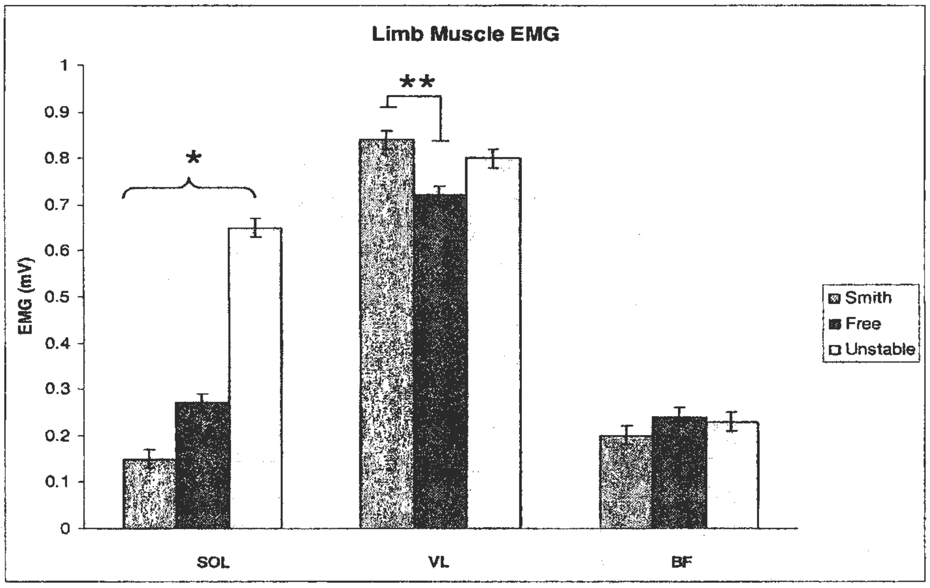


Figure 4.3. Mean (±SEM) of limb muscle EMG (SOL, VL, BF) over the three squat movements. Muscle group and squat technique are identified on the x-axis with RMS EMG (mV) on the y-axis. Significant differences ($p < 0.05$) between unstable and other squats are identified by (*). Significant difference ($p < 0.01$) between Smith squat and others are identified by a double asterisk (**).

Resistance

As resistance increased there were significant increases in EMG activity of the SOL (p<0.01), MT (p<0.001), VL (p<0.0001), and ES (p<0.0001). Increases in the BF and AS were not significant (Table 4.3).

Table 4.3. Differences in mean RMS EMG (mV) of all six muscles tested for all resistance. Parenthesis ( ) identify % increase from lowest value. Significant differences ($p < 0.05$) and ($p < 0.0001$) are identified by an (*) and (***) respectively.

	SOL	VL	ES	BF	AS	MT
Body Mass	0.27	0.58	0.52	0.18	0.20	0.21
29.5 kg	0.37 (37%)*	0.84 (44%)***	0.67 (29%)***	0.20 (11%)	0.23 (15%)	0.31 (48%)***
60%	0.44 (62%)*	0.92 (59%)***	0.83 (59%)***	0.28 (55%)	0.24 (20%)	0.38 (81%)***

Contraction Type

EMG activity was significantly greater during the concentric phase compared to the eccentric phase of the squat protocols (SOL 37% ($p<0.006$); VL 44% ($p<0.0001$); ES 29% ($p<0.01$); BF 93% ($p<0.04$); AS 31% ($p<0.0002$)). The MT showed a trend ($p<0.08$) for increased activity (14%) during the concentric phase of the lift (Figure 4.4).

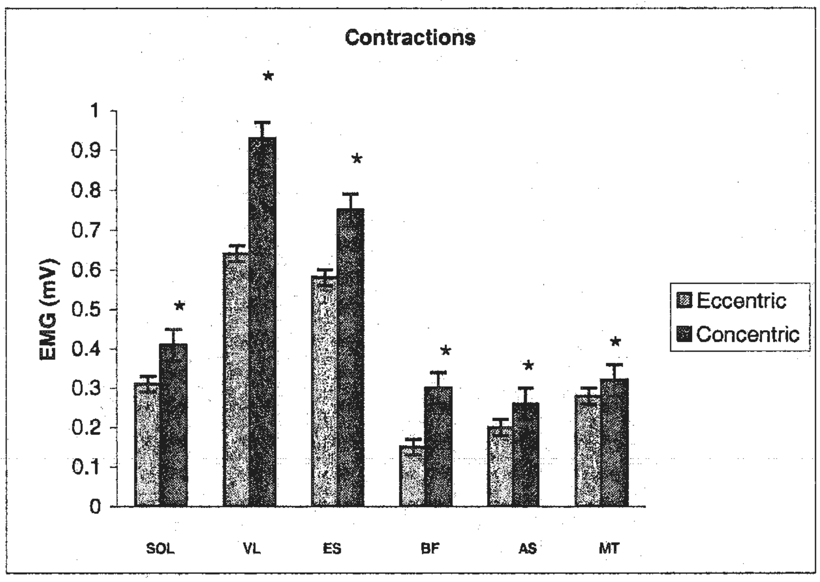


Figure 4.4. Comparison of mean RMS EMG (mV) of all six muscles tested during both eccentric and concentric contractions (x-axis). RMS EMG (mV) are plotted on the y-axis. Significant differences are identified by an asterisk (*).

Abdominal Stabilizer (AS) Contraction Duration

Upon review of the data, there was an apparent alteration in the duration of AS activity during the transition phase. There was a significant increase ($p<0.005$) in the duration of AS activation from the eccentric to concentric phase of the lifts in the unstable protocols compared to the more stable movements (0.66 sec- unstable squat, 0.54 sec-Smith squat, 0.51sec-free squat). There were no significant differences in the duration of EMG activity for any other muscles tested.

Discussion

This is the first paper to our knowledge to examine multi-axial joint resistance training movements under stable and unstable conditions. The proponents of training under unstable conditions claim that resistance training under unstable conditions provides a greater stress to the overall musculature (Sheth, 1997; Ivanenko, 1997; Gantchev, 1996 and Wester, 1996). The trunk muscles (MT, AS, ES) were more active during the unstable squat, followed by the free squat and Smith machine squat respectively. This may be explained by the stabilizing roles of these muscles (Arokoski et al. 2001, De Troyer, 1999, and Gardner-Morse, 1995). As subjects became more unstable with the balance disc squats, the MT, AS, and ES were recruited more to maintain stability of the spine and torso. Whereas Behm et al. (2002) reported that moderate instability can still utilize resistance intensities that would promote limb strength adaptations, the present study emphasizes the more pronounced activity of the trunk stabilizers with changes in stability. Therefore, performing unstable squat movements may not only develop the prime movers but also develop the trunk stabilizers as well.

EMG activity in the SOL was also greater during the unstable squat movement compared to the more stable movements. The SOL is an important muscle in maintaining erect posture as it has an important role in controlling the ankle joint which is often one of the first joints that help return the body to equilibrium after perturbation (Ivanenko et al, 1997). This finding has relevance in that strengthening of the SOL muscles may help persons with balance difficulties to lessen the number of falls attributed to uneven surfaces. Furthermore, sports performed on level (basketball, volleyball) or irregular (football, rugby) surfaces could also benefit from instability training.

Limb muscles including the BF and the VL did not show similar activation patterns under the unstable conditions as the trunk and postural muscles. There was no significant difference in the BF activity between all three squat protocols, indicating that with this squat movement, varied stability had minimal effect on hamstring activity. Similar findings were found with the VL. As these muscles are primarily identified as prime movers within the squat movement, with a minimal role in stability, the varied stability had little effect on their recruitment. However, the elevated EMG activity of the VL during the Smith machine protocol may have been a result of foot placement and the stability (bar guided on rails) of the Smith machine. Subjects may have been able to use the VL to push posteriorly and vertically against the bar in order to push backward as well as up.

The increased resistance placed on all movements resulted in a corresponding rise in EMG activity as would be expected with the classic force:EMG relationship (Bigland and Lippold, 1954; Genadry et al. 1988; Komi and Viitasalo, 1976; Lippold, 1952). However, a similar increase in EMG was not identified in the AS muscle. One possible explanation for the lack of increase in AS activity is that it aids in spinal stabilization by increasing intra-abdominal pressure (IAP) (Rab et al., 1977). Cresswell and Thorstensson (1994) found that among the abdominal muscles, the highest level of activity and the best correlation to variations in IAP was demonstrated by the transverse abdominus. Therefore, a maximum threshold may exist for the AS in increasing IAP in untrained individuals. Another hypothesis is that the AS 'turn off' as part of a protective mechanism where as trunk flexion increases, increased abdominal activity can create a shearing moment at the lumbar spine. An alternate explanation may suggest that there is not a linear relationship between increases in external resistance and IAP. However, a number of authors (Cresswell and Thorstensson, 1994; Cresswell, 1993; and Harman et al. 1988) suggest that increased resistance does not result in elevated IAP, but there is no direct correlation of this elevated IAP to AS activation. Therefore, increasing resistance may not result in a corresponding rise in AS activity.

Significant differences were also found in muscle activation between concentric and eccentric phases of the movement. The SOL, VL, ES, BF, and AS had significantly ($p<0.05$) greater EMG activity during the concentric phase of the lifts compared to the eccentric phase, which are consistent with findings by Grabiner and Owings (2002) and Cresswell and Thorstensson (1994). However, only a trend ($p<0.08$) for higher EMG during the concentric phase was evident in the MT. This may be explained as the MT is a spinal stabilizer, it contracts isometrically during both the concentric and eccentric phases of the lifts, therefore, producing lower recognizable differences. Furthermore, one may argue that as the ES and AS are also stabilizers, why was there a change between contractions? McGill and Norman (1986) provide one explanation that the ES also contributes to spinal extension as it works in unison with other spinal extensors to overcome the spinal bending moment resulting from the load. Delitto et al. (1987) states the increased activity of the AS during the concentric phase may be a requisite for increased IAP needed to protect the spine due to the considerable degree of anterior shear force that can be generated by the upper body while extending the torso and combating inertia.

The AS were most active at the bottom of the movement with the transition from eccentric to concentric phases (Figure 5). The possible mechanism responsible is known as the flexion-relaxation phenomenon (Newman and Gracovetsky, 1995). McGill and Kippers (1994) found that during hip flexion, the lumbar extensors relaxed as they were still able to generate substantial force elastically through stretching. In the case of the squat, as subjects reached the bottom (lumbar flexion), MT activity decreased (relying on elastic component) which resulted in increased AS activity to maintain support to the spinal column anteriorly (Figure 4.5). It would be interesting to discover whether individuals trained to activate their MT and AS (via core training) would demonstrate similar responses.

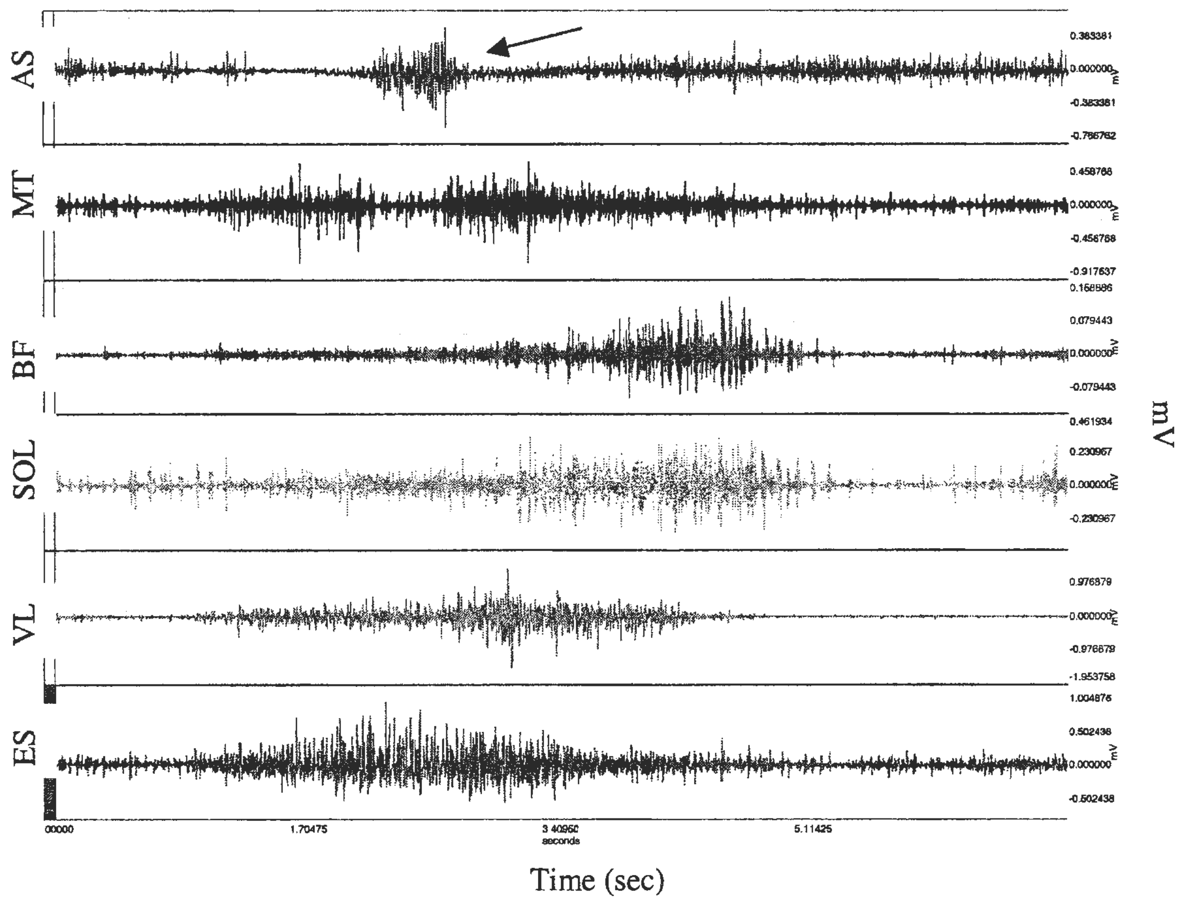


Figure 4.5. Raw data (EMG) from one subject that shows the flexion-relaxation phenomenon (first line graph is AS, second line graph is MT). Arrow indicates burst of AS activity.

Conclusion

It was identifiable in the study that as subjects became more unstable, the activity of their trunk stabilizers and postural muscles increased whereas only negligible increases in activity of the prime movers was identified. Since previous studies (Behm et al. 2002) have shown significant decreases in force and activation of prime movers with unstable conditions, the use of unstable resistance training modalities may prove to be more benefit to trunk stabilizers than prime movers. It should be pointed out however that as only the acute response to an unstable movement were measured, caution should be used when making insights into possible training effects.

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Chapter 5 Summary

The preceding manuscript attempted to look at muscle characteristics in humans when experiencing states of instability. A number of trends were identified through this research process. We first realized that as one becomes unstable, the total directed force output drops. We also identified that as instability increases, core stabilizer and postural muscles increase in activity in an attempt to maintain stability. In addition, it appeared that muscles not involved in maintaining posture or core stability showed no significant differences when unstable. Furthermore, it was recognized that muscles are less capable of reaching maximal contraction when experiencing instability as identified through electrical stimulation. However, it should be acknowledged that due to the inherent loss in muscle activation and force output when unstable, stability training may not be a superior training modality for hypertrophic gains. These findings can be integrated when training for sports or occupations where incidences of instability are common (ie. gymnastics, fisherman, etc.). If we are able to train our bodies to be more efficient during these instances, it may provide a possible benefit to sport performance or in the prevention of balance related injury.

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Appendix A

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Muscle Force and Activation Under Stable and Unstable Conditions

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ABSTRACT

The objective of this study was to determine differences in isometric force output, muscle activation (interpolated twitch technique), and electromyographic activity of the quadriceps, plantar flexors (PF), and their antagonists under stable and unstable conditions. Instability in subjects was introduced by making them perform contractions while seated on a "Swiss ball." Eight male subjects performed unilateral leg extensor (LE) and PF contractions while seated on a bench (LE), chair (PF), or a ball. Unstable LE and PF forces were 70.5 and 20.2% less than their stable counterparts, respectively. Unstable quadriceps and PF activation averaged 44.3 and 2.9% less than activation under stable conditions. Unstable antagonist/agonist ratios were 40.2 and 30.7% greater than stable ratios in the LE and PF protocols, respectively. The greater decrements with LE can be attributed to the instability of only 2 points of floor contact, rather than 3 points of floor contact as with the PF. Swiss balls may permit a strength training adaptation of the limbs, if instability is moderate, allowing the production of overload forces.

Key Words: balance, interpolated twitch technique, electromyography, quadriceps, plantar flexors

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Introduction

Balls have been used by entertainers and circus performers over 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 (27, 28), physical therapists began to integrate the use of balls into therapy. Physical therapists, especially the Germans and the Swiss, were especially active in using balls for sports training and therapy. Consequently, the name "Swiss ball" has become almost synonymous with "Physio ball."

Proponents of the Swiss ball deduce that the greater instability of the ball and human body interface will stress the neuromuscular system to a greater extent than traditional resistance training methods using more stable benches and floors. 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 (2). A number of researchers have reported that neural adaptations play the most important role in strength gains in the early portion of a resistance training program (2, 24). Rutherford and Jones (23) 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 ball and body interface would challenge the neuromuscular system to a greater extent, possibly enhancing strength gains attributed to neural adaptations.

Improvements in core stability (torso strength) have been postulated in the popular media to be enhanced with instability training. The effectiveness of Swiss ball training has been demonstrated with abdominal training. Siff (29) found that the wider range of movement (with an optimal starting position from a few degrees of active trunk extension) is preferable to similar actions performed in most circuit training gyms. However, there has been no evidence, other than anecdotal, to significantly demonstrate the overall effectiveness of Swiss ball training. Furthermore, there have been no studies documenting instability training responses on limb musculature. It is the objective of this investigation to examine the differences in force output and intramuscular and intermuscular activation of the leg extensors (LE) and plantar flexors (PF) under stable and unstable conditions.

Methods

Experimental Approach to the Problem

The same group of subjects performed isometric voluntary contractions of their knee extensors and PF under stable (seated on a bench or chair) and unstable (seated on a Swiss ball) conditions. Forces derived from the maximum voluntary contractions (MVC) and muscle activation patterns were measured using the interpolated twitch technique (ITT) as well as agonist and antagonist electromyography (EMG) to discover whether unstable conditions provided similar, greater, or lesser stress on the limb musculature than while stable. All measurements have been reported to have excellent reliability and validity in the literature (5, 35, 36). In the present study, force measures illustrated excellent reliability coefficients of 0.99 for both the LE and PF. Similarly, measures of muscle inactivation with the ITT achieved reliability coefficients of 0.96 and 0.84 for the LE and PF, respectively.

Subjects

Eight physically active male subjects (24.3 ± 6.7 years, 178.1 ± 6.1 cm, 82.3 ± 8.9 kg) were recruited from the university population. Subjects were either resistance trained or had previous resistance training experience. All subjects read and signed a consent form before experimentation. The study was approved by the School of Physical Education, Recreation, and Athletics, Memorial University of Newfoundland Ethics Committee.

Testing

Subjects were given an orientation session 2–3 days before testing, which permitted them to sit on the Swiss ball and attempt as many submaximal contractions as necessary for them to feel comfortable with the apparatus. Whereas LE and PF testing were conducted on separate days, all stable and unstable testing for a particular muscle group was performed in a single session. All subjects had some experience performing sit-ups using the Swiss balls with their prior resistance training.

Leg Extensors

Subjects performed 2–3 isometric MVCs of the quadriceps. Three-minute rest periods were provided between all contractions. During the stable leg extension, subjects were seated on a bench with hips and knees at 90°, with their foot in a padded strap attached by a high tension wire to a Wheatstone bridge configuration strain gauge (Omega Engineering Inc., LCCA 250, Don Mills, Ontario, Canada), perpendicular to the lower limb. The subject's body was secured in this position with a seat belt–type apparatus across both the hips and thighs. Unstable leg extensions were performed while seated on a Swiss ball. The size of the Swiss ball was selected to ensure that the subject's floor contact leg had the knee flexed at 90°. The testing leg was secured to the padded strap and strain gauge in the same manner as in the stable condition. In the unstable LE condition, the testing leg did not touch the floor; thus there were only 2 points of balance or contact with the floor.

Plantar Flexors

Subjects in the stable condition were seated in a straight-back chair, with hips and knees at 90°. They performed voluntary contractions of the PF, with their leg secured in a modified boot apparatus, with their ankles and knees at 90° (6). Three-minute rest periods were provided between all contractions. Unstable contractions were performed with the same apparatus while seated on a Swiss ball. The modified boot apparatus rested on the floor and securely restricted the subject's leg, resulting in 3 points of balance or contact with the floor.

Measurements

All voluntary and evoked torques were detected by the strain gauges, amplified (DA 100 and analog to digital converter MP100WSW, Biopac Systems, Inc., Holliston, MA), and monitored on a computer (Sona Phoenix PC, St. John's, Newfoundland, Canada). All data were stored on a computer at a sampling rate of 2,000 Hz. Data were recorded and analyzed with a commercially designed software program (AcqKnowledge III, Biopac Systems Inc.).

Bipolar surface stimulating electrodes were secured over the proximal and distal portions of the quadriceps and PF. Stimulating electrodes, 4–5 cm in width, were constructed in the laboratory from aluminum foil and paper coated with conduction gel (Aquasonic, Fairfield, NJ) and immersed in a saline solution. The electrode length was sufficient to wrap the width of the muscle belly. The electrodes were placed in approximately the same position for each subject.

Surface EMG recording electrodes were placed approximately 3 cm apart over the midbelly of the quadriceps and hamstrings (LE protocol) and over the midbelly of the soleus and tibialis anterior (PF protocol). Ground electrodes were secured on the tibia and fibular head. Thorough skin preparation for all electrodes included removal of dead epithelial cells with an abrasive (sand) paper around the designated areas, followed by cleansing with an isopropyl alcohol swab. EMG activity was amplified, filtered (10–1,000 Hz), monitored, and stored in a computer. The computer software program rectified and integrated the EMG signal (IEMG) over a 500-millisecond period during an MVC.

The ITT was administered during an MVC for the LE protocol and both maximal and submaximal voluntary contractions for the PF protocol. An interpolated force (IT) ratio was calculated comparing the amplitudes of the superimposed stimulation with the postcontraction stimulation to estimate the extent of inactivation during a voluntary contraction (5). Because the postcontraction stimulation represents full muscle activation, the superimposed torque using the same intensity of stimulation would activate those fibers left inactivated by the voluntary contraction. Extra or superimposed evoked force was readily apparent in the LE protocol with the ITT during an MVC. Because superimposed evoked forces could be detected during all leg extension MVCs, stimulation was provided only with maximal contractions to reduce the number of stimulations and subject discomfort. However, superimposed force during an MVC was absent in almost all subjects during the PF protocol. Thus, all maximal and submaximal (100, 75, 50, and 25% of MVC) forces were correlated with their respective IT ratios in order to generate a second-order polynomial equation for all PF subjects. Second-order polynomials using both maximal and submaximal contractions (IT ratios) have been shown to be valid and reliable, providing an accurate estimation of muscle activation (5).

Torque signals were sent through a high gain amplifier (Biopac Systems DA100 and MP100WSW), with the superimposed force isolated and further amplified by the software program (AcqKnowledge III). A doublet (2 twitches delivered at a frequency of 100 Hz) rather than a twitch was utilized for the interpolated evoked stimulation because it provided a higher signal-to-noise ratio.

Statistical Analyses

Data were analyzed with a 1-way analysis of variance with repeated measures (stable vs. unstable). F ratios were considered significant at $p \leq 0.05$. If significant interactions were present, a Bonferroni (Dunn's) procedure was conducted. Statistical power equations to determine minimum population samples to achieve significance at the $p \leq 0.05$ level with a power of 0.9 revealed that a range of 5–10 subjects was necessary, depending upon the muscle tested and measure utilized.

Results

Maximum Voluntary Contractions

The ability to exert force under stable conditions significantly exceeded force output under unstable conditions for both the LE and PF protocols. Unstable LE force was 70.5% less than stable force (Figure 1a), whereas unstable PF force was 20.2% less than stable force (Figure 1b).

Muscle Inactivation

A significant difference in muscle inactivation was detected only with the LE protocol. Quadriceps activation under unstable conditions averaged 44.3% less than that under stable conditions (Figure 2a). Although not statistically significant, unstable PF exhibited 2.9% less activation than that under stable conditions (Figure 2b).

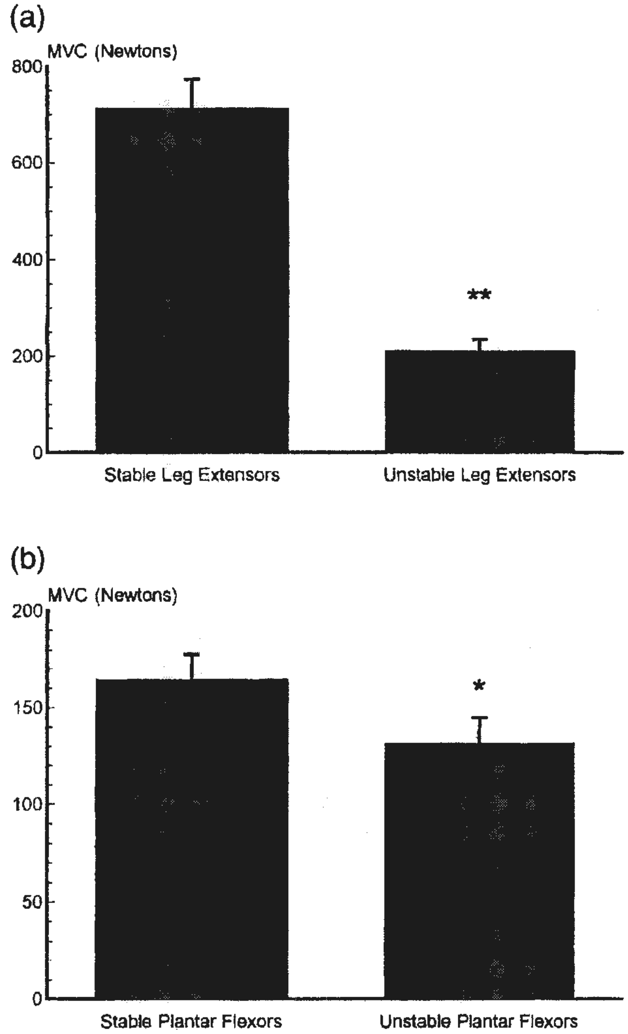

Figure 1. Bars represent changes in maximum voluntary contractions (MVC) of the leg extensors (LE) during the LE protocol (a: upper graph) and the plantar flexors (PF) during the PF protocol (b: lower graph) under stable and unstable conditions. Double asterisks indicate significant differences at the $p < 0.0001$ level, whereas single asterisks indicate significant differences at the $p < 0.01$ level. Vertical bars represent standard errors.

Antagonist and Agonist IEMG

Whereas the quadriceps experienced a dramatic decrease in activation as measured by ITT, quadriceps IEMG activity decreased only 11.3% with unstable conditions (Figure 3a). Conversely, hamstring IEMG activity increased by 29.1% under unstable vs. stable conditions (Figure 3b). Although statistically insignificant, unstable PF experienced decreases of 8.3% (Figure 4a), whereas tibialis anterior IEMG activity experienced increases of 30.3% (Figure 4b). The interaction of agonist and antagonist activity resulted in a significant difference only with the antagonist/agonist IEMG activity of the quadriceps and hamstrings. Unstable antagonist/agonist ratios were 40.2 and 30.7%

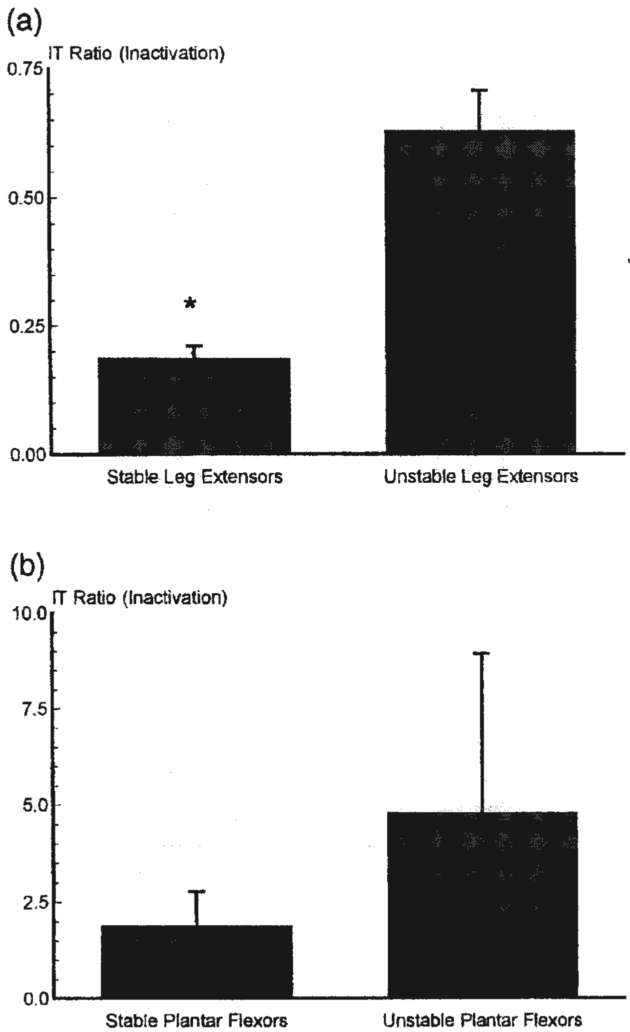

Figure 2. Bars represent changes in muscle inactivation of the leg extensors (LE) during the LE protocol (a: upper graph) and the plantar flexors (PF) during the PF protocol (b: lower graph) as estimated by the interpolated twitch technique under stable and unstable conditions. A single asterisk indicates a significant difference at the $p < 0.003$ level. Vertical bars represent standard errors.

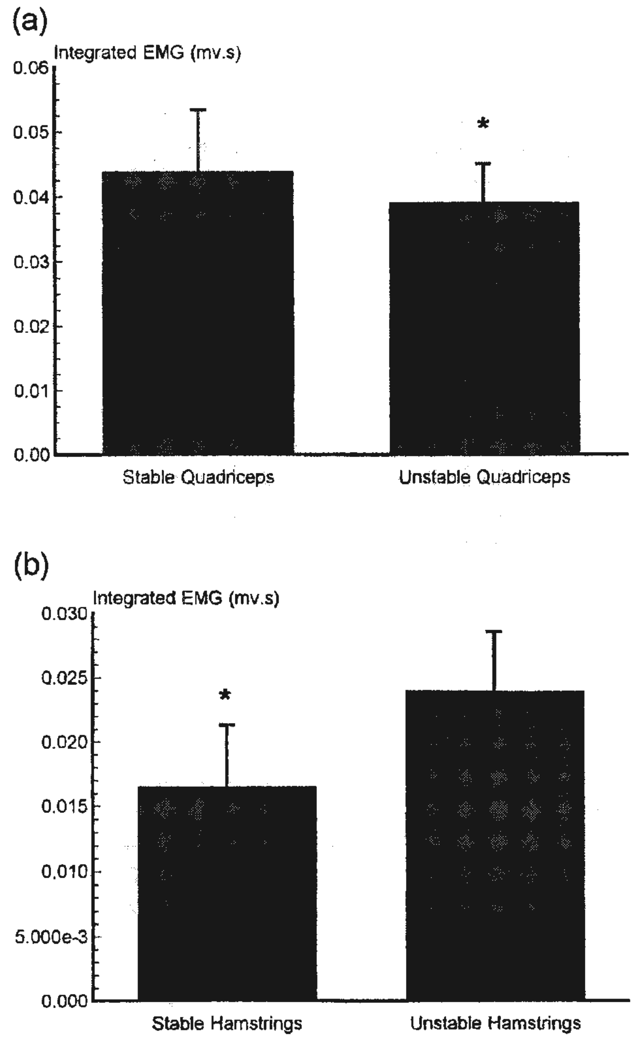

Figure 3. Bars represent changes in agonist (quadriceps) (a: upper graph) and antagonist (hamstrings) (b: lower graph) integrated electromyography activity during the leg extensor protocol under stable and unstable conditions. A single asterisk indicates a significant difference at the $p < 0.05$ level. Vertical bars represent standard errors.

greater than stable ratios in the LE (Figure 5a) and PF ($p = 0.07$) (Figure 5b) protocols, respectively.

Discussion

This is the first paper to our knowledge to examine differences in force output and muscle activation under stable vs. unstable conditions. The proponents of training under unstable conditions with a Swiss or Physio ball claim that resistance training under unstable conditions provides a greater stress to the overall musculature. Stress, according to Selye's (26) adaptation curve, is essential in forcing the body to adapt to new stimuli. Periodization models (1, 13, 31) emphasize the importance of altering the volumes, intensities, mode, or type of exercises in order to provide novel stimuli to the neuromuscular system. Furthermore, according to the concept of training specificity (2, 25), 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, and changing direction rapidly by pivoting on 1 foot on uneven natural turf in football, soccer, field hockey, or other sports), training must attempt to closely mimic the demands of the sport or occupation. There is an infinite array of exercises that can be performed on the Swiss ball for both the upper and lower body. Whereas some exercises stress the knee extensors and flexors by rolling forward and backward on a stability ball, with the body used as load, other practitioners perform feats of balance involving unassisted squats on a freely moving ball. Whether some of these

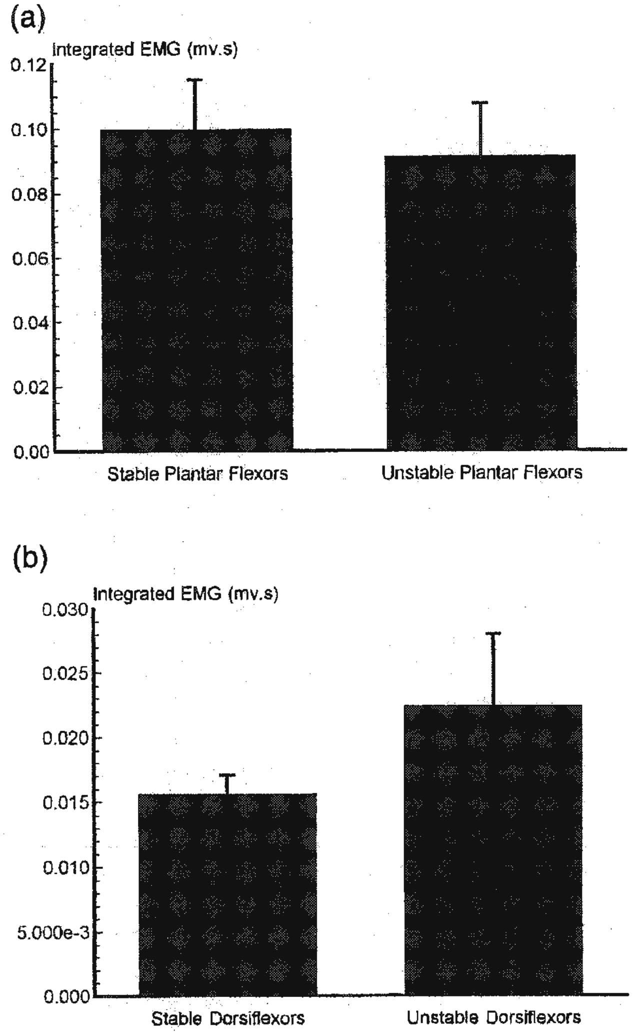

Figure 4. Bars represent changes in agonist (plantar flexors [PF]) (a: upper graph) and antagonist (tibialis anterior) (b: lower graph) integrated electromyography activity during the PF protocol under stable and unstable conditions.

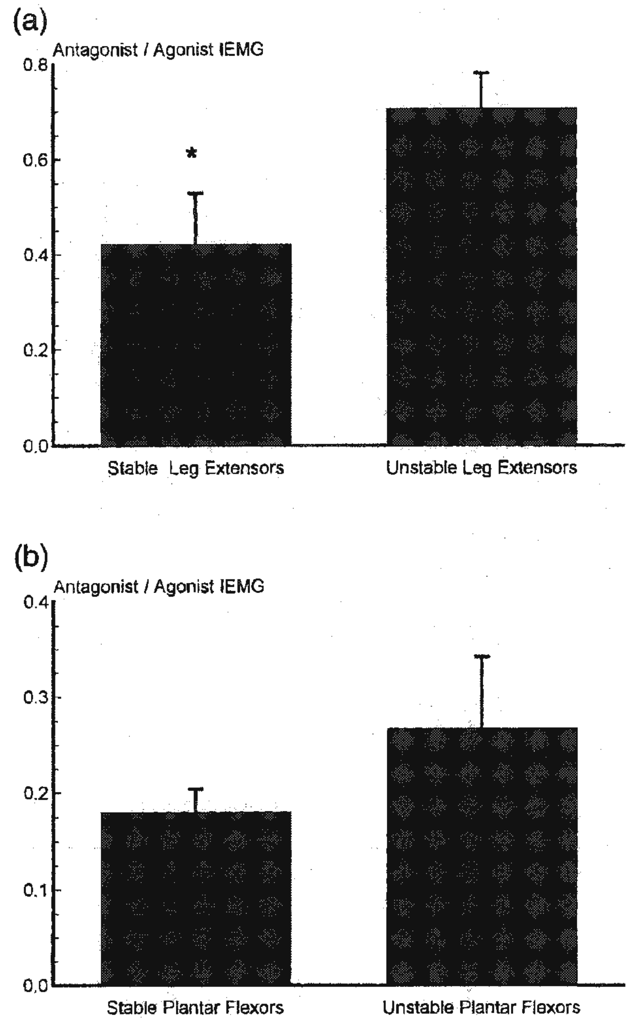

Figure 5. Bars represent changes in antagonist/agonist ratio of the leg extensors (a: upper graph) and plantar flexors (b: lower graph) under stable and unstable conditions. A single asterisk indicates a significant difference at the $p < 0.05$ level. Vertical bars represent standard errors.

circus-style maneuvers provide specific crossover training adaptations to sport is still under debate and demands further investigation.

Some authors advise the use of free weights over machines for improved training results (30) because the balance and control of free weights forces 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.

Force outputs with both LE and PF protocols were significantly lower with unstable conditions than with stable conditions. There was a much greater decrease in force with the unstable LE (70.5%) than PF (20.2%) as compared with their stable counterparts. This can be attributed to the differing degrees of instability in the 2 protocols. The LE setup provided only 2 points of contact with the floor (ball and contralateral limb on floor), whereas the PF protocol had 3 points of contact (ball, contralateral limb on floor, and testing limb in stable boot apparatus). Because there appeared to be a hierarchy of force output, with stable conditions providing the greatest forces, moderately unstable (PF) forces affected significantly, and very unstable (LE) conditions affected severely, the degree of stability or instability seems to directly affect limb force production. On one hand, this might promote the essential point of instability training; that is, 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 (2, 33). Force output with unstable LE was only 29.5% of a stable MVC. A number of authors have stated that training programs to promote general and maximal strength need repetitions, which provide a resistance intensity in the range of 40–120% of 1 repetition maximum or MVC (17, 30, 33). A very unstable environment, as provided in the present LE protocol, would not provide sufficient overload resistance (29.5%) to promote quadriceps strength adaptations. Although the PF protocol also had significantly less force than the stable condition, the degree or intensity of the contraction could still supply an overload stress (79.8% of stable MVC) on the muscle, with a limited number of contractions. Although forces and muscle activity of the torso were not measured in the present study, it may be possible that the torso musculature received an overload stress in attempting to maintain equilibrium.

Similar to force results, muscle inactivation experienced the greatest decrements under the very unstable LE condition (62.9%). Whereas some researchers have demonstrated full activation of the quadriceps under stable conditions (7, 8, 10, 22), others have reported less than full activation (5, 9, 15, 20, 32). The decreased activation under very unstable conditions could be ascribed to the excess stress associated with the increased postural demands (12). It could also be related to the dispersion of concentration (neural drive) in attempting to control 2 limbs with differing responsibilities (balance and force) (34). In an attempt to maintain balance, synergistic and stabilizing muscles would play a greater role. Synergistic muscles have been shown to provide both inhibitory and facilitatory inputs to agonist muscle groups (21). Thus, the application of 2 major stressors to the central nervous system (attempting maximal force output while balancing on 2 points) in this study severely inhibited the ability to fully activate the quadriceps.

However, the activation of the PF, which experienced only a moderately unstable condition, was not significantly affected. Unstable PF activation was only 2.9% lower than stable PF activation. However, it must be emphasized that the PF condition had 3 points of contact, minimizing the stress on the equilibrium system. Secondly, the PF may be more amenable to complete activation in many individuals. Stable PF inactivation (1.8%) was significantly less than stable LE inactivation (18.6%). Under stable conditions, both McComas et al. (19) and Belanger and McComas (6) reported that half their subjects could fully activate their PF. Similarly, Behm and St-Pierre in 2 separate studies indicated that 10 of 12 (3) and 11 of 16 (4) subjects could fully activate their PF during stable conditions. Because the PF posed a minimal challenge to the equilibrium of the body, may be accustomed to more chronic postural demands, and is a smaller muscle group than the quadriceps, which may be easier to fully activate, insignificant changes were experienced under this condition.

A question then arises as to why unstable PF forces were significantly less than stable PF forces, when there was no significant difference in muscle activation. Although not statistically significant, there was a trend ($p = 0.07$) for a greater antagonist/agonist ratio with the unstable PF condition. The unstable PF condition experienced 30.7% greater antagonist activity than the stable PF condition. Similarly, but in this instance statistically significant, unstable LE experienced 40.2% greater antagonist activity. The role of the antagonist in this case may be an attempt to control the position of the limb when producing force. Both De Luca and Mambrito (11) and Marsden et al. (18) reported that antagonist activity was greater when uncertainty existed in the required task. Increased antagonist activity may also be present to increase joint stiffness (16) to promote stability (14). 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.

Practical Applications

Unstable conditions can lead to decreases in the force output of the limb, muscle activation, and increases in antagonist activity. Greater degrees of instability exacerbate these changes. In the light of these findings, the use of Swiss or Physio balls as a resistance training modality for peripheral 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 whereby he or she cannot stay upright (attempting to stand or perform a squat maneuver on a Swiss ball), the amount of resistance that can be applied to the muscle will be negligible because all focus is on balance (extreme instability). On the other hand, performing contractions while seated on a Swiss 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 resistances. However, whereas the resistive challenge to a limb under very unstable conditions may be less than that necessary to develop strength adaptations, the 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 stability ball need not be significant strength gains but an attempt to improve balance, stability, and proprioceptive capabilities. Further research is necessary to investigate the effects of instability training on torso strength and balance adaptations as well as the effectiveness of a prolonged resistance training program using both unstable and stable conditions.

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