TRAINING ADAPTATIONS ASSOCIATED WITH INSTABILITY RESISTANCE TRAINING

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ABSTRACT

Throughout the past few years there has been an increasing awareness of the importance and significance of strengthening the trunk and shoulder girdle in an attempt to improve stability and optimize function. Traditionally, this has been done through the use of relatively stable benches and floors whereas more recently the incorporation of more unstable platforms, most notably Swiss Balls, are being utilized due to their inherent instability. It has been purported that unstable training environments enhance training effects through increased activation of stabilizers and core muscles and an improvement in neuromuscular coordination. However, the extent of this enhancement is unknown and has only been studied during a single bout of training.

As stability and balance play a vital role in activities of daily living, the prevention of falls and low back pain, as well as athletic performance, it would be valuable to identify if a specific regimen and/or technique could optimize benefits to mechanisms of balance. Thus, the objective of this study is to determine differences in physiological and performance measures following 8 weeks of stable and unstable resistance training.

It was found that instability resistance training can increase strength and balance in previously untrained young individuals as can training with more stable machines employing heavier and potentially more harmful loads on the body. Thus, instability training could be advantageous with musculoskeletal rehabilitation, since high muscle activation can be sustained while using lower intensity resistance. The findings also suggest that instability resistance training may have a tendency for being more efficient at increasing force under unstable conditions.

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CO-AUTHORSHIP STATEMENT

Dr. Behm has been a significant contributor to a number of aspects during this research. This includes the initial research idea, formulating the methods to carry out the experimental procedure, interpreting and analyzing the data and finally reviewing the text.

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LIST OF ABBREVIATIONS

ADL – Activities of Daily Living

APA – Anticipatory Postural Adjustment

AS – Abdominal Stabilizers

BF – Biceps Femoris

CNS – Central Nervous System

CMJ – Countermovement Jump

DB – dumbbell

DD – Dynadisc

DJ – Drop Jump

EMG – Electromyographic

ES – Erector Spinae

LE – Leg Extensors

LSES – Lumbo-Sacral Erector Spinae

MVC – Maximum Voluntary Contraction

MVIC – Maximum Voluntary Isometric Contraction

μV – Millivolt

μVs – Millivolt Second

M - Mean

N – Newton

NE – Neuromuscular Efficiency

OI – Internal Obliques

PAR-Q – Physical Activity Readiness Questionnaire

PEC – Pectoralis Major

PF – Plantar Flexors

RA – Rectus Abdominis

RF – Rectus Femoris

RM – Repetition Maximum

RMBP – Repetition Maximum Bench Press

SB – Stability Ball

SD – Standard Deviation

SOL - Soleus

TA – Tibialis Anterior

TrA – Transversus Abdominis

TRI – Tricep

ULES – Upper Lumbar Erector Spinae

VL – Vastus Lateralis

1 INTRODUCTION

1.0 Overview

Resistance training under situations with varying degrees of instability (such as with Swiss balls and other unstable platforms/devices) has recently enjoyed a surge in popularity. With the suggestion that there is enhanced neuromuscular training when these approaches are used, kinesiologists and other exercise specialists have begun to integrate the use of unstable bases of support into resistance training.

Proponents of instability resistance training suggest that the greater instability induced by an unstable surface (i.e. Swiss Ball) stresses the neuromuscular system to a greater extent than traditional resistance training methods using more stable benches, machines, and floors. 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). Rutherford and Jones (1986) suggested that the specific neural adaptation occurring with training was not increased by recruitment or activation of motor units but an improved co-ordination of agonist, antagonists, synergists and stabilizers. Thus, the inherently greater instability of an unstable platform and body interface should challenge the neuromuscular system to a greater extent, possibly enhancing strength gains and, in turn, possibly improving athletic performance or performance of activities of daily living.

The use of unstable training environments has been purported in the popular literature to enhance sports specific training effects through increased activation of stabilizers and core muscles (Cosio-Lima et al., 2003; Kornecki and Zschorlich, 1994; Mori, 2004; Vera-Garcia et al., 2002) in untrained adults. However, the disadvantage of instability resistance training appears to be that there is a reduction in maximal force generating capacity (Anderson and Behm, 2003; Anderson and Behm, 2005). Nevertheless, instability training may promote high muscle activation output despite lower force outputs (Anderson and Behm, 2003; Behm et al., 2002) due to some muscle energy being required for stabilization.

There is currently a lack of research investigating the effects of unstable training after an extended period of time as most only refer to an acute bout of training. Thus, the objective of this study was to investigate differences in physiological and performance measures in eighteen healthy young adults following 8 weeks of stable and unstable resistance training.

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2 REVIEW OF LITERATURE

2.0 Abstract

Resistance training using unstable platform and loads, or "instability resistance training", has recently become popular as an alternative to or in combination with traditional resistance training using weight stack machines. The suggested enhanced neuromuscular adaptations from an unstable training environment may be the result of improved coordination of agonists, antagonists, synergists, and stabilizers and consequently results in improved postural and spinal stability. The integration of peripheral and central nervous system control, anticipatory postural adjustments and muscular co-contractions also plays a vital role in maintaining and controlling body movements while unstable.

A decrease in force output is seen when training while unstable yet muscle activation may still remain high having possible positive implications for muscular rehabilitation. Balance training is closely related to instability resistance training but without the added resistance but may improve coordination and force output when integrated into an instability resistance-training program.

There is currently no research examining the effects of instability resistance training on physiological and performance measures over extended periods of time. Thus, this review of literature was conducted to address this gap in current stability training research.

2.1 Introduction

Instability training, or training with the use of unstable loads and/or platforms, has only recently begun to emerge and become recognized as an effective strategy, by itself and/or in combination with added resistance (instability resistance training), at increasing core (trunk/torso) stability and potentially improving task performance through facilitated spinal and postural stability. This stability is provided by strength, endurance, and neuromuscular coordination of prime movers and stabilizers, in particular the trunk muscles which get activated to a greater extent as movements become moderately unstable (Cosio-Lima et al., 2003; Vera-Garcia et al., 2002; Mori, 2004; Behm et al., 2003; Anderson and Behm, 2005), and to a lesser extent with extreme instability (Behm et al., 2002), during an acute bout of training.

Balance training, which is closely related to instability resistance training, has been shown to be effective for improvements in dynamic balance (Holm et al., 2004), muscular strength (Heitkamp et al., 2001), equalization of muscular imbalances (Heitkamp et al., 2001) and thus has been shown to have a functional role for vocational purposes, recreation, activities of daily living or injury prevention and rehabilitation.

The purpose of this research was to determine differences in physiological and performance measures following stable or unstable resistance training (8 week) in healthy, untrained adults and to investigate the necessity and possible implications for this type of training through a review of the literature. This may be beneficial in determining the extent to which instability resistance training, as compared to stable resistance training, challenges the neuromuscular system and provides carry over into activities whereby individuals improve their performance through the ability to exert greater forces or power when unstable.

2.2 Resistance Training

Resistance training has become an integral part of physical activity in today's culture as it provides many mental, social and physical benefits. Free-weight lifting, pin-loaded weight stack machines, and more increasingly, the use of instability devices such as Swiss balls exist as possible approaches to training. Instability devices introduce an unstable base of support while individuals perform their usual resistance training and thus there is likely an increase in demand on the global stabilizers (i.e. internal obliques (OI)) and local stabilizers (i.e. multifidus) simultaneous with the task requirements of the prime movers. Training in an unstable environment may be of particular importance to athletes as it has been shown that the best improvements in athletic performance are seen when training movements closely mimic the performance movements (training specificity) (Sale, 1988; and Komi, 1986).

Training with free-weights and machines both have been reported to offer distinct benefits (Garharmmer, 1981., and Stone, 1982). The benefits of free-weights over machines are due to the similarity in movement and stability requirements of free-weights to those seen in activities of daily living as well as those exhibited by athletes in sporting activities. Furthermore, increasing the stabilization demands while using free-weights, may be enhanced by having the individual lift dumbbells with one arm as opposed to two, as seen with barbell and bilateral dumbbell exercises (Behm et al., 2003). Generating specific results with training is an advantage of using free-weights due to the huge available option of exercise choices. Low cost, space efficiency, the capability of full body training and the fact that free weights offer an external resistance that does not vary throughout the movement, may be viewed as additional benefits of training with free-weights.

The three dimensional movement pattern of free weights versus the pre-determined one-or two dimensional pattern of weight machines is another aspect for which the latter is criticized. The free weight pattern may be viewed as more beneficial as it requires the muscles to function in more of a stabilizing fashion (Baechle, 1994). In addition, machines may be disadvantageous as some provide resistance only at a single joint, thus isolating the target muscle. Very few activities of daily living use this type of movement. Machines are frequently able to conform to a set variety of anthopometric differences among users but usually adhere to a slow to fast movement pattern, which prevents a natural acceleration through the movement. This differs from the customary fast to slow patterns seen in most sporting actions (Behm and Sale, 1993). Nonetheless, machines may offer the advantage of ensuring proper range of motion patterns which may in turn decrease the probability of injury, in particular for novice resistance trainers (McCaw et al., 1994) or in rehabilitation settings.

Many of the increasing number of available assistive training devices are currently being used to replicate real life situations in an attempt to maximize performance by transferring the effects of training under unstable conditions. One of the most popular assistive training devices is the Stability Ball, which has also been referred to as a "Swiss Ball"(Siff, 1991). The effectiveness of training with the Swiss ball through techniques that foster postural stability, has been demonstrated successfully by Siff (1991) and Stanforth et al. (1998). Also, training at fast velocities may even further enhance perfomance of a task, especially where power is an important factor (Pipes and Wilmore, 1975). Examination of movement velocity in resistance training is limited with conflicting results. An investigation by Knapik and Ramos (1980) proposed that motor tasks become more disparate and necessitate different patterns of neural recruitment and coordination the more velocities differ from each other, indicating the importance of movement specificity in training. Studies have shown that greater increases in rate of force production are generally achieved with dynamic training at higher speed whereas increases in tension are typically found with slow dynamic or isometric training (Hakkinen and Komi, 1986, and Rutherford and Jones, 1986).

Conversely, Behm (1991) trained 3 groups of 10 men on either surgical tubing, hydraulic or isotonic equipment. The exercise utilized was the shoulder press at a velocity of 180 degrees/sec. No differences were found between groups as significant ($p < 0.01$) increases at the180 degrees/sec velocity and below (60-180 degrees/sec) were evident with all research groups. This evidence against velocity specificity is in accordance with Thorstensson et al., (1976) and also Young and Bilby (1993), the latter of whom examined the effects of fast and slow squat training in two groups of nine men (velocities were not specified) and found no significant training differences between the groups. Few studies have investigated the effects of different velocities using resistance training equipment. The results of these studies are difficult to compare due to differences in training and testing protocols. Therefore suggesting recommendations for a movement velocity for resistance training to effectively improve strength, performance or function would be difficult.

It has generally been concluded that exercises using free weights are more beneficial than machine type exercises due to the motor learning adaptations that develop and the consequent enhancement of neuromuscular coordination (Gantchev, 1996; Ivanenko, 1997; Seth, 1997). It has yet to be examined, however, if the inherently greater instability elicited by a combination of unstable platforms and loads can enhance strength gains and improve performance to a greater extent than unstable loads alone by further challenging the neuromuscular system. Thus, the current thesis will attempt to address this gap in the literature.

2.3 Postural Stability

Coordination of the neuromuscular system plays an important role when applying a force on an external object; this would allow simultaneously coupled movements to take place in certain target joints due to the inhibition of muscles in other joints (Anderson and Behm, 2005). Consequently, instituting muscular contractions to reduce the degrees of freedom within a joint and control extreme movement of external objects is necessary for the process of postural stabilization (Anderson and Behm, 2005). To add to the limited available literature on the role an instability resistance training program may play in the facilitation of postural stability, the current thesis evaluates muscle activity, force output and variable performance measures after an 8 week instability training program. Although postural stability utilizes many of the same physiological theories as spinal stability, such as muscular co-contractions, there will be more of an emphasis on postural stability since instability resistance training induces greater stabilization not only in the trunk but the limb joints as well. Hence, a discussion of spinal stability alone would be too limited for the effects of instability resistance training.

Peripheral and Central Control

Postural stability is a crucial necessity for activities of daily living and injury prevention, especially in an aging population. It is hypothesized that systems related to the adjustment of proprioceptive information at the peripheral level as well as central processing account for the disparity of postural instability on balance (Ivanenko et al., 1997). Maintenance of postural stability, proposed by Kollmitzer et al. (2000), is obtained through tactical control of afferent and efferent information and multimodal feedback loops in the sensorimotor system. When this system of feedback loops is diminished or adversely affected however, body movement increases and maintenance of balance is achieved through an increase in muscle activity (Nardone, 1988). In response to forward and backward sway, the associated postural muscles on the anterior and posterior sides of the body, respectively, from the leg to the thigh to the trunk are activated sequentially in an ascending pattern (Lin and Woollacott, 2002). In addition, Nasher (1976) proposed that when ankle motions are small, disturbances to upright posture may be minimized through the intrinsic viscoelastic forces of the ankle musculature. If not, stability may perhaps be achieved through active voluntary contractions or contractions resulting from vestibulospinal or stretch reflexes (Mizuno et al., 2000) as cited by Anderson and Behm, (2005).

The response of feedback loops and the sensitivity of the position sense of both agonistic and antagonistic muscles are improved by motor skill training (Kollmitzer et al., 2000). The performance of a muscle with training varies between individuals, as does performance of a group of muscles within an individual (Johnson et al., 1973).

Central processing in the brain, whereby accurately controlled movement tasks are facilitated when the cerebellum receives information from the cerebral cortex and spinal cord (Enoka, 2002), also plays an essential role in the maintenance of balance and postural stability. The amount of postural sway may rely on when the individual recognizes position change including an increase in velocity and acceleration and the ability to accurately judge and maintain joint torque impulses (Loram et al., 2001). Difabio et al. (1990) suggest alterations to functional balance reactions are made efficiently by sensory feedback at a subconscious level. They also suggested that when a threshold level of sensory feedback is achieved, postural responses are then produced through central triggers.

On the whole, postural stability is governed by the central nervous system and is facilitated by visual, proprioceptive and vestibular inputs, which may vary depending on the availability of sensory information at centers initiating and modulating muscle activity. It may therefore be valuable to evaluate how effectively instability resistance training can challenge the neuromuscular system to potentially improve postural stability and further enhance functional performance.

Anticipatory postural adjustment

During task performance, postural stability is facilitated by anticipatory postural adjustments (APA's). Preceding the onset of voluntary movement of the trunk or upper limb, the instigation of postural adjustments of the trunk or legs are evident and have been hypothesized to play a role in reducing disruptions in the body's equilibrium (Mizuno et al., 2001) as cited by Anderson and Behm (2005). These postural adjustments have been shown to be non-existant or greatly decreased when participants are given external support and increase with moving or oscillatory support surfaces (Cordo and Nasher, 1982). Nouillet et al. (1992) examined APA's during maximum flexion velocity of the lower limb in subjects standing on both one and two feet. EMG activity of the tibialis anterior, soleus, sartorius, and tensor fascia latae were measured and activated approximately 30msec before the intended movement. These findings are in accordance with results by Kornecki et al. (2001) and have led to hypotheses that these trends are APA's and are intended to facilitate postural stabilization. It has been hypothesized that a voluntary movement itself is a perturbation of stability, and in order for that movement to be fluent and proficient, a counter-pertubation must exist (Nouillet et al., 1982).

Successful stabilization and maintenance of vertical posture have been suggested by Slijper and Latash (2000) to relate to balancing the body so that the projection of its center of mass does not move beyond a small area of support, as well as to the effect of external forces, torques, and changes in body geometry that occurs during voluntary movements. It should be noted, however, that an APA in itself can be considered a pertubation as it can move the center of mass outside the reduced support area (Anderson and Behm, 2005). In accordance with Stokes et al., (2000), Slijper and Latash (2000) examined subjects during unstable standing and found an anticipatory increase in the EMG activity of the TA, biceps femoris (BF), erector spinae (ES), and rectus abdominus (RA). Changes in the SOL and rectus femoris (RF) were not as great.

Although instability resistance training should stimulate neuromuscular and proprioceptive control of posture, there are no definite conclusions on whether APA's can intercede positive adjustments to postural stability (Anderson and Behm, 2005).

Muscle Stiffness and Co-contractions

Researchers have suggested that muscular stabilization consists of an increase in the tissue's stiffness, connected with the joint under stabilization (Loram et al., 2001) in addition to the controlling and inhibiting effect of the central nervous system (Kornecki, 1992). Joint stability has been shown to improve through coactivation of agonist and antagonist muscles (Stokes et al., 2000; Milner et al., 1995). This is in accordance with Milner and Cloutier (1993) who found that as joint torque increased so did muscle stiffness and viscosity. Furthermore, while examining the role of multi-joint muscles, McIntyre et al. (1996) found that the stiffness needed at one joint may be affected by the level of torque applied at another. In order to maintain limb stability each muscle's stiffness needs be a function only of its own force output. Similarly, Crisco and Panjabi (1991) showed that the positional equilibrium of a joint is enhanced with the more muscles that cross it, thus allowing passive control of a global property of the system.

The aforementioned research (peripheral and central control, anticipatory postural adjustments, muscle stiffness and cocontractions) attempts to show how the central nervous system uses unique strategies to control postural stabilization and generate muscle force patterns necessary to perform a given movement task. It is necessary to understand these concepts in order to evaluate the possible adaptations of the neuromuscular system during instability resistance training. The current thesis will attempt to evalutate neuromuscular efficiency after 8 weeks of instability training.

2.4 Spinal Stability

A brief overview of current theories of spinal control is necessary in this review of literature as extremity functioning is inherently related to the stability and position of the spine. These theories include muscle co-contractions and integration of local and global muscles.

Muscle Co-contractions and Spinal Stability

Many factors affect the stabilization of the spine. Muscle co-contractions are one of these important factors and has been shown to improve spinal stability (Cholewicki et al, 1997). Zetterberg et al. (1987) demonstrated significant muscle activity in trunk flexor muscles during extension or lifting tasks. This trunk muscle co-contraction, however, may contribute to spinal loading, which has been shown to be associated with failure of the vertebral tissue at compression loads of 12000 N (Granata et al. 2000). However, Gardner-Morse and Stokes (1995) suggested that spinal stability can be enhanced by antagonistic co-contraction recruitment of the trunk muscles, allowing the spine to safely accept extreme compressive loads. Furthermore, two additional studies by Gardner-Morse and Stokes (1998) and Granata and Marras (1995) found that this co-activation of the trunk musculature increased compressive loads on the spine by 16-19% and 26-45%, respectively.

More specifically, the CNS, which controls timing and muscle recruitment strategies based on lumbar movement and demands, also helps maintain stability and movement between levels of the lumbar spine (Hungerford, 2003). Deep muscles of the trunk, including the transverses abdominis (TrA) and multifidus, increase stiffness of the spine through co-contraction strategies and appear to fire before limb or trunk movement. (Cholewicki et al.,1997; Hungerford et al., 2002). These results are in accordance with previous research that has recognized activation of TrA, OI, and multifidus preceding limb movements that challenge spinal stability (Hodges and Richardson, 1997; and Moseley et al., 2002).

As the relationship between spinal load and stability may seem debatable, most studies agree that the overall effect of antagonist co-contraction is the reduction of risk in terms of spinal load versus stability of the spine (Granata et al.,2000; Hughes et al. 1995, and Cholewicki et al. (1997). These studies ultimately demonstrate a significantly lesser increase in spinal load compared to the concomitant increase in stability, during antagonistic co-contractions. Hence, it may be suggested that the co-contractions during the lifting of an unstable load or with unstable resistance training may be considered beneficial by providing stability at a joint. It should be noted however that internal muscle tension during these co-contractions may need to be examined to fully understand their effects on a joint.

Local and Global Stabilization

Instability resistance training can be defined as training with the use of unstable loads (i.e. free weights) and/or platforms (i.e. Swiss balls, BOSU balls, dyna discs) to achieve an increase in muscle strength. Recent research by Anderson and Behm, (2004) has suggested and is attempting to explore the idea that strength of the trunk muscles may be increased, through the use of instability resistance training, to the extent of possibly modifying stabilization functions in order to improve motive forces. But to visualize this concept, one must first understand how the body is stabilized and that functional stability is dependent on local and global muscle function (Arokoski 2001; Comerford and Mottram 2001; Kiefer 1997).

Based on anatomical, biomechanical and physiological features, a muscle function classification system has been put forward by Comerford and Mottram (2001) that differentiates muscles as local stabilizers, global stabilizers, and global mobilizers. This system concurs with those defined by Norris (2001), O'Sullivan et al. (1997), O'Sullivan (2000), and Richardson et al. (1992). The stabilizers and mobilizers have been characterized by Norris (2001) as "anti-gravity" and "task muscles", respectively, based on their structure and function. In addition to lending stability under conditions of increased load or stress, the global mobilizers characteristically enable full range of motion around a joint without causing undue strain in the movement system (Comerford and Mottram, 2001).

The local or primary stabilizers' role is to provide a supportive constant low grade muscular force in all positions and directions of joint movement. These are muscles such as the multifidus and transverses abdominis (TrA) whose increased activity in anticipation of movement aids in joint protection but does not generate significant movement at a joint (Norris, 2001). The global or secondary stabilizers provide adequate stabilization but also generate torque and provide joint movement (i.e. internal obliques).

Generally speaking, the major movers for flexion of the trunk are reported to be the rectus abdominis and external oblique, while the internal oblique and transverses abdominis are the major stabilizers (Norris, 2001; and Arokoski et al., 2001). The internal oblique and transverses abdominis muscles are also proposed to be the only two that have a vital function in lumbar stability (Cresswell et al. 1994).

A number of studies have been conducted to assess the muscle recruitment patterns during different types of lifting (Arokoski et al., 2001; Daneels et al., 2001). Symmetrical co-contraction was seen with all types of uneven/unbalanced lifting in the rectus femoris, left and right internal obliques, and multifidus in the Daneels et al. (2001) study. Similarly, research by Pope et al. (1986), and McGill (1991) imply that during asymmetrical movements of the spine, local system muscles display bilateral patterns of activation consistent with a stability role, whereas global system muscles display patterns of activation more consistent with torque production.

The ligamentous attachments of the vertebrae of the lumbar spine cannot solely prevent the spine from being inherently unstable. Stability in this context is defined as the ability of a system to return to its equilibrium position after a small perturbation (Stokes et al., 2000). The spine must be stabilized by the stiffness of the muscles and motion segments to prevent buckling. Otherwise, a sudden excessive displacement could occur and result in tissue injury (Stokes et al., 2000). It has been shown that muscle stiffness, which increases with intensity of muscle activation, can maintain the neutral lumbar position and prevent lumbar spine buckling that would occur otherwise in subjects under loaded conditions or when experiencing a perturbation (Bergmark, 1986; Cholewicki et al., 1997 and Gardner-Morse and Stokes, 1998). Therefore, the patterns of human trunk muscle recruitment not only must provide static equilibrium and appropriate response to changes in loading and displacement perturbations, but also must provide sufficient stiffness to ensure stability of the vertebral column (Cresswell et al., 1994; Gardner-Morse et al., 1995 and Hughes et al., 1994). Coactivation of antagonistic muscles is part of a strategy that can increase the muscular stiffness and hence stability, but at the cost of increased spinal loads (Lavender et al., 1992; Gardner-Morse and Stokes, 1998; Granata and Marras, 1995).

Cholewicki and McGill (1996) reported that the lumbar spine is more vulnerable to instability in its neutral zone and at low load when the muscle forces are low. They confirmed that under these conditions lumbar stability is maintained by increasing the activity (stiffness) of the lumbar segmental muscles (local muscle system). They also emphasized the importance of motor control to coordinate muscle recruitment between large trunk muscles (the global muscle system) and small intrinsic muscles (the local muscle system) during functional activities to ensure mechanical stability is maintained. Cresswell et al. (1994) proposed that maximal stiffness at a joint can result from muscle contractions as low as 25% of maximal voluntary contraction (MVC). Similarly, it has been suggested that the efficiency of the predominantly slow twitch multifidus muscles can be improved by training with relatively low loads (approximately 30-40%MVC) (Cholewicki and McGill, 1996). These findings have lead to speculation that dynamic stability training is influenced not just by muscle strength and that an appropriate training environment for spinal stability may not necessarily be provided by unstable resistance training conditions using relatively high loads (Anderson and Behm, 2005).

A more in-depth look at the effects of acute bouts of instability resistance training on motor control will be reviewed in the following sections. It is not known, however, to what extent longer term instability resistance training can modify stabilization functions in order to improve motive forces, and thus will be a focus of the current thesis.

2.5 Effect of Instability on Muscle Activity and Force Output

The popular use of the "Swiss Ball", also referred to as a "gym ball", or "Stability ball" has been utilized by physical therapists, especially by the Swiss and Germans since before World War II for therapeutic as well as sport training techniques (Behm et al., 2002). Even though exercise balls are becoming more commonly used, little scientific evidence is available regarding their efficacy. The literature , however, only examines the effects of instability on muscle activation, coactivation, and force output of the core and limb muscles during a single bout of exercise.

Evidence supporting the hypothesis of improved core strength has only recently started to come forth, but nonetheless conflicting research has been published. Cosio-Lima et al. (2003) showed greater gains in both trunk balance and EMG activity after five weeks of stability ball training compared to traditional floor exercises. This is in accordance with studies by Vera-Garcia et al. (2002) and Mori (2004) that used abdominal curl ups as well as a variety of gym ball stabilization exercises respectively to show increases in trunk stabilizer muscle activity.

Conversely, Hildenbrand and Noble (2004) showed that performing abdominal exercises with a "FitBall" did not elicit greater activity of the upper rectus abdominis (URA) and lower rectus abdominus (LRA) than performing traditional trunk curls. This concurs with Stanforth et al. (1998) who stated that training with a "stability ball" for activating the back and abdominal muscles was comparable to traditional floor work.

Most studies of muscle response and postural control during load handling have focused on stable (fixed) loads. It has been speculated that muscle activation will increase as a result of the demands of an unstable surface (Vera-Garcia et al, 2000) as well as the demands of an unstable load (Lee and Lee, 2002a; Lee and Lee, 2002b). In a study to evaluate the effect of unstable exercises on trunk muscle activation Behm et al. (2003) examined eleven subjects performing six trunk exercises under stable (bench) and unstable (Swiss ball) conditions. Results showed that instability with trunk strengthening exercises significantly increased activation of the upper lumbar, lumbo-sacral erector spinae and lower abdominal muscles.

Subsequent research by Anderson and Behm (2003) had fourteen male subjects performing squats with different degrees of stability (Smith machine – very stable, free squat – relatively stable, standing on balance discs – relatively unstable) and with varying resistance. Differences in EMG of the soleus, vastus lateralis (VL), biceps femoris (BF), abdominal stabilizers (AS), upper lumbar erector spinae (ULES), and lumbo-sacral erector spinae (LSES) were examined. The results showed as subjects became more unstable, the LSES, ULES, and AS were recruited more to maintain stability of the spine and torso. Therefore, activation of the trunk musculature may be supplemented by the use of unstable platforms during specific trunk strengthening exercises or in combination with limb strengthening activities. Once again, these results only examine the acute response to an unstable movement therefore it would be beneficial to examine the longer term muscle activity responses to training in an unstable environment. Hence, this is one of the objectives of the current thesis.

Conditions of instability, such as those utilizing unstable platforms and loads, require the additional use of the body's stabilizing muscles, thus decreasing the ability of prime movers to exert force or power. Characteristically, strength-training adaptations are mostly elicited through overload tension on the muscle (Behm, 1995; Tan, 1999), however, under unstable conditions, the capability to exert force or power is reduced (Anderson and Behm, 2003). Thus, when developing a resistance-training program the amount of instability prescribed when performing exercises may be of functional critical importance, as the desired physiological and performance outcome may not always be achieved.

Kraemer and Fleck (1988) stated that exercise regimens need repetitions which provide resistance intensity in the range of 40-120% of 1 repetition maximum (RM) or isometric maximum voluntary contraction (MVC) is required to facilitate the production general and maximal strength. This is consistent with the views of Stone et al. (1998) and Tan (1999). Behm et al.'s (2002) protocol showed that the plantar flexors generated significantly less force in the unstable condition than the stable condition, as did the leg extension protocol. At a closer look, the 79.8% of stable MVC seen by the plantar flexor could still supply an overload stress on the muscle with a limited number of contractions, whereas the leg extension protocol would not provide sufficient overload resistance (29.5%) to encourage strength adaptations. This finding suggests that that not all training should be performed under very unstable conditions if one desires to build limb muscle strength. Thus, it seems likely that a combination of concurrent stable and unstable resistance training may impart both the balance and limb strength for an individual to excel in most sport or ADL's. Further findings of this study showed that during leg extensions, antagonistic hamstring activity increased by 29.1% ($p = 0.05$) under unstable vs. stable conditions. The antagonist tibialis anterior during PF showed an increase of 30.3% in EMG activity during the unstable PF, however, these results were not statistically significant. Hence, it was suggested that an unstable training condition may allow a strength training adaptation of the limbs and that the increased function of the cocontracting antagonist when producing force may have been to manage and hold the position of the limb. Other research has shown that increased joint stability (Hogan, N., 1984) and stiffness (Karst and Hasan, 1987) may result and be a function of an increase in antagonist activity.

In addition to utilizing motor control and balance, an increase in antagonist activity, with the use of unstable conditions, would as well contribute to a greater decrease in force. This would be due to the greater resistance and demand now applied to the intended movement. When examining the literature it seems that antagonist activity varies depending on the type of task and how familiar the task is to each subject. Englehorn (1983), for example reported increased antagonist activity as subjects mastered a learned task, whereas both Deluca and Mambrito (1987) and Marsden et al. (1983) reported greater antagonist activity when a lack of certainty was apparent in the task.

Furthermore, the findings of decreased force output with unstable support conditions found by Behm et al. (2002) is in accordance with the findings of Kornecki and Zschorlich (1994) who observed 20-40% decreases in force output when exerting muscular power against an unstable pendulum-like device. Although unstable force output has been shown to be lower in situations where the support surface is unstable it has been observed that muscle activity, measured by EMG, remains relatively consistent between unstable and stable exercise movements. Anderson and Behm (2004) compared stable and unstable isometric chest press and saw no significant difference between EMG activity of the pectoralis major, anterior deltoid, triceps, latissimus dorsi, and rectus abdominus. This finding coexisted with a decrease in chest press force of 60% under unstable conditions, leading the authors to suggest that motive forces of the muscles were transferred into larger stabilizing forces. Consequently, muscle activation can be sustained or increased due to the increased dependence on stabilization functions while externally measured forces may be impaired by instability. Thus, an objective of this thesis is to examine the potential decrease in deficit of force ouput and the amount of co-contractions through an adaptation to the unstable environment.

2.6 Balance Training and Muscular Strength

The relationship between balance, instability and strength is not fully understood as the isolated effect of balance training on muscle strength, without accompanying strength training, has not been researched in the past. When examined, it was usually in connection with complicated injuries, during which coordination training was normally coupled with a strength training program and in very old persons for research on prevention of falls (Judge et al., 1994). Balance training is closely related to and may sometimes be considered synonymous with instability training and usually involves the use of instability training devices such as wobble boards, dyna discs, trampolines and stability balls. Instability resistance training, on the other hand, is closely related to balance training, but with added resistance (i.e. using dumbbells), or in the case of a training program, a progressive added resistance. Therefore, results from a balance training program may have some implications for instability training programs.

A study by Heitkamp et al. (2001) compared the effects of a balance training program alone to a strength training program on strength of the knee flexors and extensors. Balance training was performed on instability training devices such as a rolling board, mini trampoline and large rubber ball. The strength training group (n= 15) trained on machines for leg curls and on leg presses for 25 minutes per unit. Results showed that strength gain was similar for the flexors and extensors in both groups. One-leg balance improved after balance training with a 100% increase over the strength training group. These findings suggest that muscular strength can be improved with 6 weeks of balance training.(Heitkamp et al., 2001). On the contrary, Judge et al. (1994) conducted a 3 month study with 110 persons over the age of 75 whereby resistive training or the combination with balance training showed an improvement in strength. Balance training on its own, however, showed no improvement in strength. It should be noted that balance exercise was conducted at a much lower intensity than in the previously mentioned investigation by Heitkamp et al. (2001).

In addition, improved muscular balance is an important part of injury prevention. A study by Odd-Egil Olson et al. (2005) had 120 youth (15-17yr) handball teams (61 teams in the intervention group, 59 in the control group) follow a warm-up program for 8 months. The intervention groups warm up consisted of regular running and jogging drills and exercises with a rubber ball, including the use of wobble boards and exercise mats, for warm up, technique, balance, and strength. The control group only performed the running and jogging exercises for their warm-up. Results showed that the incidence of knee and ankle injury was reduced by approximately 50% in the intervention group. This is concomitant with another study from senior men's elite soccer that also showed a significant decrease in the rate of injuries to the anterior cruciate ligament as a result of a static balance training program using a balance board (Caraffa et al., 1996). These findings indicate that a well designed balance training program may not only prevent injuries but also improve dynamic balance and that this effect is maintained for at least 12 months (Holm et al., 2004).

A study by Bullock-Saxton et al. (1993) demonstrated that the increase in proprioceptive flow from wearing "balance shoes"(shoes that have contoured bottoms as to provide an unstable surface when worn) as one means of labile support during walking was effective in significantly facilitating the activation of the gluteus maximus (208.8%) and gluteus medius (195.2%). It also showed that after only one week of introducing brief periods of such walking in balance shoes to the daily routine, a motor program for gait was established that included a more effective activation of gluteal muscles. This may suggest that the use of "balance shoes," worn during various resistance training exercises, could be used as another method of increasing stabilization while, at the same time, strengthening the limb muscles in a progressive manner.

Furthermore, Kean et al. (2006) investigated the effects of fixed foot (wobble board) and functionally directed balance training (jumps and landings) on muscle activation and co-contraction during jump landings in 24 recreationally active women. The fixed foot balance group showed a 33% increase in reactive rectus femoris (RF)

EMG activity ($p < 0.01$) when landing and an increased countermovement jump height. Researchers concluded that fixed foot balance training improves static balance measures but not force output or sprinting performance in recreationally active women.

Conversely, balance, co-ordination, force and performance could be hindered when unstable by an increase in the stiffness in the joints performing the action. 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. This is in accordance with Carpenter et al. (2001) who suggested that a stiffening strategy was implemented when individuals were faced with the threat of instability. This increase in stiffness may improve perfomance by allowing balance to be maintained, however, depending on the amount of force needed to stabilize the joint, this may decrease the available force for the actual task at hand.

2.7 Conclusions

There are very few studies available, which examine the effects of instability resistance training programs on physiological and performance measures over any extended period of time. Through this research we will attempt to explore whether longer-term instability resistance training can modify stabilization functions in order to improve motive forces, and if so, to what extent. The literature shows a deficit in force output with similar amounts of EMG when performing movements under unstable conditions during a single bout. Thus, it was hypothesized that 8 weeks of resistance training under unstable conditions will decrease this deficit of force to a greater degree while maintaining or decreasing muscle activity compared to 8 weeks of resistance training under stable conditions. It was also hypothesized that resistance training under unstable conditions will improve balance and other unstable performance measures to a greater extent than resistance training under stable conditions

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3 TRAINING ADAPTATIONS ASSOCIATED WITH INSTABILITY RESISTANCE TRAINING

3.0 Abstract

The objective of this study was to determine differences in physiological and performance measures following stable and unstable resistance training. Physiological measures included stable and unstable chest press isometric force and electromyographic (EMG) activity of the triceps brachii and pectoralis major. Performance measures included one-legged throwing distance, balance, countermovement and drop jump heights. Eighteen healthy subjects resistance trained 3 days a week under stable or unstable conditions for 8 weeks. No significant training-specific effects were found with any of the outcome measures There was an overall (main effect for type of testing) significant 42.2% greater maximum voluntary isometric contraction (MVIC) force output with stable isometric chest press than unstable isometric chest press, independent of the training groups as well as an overall (main effect for time) significant 13.3% training-related increase in MVIC force output (training groups combined). Overall the ratio of unstable / stable pectoral EMG activity and force output showed a significant 18.9% decrease and 18.2% increase post-training, respectively, independent of the training group. There was a tendency (p=0.06) for the unstable training group to improve the unstable/stable force ratio to a greater degree (24.8%) than the stable training group (10.8%). Neuromuscular efficiency results (data collapsed over time) indicated that triceps and pectoral EMG were 43.2% and 33.2% more efficient when performing the stable versus the unstable chest press, independent of the training group. Significant pre- to post-training improvements in 3 repetition maximum (RM) bench press (11%) and squat (14.9%), countermovement (11.2%) and drop jumps (3.3%), as well as wobble

board contacts (12.4%) and on-off time ratios (62%), were independent of the training groups. It appears that instability resistance training, which utilizes lower forces, can increase strength and balance in previously untrained young individuals similar to training with more stable machines employing heavier loads on the body.

3.1 Introduction

There has been a lack of research examining the use of unstable platforms and their effects on the physiological measures of force and muscle activation in untrained adults. The use of unstable training environments has been purported to enhance movement specific effects through increased activation of stabilizers and core muscles (Kornecki, 1994; Siff, 1991; Vera-Garcia, 2000) and thus has been advocated as more beneficial than machines. Behm et al. (2002) suggested that moderate but not extreme instability may allow for overload stress to be placed on the body. Furthermore, balance training, which is closely related to instability resistance training but without the added resistance, has been shown to be effective for improvements in dynamic balance (Holm et al., 2004), muscular strength (Heitkamp et al., 2001), equalization of muscular imbalances (Heitkamp et al., 2001) and may be an important part of injury prevention (Caraffa et al. 1996). Balance has also been shown to improve with strength training in older adults (Wolfson et al., 1995; Daubrey and Culham, 1999; Wolfson et al., 1993). However, there are no studies which examine and compare the effects of long-term stable and unstable resistance (balance training with added resistance) training regimens on physiological, performance and balance measures in untrained adults.

The objective of this study was to determine differences in physiological and performance measures following 8 weeks of stable and unstable resistance training in eighteen healthy untrained adults.

3.2 Methodology

Subjects

The sample size in the present study was eighteen, which included 10 males (24.6 ± 5.4 yrs, 176.8 ± 6.2 cm, 80.2 ± 8.4 kg) and 8 females (24.2 ± 6.2 yrs, 170.4 ± 6.6cm, 64.1 ± 10.3kg) between the ages of 18 and 30 years old from Memorial University of Newfoundland who participated in the study. All subjects volunteered and were randomized into a stable or unstable resistance training protocol. Gender was controlled to ensure an equal ratio of male to female in each training group. The Memorial University of Newfoundland Human Investigation Committee approved the study.

Inclusion criteria:

Participants in the study had not performed any resistance training in the previous two years and were free of any health problems (as identified by the Physical Activity Readiness Questionnaire (PAR-Q) form). Participants also provided written informed consent (they fully understood and were aware of possible benefits and risks related to participation in study).

Protocol

Subjects were randomly separated into stable and unstable resistance training groups. The stable group was assigned a whole body resistance training, which emphasized machine exercises (see appendix A). The unstable group worked the same muscle groups using unstable bases (stability ball -SB, dynadisc -DD) and loads (dumbbells -DB) (see appendix B). Each training program was designed to work all major muscle groups in the body – chest, back, abdominals, shoulders, arms and legs (quadriceps, hamstrings, and calves). This was accomplished by requiring each subject to perform a variety of exercises in standing, sitting, supine and prone positions.

Subjects performed 2 sets of 10 repetitions for each exercise with 1-minute rest between each set. Each group trained for 1 hour per session, 3 days per week for 8 weeks (Day one – upper body; Day two – lower body; Day three – upper body; the next day one would then start with a lower body workout, etc.). Subjects were instructed to warm up for 5-10 minutes on bike/treadmill before every workout. To help ensure compliance with the program each subject was called on the phone twice per week by the researcher and was asked about how the program was going and addressed any questions and/or concerns they had.

During an orientation session of the exercise program each subject was instructed on proper technique and resistance progression for each exercise. A starting resistance (a 10 repetition maximum load) was determined by instructing subjects to perform 10 repetitions of a certain weight such that a successive repetition (> 10) would not be possible without a compromise in proper technique. Once proper technique could be attained with greater than 10 repetitions, the resistance could be increased by one increment (which would vary depending on the type of load being lifted – dumbbell or machine) such that only 10 repetitions with proper technique could be completed with that particular weight.

Prior to experimental data collection (week 1), subjects were given an orientation session where they were instructed on proper technique for unstable and stable isometric bench press. These measures were tested pre-exercise (week 1) and post-exercise (week 10) to establish whether any differences in performance could be attributed to the stable versus unstable training programs. All tests were performed under the supervision of a trained fitness instructor (certified as a Professional Fitness and Lifestyle Consultant with a Bachelor of Science degree in Kinesiology). Pre- and Post- testing sessions were completed consecutively in three different areas at Memorial University of Newfoundland (MUN) based on availability and location of equipment. Each area was randomly chosen as a starting point and standardized so each subject performed the tests in the same sequence. The first test done was the one-legged overhead throw. This was performed at the MUN fieldhouse as a large throwing area was needed. The next tests were performed in the Strength and Conditioning Center and included the 3 repetition maximum bench press and squat. The final series of tests were performed in the Human Kinetics laboratory and included the isometric bench press, balance tests, and jumps.

The isometric chest press was chosen for physiological testing (MVC, EMG) in this research as were the monitoring of the triceps and pectoralis major due to its similarity to the Anderson and Behm (2004) research. As they examined the acute effects of instability resistance training on muscle activation and force output, the present research attempted to provide the longer term (8 week) effects of instability resistance training on muscle activation and force output using the same isometric chest press test. The repetition maximum (RM) tests were chosen for training specificity since the participants trained with these exercises (squat and bench press). Furthermore, since instability was a major aspect of the study the wobble board test was used to investigate any differentiating effects of the two programs on balance. Finally a functional test that stressed balance was chosen (one-legged throw) to show the ability of the training to transfer to functional activities (i.e. throwing). Overall, the tests were based on training mode specificity in an attempt to differentiate various physiological and functional consequences of the training.

Isometric Bench Press

Platform

A flat exercise bench was used as the stable platform whereby participants were instructed to lie supine with head, shoulders, and hips to remain resting on the bench while feet were flat on the floor and knees positioned at an angle of 90 degrees.

A 55cm Thera-Band Exercise Ball was used as the unstable platform whereby participants were instructed to lie supine with shoulders on the ball and feet shoulder with apart and flat on the floor for stability. The head and hips were not supported and remained horizontal during the test. One session was used to perform all testing.

Resistance

Subjects performed 2-3 practice attempts before the isometric protocols (stable and unstable) to get accustomed to the test. Subjects pushed using modified foam handgrips grips that attached to a bar which was anchored to a steel platform on the floor. A strain gauge connected the bar to the platform. The upper arm and lower arms were positioned parallel and perpendicular to the ground, respectively, with elbows at a 90 degree and in line with the mid chest. Subjects were asked to perform a maximal voluntary isometric contraction (MVIC) which started on the "Go!" of "Ready, Set, Go!" which was verbalized by the researcher. Thereafter each subject would receive further motivation by the researcher to keep pushing until the trial was complete (6 seconds).

Each MVIC was held for 6 seconds (to obtain an accurate reading of maximal force output and muscle activation) followed by 3 minutes recovery time to prevent fatigue between trials. Force output and EMG activity of the triceps and pectoralis major muscles were recorded.

3 RM Bench Press and Squat

The 3 RM bench press test is characterized by the maximum amount of weight that can be lifted three times and was performed using a standard Olympic bar (20.45kg). Subjects were familiarized with proper technique and a 3RM was performed within fewer than 5 trials to prevent fatigue from being a factor in obtaining a true measure of strength. The 3RM was discovered by starting with the bar (20.45kg) alone and increasing the amount of weight incrementally based on the quality of that set observed by the fitness instructor (technique, difficulty with weight) and the subjective information given by the subject on how difficult they perceived the set to be. In addition, two minutes rest between trials was given in order to ensure adequate recuperation (Baechle, 1994). During the squat exercise subjects were required to descend so that their thighs reached parallel to the floor. A fitness instructor was present to spot each participant and assess the quality of each repetition during the exercise. Safety bars were also put in place and were adjusted just below parallel for each subject during the squat. These tests were performed under stable conditions only.

Balance test

Subjects were required to balance on a circular wobble board for 30 seconds. The duration and frequency (during the 30 s test) of contact was recorded by the software (Kinematics Measurment System, 2001). Each person was given two trials with a 2 minutes break between trials to prevent fatigue. All scores were recorded with the best score of the two trials used for analysis. Subjects received an orientation session for the balance board on a separate day as well as 1-2 practice attempts on the day of testing.

Jumps

Countermovement Jump (CMJ): The participants initially stood on the contact mat as the starting position and when cued by the investigator, were instructed to jump straight up as high as possible. Participants left the mat with the knee and ankle fully extended and landed back on the contact mat with two feet in a similarly extended position to ensure that accurate flight time was recorded. Each participant was permitted to use whatever jumping method they felt comfortable with (i.e. swinging of arms). To ensure validity when performing the post-testing, the jumping method used by each participant was recorded during pre-testing.

Drop Jump (DJ): The participants performed a DJ from a 30 cm high platform. Based on previous studies (Young and Behm, 2002; Young and Power, 2006) this drop height was felt to be sufficiently high to stress the stretch-shortening cycle and yet allow the participants to emphasize a short transition or contact time. The participants were instructed to place their hands on the hips and step off the platform with the leading leg straight to avoid any initial upward propulsion ensuring a drop height of 30 cm. They were instructed to jump for maximal height and minimum ground contact time. The participants were again instructed to leave the mat with knees and ankles fully extended and to land in a similarly extended position to ensure the validity of the test as the software assumes flight time up and down are equal. Jump height was determined by the following forumula: Jump height = (g x flight time x flight time) / 2, where g is gravitational acceleration (9.81 m/s/s) (Kinematic Measurement System, 2001).

One-legged Overhead Throw

For this test subjects were given a medicine ball (male 4.55kg, female 1.82kg) and instructed to use both hands and throw the ball overhead in a straight path as far as they could while standing on one leg. Subjects were required to remain on one leg until after the ball was released from their hands. The distance thrown was then marked, measured and recorded in meters by an investigator.

Measurement and Instrumentation

Electromyography (EMG) - EMG signals were measured from two locations on the right side of the body; mid-belly of the long head of the triceps, and the sternal origin of the pectoralis major. EMG locations were shaved (to remove hair), abraded (to remove dead epithelial cells), and cleansed with rubbing alcohol to decrease resistance and achieve maximal adhesion of the electrode. EMG activity was sampled at 2000 Hz, with a Blackman -61 dB band-pass filter between 10-500 Hz, amplified (bi-polar differential amplifier, input impedance = 2MΩ, common mode rejection ratio $\geq$ 110 dB min (50/60 Hz), gain x 1000, noise $\leq 5\ \mu V$), and analog-to-digitally converted (12 bit) and stored on personal computer for further analysis. EMG was full-wave rectified and integrated (filter frequencies 10-500Hz). This integration was a summation of the EMG data under the curve with units measured in microvolt-seconds ($\mu V*s$). The formula used for the integration is as follows: $f_{output}(n)$ = the sum of $f_{input}(k) + ((f_{input}(n-1) + f_{input}(n))/2)* \Delta Ts)$, where f are the data values and ΔTs is the sampling interval. EMG was examined between the one second before and one second after the highest force reading of the selected trials. EMG was evaluated with the Acqknowledge™ software program (Acqknowledge III, Biopac Systems Inc., Holliston, MA).

Force - Handgrips were connected to a strain gauge (Omega, BLH Electronics, Universal 3SB load cell) which was fastened to the floor underneath the steel platform used for lifting. Signals were amplified (Biopac Systems MEC 100 amplifier Hollistion, MA) and observed/monitored on computer (Daytek computer monitor) after being directed through an analog-digital converter (Biopac Systems Inc., DA 100: analog-digital converter MP100WSW; Holliston, MA). Data was analyzed with Acqknowledge™ software program and recorded on a Sona Phoenix computer at a sampling rate of 2000Hz. Two trials were performed for each condition and were required to be within 5% of each other. The highest maximum voluntary isometric contraction (MVIC) was used for evaluation. A third trial was required if the force readings were not within 5% of each other. In this case the mean of the two highest MVIC's was used for evaluation.

Contact Mat - All jumps were performed on a contact mat (Innervations, Muncie, IN, USA) and analyzed using a commercially available software program (Kinematics

Measurement Systems, Innervations, Muncie, IN, USA). The measurement variable for the countermovement jump (CMJ) and drop jump (DJ) was jump height. A minimum of two CMJ's and DJ's were performed during the pre-test unless there was greater than a 5% difference in jump height, which resulted in a third jump. The jump with the greatest height was used for analysis. Only two CMJ's and DJ's each were performed during each post-test to reduce the effects of fatigue. A comparison of CMJ and DJ provided a comparison of vertical jumps emphasizing impulse versus the stretch-shortening cycle respectively.

Wobble board - A balance ratio (contact with floor to no contact time) and the number of contacts were calculated by a software program (Innervations, Muncie, Indiana) from a 30 s wobble board test (Kinematic Measurement Systems, Muncie Indiana). A metal plate connected to the computer hardware was placed under the wobble board. When the perimeter of the wobble board made contact with the metal plate, the duration and frequency (during the 30 s test) of contact were recorded by the software. Subjects were given two trials with a 2 minutes break between each trial. All scores were recorded with the best score of the two trials used for analysis.

Data Processing:

The data for the unstable isometric chest press were normalized by calculating a ratio of the unstable chest press isometric force to the stable isometric force during the pre- and post-tests. A similar ratio (unstable to stable isometric testing) was also used to normalize EMG data when tricep and pectoral EMG were compared pre- and post-training. Since EMG variability is high in a longitudinal training study due to possible changes in electrode positioning, subcutaneous fat deposition, skin thickness and other resistive factors, the ratios decrease variability by allowing each subject to be used as their own control, thus any changes in the ratios should be due to training and not experimental error or anthropometric factors. Since resistance training should increase strength overall, the unstable / stable ratio should reflect whether one form of training was better at relatively improving force output or muscle activation while unstable. For example, since force is typically depressed with instability (Anderson and Behm, 2003; Anderson and Behm 2005; Behm et al., 2000), changes in the unstable/stable isometric force ratio with training would illustrate the ability to exert greater or lesser force with unstable conditions.

A measure of neuromuscular efficiency (NE) was determined to identify any training-related changes in muscle activation per unit of force production. NE in this study was defined as integrated EMG amplitude/ force. A more efficient neuromuscular system would need less activation post-training to exert similar forces from the pre-training session (lower EMG / force ratio). For example, an increase in neuromuscular efficiency from pre- to post-testing after training with a particular program (stable or unstable) would be shown by a decrease in the EMG (μVs)/force (N) ratio indicating that the particular muscles tested (triceps and pectoralis major) were able to exert the same force (during the isometric bench press test) after training using less muscle activation.

Statistical Analysis

Three and two way ANOVAs with repeated measures were used with the factors:

type of training (stable versus unstable); type of testing (stable versus unstable); time: pre- and post-training. Three way ANOVAs were used with tests that included neuromuscular efficiency, unstable versus stable isometric force ratio, unstable versus stable EMG amplitude ratio, EMG activity, and isometric force production. Two way ANOVAs with repeated measures were used with tests that were only tested under either stable or unstable conditions. These included the one legged throw and balance tests (unstable) and the 3 RM bench press and squat and jump tests (stable).

Differences were considered significant at a $p \leq 0.05$ level. Post hoc tests used were Bonferroni (Dunn's) Procedure. Effect sizes (ES = mean change / standard deviation of the sample scores) were also calculated and reported (Cohen, 1988). Cohen applied qualitative descriptors for the effect sizes with ratios of <0.41, 0.41-0.7, and >0.7 indicating small, moderate and large changes respectively. All data were analyzed using GB-Stat (version 7.0 Dynamic Microsystems, Inc., Silver Spring, MD) for Microsoft Windows. Descriptive statistics include means (M) and standard deviations (SD).

3.3 Results

Sample: There were no significant pre-testing differences in any measures between the training groups except for the one-legged throw (see results for one-legged throwing distance).

Isometric force production: There were no significant interaction effects between training groups for MVIC force production (Table 1). However, there was an overall (main effect for type of testing) significant 42.2% ($p<0.0001$) greater MVIC force output (stable = 556N ± 226N; unstable = 322N ± 138N) with stable isometric chest press than unstable isometric chest press, independent of the training groups.

There was an overall (main effect for time) significant 13.3% ($p<0.0001$) training-related increase in MVIC force output (both training groups combined) (Fig 1).

Fig 1. Overall training related mean of combined stable and unstable MVIC force in Newtons. Significant difference ($p<0.0001$) is indicated by an asterisk (*).

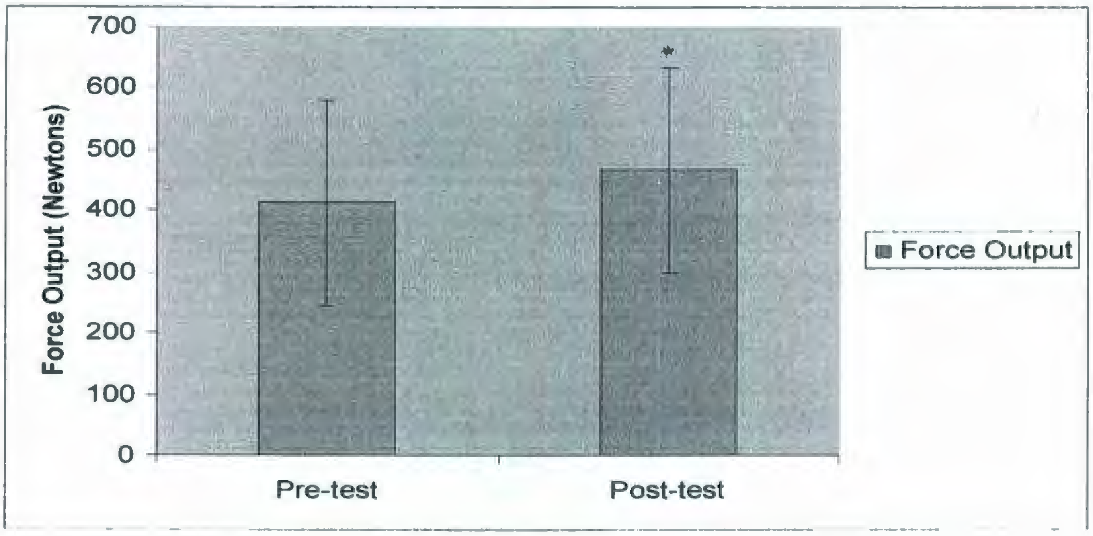


Table 1: Pre and Post-testing Mean and Standard Deviation values of MVIC force output (in Newtons) between unstable and stable training groups during unstable and stable testing conditions. Significant difference ($p\leq0.0001$) from pre-test values within the row are indicated by an asterisk (*).

	Pre-test	Post-test	Pre-test	Post-test
	stable testing (bench)	**stable testing (bench)**	**unstable testing (ball)**	**unstable testing (ball)**
Unstable training group	498 ± 220.8	540 ± 268.8	286 ± 117.5	373 ± 144.9
Stable training group	575 ± 196.4	617 ± 217.1	290 ± 138.7	339 ± 152.5
Mean (stable and unstable training groups)	537 ± 208.6	579 ± 242.9*	288 ± 128.1	356 ± 148.7*

Electromyographic (EMG) Muscle Activity:

There were no main or interaction effects between the training groups for EMG muscle activity (Table 2).

Table 2: Pre and Post-testing Mean and Standard Deviation values of EMG amplitude in microvolt-seconds (μVs) between unstable and stable training groups during unstable and stable testing conditions.

	Pre-test	**Post-test**	**Pre-test**	**Post-test**
TRICEPS	**stable condition (bench)**	**stable condition (bench)**	**unstable condition (ball)**	**unstable condition (ball)**
Unstable training group	103 ± 17	135 ± 34	90 ± 24	124 ± 41
Stable training group	152 ± 49	164 ± 36	191 ± 28	121 ± 43
PECTORALIS MAJOR				
Unstable training group	113 ± 54	122 ± 55	109 ± 68	119 ± 69
Stable training group	205 ± 109	265 ± 166	167 ± 43	153 ± 37

Unstable/Stable EMG amplitude ratio: There were no main effects between the training groups for unstable/stable EMG ratios. There was however a main effect for time with unstable/stable chest press EMG ratios. Overall the ratio of unstable / stable pectoral EMG activity showed an 18.9% significant (p=0.05; ES = 0.6) decrease after training (pre-test 0.87 ± .68 to post-test 0.70 ± .48) independent of the training group. The overall ratio of unstable / stable tricep EMG activity showed a 26% (p=0.46) decrease after training, independent of the training group (Table 2).

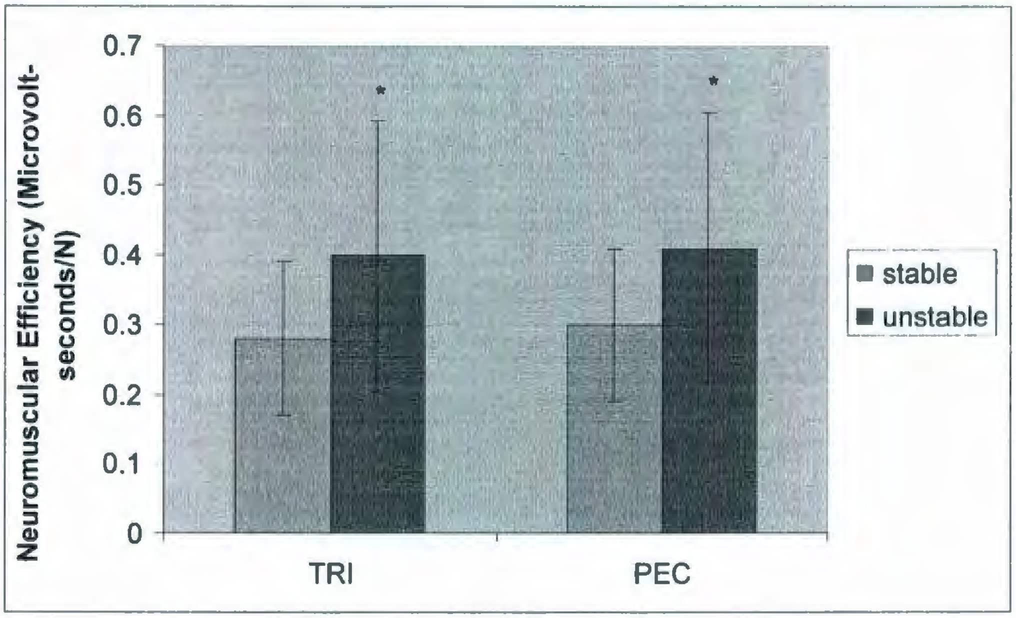
Unstable/Stable Isometric force ratio: Overall (main effect for time with data collapsed over type of training), there was a significant 13.0% (p=0.0005; ES=0.7) training-related improvement in the unstable / stable isometric force ratio (Table 3). There was a tendency (p=0.06) for the unstable group to improve to a greater degree than the stable training group. The unstable training group improved the ratio by 21.0% (p=0.06; ES=1.0) while the stable training group improved by 10.0% (p=0.06; ES=0.4) (Table 3).

Table 3. Pre- and Post-test training differences in unstable/stable isometric chest press force ratios. Parenthesis ( ) identify % increase from pre-test values. Significant difference (p< 0.0005) are identified by an (*).

	Pre-test	Post-test
main effect for time	0.54	0.61 (13.0%)*
stable training	0.50	0.55 (10.0%)
unstable training	0.57	0.69 (21.0%)

Neuromuscular Efficiency: There were no significant training effects on neuromuscular efficiency. A main effect for type of testing (data collapsed over time) indicated that triceps EMG was 43.2% more efficient when performing the stable versus the unstable chest press (p=0.003; ES = 1.5). A similar effect was found for pectorals EMG, which were 33.2% more efficient when performing the stable versus the unstable chest press (p=0.005; ES = 0.9) (Fig 2).

Fig 2. Comparison of the neuromuscular efficiency (Microvolt-seconds/Newton) of the triceps (TRI), and pectoralis major (PEC) when performing stable vs. unstable chest press. Significant differences ($p < 0.05$) are identified by (*).



One-legged throwing distance: The one-legged throw was the only measure to show significant differences between training groups. The unstable group exhibited a significant 38.4% greater throwing distance (data collapsed over time) than the stable group. However, the unstable group had 27.3% significantly greater distances pre-test as well (unstable 36.2m: versus stable 26.3m). A main effect for time (data collapsed over both groups) indicated that there was a significant 5.8% improvement in throwing distance from pre- to post-training (Table 4).

3RM Bench Press and Squat: There were no significant interaction effects between training groups for the 3RM bench press or squat. A main effect for time indicated that there was a significant 11% and 14.9% improvement in 3RM bench press and squat strength from pre- to post-training, respectively (Table 4).

Balance: There were no significant interaction effects between training groups for the number of contacts and on-off time ratio with the wobble board. A main effect for time indicated that there was a significant 12.4% and 62% improvement in wobble board contacts and on-off time wobble board ratio from pre- to post-training, respectively (Table 4).

Jumps: There were no significant interaction effects between training groups for drop jump and counter-movement jump height. A main effect for time indicated that there was a significant 11.2% and 3.3% improvement in drop jump and counter-movement jump height from pre- to post-training (Table 4). There was a tendency (p=0.08) for the unstable group to improve to a greater degree than the stable training group with counter-movement jump height. The unstable training group improved the by 5.7% (p=0.08; ES=1.0) while the stable training group improved by 1.5% (p=0.08; ES=0.4).

Table 4: Pre- and Post-test means, standard deviations (SD), P values (main effect for time), and effect sizes (ES) for the 3 repetition maximum (RM) Bench Press (3RM BP), 3 repetition maximum (RM) Squat, countermovement jump (CMJ), drop jump height, throwing distance, balance on-off ratio, and balance contacts.

Test	Pre-test mean ± SD	Post-test mean ± SD	P value	Effect Size
3 RM BP	112 ± 44.1	125 ± 45.6	<0.0001	0.29
3 RM Squat	154.2 ± 49.2	176.9 ± 50.1	<0.0001	0.46
CMJ (m)	0.366 ± 0.14	0.379 ± 0.094	0.002	0.09
Drop Jump Ht. (m)	0.205 ± 0.07	0.228 ± 0.06	0.001	0.33
Throwing Distance (m)	9.51 ± 1.22	10.06 ± 1.30	<0.0001	0.45
Balance On-Off ratio	2.14 ± 1.08	3.36 ± 1.56	0.005	1.13
Balance Contacts	12.9 ± 1.91	11.3 ± 2.56	0.03	0.84

3.4 Discussion

The most important finding of this study was the lack of difference between unstable and stable resistance training groups following an 8-week training program in young, untrained adults. There were no significant differences found with the training-induced improvements between training groups in pre- to post-test isometric force production, unstable/stable isometric force ratio, EMG activity, neuromuscular efficiency, balance, countermovement and drop jump heights, throwing distance or 3RM bench or squat. However, following training, the unstable training group had a tendency (large effect size magnitude) to be more efficient than the stable training group at decreasing the deficit of force production when training under unstable conditions. This suggests that there may be a tendency for unstable training to be more efficient at increasing force production under unstable conditions.

These findings can be interpreted in two rather divergent ways. First of all, it might be interpreted that traditional stable resistance training provides similar adaptations as instability resistance training and thus there is no need for the inclusion of instability devices such as Swiss balls, inflated discs, BOSU balls and others similar devices in a resistance training program for young, untrained adults. This interpretation, however, was based only on the tests performed in the current study, which examined activation and force output of the tricep and pectoralis muscles, as well as functional performance measures. It did not target postural muscles of the leg or trunk, which have shown to be highly influential when performing tasks while unstable (Anderson and Behm, 2004; Anderson and Behm, 2005; and Behm et al., 2002). An assessment of these muscles may have yielded more significant findings and/or provided more insight into the training adaptations when comparing unstable vs. stable training protocols. This is an area for future research.

Conversely, as it has been shown that unstable exercises utilize lower external forces (Behm et al. 2002, Anderson and Behm 2004) with similar muscle activation intensity (Anderson and Behm 2004), then the similar training results with instability resistance training might provide less injury-inducing torque on the musculotendinous tissue and joints. It should be noted however, that as no significant differences in EMG were found between unstable and stable training in the current study, the isometric contractions utilized in testing, from which linear relationships of force and EMG have been shown (citiation), do suggest similar amounts of force production with both types of training. Thus, internal muscle tension may remain high with instability due to perhaps similar forces on the joint produced through co-contractions (Behm et al., 2002). Hence, caution should be used if utilizing this type of training in a rehabilitation setting as internal muscle tension was not measured in this study and is ultimately what affects the force felt a joint. This is an area for future research. This is the first identified study to examine the effects of instability resistance training (8 weeks) on physiological and performance measures in healthy, young, untrained adults.

Previous studies have shown instability training to be advantageous for trunk activation, which serves to increase core stability (Cosio-Lima et al., 2003; Vera-Garcia et al., 2002; Mori, 2004; Behm et al., 2003; Anderson and Behm, 2005). The disadvantage of instability resistance training, however, is the reduction in force output (Behm and Anderson 2006). However, another advantage of instability resistance training is the high muscle activation that can be achieved with lower external force output. Anderson and Behm (2003) compared stable and unstable isometric chest press and saw no significant difference between EMG activity of the pectoralis major, anterior deltoid, triceps, latissimus dorsi, and rectus abdominus. This finding coexisted with a decrease in chest press force of 60% under unstable conditions, which may suggest that motive forces of the muscles were transferred into greater stabilizing forces. In accordance, our research showed no significant difference between EMG activity of the pectoralis major and triceps when stable and unstable isometric chest press were compared (main effect for type of testing, data collapsed over time and groups). Also, decreases in isometric chest press force of 46% and 39% under unstable conditions (stable and unstable training groups combined) were found during pre- and post-testing, respectively. Consequently, muscle activation can be sustained or increased due to the increased dependence on stabilization functions while externally measured forces are impaired by instability (Anderson and Behm, 2005; Behm and Anderson 2006). The improved isometric force ratio and decreased EMG ratio found during the post-testing (main effect for time with data collapsed over groups) suggests that resistance training overall (stable or unstable) may increase the mobilizing functions while decreasing the need for excessive stabilizing functions.

Neuromuscular efficiency, which represents the muscle activity necessary to exert a particular force did not show any significant training effects. Triceps and pectoral EMG were 43.2% and 33.2% more efficient respectively when performing stable versus unstable chest press (main effect for type of test with data collapsed over training groups and time). This again suggests that under more stable conditions muscles are better able to direct more of their activity to motive forces rather than being used for stabilization.

The present study showed a decrease in the unstable/stable EMG ratio after training (main effect for time with stable and unstable training groups combined). Combined with an increase in the post-training unstable/stable force ratio, it is suggested that resistance training overall (stable or unstable) may increase mobilizing functions while decreasing the need for excessive stabilizing functions in the body. Interestingly, unstable training had a tendency (large effect size magnitude) to be more efficient than stable training at decreasing the deficit of force production seen when training under unstable conditions.

Balance training, which is closely related to instability resistance training but without the added resistance, has been shown to be effective for improvements in dynamic balance (Holm et al., 2004), muscular strength (Heitkamp et al., 2001), equalization of muscular imbalances (Heitkamp et al., 2001) and may be an important part of injury prevention (Caraffa et al. 1996 and Odd-Egil Olson et al., 2005). Kean et al. (2006) investigated the effects of fixed foot (wobble board) and functionally directed balance training (jumps and landings) on muscle activation and co-contraction during jump landings in 24 recreationally active women and concluded that fixed foot balance training improves static balance measures but not force output or performance with sprinting. Similarly, the unstable resistance-training group in the present study showed an increase in static balance measures, but also an increase in force output as a result of instability training, perhaps due to the added resistance during the unstable exercises and the use of untrained individuals. Since the traditional stable resistance group also showed improved balance measures, the adaptation of increased balance with strength training in the untrained individuals may also be due to the increased ability of stronger muscles to return to a more stable position, which is similar to studies with older adults showing increased balance in response to strength training (Wolfson et al., 1995; Daubrey and Culham, 1999; Wolfson et al., 1993).

Kean et al. (2006) also elicited a balance training-induced increase in jump height. They postulated that the proportion of prime mover muscles responsible for stabilization could be decreased by an improvement in balance, allowing them to play a larger role in the propulsion of the body when jumping or running. An individual with an unstable base may not direct all their propulsive forces in the optimal direction (Kean et al., 2006). The present study also found an overall (main effect for time with both groups combined) improvement in countermovement and drop jump height with a tendency for unstable training to increase countermovement jump height by 4.7% ($p=0.08$) greater than stable training. This again suggests that training with unstable bases may enable prime movers to direct propulsive force in a more optimal direction through a general strengthening adaptation and provision of a better optimal take off angle in untrained individuals. It may also suggest that the countermovement jump may provide more of a challenge than the wobble board and thus may more effectively show the strength and balance adaptations of instability resistance training.

Since tension is a primary factor for promoting strength gains (Crewther et al. 2005) how could instability training with its lower tension produce similar gains in strength? Minimal stress is necessary to induce strength gains in untrained individuals. Training programs using just 1 set of 8 repetitions (Hass et al. 2001) or training once a week (Graves et al. 1988) have demonstrated improvements in strength in untrained individuals. The resistance training protocol used in the present research for increasing strength in untrained individuals was based on guidelines taken from the American College of Sports Medicine (2002) and is in accordance with guidelines found in the meta-analysis of more than 140 training studies (Rhea et al., 2003a; Rhea et al., 2003b). However the present results may not apply to all segments of the population.

Studies have shown that highly trained individuals may not experience the same degree of stress from some instability devices as untrained individuals do. Wahl and Behm (2006) measured EMG activity of the soleus, bicep femoris, rectus femoris, lower abdominals and lumbo-sacral erector spinae (LSES) with a variety of instability devices using stable and unstable exercises as well as a fatiguing exercise in 16 highly conditioned individuals. There were no significant changes in muscle activity with the use of moderately unstable devices indicating that the use of these training devices (BOSU and Dyna discs) did not impart adequate challenges to the neuromuscular system in highly resistance-trained individuals. Thus since highly trained individuals may already possess enhanced stability from the use of dynamic free weights, a greater degree of instability may be required in order for efficiency gains to occur (Wahl and Behm, 2006). On the contrary, our findings of improved isometric force ratio and decreased EMG ratio at post-testing suggest that training under either moderately unstable or stable conditions does provide adequate challenge to the neuromuscular system, but may only apply to young adults with no previous resistance training experience.

It has also been shown that training using traditional exercises such as squats and deadlifts using heavy loads can provide higher trunk activation than callisthenic type instability exercises. Hamlyn and Behm (2006) examined trunk activation under stable and unstable conditions showing that squats and deadlifts using 80% of the 1 repetition maximum (1RM) performed on stable floor induced a greater activation of the trunk musculature than unstable trunk callisthenic exercises. This is in accordance with Siff (2000) who suggested that exercises that load the trunk with external resistance such as a squat or deadlift are the best exercises for stimulating the trunk muscles. However, not all untrained individuals are comfortable with some of these traditional exercises (Behm and Anderson, 2006). Thus, instability resistance training is especially practical for the untrained, recreational fitness enthusiast and perhaps rehabilitation where high forces should or need not be exerted.

In the current study isometric force increased for both training groups while the unstable to stable chest press isometric pectoral EMG ratio decreased overall for both groups. This suggests that both groups became stronger with training but that under unstable conditions there was less relative EMG activity post-training. Hence during the pre-training test the higher muscle activity did not produce as much force. It is believed that this "extra" muscle activity was likely used for stabilization. Thus, after training both groups could utilize relatively more of their muscle towards mobilizing force and needed relatively less muscle activation towards stabilizing the upper body. A similar finding was evident in the aforementioned Anderson and Behm (2003) chest press study, however, it showed that there was similar EMG activity even though there was less force with unstable conditions. Again, it was suggested that much of the muscle activation was used for stabilization rather than mobilization.

3.5 Conclusions

In conclusion, the current study indicates that instability resistance training, which inherently utilizes lower resistive forces, can increase strength and balance in previously untrained young individuals as can training with more stable machines employing heavier and potentially more harmful loads on the body. Thus, instability training could be advantageous with musculoskeletal rehabilitation, since high muscle activation can be sustained while using lower intensity resistance. Caution should be taken however, as the internal muscle tension produced during unstable exercises may in fact be the same due to the added joint forces produced through co-contractions. The findings also suggest that instability resistance training may have a tendency to be more efficient at increasing force under unstable conditions. This may be beneficial in facilitating individuals in becoming more functional in their activities of daily living without the added stress on the body's joints, in particular the lower back. There are very few studies available that examine the effects of instability resistance training programs on untrained adults over any extended period of time. Thus, it is recommended that research be conducted which examines strength-training programs that incorporate exercises under both stable and unstable conditions, in an attempt to identify muscle activation during both these conditions and decide which exercises offer the most benefit and carry-over into daily life.

3.6 Limitations

Limitations of this study were the absence of the measurement of trunk muscle activity, the analysis of only two prime movers and the use of only one exercise (isometric bench press) for pre- and post physiological testing. Conclusions about the relationship between muscle activity and force output may have been more valid if an increased number prime movers and tests were used for evaluation.

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3.8 Appendices

APPENDIX A

Resistance Training Program (Stable)

DAY 1		sets	repetitions	rest
UPPER BODY				
Machine Bench Press (supine)	**Triceps Pushdown (standing)**	**2**	**10**	**1 min**
Machine flyes (seated)	**Shoulder Press (machine-seated)**	**2**	**10**	**1 min**
Lat Cable Pulldown (seated - machine)	**Biceps cable curl (standing/seated)**	**2**	**10**	**1 min**
Seated Row (machine)	**Abdominals (seated machine)**	**2**	**10**	**1 min**
DAY 2				
LOWER BODY				
Machine Leg Press	**Leg Extension (seated)**	**2**	**10**	**1 min**
Lying Leg Curl (prone)	**Standing Calf Raise (machine)**	**2**	**10**	**1 min**
Seated Leg Curl (machine)	**Abdominals (seated machine crunch)**	**2**	**10**	**1 min**
Seated Calf Raise (machine)		**2**	**10**	**1 min**
*Warm up – 5-10 minutes on bike/treadmill, etc. before every workout. Alternate upper and lower body for third workout every other wk.				

Stable Training Program - Exercises

Leg Press

Lying Leg Curl

Seated Row

Abdominal Crunch

Leg Extension

Leg Curl

Tricep Pushdown

Machine Chest Flyes

Machine Chest Press

Standing Calf Raise

Seated Calf Raise

Bicep Cable Curl

Machine Shoulder Press

Lat Cable Pulldown

Appendix B

Resistance Training Program (Unstable)

DAY 1		sets	repetitions	rest
UPPER BODY				
Bench press (supine -feet up)	SB seated tricep extension	2	10	1 min
SB dumbbell press (supine)	DD dumbbell shoulder press (standing/seated)	2	10	1 min
SB dumbbell row (one knee and hand on ball)	DD standing biceps curl (DB)	2	10	1 min
SB back extension (prone)	SB crunches (supine)	2	10	1 min
DAY 2				
LOWER BODY				
Squat (DD)	SB squat (one leg w/DB)	2	10	1 min
SB cable leg curl (supine)	SB crunches (supine)	2	10	1 min
Dumbbell calf raises w/SB (standing)	Dumbbell Lunges (SB) (standing-one foot on ball)	2	10	1 min
Seated DD calf raise		2	10	1 min
DB - Dumbbell				
4 DD - Dynadisc				
5 SB – Stability Ball				
*Warm up – 5 – 10 minutes on bike/treadmill, etc. before every workout. Alternate upper and lower body for third workout every other wk.				

Unstable Training Program – Exercises

(Dumbbell – DB; Swiss ball – SB; Dynadisc – DD)

Tricep DB Extension

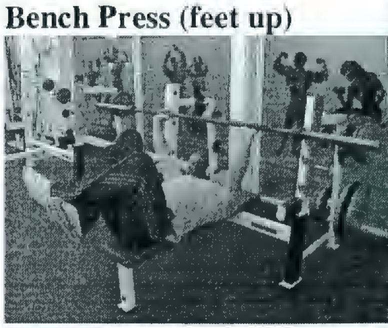
One arm DB row

Squat (one leg w/DB)

One-legged Calf Raises

DB lunges

Bench Press (feet up)



Cable Leg Curl

DB Chest Press

Back Extension

Abdominal Crunch

DD squat

Seated DD calf raise

Standing DD DB bicep curl

Standing DD DB shoulder press