

THE EFFECT OF TRUNK STABILITY AND LEG STRENGTH TRAINING
ON VERTICAL TAKE- OFF VELOCITY IN ATHLETES

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ABSTRACT

THE EFFECT OF TRUNK STABILITY AND LEG STRENGTH TRAINING ON VERTICAL TAKE-OFF VELOCITY IN ATHLETES.

The purpose of this study was to determine the effect of trunk stability training on the performance of vertical jumping as assessed by vertical take-off velocity. Athletes (20 males, 35 females) were randomly assigned to one of four training groups: trunk stability (TS), leg strength (LS), trunk stability and leg strength (TL), and control (CO). Subjects were tested for pre-training scores; after three weeks of training; and at the end of a nine-week training period. A repeated measures ANCOVA was used to examine differences between groups for vertical take-off velocity using a force plate and fatigue index using a repeated vertical jump test. Pre-training take-off velocity and pre-training body mass were used as covariates. After three weeks of training, only the TS group had a significantly greater vertical take-off velocity compared to the control group ($p < 0.05$). After nine weeks of training, however, all three training groups were statistically different from the control group ($p < 0.05$), but not different from each other. Only the TL group increased significantly in vertical take off velocity between the third and ninth week testing periods. There were no significant differences in fatigue index between the treatment groups. Trunk stability training appears to be most effective for early (three weeks) improvement in vertical jumping ability. This finding implies that improvements in take-off velocity as a result of greater trunk stability most likely stem from neuro-muscular control rather than from muscular physiological changes.

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TABLE OF CONTENTS

PERMISSION TO USE.....	i
ABSTRACT.....	ii
ACKNOWLEDGEMENTS.....	iii
DEDICATION.....	iv
TABLE OF CONTENTS.....	v
LIST OF TABLES.....	viii
LIST OF FIGURES.....	ix
LIST OF APPENDICES.....	x
CHAPTER ONE SCIENTIFIC FRAMEWORK.....	1
1.1 INTRODUCTION.....	1
1.2 REVIEW OF LITERATURE.....	2
1.2.1 Control of the Trunk and Pelvis.....	2
1.2.2 Definitions of Trunk Stability.....	6
1.2.3 The Stabilizing System.....	8
1.2.4 Trunk Stability Mechanisms.....	11
1.2.5 Muscular Contributions to Stability.....	12
1.2.6 Abdominal Hollowing Maneuver and Co-contraction.....	16
1.2.7 Trunk Stability Testing	17
1.2.8 Trunk Stability Training.....	19
1.2.9 Stability For Performance Enhancement.....	22
1.2.10 Vertical Jump.....	29
1.2.11 Repeated Vertical Jump.....	32
1.2.12 Previous Studies.....	33
1.2.13 Summary.....	34
1.3 STATEMENT OF PROBLEMS AND HYPOTHESES.....	35
1.3.1 Problems.....	35

1.3.2	Hypotheses.....	36
1.3.3	Assumptions.....	36
1.3.4	Limitations.....	36
1.3.5	Delimitations.....	37
CHAPTER TWO METHODS.....		38
2.1	RESEARCH DESIGN.....	38
2.2	SUBJECTS.....	40
2.2.1	Inclusion Criteria.....	42
2.2.2	Exclusion Criteria.....	43
2.3	PROCEDURES.....	43
2.3.1	Education Session.....	43
2.3.2	Testing Procedures.....	45
2.3.2.1	Pre-testing Questionnaire.....	45
2.3.2.2	Trunk Stability Testing.....	45
2.3.2.3	Vertical Jump.....	49
2.3.2.4	Leg Strength Testing.....	52
2.3.2.5	Repeated Vertical Jump.....	53
2.3.3	Training Programs.....	53
2.3.3.1	Trunk Stability Training Program.....	54
2.3.3.2	Leg Strength Training Program.....	55
2.3.3.3	Trunk Stability and Leg Strength Training Program.....	56
2.3.3.4	Control Group.....	56
2.4	STATISTICAL ANALYSIS.....	56
CHAPTER THREE RESULTS AND DISCUSSION.....		58
3.1	RESULTS.....	58
3.1.1	Manipulation Check.....	58
3.1.1.1	Trunk Stability.....	58
3.1.1.2	Leg Strength.....	63
3.1.2	Primary Analysis.....	63
3.1.2.1	Vertical Take Off Velocity.....	63
3.1.3	Secondary Analysis.....	70

3.1.3.1 Fatigue Index.....	70
3.2 DISCUSSION.....	74
CHAPTER FOUR CONCLUSIONS.....	83
4.1 SUMMARY.....	83
4.2 CONCLUSIONS.....	85
4.3 RECOMMENDATIONS FOR FUTURE RESEARCH.....	85
REFERENCES	86
APPENDICES.....	94

LIST OF TABLES

TABLE		PAGE
2.1	Research Design	39
2.2	Subject Descriptive Characteristics by Group and Gender	41
3.1	Adjusted Means for Trunk Stability by Group	61
3.2	ANCOVA table for Trunk Stability	62
3.3	Adjusted Means for Leg Strength by Group	65
3.4	ANCOVA table for Leg Strength	66
3.5	Adjusted Means for Vertical Take off Velocity by Group	67
3.6	ANCOVA table for Vertical Take off Velocity	69
3.7	Adjusted Means for Fatigue Index by Group	71
3.8	ANCOVA table for Fatigue Index	73

LIST OF FIGURES

FIGURE		PAGE
1.1	Diagram of the Neutral Spine and Pelvis	4
1.2	Diagram of the Double Straight Leg Lowering Test	20
1.3	Diagram of a Vertical Jump with Adequate Trunk Stability	25
1.4	Diagram of a Vertical Jump with Inadequate Trunk Stability	26
1.5	Free Body Diagram of the Lower Body Segments in a Vertical Jump	27
2.1	Diagram of the biomechanical relationship of leg lowering angle and resulting torque produced at the hip joint	50
2.2	Graph of the comparison of the relationship between leg lowering angle and relative torque value for a cosine and a linear relationship	51
3.1	Graph of relative torque of the groups measured at the third and the ninth week testing periods	60
3.2	Graph of predicted 1RM scores for leg strength of the groups measured at the third and the ninth week testing periods	64
3.3	Graph of vertical take off velocity of the groups measured at the third and the ninth week testing periods	68
3.4	Graph of Fatigue Index of the groups measured at the third and the ninth week testing periods	72

LIST OF APPENDICES

APPENDIX		PAGE
A	Consent Form and Cover Letter	95
B	Table of Frequency of Participation by Sport, Group and Gender	100
C	Training Logs	102
D	Photographs of Testing Procedures and Equipment	104
E	Pre-testing Questionnaire	108
F	Exercise Program Guides	112
G	Data Sheets	125
H	Calculation of Simple Main Effects Using SPSS	127
I	Post Hoc Analyses Using Simple Main Effects	129

Chapter One

SCIENTIFIC FRAMEWORK

1.1 INTRODUCTION

Attaining the best possible performance is a goal of all athletes. Athletes, coaches and sport scientists are constantly striving to find better, more efficient ways of achieving optimal performance. Strength training has been well established as a method of enhancing performance. In order to make gains in the performance of a particular skill, it is important to ensure that the muscles that contribute to that skill are as strong and powerful as possible. Abdominal muscle training is an integral component of many training programs (Norris, 1993); however, the specific mechanism of action of the abdominals to enhance performance is poorly understood.

Trunk stability is a popular concept in the areas of sport training and physical therapy. It has been previously used for the treatment of low back pain (O'Sullivan, Twomey, and Allison, 1998) and there have been recent attempts to justify its place in the athletic performance enhancement arena (Norris, 1993). To date, there are no empirical studies that support the use of trunk stability training in performance enhancement. The concept, however, justifies further investigation. For optimal force production of a particular muscle to occur, a

stable base must be provided (Kisner and Colby, 1990). Stability of a proximal body segment is essential before effective movement of an adjacent body segment can occur. This paper will examine the effect, if any, of training for enhanced trunk stability on vertical jump performance.

1.2 REVIEW OF LITERATURE

The goal of this review of the literature is to examine the importance of trunk stability and its influence on athletic performance. The review will begin by defining trunk stability and the possible mechanisms behind trunk stability. The review will continue by examining the available literature regarding stability testing and training and will finish by attempting to relate trunk stability training with athletic performance.

1.2.1 Control of the Trunk and Pelvis

The role of the lumbar spine and its muscles is to provide support for the weight of the upper body in static and dynamic situations (Norkin and Levangie, 1992; Panjabi, 1992a). This system allows force to be generated by and transmitted to and from the upper body and the pelvis and lower extremities (Alexander, 1985; Tesh, Dunn and Evans, 1987). At the same time, it is important that there be ample flexibility to allow for complex three dimensional movements (Parnianpour, Ahmed, Hemami, Barin and Crowell, 1994).

Movements and skills in daily life or in sporting situations require some trunk movement; however, it is the control of these movements in a range of

motion that will prevent tissue deformation and injury, and maximize performance that is important (Maffey-Ward, Jull and Wellington, 1996). Some research regarding lifting and posture has suggested that a hypolordotic or kyphotic posture while lifting (Farfan, 1975) may result in the greatest performance compared with other postures. Vakos, Nitz, Threlkeld, Shapiro and Horn (1994) suggested that maximal isokinetic torque of the spinal extensors is best achieved in a kyphotic posture. These studies, however, relate isokinetic or isometric torque production in non-functional situations to performance. Most studies purport the use of a neutral spinal posture or curvature to maximize stability and function, in functional situations (Cholewicki, Panjabi and Khachatryan, 1997; Kumar, 1997; O'Sullivan, Twomey, Allison, Sinclair, Miller and Knox, 1997).

Kendel, McCreary and Provance (1993) define the neutral position of the pelvis as one in which the anterior superior iliac spines are in the same horizontal plane and the anterior superior iliac spines are in the same vertical plane as the symphysis pubis (See Figure 1.1). Neutral spinal position can be defined as the posture of the spine in which the overall internal stresses in the spinal column and the muscular effort to hold the posture are minimal (Panjabi, 1992b). A neutral pelvic position is essential for maintaining optimal alignment of body segments above and below the pelvis. According to Kendel et al. (1993), a neutral pelvic position will result in a neutral lumbar spine position. Conversely, an anteriorly tilted pelvis will result in a lordotic curve or relative lumbar extension and a

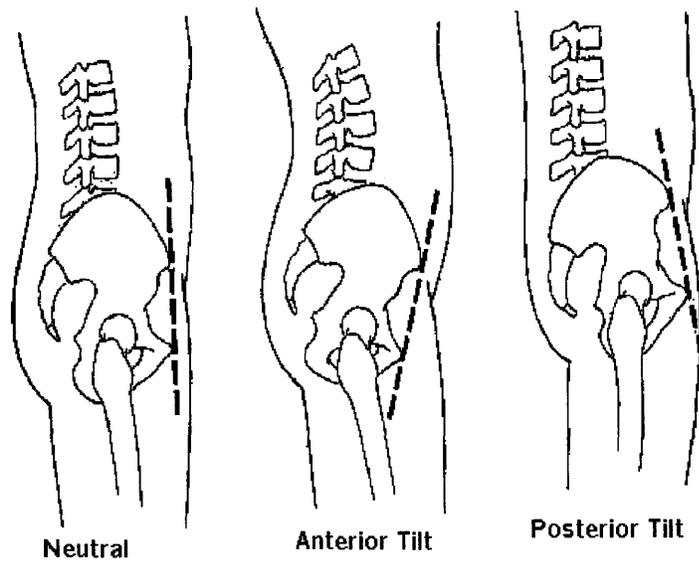


Figure 1.1 Sagittal diagrams of the lumbar spine and pelvis showing a neutral pelvis and associated neutral spine as compared with an anteriorly and a posteriorly tilted pelvis associated with a hyperlordotic and a hypolordotic spine, respectively.

posterior tilted pelvis will result in a hypolordosis or relative lumbar flexion.

This notion, however, has been recently questioned. Several recent studies have shown little or no correlation between degree of pelvic tilt and degree of lumbar lordosis across individuals (Youdas, Garrett, Harmsen, Suman and Carey, 1996; Levine, Walker and Tillman, 1997). However, other studies have shown a strong correlation between changes in pelvic tilt and changes in lumbar lordosis for the duration of the test (Day, Smidt and Lehmann, 1984; Levine and Whittle, 1996). Although there may not be a consistent association between degree of tilt and degree of lordosis across individuals to provide normative data, it is apparent that altering pelvic tilt will alter lordosis.

Maintaining a neutral lumbar spine and pelvis is an essential concept in the development of optimal trunk stability. A neutral position will effectively accomplish several objectives. In general, the upright, neutral posture will result in the body's ability to maintain that posture using the least amount of muscular energy as possible (Basmajian and De Luca, 1985). Maintenance of sagittal plane neutral (i.e. anterior versus posterior and flexion versus extension) will also help to ensure optimal length tension relationships between the abdominal muscles and lumbar extensors (Kendel, McCreary, and Provance, 1993). If a posterior tilt is predominant, the lumbar extensors will be in a more lengthened position and the abdominals will be in a more shortened position. This will decrease the ability of these muscles to generate force (Kendel et al., 1993). A neutral lumbar spine also increases the intrinsic stability of the spine compared to a hyperlordotic spine (Aspden, 1992).

Aspden (1992) proposes a theoretical model for the spine using an arch model. If the arch is such that if a force is transmitted through the bodies of the vertebrae, as is the case with the neutral spine, the arch will remain stable. If the force cannot be transmitted through the vertebral bodies, the arch will become unstable. This case is possible with a lumbar spine that is in a hyperlordotic or hypolordotic position, where the vertical force will pass either posteriorly or anteriorly to the vertebral bodies, respectively. Another rationale for maintaining a neutral lumbar spine is that the potential for ligamentous injury is higher in a flexed spine as compared with a neutral spine (McGill, 1997). The anterior-posterior shear force at the intervertebral level is less in the neutral position, which reduces risk of injury. Other studies have shown that maintaining a neutral position increases trunk muscle co-contraction to a greater degree than non-neutral positions and this co-contraction helps to maintain trunk stability (Cholewicki et al., 1997; McGill, 1997), as will be explained later.

1.2.2 Definitions of Trunk Stability

Trunk stability is a complex concept that is not easily defined. Consequently, a review of the literature reveals that there is no decisive definition of stability. Most of the recent literature regarding trunk stability has attempted to define clinical instability. This reflects the tendency to discuss stability in terms of various forms of low back pain or injury. Instability can be defined as abnormally large intervertebral motions that may produce pain sensations (Panjabi, 1992a). This definition relates only to clinical populations who have

spinal pathology. We may infer, however, that stability would be the lack of such abnormal motions. Stability, as defined by Webster's dictionary (1984), "is the state or quality of being firm or unmoving." Trunk stability, then, would be the ability of the spine and pelvis to remain firm or unmoving. This definition, however, does not take into consideration the fact that the trunk is required to move when performing sport skills or activities of daily living. A more functional definition would be the ability to maintain active control of spinal and pelvic posture and position during dynamic loading and movement conditions. Therefore, neural control of the trunk musculature is essential to maintain stability. This definition implies that both neural control and muscle strength are important (Bergmark, 1989). When discussing trunk stability, it is incorrect to define stability as purely either trunk control or trunk strength. Both components are required (Richardson and Jull, 1995).

Trunk stability incorporates the components of both pelvic and spinal stability. Crisco and Panjabi (1991) define spinal stability as it relates to a column. A column is stable at loads less than the critical load and unstable at loads greater than the critical load. The critical load is the maximum possible load imposed prior to buckling. This implies that the stabilizing potential of the spine is one that optimizes the critical load, but is able to prevent buckling.

1.2.3 The Stabilizing System

There are several theories regarding the mechanism of trunk stability, most of which surround theoretical concepts described by Panjabi (1992a; 1992b). He describes the spinal stabilizing system as being comprised of three interrelated subsystems. The passive subsystem includes musculoskeletal structures such as the vertebrae and their facet articulations, intervertebral discs, spinal ligaments and the passive mechanical properties of the musculature. The active subsystem consists of the active, contractile properties of the muscles and tendons. The neural subsystem consists of the various force and motion transducers (proprioceptors) located in the active and passive structures as well as the neural control centers. Each of these three systems can be conceptualized separately, but are functionally interdependent. The function of this system is to provide sufficient stability to the spine to match the instantaneously varying stability demands due to changes in spinal posture, and static and dynamic loads (Panjabi, 1992a).

A conceptual relationship between the three subsystems can be described as follows. The neural subsystem force and motion transducers located in the passive subsystem structures monitor position, motion and loads to determine the specific stability requirement at one instant in time. The neural control unit is then responsible for setting the required individual muscular tensions. This control message is then sent to the active subsystem musculature to generate force. This achieved force is monitored by the neural transducers and adjusted according to feedback regarding differences between the required and achieved

force. The stability system is capable of adaptation or enhancement. If there is dysfunction of one or more of the subsystems there must be compensation by the other subsystems. Enhancement may also occur if unusually demanding loading conditions require stability beyond the normal level (Panjabi, 1992a). Athletic performance and movement can be considered a situation where an enhancement of the system is required to achieve appropriate spinal stability.

The neural control subsystem is the most complex of the subsystems as it acts as a moderator of the passive and active subsystems. The two primary functions of this system in relation to trunk stability are to control co-contraction of agonist and antagonist muscle groups and to maintain tonicity and stiffness in the musculature (Hodges and Richardson, 1996).

The action of the neural system has been shown to be impaired in clinical populations. O'Sullivan, Twomey, Allison, Sinclair, et al. (1997) studied the recruitment patterns of the abdominal muscles in 12 patients with chronic low back pain compared with 10 healthy controls. They found that the controls were able to preferentially activate the appropriate muscles required for stability (as will be discussed later) and the chronic low back pain patients had an impairment to do so. Several other studies have confirmed this finding (Hodges and Richardson, 1996; O'Sullivan, Twomey and Allison, 1997b). There is evidence that the neural control subsystem may be enhanced with training (Stevens and Hall, 1998; Hagins, Adler, Cash, Daugherty and Mitrani, 1999) and that this is a more important factor for enhancing stability than any other.

The passive subsystem contributes the least to enhancing trunk stability. Although the passive structures of the spine and pelvis provide a structure upon which movement can occur, they cannot control this movement. Panjabi (1992b) describes the concept of a joint's neutral zone of motion in a neutral position. The neutral zone is the part of the physiological intervertebral motion, measured from the neutral position, within which the spinal motion is produced with a minimal internal resistance. It is the zone of high flexibility or laxity. In populations with low back injury, the neutral zone has been shown to increase. However, a corresponding increase in muscle activity to control the neutral zone can reverse this increase and even enhance stability by decreasing neutral zone motion beyond normal.

Despite the intrinsic stability inherent in an arch such as the spine, as modeled by Aspden (1992), the neutral lumbar spine, in absence of musculature, has been shown to buckle under critical loads as low as 1.81 (Crisco and Panjabi, 1991) and 2.00 (Panjabi, Abumi, Duranceau and Oxland, 1989) kilograms. This is markedly less than the weight that it is required to withstand in relaxed standing. The neuromuscular system must therefore contribute the bulk of the force required for maintenance of stability. It is, therefore, evident that the active and neural subsystems are essential to maintenance of stability.

The active subsystem has received the most attention in the literature. This is expected because this subsystem (along with its neural control) is most easily measured and defined. As well, training of the muscular and neurological

systems can affect the greatest change in performance (Aspden, 1992). The specific components of the active subsystem will be discussed below.

1.2.4 Trunk Stability Mechanisms

There are several proposed mechanisms by which enhanced trunk stability can be achieved. These include motor control of pelvic and spinal position (Hodges, 1999) and increasing the overall stiffness of the spine (Wilke, Wolf, Claes, Arand and Wiesend, 1995). Although specific physiological mechanisms have been identified, it is important to remember that the motor control of pelvic and spinal position is central to the maintenance of stability. This control is usually achieved by activation of the ‘global musculature’ as will be defined and discussed in section 1.2.5.

Increasing the overall stiffness of the spine involves combining tension on the thoracolumbar fascia and increasing intra-abdominal pressure (Hodges, 1999; Tesh, Dunn and Evans, 1987). The thoracolumbar fascia is said to have a role in enhancing stability by creating an extensor moment through contraction of the internal oblique and transversus abdominis muscles. Contraction of these muscles produces a lateral pull on the fascia, which draws the spinous processes together in an extension movement (Tesh, Dunn and Evans, 1987). This effect is most pronounced in a neutral spine posture and contributes to both sagittal and frontal plane stability.

Intra-abdominal pressure contributes to spinal stability by one of two mechanisms. One mechanism is that the force produced on the spine by

increasing intra-abdominal pressure is such that it adds tension to the spine, thereby increasing the overall stiffness. The other mechanism is that the muscle activity required to produce increased intra-abdominal pressure provides a much more rigid abdomen, thereby enhancing stability (Cholewicki, Juluru, and McGill, 1999). The exact mechanism of enhancing stability through increasing intra-abdominal pressure is unknown. However, it is evident that increased intra-abdominal pressure is essential to the maintenance of stability (Cholewicki, Juluru, Radebold, Panjabi and McGill, 1999). The relationship between intra-abdominal pressure and muscle activity will be discussed below.

1.2.5 Muscular Contributions to Stability

Although certain muscles have been targeted as primary stabilizers, all trunk muscles have a role in stabilizing the trunk (Jull and Richardson, 1994). Bergmark (1989) classified stabilizers into local and global muscles. Global muscles, also referred to as multisegmental muscles, are the large torque producing muscles linking the pelvis and spine to either the thoracic cage or the femur. These muscles provide general stabilization to balance external loads, help minimize the resulting forces on the spine and control trunk orientation and posture (Hodges, 1999). They also will have significant roles as prime movers of the trunk or hip. The internal and external obliques, quadratus lumborum, erector spinae, the gluteals, psoas major and rectus abdominus have been identified as global stabilizers (McGill, 1991a). Local muscles, also described as prime stabilizers (Richardson and Jull, 1995) or intersegmental muscles, are responsible

for contributing to segmental stability as well as controlling the positions of the lumbar segments (Crisco and Panjabi, 1991). Transverse abdominis and multifidus muscles have been identified as the primary local stabilizers (Basmajian and DeLuca, 1985; Hodges and Richardson, 1996; Ng, Richardson and Jull, 1997,).

Studies of transverse abdominis provide a rationale for its involvement. Cresswell, Grundstrom and Thorstensson (1992) studied changes in intra-abdominal pressure and abdominal muscle activity during various loading and movement tasks. It was found that for maximal isometric trunk flexion, all of the abdominal musculature were involved in producing torque. For maximal isometric trunk extension, however, all abdominal muscle activity significantly decreased except for transverse abdominis. Transverse abdominis activity was found to be highly correlated with levels of intra-abdominal pressure, and both transverse abdominis activity and intra-abdominal pressure remained relatively constant between maximal flexor and extensor activities. It is suggested that transverse abdominis has a general stabilizing function and this function is related to changes in intra-abdominal pressure.

Cresswell, Oddsson and Thorstensson (1994) later studied the influence of sudden perturbations on intra-abdominal pressure and trunk muscle activity. They found that unexpected movements induced abdominal muscle activity well in advance of erector spinae activity and that transverse abdominis was invariably the first muscle active, regardless of force direction. It is further suggested that during loading, early reflexive activation of transverse abdominis and a

subsequent increase in intra-abdominal pressure may result in increased intervertebral stiffening; and enhance stability.

Hodges and Richardson's (1996; 1997a; 1997b) and Hodges, Cresswell and Thorstensson's (1999) research involving trunk muscle activity related to voluntary arm and leg movements have confirmed the importance of transverse abdominis activity and function. It was found that for all movement directions of the arm and leg, transverse abdominis was the first muscle active and this activity occurred prior to activity of the prime movers. All other trunk muscles were active, but activity and timing varied depending on body part and movement direction. In patients with low back pain, transverse abdominis activity preceded movement; however, the magnitude of firing was significantly less than healthy controls. The mechanism of action of transverse abdominis on spinal stability is unclear, but likely it is the combined effects of increased intra-abdominal pressure and increased tension on the thoracolumbar fascia that act to increase the intervertebral stiffness and enhance stability (Aspden, 1992; Cresswell et al., 1994).

Multifidus has also been identified as a prime local stabilizer. Wilke et al. (1995) studied the increase in stability *in vitro* with different muscle groups. It was found that the addition of muscle parameters decreased range of motion and neutral zone motion up to 90%. It was determined that multifidus alone contributed two thirds of this increased stability. Aspden (1992) reviewed the function of multifidus in relation to the spinal arch model. The multifidus is capable of precisely controlling the bending moment in the arch and the local

curvature of the lumbar spine segments to match the loading being imposed. It is the overall curvature, or posture, of the spine which determines its stability and therefore this control is necessary to its function as an arch-like structure.

Basmajian and Deluca (1985) describe that the lumbar multifidus acts as a spinal stabilizer by assisting in adjusting intervertebral position, providing the necessary compressive forces along the spine and controlling the curvature of the spine.

The combination of these factors together stabilizes the spine.

Despite the growing evidence that the local muscular system is responsible for primary trunk stability, the global muscular system remains important. The local system contains small, deep muscles that are capable of limited force production and act to maintain segmental position (Jull and Richardson, 1994). These muscles act independently of direction of movement (Hodges and Richardson, 1997b).

The global system consists of multisegmental muscles, which are larger and capable of increased force production. These muscles are dependent upon direction of movement (Hodges and Richardson, 1997a) and are considered the prime movers in trunk movements. The local system has been shown to be effective for segmental stability at one to three percent of their maximal voluntary contraction (Crisco and Panjabi, 1991; Cholewicki et al, 1997). Therefore, at the local level, only small amounts of force are required to maintain stability. However, when an external load is directionally applied to the spine, large increases in force production are required to maintain stability. This can most effectively be achieved through contraction of the global, multisegmental muscles

(Crisco and Panjabi, 1991), and this will occur directionally, to counterbalance the imposed external load. Optimal trunk stabilization, however, can only occur when co-contraction of the transverse abdominis and multifidus is maintained with contraction of the appropriate global muscles (Richardson, Jull, Toppenberg and Comerford, 1990; Richardson and Jull, 1995).

1.2.6 Abdominal Hollowing-In Maneuver and Co-contraction

Appropriate transverse abdominis contraction has been shown to occur in an abdominal hollowing-in maneuver (Richardson et al., 1990). This maneuver involves hollowing the abdomen such that muscle contraction pulls the navel up and in towards the spine. This hollowing must occur without compensatory abdominal protrusion by rectus abdominis (Richardson and Jull, 1995). When the hollowing-in maneuver was performed in a neutral spine posture, co-contraction with lumbar multifidus occurred. This co-contraction would then act to increase the ability to maintain stability in the neutral position.

Cholewicki et al. (1997) confirmed this finding in their study of the stabilizing function of the trunk flexor-extensor muscles around a neutral spine posture. It was found that co-contraction occurs in a neutral posture and that this co-contraction increases as loads increase in order to add mechanical stability to the spine. The pattern of activation of these muscles varied across subjects but the most consistent pattern was co-contraction of the deep abdominal (transversus abdominis and internal oblique) and multifidus muscles. O'Sullivan et al. (1998) found that training co-contraction of the deep abdominals and multifidus resulted

in an increased ability to recruit these muscles to enhance dynamic stability. Hagins et al. (1999) found that the ability to perform stabilization exercises improved with practice. Evidence to support the use of co-contraction in stabilization maneuvers has direct consequences for testing of and training for trunk stability.

1.2.7 Trunk Stability Testing

There is no known reliable and valid test that sensitively measures trunk stability. Because trunk stability is a combination of trunk muscle strength and control, conventional trunk strength measures cannot be used. Therefore, a measure that incorporates elements of both strength and control must be used to assess stability. Originally, Kendel et al. (1993) described a measure of lower abdominal strength using a double straight leg lowering (DSLL) test. The test involved the subject lying supine, with both legs held straight and elevated to vertical. The examiner placed one hand under the lumbar spine and instructed the subject to slowly lower both legs toward the table, keeping the lumbar spine pressed against the table. The angle of the legs was recorded the instant the spine and pelvis began to move. This test, in this form, has been criticized for its lack of range of resistance in the lower grades, and for the inability to objectively determine pelvic and spinal movement (Gilleard and Brown, 1994).

Other tests have been introduced to attempt to correct the faults of the DSLL. Shields and Givens Heiss (1997) performed an electromyographic (EMG) comparison of the curl up and the DSLL with control of pelvic position using a

pelvic electrogoniometer. They found that when controlling for pelvic position, the DSLL was a more accurate measure of trunk muscle activity, but that activation may or may not involve a high level of rectus abdominis activity. Gilleard and Brown (1994) added the use of a sphygmomanometer cuff under the lumbar spine and pelvis to obtain an objective measure of trunk movement as shown by pressure changes. Hodges and Richardson (1996) recognized that the literature points to the abdominal hollowing-in exercise as a potential measure of local stability. They used an abdominal hollowing test with a pressure biofeedback unit under the lumbar spine as an objective measure. This test was scored in stages by increasing the difficulty of each successive movement. The last stage performed successfully was recorded. This test, although shown to be valid, uses relatively low loads and stresses only the local muscular system.

Hodges (1999) advocates the use of global stabilization superimposed upon local stabilization for increasing loads during training. Theoretically, this may also apply to testing. The double straight leg lowering test could be used to measure both global and local stabilization. Placing a pressure biofeedback unit, or a sphygmomanometer, under the spine and teaching the appropriate co-contraction required for local stability could effectively measure trunk stability if the spine were held in the neutral position. To the knowledge of the present author, this method of testing has never been used. It must be noted that applying the test in this manner will test the local stability system and the global system directionally to prevent relative lumbar extension and an anterior pelvic tilt. This is not the only direction of stability required during function. Most performance

skills require strong contraction of the lumbar extensors to prevent relative lumbar flexion superimposed upon local stability (Zetterberg, Gunnar, Andersson and Schultz, 1987). Maximally testing this directional stability would be inherently difficult. Further research is required in this area to determine appropriate stability measures that are valid and reliable.

The modified DSLL test used in this study is described completely in section 2.3.2.2. Figure 1.2 shows a conceptual model of the initial position of the test. The test was designed to require maintenance of local and global stability in a situation where appropriate co-contraction can be achieved. As such, the subjects were asked to achieve a (relatively) neutral lumbar spine and perform the abdominal hollowing-in maneuver during the test.

1.2.8 Trunk Stability Training

There has been considerable recent literature regarding training for improved trunk stability (Jull and Richardson, 1994; Hagins et. al., 1997). The principle of specificity states that optimal training gains occur when training specifically includes the exercise that is desired to improve (Wilson, Murphy and Walshe, 1996). This principle should be applied when training for improved trunk stability. Curl ups or sit ups have commonly been used to train the abdominal muscles (Smidt and Blanpied, 1987). It has been shown that these training methods have poor correlation with methods specifically designed to train trunk stability (Shields and Givens Heiss, 1997). In fact, trunk stabilization has been shown to decrease during fast curl up maneuvers (Wohlfahrt, Jull and

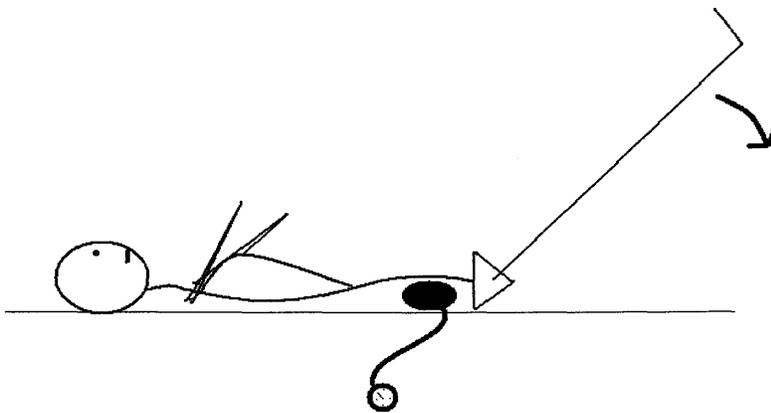


Figure 1.2 Conceptual diagram of the double straight leg lowering test (DSL) showing the blood pressure cuff as a pressure biofeedback unit.

Richardson, 1993). Therefore, training for trunk stability should include exercises that incorporate both strength and control. Richardson et al. (1990), Hodges et al. (1996), and O'Sullivan et al. (1997b; 1998) have recently established the use of the abdominal hollowing-in exercise as a method of training local trunk stability. This method of training uses low load requirements and trains for enhanced neuromuscular control. Although this local stability is important to establish, progression of higher loads is necessary to challenge the global stability requirements of athletic movements.

Studies regarding muscle activation patterns in healthy subjects and those with low back pain reveal that healthy subjects can recruit the appropriate muscles required for stability to a much higher degree than those with low back pain (Hodges and Richardson, 1996; O'Sullivan et al, 1998; 1997). If applying trunk stability training to healthy subjects, motor control of the appropriate synergists may occur after as little as one training session, but may take up to two or three weeks (Richardson and Jull, 1995). Although the training of the local system is essential to achieving the appropriate local muscle activation patterns, very little time may be needed to accomplish this.

Jull and Richardson (1994) recommend a progression of training that first involves teaching and training the local stability system, then adding higher loads while maintaining control of the local system. Maintaining local control is essential in maintaining trunk stability during progression of exercise. Applying functional situations follows this progression. According to Panjabi (1992a), the stability system is required to enhance stability to meet the high loading demands

of sport activities. For athletes in such situations, it is essential that the global muscular system be trained while maintaining local stability control. Because athletes have multidirectional stability requirements, it is essential that the global system be trained multidirectionally. Current training modalities for trunk stability include the use of theraballs, progressive loading exercises, and functional tasks superimposed upon maintaining local stability (White and Sahrmann, 1994; Norris, 1995b).

1.2.9 Stability For Performance Enhancement

Athletes have higher stability requirements that necessitate enhancement of the stability system (Panjabi, 1992a). There is much literature that validates the use of trunk stability training programs for the treatment and prevention of low back pain and injury (McGill, 1998; Mulhearn and George, 1999). However, there are few studies that validate the use of trunk stability training programs to enhance performance in athletes. The application of high external loads in sport requires trunk stability to maintain an appropriate posture and to prevent excessive range of motion. This would apply to contact movement skills such as blocking in football, preventing a throw in wrestling or tackling or scrummaging in rugby. Enhancing trunk stability may also enhance body mechanics and optimize force production for skills that require internal loads, such as jumping or lifting (Cholewicki, Juluru and McGill, 1999).

Rutherford and Jones (1986) studied the effect of three separate stability conditions on the training of the quadriceps in knee extensions. They found that

seated knee extension training with the body and trunk unsupported resulted in large increases in training load but with minimal increases in isolated quadriceps strength. They attributed the increases in training load to the recruitment of other 'fixator' muscles to stabilize the trunk and prevent trunk flexion when the quadriceps contract. They speculated that the back and abdominal muscles stabilized the trunk and were essential for maximum force production. The ability of the quadriceps to generate force will be limited by the strength and/or activation of these muscles. The improvement in training weights seen in this study may be either an increase in the intrinsic strength or an improved ability to activate and coordinate the contractions of these muscles.

The requirement for movement to occur on a stable base, or proximal stability, is a well-documented concept in neurological and orthopedic physical therapy literature (Shumway-Cook and Woollacott, 1995). Several leg and hip muscles originate or insert onto the pelvis or spine. In order for these muscles to generate optimal force, the pelvis and spine must provide a stable base. Without a stable base, contraction of the limb musculature will result in movement of both the proximal and distal segments, and the total force produced will be less than optimal (Kisner and Colby, 1990). For example, if the hip extensors are contracting in a movement such as a vertical jump, there will be a posterior pelvic tilting moment created. If the lumbar spinal extensors do not stabilize the pelvis, a posterior pelvic tilt, as well as the desired hip extension, will result. Therefore, part of the muscle contraction generated by the hip extensors will result in undesirable movement of the pelvis and the net potential hip extension torque will

be reduced (see Figures 1.3 and 1.4). Figure 1.5 shows a free body diagram illustrating the forces and torques that would occur at the hip, knee and ankle during a vertical jump. Contraction of the trunk muscles would not directly contribute to torque production or overall performance. Enhancing trunk stability would only optimize the available torque of a particular muscle or muscle group. Gains in performance due to performing trunk stability exercises would be limited to the available strength and power in the prime movers. Therefore, unless the available strength in the prime movers involved with a vertical jump is improved, there will likely be an end point to the performance gains possible. In order to increase performance once optimal trunk stability has been gained, leg strength must also be improved.

The application of external pelvic stability devices has been shown to increase knee flexor and extensor torque production (Hart, Stobbe, Till and Plummer, 1984; Magnusson, Geismar, Gleim and Nicholas, 1993). Hart et al. (1984) examined the differences in concentric torque and power production of the quadriceps femoris when the trunk was and was not stabilized. Seven adult male subjects were tested on four maximal quadriceps contractions on a Cybex isokinetic dynamometer at a combination of three separate starting angles and velocities of 0, 30 and 105 °/s. Two trials were completed with the trunk stabilized and two trials were completed without the trunk stabilized at each of the nine starting and velocity conditions. External trunk stabilization was achieved by having the subjects strapped to the seat and back rest using a hip-waist belt and two crossing-trunk belts.

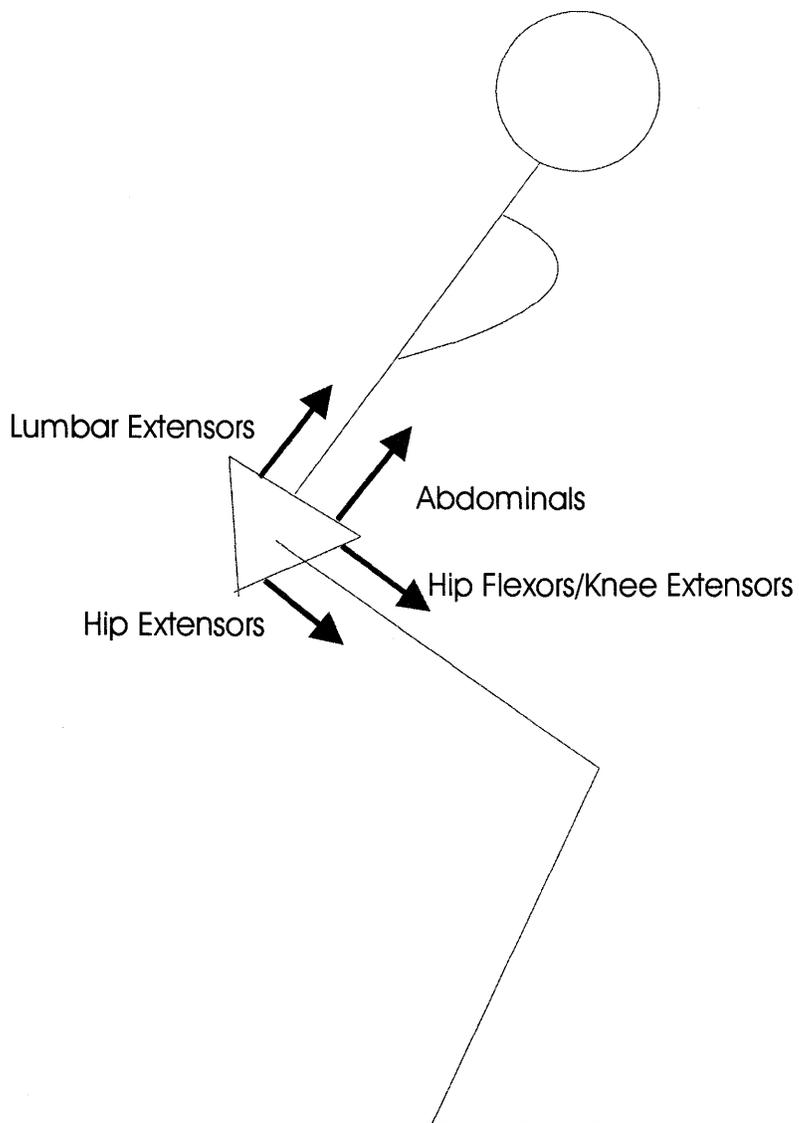


Figure 1.3 Diagram of the desired position and muscle forces used in the vertical jump with a stable pelvis and spine.

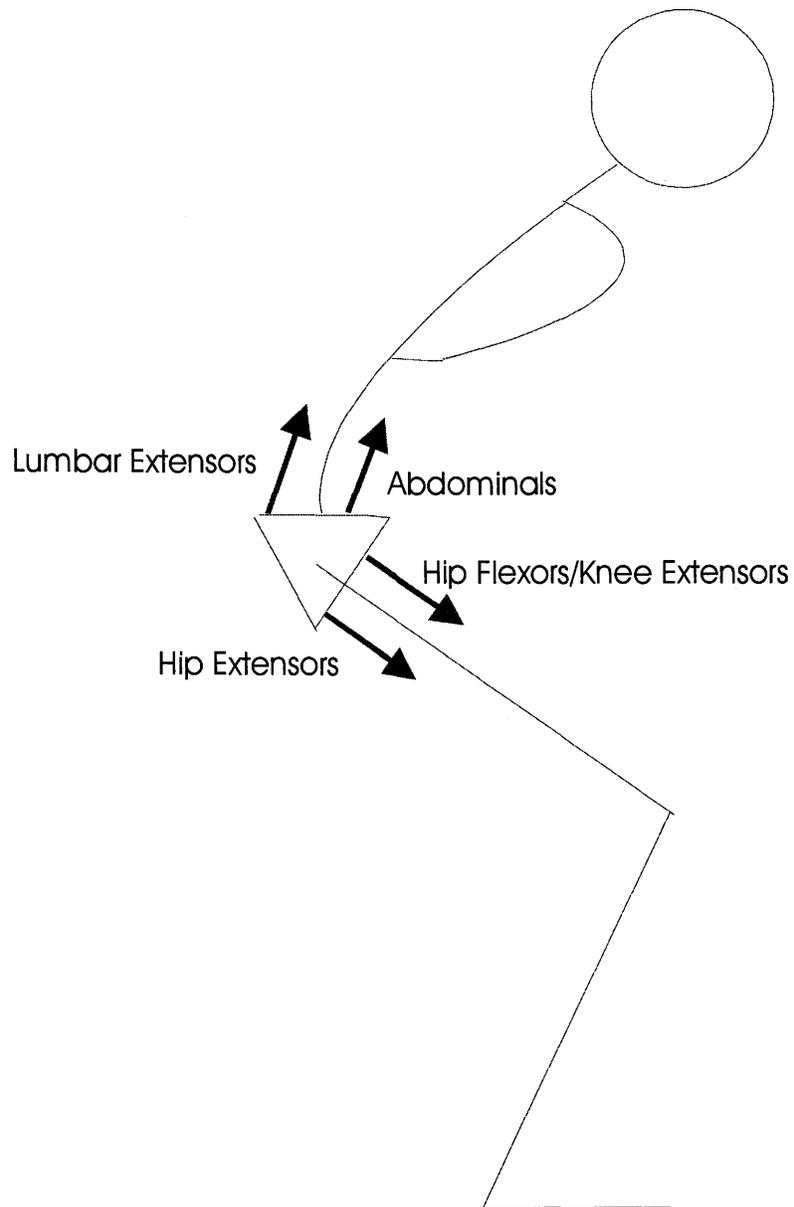


Figure 1.4 Diagram of a squat jump with poor trunk stability in which contraction of the hip extensors produces a posterior pelvic tilt that is not controlled by the trunk stabilizers.

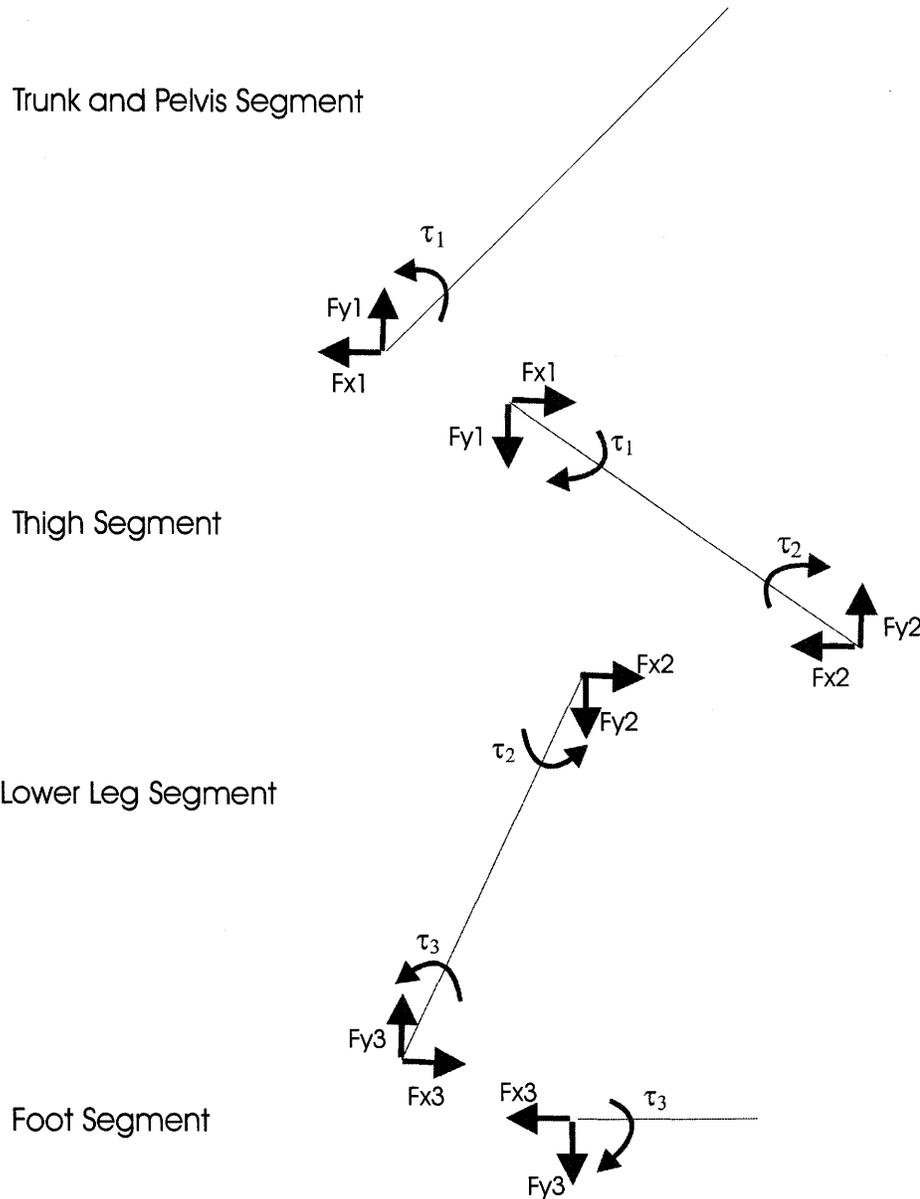


Figure 1.5 Free body diagram of the trunk and lower extremity showing the individual joint forces and torques. Fx and Fy are the resultant horizontal and vertical force components, respectively and τ is the torque produced at the joint. Note: this diagram assumes the trunk and pelvis are rigid.

The results showed that for all conditions, torque, power, torque-velocity and power-velocity were greater in the trials for which the subjects were stabilized. As well, the increase in torque and power in the trunk stabilizing condition was greater at higher velocities and ranges of motion. This finding suggests that the torque enhancing potential of increased trunk stability is more significant in higher velocity and greater range of motion movements.

Magnusson et al. (1993) examined the effect of four methods of external stabilization on maximal reciprocal isokinetic knee extension and flexion. Twenty recreational athletes were tested on a Cybex isokinetic dynamometer. Three trials of knee extension and flexion at 60 °/s were completed for each of the four stability conditions. The four stability conditions were: 1) no stabilization, 2) hand stabilization, 3) back stabilization, and 4) hand and back stabilization. Back stabilization was achieved by applying a hip and a chest strap to the subjects while seated against the back rest. Hand stabilization was achieved by allowing the subjects to hold the handgrips on the dynamometer. Hand and back stabilization was achieved by combining both hand stabilization and back stabilization. The results showed that all three of the stabilization methods produced torque values significantly greater than those of the no stabilization condition for both knee extension and flexion. Also, knee extension torque during the hand and back condition was significantly greater than that during the back stabilization. The authors concluded that torque production in knee extension and flexion will not be maximal if proximal stabilization is inadequate.

The results of these studies do not necessarily indicate that improving trunk stability will enhance functional performance. Trunk stability is proposed to enhance gains made by training the entire body in terms of strength, power, endurance, and motor skill. Trunk stability training should likely be a supplement to other methods of training. However, the optimization of performance by enhancing trunk stability is theoretically possible.

1.2.10 Vertical Jump

The ability to jump vertically to a maximum possible height is a common skill that is required for many sports. Although each sport and sport skill requires different variations of vertical jumping, the basic movement patterns are similar. Recent research has documented the segmental contributions of different joints to production of vertical jump height. Harman, Rosenstein, Frykman and Rosenstein (1990) found that adding arm swing during a jump will enhance jump performance by 12 %. Hubley and Wells (1983) found that using a work-energy approach, the hip muscles contributed 28%, the ankle muscles 23%, and the knee muscles 49%. It is clear that vertical jump is a movement that requires significant contribution from all lower body segments with coordination and control of trunk and upper extremity movement.

A countermovement jump is one in which a fast descending phase is immediately followed by an explosive ascending phase (Bobbert, Gerritsen, Litjens and Van Soest, 1996). Several studies have shown that countermovement jumping will produce up to a 12% greater vertical height than will jumping from a

static squatting position (Harman, Rosenstein, Frykman and Rosenstein, 1990; Bobbert et al., 1996). A countermovement vertical jump test is used to obtain a greater vertical take off velocity than in a squat jump and to provide a more sport specific test.

Vertical jump performance is determined by the relationship between several key factors. These include the maximal force that the body can develop, the maximal speed at which the force can be developed, and the neural coordination and control of the movement pattern (Kraemer and Newton, 1994). These concepts can be discussed in terms of power. Power has been defined as the rate of performing work and is the product of force and velocity (Komi, 1992). Dowling and Vamos (1993) have shown that maximal power output is highly correlated with vertical jump performance and that a base level of strength that is greater than twice body weight may be necessary for optimal power production. Therefore, in order to achieve maximal vertical height, maximum force must be produced through a high velocity.

Considine (1970) studied the differences in vertical jump height and vertical take off velocity as determined from a force plate. A high correlation between the two measures was found. Dowling and Vamos (1993) found that vertical take off velocity was a greater predictor of vertical jump height than any other force plate measurement. These results are to be expected because, assuming minimal air resistance, vertical jump height can be precisely calculated if take off velocity, and corresponding height of the center of mass at take off, is known.

Strength is defined as the maximal force that a muscle or muscle group can generate in a specified movement pattern at a specified velocity (Fleck and Kraemer, 1997). A popular method for enhancing strength is traditional strength training using either free weights, isotonic or isokinetic machines. Comparison of these training modalities show that for functional strength gains, free weights using a movement pattern that is similar to the movement that is desired to be improved are superior to machine training (Augustsson, Esko, Thomee and Svantesson, 1998; Blackburn and Morrissey, 1998). The traditional weight training method of using the squat exercise is most related to the movement pattern required for vertical jumping. However, free weight training has also been shown to increase the use of the trunk muscles to stabilize the trunk and pelvis. This occurs to a higher degree than during machine training (Robertson, Witt and Gross, 1997).

Trunk stability is proposed to enhance vertical take off velocity by optimizing the maximum force output of the lower extremity muscles. Trunk muscle contraction likely does not directly contribute to maximal force output and therefore has no direct effect on vertical jump. However, providing a stable base from which the lower extremity muscles can contract will optimize the force output of those muscles.

Hart et al. (1984) found that external stabilization of the pelvis and spine increased the potential force generated by the quadriceps during maximal isokinetic seated knee extensions. This effect was greatest with higher velocity knee extensions using the maximal force possible. Although this finding cannot

be used to generate claims regarding functional movements such as vertical jumping, it can be speculated that enhancing trunk stability may enhance the potential force output of the leg muscles at higher velocities. Trunk stability training would then have a greater effect on maximal torque production at higher velocity movements such as jumping.

1.2.11 Repeated Vertical Jump

A single vertical jump is a test that allows for analysis of a single value for vertical take off velocity. Most jumping sports, however, involve several successive jumping movements. A test that incorporates repeated jumping movements would be more sport specific. Bosco, Luhtanen and Komi (1983) have recommended a repeated vertical jump test for determining maximal anaerobic power output. Using a photocell jump mat, they claim that peak power, average power, and fatigue index could be calculated over a period of 15 to 60 seconds. This test was found to correlate with the Wingate anaerobic power test with coefficient values of between 0.54 and 0.87. Fatigue index can be calculated by dividing the average power over the final three jumps by the average power over the first three jumps. This value can be used to examine the relative decrements in jump performance over a specific time period.

It can be speculated that enhancing vertical jump ability may result in conservation of energy over a series of several jumps. If the energy that contributes to muscle contraction goes towards producing movement of only the desired limb segment, less overall energy may be expended than if a portion of

that energy went towards producing movement of a proximal segment.

Therefore, for a given level of performance, less energy will be expended in a movement that maintains proximal stability of that limb segment. If less energy is expended, the given level of performance should be able to be maintained for a longer period of time. The fatigue index would then be greater than if more energy were expended.

1.2.12 Previous Studies

There have been a limited number of studies that have attempted to determine the effect or influence of trunk stability on various performance measures. An unpublished study completed at the College of Kinesiology, University of Saskatchewan (B.R. Craven, personal communication, September, 1999) examined the influence of trunk stability and leg strength on vertical take-off velocity in male athletes. Eighty-two athletes were assessed on a double leg lowering test, leg press and a loaded vertical jump. The load was achieved by placing a barbell with a mass equivalent to 30% of the subject's mass across the subject's shoulders. The load that was added to the vertical jump was speculated to increase the influence of the trunk extensors and therefore require more trunk stability. The results were analyzed using a multiple linear regression model. It was found that trunk stability and leg strength X mass interactions were significant. It was concluded that both leg strength and trunk stability contribute to vertical take off velocity in a loaded vertical jump.

1.2.13 Summary

Adequate trunk stability is required to provide a controlled and relatively unmoving spine and pelvis. The function of this stability is to match the demands of changes in spinal posture, and static and dynamic loads. These demands vary across all types of movements, activities, and skills and are diverse. Therefore, it is impossible to identify all specific muscles that will be required in every situation. However, recent research regarding the feed forward and feed back control of spinal position has led to the identification of a local stability system that is most likely required in most, if not all, situations.

Stabilization of the spine and pelvis can be achieved through developing improved control of the spine and pelvis. This control can be combined with increasing the intra-abdominal pressure, the tension on the thoracolumbar fascia and the segmental stiffness of the spine to optimize local trunk stability.

Achieving a co-contraction between the deep abdominal and multifidus muscles in a neutral spine posture will facilitate obtaining local stability. The global system is then recruited preferentially depending on the demands of the required skill.

There have been a limited number of studies that attempt to specifically determine the effect or influence of trunk stability on performance. Although a correlation between trunk stability and vertical take off velocity has been determined, there is no empirical evidence to support the claim that trunk stability training will enhance vertical jump performance. Theoretically, however, maintaining a stable base from which the lower extremity muscles can contract

should optimize the force production of these muscles. Enhancing trunk stability will help the athlete to maintain a stable spine and pelvis and optimize vertical jump performance. Richardson and Jull (1995) have suggested that to enhance trunk stability, specific exercises that activate the local stability system and superimpose global stability demands can be performed.

The purpose of this study is to determine the effect that trunk stability training and leg strength training have on vertical jump performance. The relationship between leg strength and vertical jump has been established and it is known that leg strength training should increase vertical take off velocity (Kraemer and Newton, 1994). The effect of trunk stability training on vertical take off velocity and fatigue has yet to be determined. If a significant effect can be established, training protocols can be better designed to enhance vertical jump performance.

1.3 STATEMENT OF PROBLEMS AND HYPOTHESES

1.3.1 Problems

1.3.1.1 What effect does increasing trunk stability have on vertical jump performance as assessed by vertical take off velocity?

1.3.1.2 How does trunk stability training compare with leg strength training for improvements in vertical jump performance as assessed by vertical take off velocity?

1.3.2 Hypotheses

1.3.2.1 Increasing trunk stability will improve vertical take off velocity in athletes by enhancing available leg strength during a single vertical jump test.

1.3.2.2 Increasing trunk stability will improve fatigue index score in athletes by helping to conserve energy during a repeated vertical jump test.

1.3.2.3 For athletes, trunk stability training combined with leg strength training will produce greater gains in vertical take off velocity than either group alone.

1.3.3 Assumptions

It was assumed that all athletes would complete the testing and training protocols with maximal effort. It was also assumed that all athletes followed the guidelines for training for their particular group closely. It was assumed that all experimental groups were representative samples of the population. It was assumed that the measures used in the study are valid measures of the construct they are designed to evaluate.

1.3.4 Limitations

Decreases in accuracy and sensitivity of the test measures may affect the results. Small sample sizes may also affect the results and prevent analysis of potential subgroups such as gender or sport. Decreases in adherence to the exercise program guidelines or inaccurate reporting on training logs could limit the potential results.

1.3.5 Delimitations

The results of this study can only be generalized to recreational and competitive athletes between the ages of 18 and 30 without low back pain or injury.

Chapter Two

METHODS

2.1 RESEARCH DESIGN

A repeated measures experimental design was used for this study. Subjects were randomly assigned into one of four training groups: trunk stability (TS), leg strength (LS), combination of trunk stability and leg strength (TL), and control (C). Subjects in the three training groups were given a periodized nine-week training program consisting of trunk stability training exercises and education for the TS group, leg strength training for the LS group, and both of the above programs for the TL group. A conceptual model of the research design is presented in Table 2.1. Subjects were instructed to perform their respective programs three times per week and to attend a monitoring session every three weeks to determine weight adjustments, exercise progressions and compliance, and to deal with problems that may arise during training. Subjects in the TS, TL, and LS groups completed three three-week training phases through the nine weeks. During Phase One, subjects trained for anatomical adaptation and for motor control. During Phase Two and Three, subjects trained for gains in maximum strength and/or stability.

Subjects were given an initial questionnaire to determine age, the sport involved with, the number of years played, the number of times and hours

Table 2.1 Research Design

	Education Session	Pre Test	Phase One	Inter-phase Test 1	Phase Two	Phase Three	Post Test
Week	Week 0	Week 0	Weeks 1 – 3	Week 3	Weeks 4 – 6	Weeks 7 – 9	Week 10
Trunk Stability Group (TS)	Familiarization trials for VJ, LP, DSLL, RVJ Tests. Instruction of proper technique for DSLL/Trunk stability. Flexibility Testing.	DSLL, VJ, LP, RVJ.	Basic trunk stability exercises	DSLL, VJ, LP, RVJ.	Second level stability exercises	Maximal load stability	DSLL, VJ, LP, RVJ.
Leg Strength Group (LS)			Anatomical Adaptation		Maximal strength 1	Maximal strength 2	
Trunk Stability and Leg Strength Group (TL)			Basic trunk stability exercises and anatomical adaptation		Second level stability exercises and Maximal strength 1	Maximal load stability and Maximal strength 2	
Control Group (C)			No treatment		No treatment	No treatment	

VJ: vertical jump, LP: leg press, DSLL: double straight leg lowering, RVJ: repeated vertical jump.

played/performed per week and whether this study occurred in the subject's in-season or off season.

Testing of the research variables occurred before training, between Phases One and Two, and after training. Prior to pre-testing, education sessions were held for all subjects to achieve familiarization of the testing procedures and to instruct in the proper muscle activation pattern required for the double straight leg lowering (DSL) test. Previous research (Hagins et al. 1999) and observations during pilot testing indicate that most subjects cannot begin trunk stability testing until they have been given the opportunity to practice achieving the muscular activation pattern that is required for proper testing. The education session is described in section 2.3.1.

2.2 SUBJECTS

Sixty-six volunteer athletes (28 males and 38 females) were recruited from Saskatoon and area sport organizations, clubs and teams. Recruitment was achieved through direct contact with athletes, organizations and teams, as well as through posters placed within local educational institutes and sport facilities. Subject descriptive data is presented in Table 2.2 and Appendix B. Of the original 66 subjects, 55 successfully completed the study. Four subjects (one from the control group, one from the leg strength group and two from the trunk stability group) dropped out due to reasons not related to the study. Of the four

Table 2.2 Subject descriptive characteristics by group and gender.

Group	Gender	Number	Mean \pm Standard Deviation			
			Age (years)	Height (cm)	Mass (kg)	Years in their sport
TS	M	6	24.2 \pm 3.3	176.8 \pm 9.8	85.9 \pm 24.8	6.5 \pm 4.3
	F	8	22.6 \pm 2.2	167.7 \pm 4.9	67.4 \pm 9.9	5.4 \pm 5.8
	Total	14	23.3 \pm 2.7	171.6 \pm 8.5	75.3 \pm 19.5	5.9 \pm 5.1
TL	M	6	23.3 \pm 4.6	182.7 \pm 6.2	85.8 \pm 8.7	9.5 \pm 5.5
	F	8	22.1 \pm 2.8	166.6 \pm 6.1	67.0 \pm 14.5	5.3 \pm 2.9
	Total	14	22.6 \pm 3.5	173.5 \pm 10.2	75.1 \pm 15.4	7.1 \pm 4.6
LS	M	3	21.7 \pm 4.0	178.0 \pm 12.8	82.8 \pm 16.8	6.7 \pm 3.8
	F	10	20.8 \pm 2.8	163.3 \pm 6.0	65.7 \pm 8.6	4.1 \pm 1.2
	Total	13	21.0 \pm 3.0	166.7 \pm 9.8	69.7 \pm 12.6	4.7 \pm 2.2
CO	M	5	23.2 \pm 5.17	183.0 \pm 7.9	86.5 \pm 12.8	5.6 \pm 4.6
	F	9	23.8 \pm 2.9	166.9 \pm 6.0	69.4 \pm 15.3	7.4 \pm 4.8
	Total	14	23.6 \pm 3.7	172.6 \pm 10.2	75.5 \pm 16.4	6.8 \pm 4.6
Total		55	22.7 \pm 3.3	171.1 \pm 9.8	74.0 \pm 15.9	6.1 \pm 4.3

drop outs, one sustained an injury during his soccer practice and three stated lack of time as an issue. The data of the remaining seven subjects who did not successfully complete the study (two from the control group, three from the leg strength group, and one from each of the trunk stability and trunk stability and leg strength groups) could not be used because the standards of compliance were not met. All subjects were required to complete the training nine times over a three-week period, amounting to three times per week. Subject data was excluded if less than six training sessions occurred over any of the three-week training periods.

This study was approved by the University of Saskatchewan Advisory Committee on Ethics in Human Experimentation. All subjects signed a consent form (Appendix A) and were given the opportunity to withdraw at any time.

2.2.1 Inclusion Criteria

1. Participation in any competitive or recreational sport for at least a period of two consecutive seasons.
2. Participation in sport within the previous twelve months.
3. Male or female within the ages of 18 to 30.

2.2.2 Exclusion Criteria

1. Present or recent (within twelve months) lower back pain or lower extremity injury that required treatment or that may inhibit performance or become exacerbated with testing or training.

2. Inability to achieve the starting position for the double straight leg lowering test without increasing the pressure on the sphygmomanometer past 40mmHg or without flexing the knees.
3. Completion of the training protocol less than six times over any of the three three-week training phases as assessed by training logs (Appendix C).

2.3 PROCEDURES

All subjects attended a ten-minute education session immediately prior to pre-testing. Testing consisted of measures for trunk stability, vertical take off velocity, leg strength, and fatigue index. The following subsections describe the testing and training procedures.

2.3.1 Education Session

The education sessions were conducted immediately prior to initial testing. Sessions were completed by showing a video of the investigator instructing the proper technique and activities described below. Following the video sessions, subjects were encouraged to ask questions regarding any aspect of the testing procedures or the video shown.

Richardson and Jull (1995) describe in detail a method of teaching and achieving local trunk stability in a neutral spine position through co-contraction of transverse abdominis and multifidus. Hagins et al. (1999) have used these principles to design and implement a trunk stability education session. This

protocol has been modified for the purposes of this study to allow for practice of the DSLL test.

The first activity was in four point kneeling. Subjects performed a maximal range posterior tilt and associated lumbar flexion followed by a maximal range anterior tilt and associated lumbar extension. The subjects were then asked to find a comfortable position in the mid-range in which their lumbar spines were in a 'slightly forward curved position'. This was deemed to be the probable neutral position for that subject. Subjects were instructed in the abdominal hollowing-in maneuver as described by Richardson and Jull (1995). Subjects were allowed time to practice this maneuver.

The second activity was to perform the same actions described above in supine lying. Subjects performed maximal anterior and posterior pelvic tilts and then found their probable neutral position. The abdominal hollowing-in maneuver was again performed and practiced.

The final activity was explanation and practice of the movements and positions required for the DSLL test. Subjects were instructed regarding the purpose and methods of the DSLL testing procedures, followed by the opportunity to practice the movement.

During the practice of the testing procedures, each subject was examined to determine the effectiveness of muscular activation and to ensure that inappropriate compensation did not occur. Performance was successful if the movement pattern was achieved without elevation of the shoulders from the table,

flexion or extension of the neck, or anterior or posterior tilting of the pelvis (Hagins et al., 1999).

2.3.2 Testing Procedures

Following the education session, subjects were tested on four measures. Each subject was required to complete the DSLL, vertical jump, leg press and repeated vertical jump tests as well as a pre-testing questionnaire. Photographic examples of a subject performing the tests are presented in Appendix D. Each subject completed a five-minute warm up at a low to moderate intensity using a cycle ergometer prior to beginning the leg strength testing.

2.3.2.1 Pre-testing Questionnaire

Subjects were given a pre-testing questionnaire to determine demographic data including age, gender, sport involved with, number of years played, number of times and hours per week, and if the training period was within the subject's inseason or offseason. An example of the questionnaire is presented in Appendix E.

2.3.2.2 Trunk Stability Testing

For the purposes of the present study, trunk stability was defined as the ability to maintain a neutral pelvis and lumbar spine position while performing leg movements including leg lowering and jumping. Trunk stability was assessed using a modified double straight leg lowering (DSLL) test. A Plexiglas support

was constructed that was shaped such that when placed under the subject's lumbar spine, the support creates a relatively neutral lumbar curve. This Plexiglas support (shown in Appendix D) had two plates. The base plate was 30.48 cm wide and 15.24 cm long. The top plate was in the shape of an arc 15.24 cm long and 1.27 cm high at its apex. No normative data could be found so estimates were used to determine these dimensions.

The support was held together by Velcro straps so that one side was hinged and the other able to open and close tightly. A small divot was cut through the top plate to allow the incoming and outgoing pressure tubes of the sphygmomanometer to pass without impingement. The sphygmomanometer was placed within the support and inflated to 40mmHg (Wohlfahrt et al., 1993). The sphygmomanometer was then removed and the level of inflation kept constant. This procedure was completed before each trial for each subject to ensure proper inflation.

Each subject was positioned supine on a hard table such that his/her gluteal folds were at the edge of the table (Appendix D). The inflated sphygmomanometer was inserted under the subject's lumbar spine so that the inferior edge was positioned at the level of the subject's posterior superior iliac spines. An assistant then held both of the subject's legs at an angle of 70° from horizontal. The angle of 70° was used to minimize the effect of tension of the hamstring muscles that may influence the available pelvic and spinal position. The subject's arms were crossed so that his/her hands were resting on the opposite shoulders.

Once positioned correctly, the subject was instructed to adjust the position of the pelvis so that the lumbar spine and pelvis produce enough pressure on the sphygmomanometer to reproduce 40mmHg. It is suggested that this would create a relatively neutral lumbar spine by approaching a similar position as that that would be created with the Plexiglas support underneath the lumbar spine. This method was used to standardize the testing position in a posture that is closer to a neutral lumbar spine than has been used by those previously using the DSLL as a test measure.

A Lafayette guymon electronic goniometer was raised to the level of the subject's left greater trochanter and aligned through its axis. The measurement lever of the goniometer was aligned with the lateral epicondyle of the left femur, and both the subject's legs and the goniometer brought to exactly 70°. The subject was instructed to perform the abdominal hollowing-in maneuver and to maintain 40mmHg on the sphygmomanometer while he/she lowers his/her legs from the starting position. The assistant released the subject's legs and the subject lowered them as far as possible while attempting to maintain 40mmHg and the corresponding lumbar spine position. The test was deemed successful if the subject completed the test in less than eight seconds (Motzkin, Cahalan, Morrey, An and Chao, 1991) with no compensatory abdominal protrusion (Richardson and Jull, 1995).

The angle at the instant that the pressure on the sphygmomanometer rose above 50mmHg or fell below 30mmHg was recorded. This angle was then converted into a value that represents the relative leg gravitational torque that

would be created at the hip joint due to the weight of the legs. This value is expressed as a percentage of the total potential torque that would be created if the legs were held horizontal (a perfect score). In simple terms, this relative leg gravitational torque value is the cosine of the test angle achieved multiplied by 100% as described in more detail below. Three trials were recorded with a one-minute break between trials. The best score was used in the analysis.

Previously, the double straight leg lowering test has been used to merely record the angle at which the pressure on the sphygmomanometer changed (Gilliard and Brown, 1994). Using the test in this way implies a linear relationship between the angle achieved and the torque produced. Because the center of mass of the legs moves in a rotary fashion during leg lowering, the horizontal change in distance between the center of mass and the hip joint is not linear across all angles of the hip. A cosine relationship exists between the angle of the hip and the torque produced. This relationship can be expressed by the following formula as adapted from Hibbeler (1995): $\tau = mgL \cdot \cos\theta$, where τ is the torque produced at the hip, m is the mass of the legs, g is the acceleration due to gravity, L is the actual distance between the hip joint and the leg's center of mass, and θ is the angle of the hip joint from horizontal. For the purposes of this study, it is assumed that the mass of the legs was constant for any given subject, thus the term mgL is constant for an individual but not across individuals. Because this term is constant, it can be cancelled out in the equation for calculating the relative leg gravitational torque as is described below. Therefore, for a recorded leg

lowering angle of 60°, the relative leg gravitational torque would be calculated as follows:

$$\begin{aligned}\text{Relative leg gravitational torque} &= \frac{mgL * \cos\theta_{\text{recorded}}}{mgL * \cos\theta_{\text{perfect score}}} * 100\% \\ &= \frac{mgL * \cos(60)}{mgL * \cos(0)} * 100\% \\ &= \frac{0.5}{1} * 100\% \\ &= 50\%\end{aligned}$$

A diagram of the leg and the corresponding forces and torques produced is presented in Figure 2.1 and a graphical representation of a comparison of a linear and a cosine relationship is presented in Figure 2.2.

Prior to the start of the present study, a reliability study was completed to assess this method of trunk stability testing. The results of the reliability study are presented in Section 3.1.3.1.

2.3.2.3 Vertical Jump

Vertical take off velocity from a force platform was used to assess vertical jump ability. Because the arms contribute to the jump and directly influence pelvic position and movement, they were eliminated from the jump. A wooden bar was placed across the subject's upper shoulders. The subject stepped onto the platform and was instructed to perform a maximal countermovement jump while gripping the bar using a pronated grip (Appendix D). Three trials were recorded with a one minute rest between trials for recovery. Customized

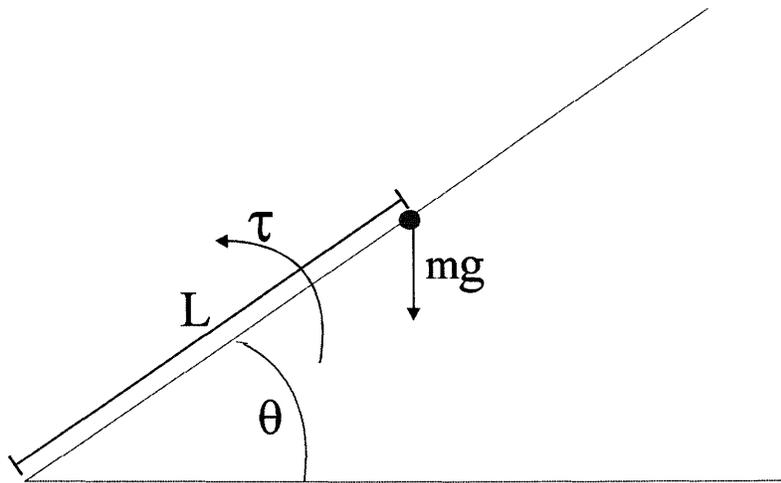


Figure 2.1 Diagram of the biomechanical relationship between leg lowering angle and the resulting torque produced at the hip joint.

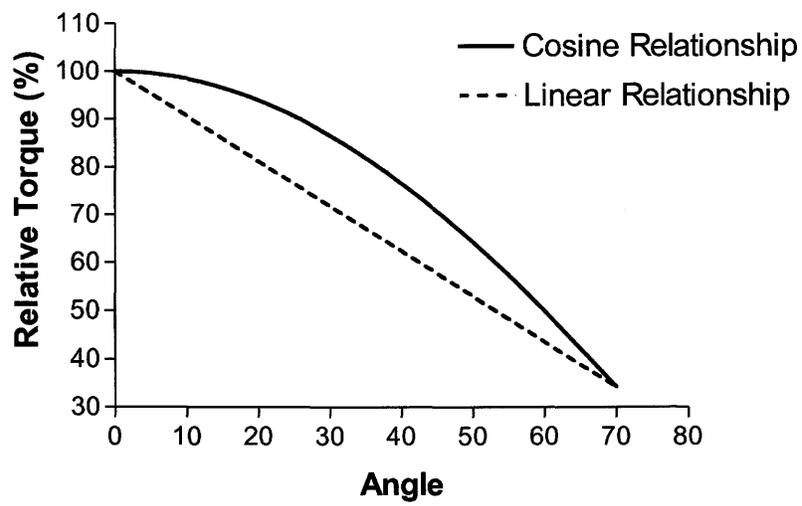


Figure 2.2 Graph of a comparison of the relationship between leg lowering angle and relative leg gravitational torque value for a cosine and a linear relationship.

software was used to determine vertical take off velocity and the best score was used in the analysis.

2.3.2.4 Leg Strength Testing

A seated leg press was used to predict the one repetition maximum for each subject. Subjects were seated on the leg press with the seat adjusted so that the starting knee angle was 70° from the fully extended position as measured manually using a goniometer. This seat position was recorded to standardize subsequent testing procedures. The subject placed his/her feet at a specified position on the leg press platform. A strap was used to attempt to control pelvic stability externally and minimize the influence of the trunk musculature during testing. This strap was positioned across the subject's anterior superior iliac spines anteriorly and behind the seat posteriorly. The subject was required to grip the seat handles throughout the test (Appendix D). The subject performed two warm up sets of 10 repetitions at a low weight with a one minute rest between sets. After a two minute rest period following the second warm up set, the subject performed progressive repeated maximal trials until a maximum of less than 10 repetitions was performed. Between one and four trials were completed by the subjects on each testing day. Two minutes was allowed for recovery between trials. Using the final number of repetitions performed at that load, a one repetition maximum was calculated from the following formula (Ware, Clemens, Mayhew and Johnston, 1995):

One repetition maximum = (weight lifted)(0.033)(repetitions) + (weight lifted)

2.3.2.5 Repeated Vertical Jump

Repeated vertical jump testing was included in this study to examine the effects of the training programs on a more sport specific test. Repeated vertical jump ability was assessed using a PowerJump photocell contact mat (Visionary Controls). The subjects held the wooden bar across the back of the upper shoulders to once again limit the effect of the arms. The subjects stepped onto the mat and performed maximal repeated vertical jumps for 30 seconds (Appendix D). This protocol has been recommended for anaerobic power testing by Bosco, Luhtanen and Komi (1983). Customized software was used to determine fatigue index over the 30 seconds.

2.3.3 Training Programs

As previously mentioned, the three training groups performed a nine-week periodized program designed for gains in maximal strength (LS and TL groups) and for maximal gains in trunk stability (TS and TL groups). Subjects were instructed to perform their respective programs three times per week. Monitoring sessions were held to monitor progress, compliance, and to adjust training weights between each phase of the program. The nine week programs were divided into three three-week training phases. The training program handouts for each phase of the program are presented in Appendix F.

2.3.3.1 Trunk Stability Training Program

The trunk stability training program was designed to achieve progressively increasing global stability demands while maintaining local stability around a neutral spine posture. Phases of training were progressed by increasing the demands on the global stability system. Phase one consisted of basic trunk stability exercises with a low external load. The focus of this phase was control of movement and pelvic position while performing low load lower extremity movements. Subjects in the TS and TL groups were instructed to maintain the abdominal hollowing-in maneuver while performing all exercises. Subjects performed each stability exercise for 3 sets of 5 repetitions. Each repetition was held for five seconds at the maximum possible load without losing pelvic control. The time to reach maximum load and to return to the starting position was one second. The tempo, then, was one second to lower, five seconds to hold, and one second to return to starting position. The load was increased by increasing the horizontal distance of the lever arm of the leg away from the body. There was a ten second rest between each repetition and a one minute rest between each set. The stability exercises included heel slides, single leg lowering with leg support, knee outs, four-point arm lifts, and prone lumbar extensions (alternate arm and leg).

Phase Two involved progressively more difficult exercises. The focus of Phase Two was to increase the external load requirements while still maintaining local co-contraction. The Phase Two exercises included alternating leg lowering, diagonal leg lowering, four-point arm and leg lifts (individual), side supports, and

prone lumbar extensions (both arms and legs). The guidelines for sets, repetitions and rest remained the same.

The focus of Phase Three was to maximize the strength requirement for global stability while maintaining local control and co-contraction. Exercises included double straight leg lowering, diagonal leg lowering, side supports, four point opposite arm and leg lifts, and prone lumbar extensions (both arms and legs). Subjects now performed each repetition for eight seconds, with a fifteen second rest between each repetition and a two minute rest between sets (Appendix F).

2.3.3.2 Leg Strength Training Program

Each subject in the LS group performed the same exercises over the nine week period. Leg press (hip and knee extension), leg extension (knee extension) and leg curl (knee flexion) exercises were performed and the program periodized based on guidelines determined by Bompa (1999). Phase One was the anatomical adaptation phase where subjects trained with high repetitions at a low, submaximal load to allow for non-contractile tissue adaptation (Bompa, 1999). Exercises were performed for three sets of 10 repetitions. The initial load was approximately 75% of 1RM and subjects were instructed to adjust the load so that only 10 repetitions were achieved on every set. Tempo was slow and controlled. There was a 90-second rest between sets. Phase Two was the transition to maximum strength phase. Exercises were performed for 4 sets of 6 repetitions. The initial load was set at 85% of 1RM and adjusted as required to maintain 6

repetitions. There was a three-minute rest between sets. Phase Three was the maximum strength phase. Exercises were performed for 4 sets of 4 repetitions at a load of 90% 1RM. There was a three-minute rest between sets.

2.3.3.3 Trunk Stability and Leg Strength Training Program

Subjects in the TL group performed both of the trunk stability and leg strength programs. The leg strength program was performed prior to, but on the same day as, the trunk stability program.

2.3.3.4 Control Group

Subjects in the control group were tested on all of the measures used for the other groups but did not complete any training protocol within the confines of this study.

2.4 STATISTICAL ANALYSIS

The primary statistical analysis compared the training effects of each group on vertical take off velocity as assessed by the single vertical jump. Secondary analysis compared the training effect of these groups on the repeated vertical jump. Vertical take off velocity and fatigue index were analyzed separately using a 4 x 2 repeated measures ANCOVA (group x time) with SPSS for Windows version 10.0.5. Both pre-training scores and body weight were used as covariates. Manipulation checks were performed for the trunk stability and leg strength scores to determine the effect of the training programs on trunk stability

and leg strength. This effect was determined using a repeated measures ANCOVA with initial scores and body weight as covariates for DSLL and leg press. When statistical significance was evident ($p < 0.05$), post hoc tests were completed using simple main effects for interactions. Because simple main effects are not a standard output using SPSS, a description of how to modify the SPSS output to compute simple main effects is presented in Appendix H. All analysis were completed using $\alpha < 0.05$. Size of effect was determined using omega squared (ω^2). Determining size of effect is an accurate way of comparing treatment effects that are independent of sample size. Omega squared attempts to account for the unexplained variance produced in the analysis and represents the proportion of the variance that can be accounted for by the treatment effects (Vincent, 1999).

Chapter Three

RESULTS AND DISCUSSION

3.1 RESULTS

The results of the statistical analyses are presented below. All analyses were completed using $\alpha < 0.05$. The assumption of sphericity was met for all analyses.

3.1.1 Manipulation Check

Although scores for trunk stability and leg strength were not used in the analysis, they were analyzed to determine the effect of the training programs. Analysis of covariance with pre-training scores and body weight as covariates was used to determine significant differences for each parameter.

3.1.1.1 Trunk Stability

Trunk stability was assessed by using a modified double straight leg lowering (DSL) test as described in Section 2.3.2.2. Prior to the present study, a reliability study was completed to assess the present method of determining trunk stability. Nine athletes (four males and five females) with a mean (\pm standard deviation) age of 23.56 ± 2.60 years completed three trials of the DSL test in each of two sessions. Sessions were greater than three days apart. The Intraclass

Correlation Coefficient was determined to be 0.98, which is considered a strong correlation (Vincent, 1999). Intraclass correlation is a method of determining reliability that is more accurate than using a simple correlation because it is sensitive to changes in both the order and the magnitude of the between trial mean scores (Vincent, 1999). Simple reliability analyses like Pearson's r are sensitive to changes in order of values only.

For the present study, an ANCOVA with pre-training trunk stability scores and pre-training body mass was used to determine if differences exist between groups over time. Pre-training body mass was found to be non significant ($p=0.326$) and was removed from the analysis. There was a significant group by time interaction ($F_{(3,49)}=3.439$, $p=0.02$, $\omega^2=0.087$). This size of effect indicates that 8.7% of the total variance was accounted for by the interaction. Post hoc differences were assessed using a simple main effects at each level of both group and time and are presented in Appendix I. The TL and TS groups exhibited significant increases in trunk stability scores between the third week and ninth week testing periods at $p<0.05$. At both the third week and the ninth week testing periods, both the TS and TL groups were significantly greater than both the LS and CO groups. At the end of both time periods, there was no significant difference between the LS and CO groups or between the TS and TL groups. A graph of the interaction is presented in Figure 3.1 and full results are presented in Tables 3.1 and 3.2. These results indicate that the trunk stability training program was effective in achieving gains in trunk stability.

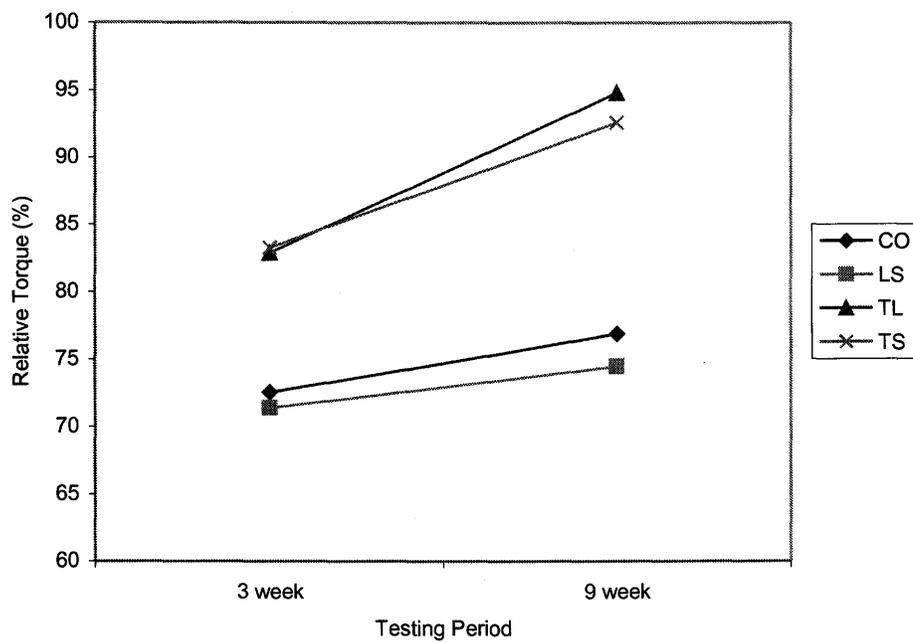


Figure 3.1 Graph of relative leg gravitational torque of the adjusted group means measured at the third week and ninth week testing periods.

Table 3.1 Adjusted means and standard error of trunk stability results for each group at three weeks (TSt₃) and nine weeks (TSt₉).

	Group			
	TS	TL	LS	CO
N	14	14	13	14
TSt ₃	83.27* ^a ± 2.58	82.89* ^a ± 2.55	71.41 ± 2.65	72.56 ± 2.57
TSt ₉	92.60* ± 2.70	94.83* ± 2.68	74.50 ± 2.78	76.90 ± 2.70

*: Significant difference from CO and LS at p<0.05
a: Significant time effect at p<0.05
All results are expressed as mean ± standard error.

Table 3.2 ANCOVA source table for trunk stability (TSt) using trunk stability pre-training score (TSt₀) as covariate.

Source	SS	df	MS	F	Sig	ω^2
Group	5743.309	3	1914.436	12.158	0.000	0.132
TSt ₀	17390.298	1	17390.298	110.440	0.000	0.423
Error (group)	7873.220	50	157.464			
Time	974.890	1	974.890	28.571	0.000	0.245
TSt ₀ * Time	493.719	1	493.719	14.470	0.000	0.110
Group * Time	352.038	3	117.346	3.439	0.024	0.087
Error (time)	1706.063	50	34.121			

3.1.1.2 Leg Strength

Leg strength was assessed using a seated leg press as described in Section 2.3.2.4. The ANCOVA revealed a significant group by time interaction at $\alpha=0.05$ ($F_{(3,48)}=3.454$, $p=0.02$, $\omega^2=0.122$). The size of effect indicates that 12.2% of the total variance is accounted for by the interaction. Simple main effects are presented in Appendix I. Only the TL and LS groups changed significantly between the third week and the ninth week testing periods. At the third week testing period, only the LS group was significantly different from the CO group. At the ninth week testing period, both the TL and the LS groups were significantly greater than the CO group at $p<0.05$, but not from each other. A graph of the interaction is presented in Figure 3.2 and full results are presented in Tables 3.3 and 3.4. These results indicate that the leg strength training program was effective in achieving gains in leg strength after nine weeks of training.

3.1.2 Primary Analysis

3.1.2.1 Vertical Take-off Velocity

Analysis of covariance for vertical take off velocity was performed using pre-training scores and body mass as covariates. Adjusted mean and standard deviation scores for each group at each time period are presented in Table 3.5. There was a significant group by time interaction ($F_{(3,49)}=4.364$, $p=0.008$, $\omega^2=0.160$) for vertical take-off velocity (see Figure 3.3 and Table 3.6). The size of effect indicates that 16% of the total variance is accounted for by the

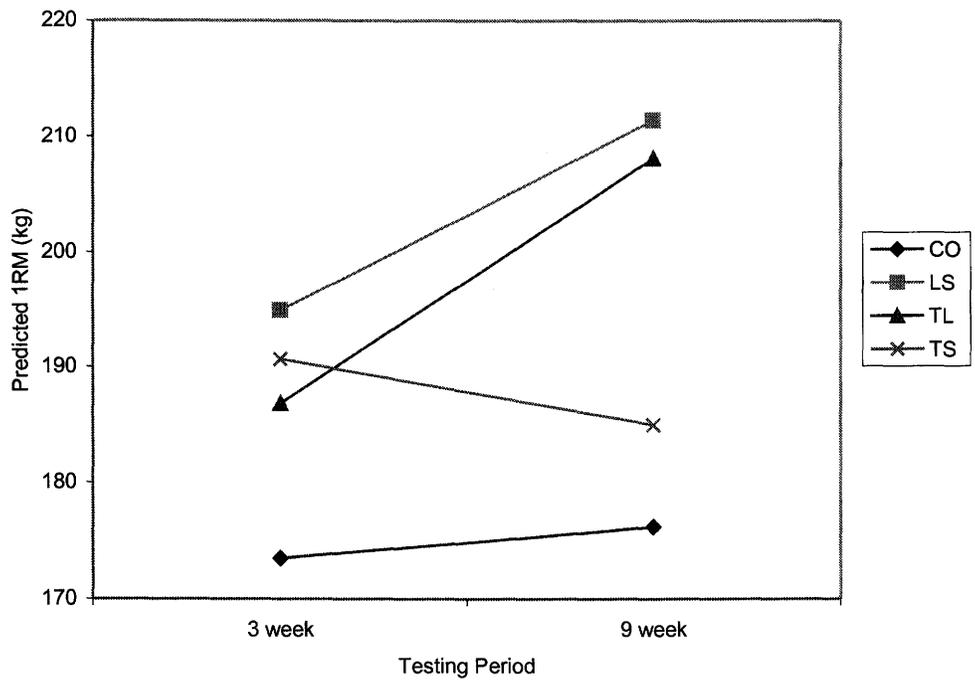


Figure 3.2 Graph of the predicted 1RM scores for leg strength of the adjusted group means measured at the third week and the ninth week testing periods.

Table 3.3 Adjusted means and standard error of leg strength results for each group at three weeks (LSt₃) and nine weeks (LSt₉).

	Group			
	TS	TL	LS	CO
N	14	14	13	13
LSt ₃ (kg)	190.66 ± 14.48	186.85 ^a ± 14.53	194.94 ^{*,a} ± 15.17	173.52 ± 15.23
LSt ₉ (kg)	184.97 ± 16.81	208.15* ± 17.98	211.45* ± 17.61	176.22 ± 17.67

*: Significant difference from CO at p<0.05

a: Significant time effect at p<0.05

All results are expressed as mean ± standard error

Table 3.4 ANCOVA source table for leg strength (LSt) using leg strength pre-training score (LSt₀) and pre-training body mass (BM₀) as covariates.

Source	SS	df	MS	F	Sig	ω^2
Group	56315.512	3	18771.837	3.476	0.023	0.025
BM ₀	59426.392	1	59426.392	11.004	0.002	0.027
LSt ₀	1215199.765	1	1215199.765	225.014	0.000	0.746
Error (group)	259226.350	48	5400.549			
Time	83.951	1	83.951	0.057	0.812	0.000
BM ₀ * Time	15.995	1	15.995	0.011	0.917	0.000
LSt ₀ * Time	1575.295	1	1575.295	1.068	0.307	0.001
Group * Time	15282.049	3	5094.016	3.454	0.024	0.122
Error (time)	70782.344	48	1474.632			

Table 3.5 Adjusted means and standard error of vertical take-off velocity (VTV) scores for each group at three weeks (VTV₃) and nine weeks (VTV₉).

	Group			
	TS	TL	LS	CO
N	14	14	13	14
VTV ₃ (m/s)	2.42* ± 0.53	2.36 ± 0.53	2.33 ± 0.56	2.25 ± 0.53
VTV ₉ (m/s)	2.38* ± 0.53	2.51* ^a ± 0.54	2.41* ± 0.56	2.23 ± 0.53

*: Significant difference from CO at $p < 0.05$.

a: Significant time effect at $p < 0.05$.

All results expressed as mean ± standard error.

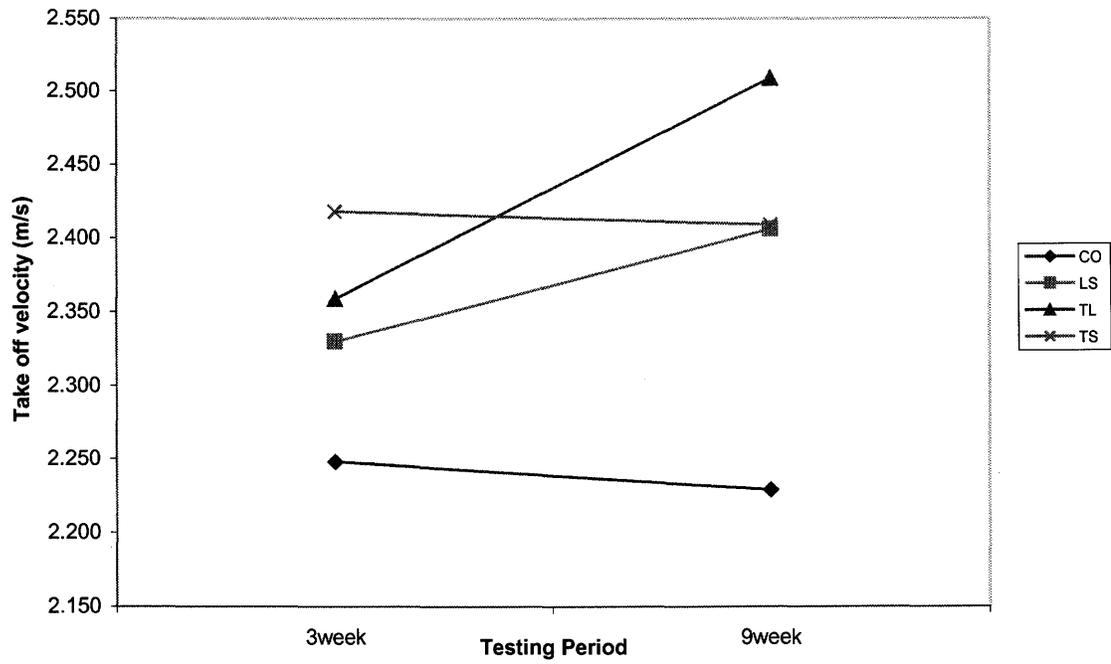


Figure 3.3 Graph of vertical take off velocity of the adjusted group means measured at the third week and the ninth week testing periods.

Table 3.6 ANCOVA source table for vertical take off velocity using vertical take off velocity pre-training score (VTV₀) and pre-training body mass (BM₀) as covariates.

Source	SS	df	MS	F	Sig	ω^2
Group	0.644	3	0.215	3.143	0.033	0.015
VTV ₀	5.194	1	5.194	76.073	0.000	0.506
BM ₀	0.254	1	0.254	3.723	0.059	0.005
Error (group)	3.346	49	0.0623			
Time	0.00502	1	0.00502	0.506	0.480	0.000
VTV ₀ * Time	0.00897	1	0.00897	0.903	0.347	0.000
BM ₀ * Time	0.00771	1	0.00771	0.777	0.382	0.000
Group * Time	0.130	3	0.0433	4.364	0.008	0.160
Error (time)	0.487	49	0.00993			

interaction. Analysis of simple main effects was performed to determine post hoc group differences and are presented in Appendix I. After the three week time period, only the trunk stability (TS) group was significantly different than the control (CO) group ($p=0.03$). After the nine week time period, the trunk stability (TS), leg strength (LS), and trunk stability and leg strength (TL) groups were all significantly different than the control (CO) group ($p=0.02$, $p=0.03$ and $p=0.001$, respectively), but not from each other. Across groups, there was a significant time effect between testing period three and nine for only the TL group ($p=0.001$) (Table 3.5).

3.1.3 Secondary Analysis

3.1.3.1 Fatigue Index

Analysis of covariance for fatigue index was performed. No significant differences or interactions were found. Adjusted means and standard deviations are presented in Table 3.7 and the results in Figure 3.4 and Table 3.8.

Table 3.7 Adjusted means and standard error of fatigue index (FI) results for each group at three weeks (FI₃) and nine weeks (FI₉).

	Group			
	TS	TL	LS	CO
N	12	14	13	9
FI ₃ (%)	70.68 ± 4.94	63.48 ± 4.56	59.11 ± 4.78	70.52 ± 5.79
FI ₉ (%)	61.92 ± 5.06	59.17 ± 4.67	65.52 ± 4.89	68.73 ± 5.93

All results are expressed as mean ± standard error.

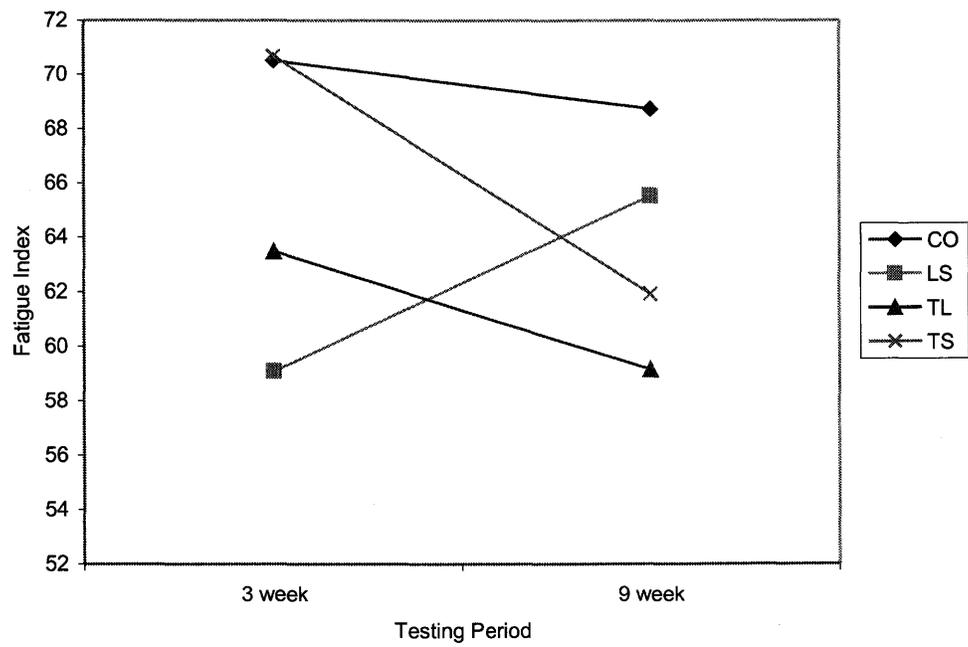


Figure 3.4 Graph of Fatigue Index of the adjusted group means measured at the third week and ninth week testing periods.

Table 3.8 ANCOVA source table for fatigue index (FI) using fatigue index pre-training score (FI₀) and pre-training body mass (BM₀) as covariates.

Source	SS	df	MS	F	Sig
Group	940.865	3	313.622	0.905	0.447
FI ₀	50.124	1	50.124	0.145	0.706
BM ₀	64.195	1	64.195	0.185	0.669
Error (group)	14551.837	42	346.472		
Time	1.372	1	1.372	0.006	0.941
Group * Time	768.171	3	256.057	1.035	0.387
FI ₀ * Time	400.599	1	400.599	1.620	0.210
BM ₀ * Time	261.934	1	261.934	1.059	0.309
Error (time)	10386.535	42	247.298		

3.2 DISCUSSION

The purpose of this study was to determine the effect that trunk stability training and leg strength training have on vertical jump performance in athletes as determined primarily by vertical take off velocity and secondarily by fatigue index. The primary results indicate that for vertical take off velocity measured at the end of the three week time period, only the trunk stability training group was significantly greater than the control group. At the end of the nine week time period, all three training groups differed significantly from the control group, but not from each other. Only the TL group showed a significant increase in vertical take off velocity between the third and ninth week testing periods (see Figure 3.3).

These findings support the first hypothesis that increasing trunk stability will improve vertical take off velocity in athletes. In fact, trunk stability training alone, that enhances available leg strength, will produce immediate gains in vertical take off velocity that are greater than those produced by leg strength training or combined training. Enhanced trunk stability in athletes provides a more stable base for the leg and hip musculature to generate force (Kisner and Colby, 1990) in producing a vertical jump. In activities such as a vertical jump, stability can be enhanced by increasing the muscular co-contraction of the deep abdominal muscles and the lumbar multifidus muscles and by increasing the ability to increase intra-abdominal pressure (Cholewicki, Juluru and McGill, 1999). These increases in co-contraction and ability to increase intra-abdominal pressure are ones that do require training, but are related more to changes in

neural control and muscle activation than to physiological changes (Richardson and Jull, 1995). It is expected that physiological muscle changes will not be evident after only three weeks of training and gains in performance are likely due to increases in the neural control and activation of the muscles involved (Sale, 1992). This indicates that trunk stability is likely more a function of neural control and muscle activation than changes in the musculature itself.

During the first three weeks of the training protocol, trunk stability exercises were designed to increase the overall awareness and control of trunk and pelvic position and to allow for practice of the abdominal hollowing-in maneuver. The exercises, therefore, were not at a level that would challenge the athlete's trunk strength, but would improve the athlete's pelvic and trunk control. Because only the TS group improved enough in vertical take off velocity between the pretest and the three week test to be different than the CO group, it can be assumed that the improvement was due to either improvements in neuromuscular control due to the training program or a significant learning effect due to the testing procedures. A significant learning effect due to the trunk stability test, however, likely did not occur over the course of the study because on the trunk stability measure, only the groups that trained trunk stability significantly improved their trunk stability score. As well, on the measure of vertical take off velocity, the CO group did not improve over time. The adjusted mean value of vertical take off velocity at the third week testing period for the CO group (2.25 m/s) is, in fact, less than the covariate value for the take off velocity pre-training score (2.28 m/s). It can be assumed, then, that a significant learning effect due to

the vertical jump testing procedures did not occur. Therefore, early improvements in vertical take off velocity are likely due to improvements in neuromuscular control achieved by the training protocol.

The intent of the education session performed prior to trunk stability testing was to minimize the potential learning effect by allowing the subjects to practice the test. Richardson and Jull (1990) however, report that the learning associated with trunk stabilization training may occur anywhere between one or two sessions and several weeks. This observation implies that some of the subjects may not have achieved full learning during the education session. It is unclear, however, whether the potential gains in vertical take off velocity would occur only after a period of training, or if the gains may occur after the initial learning has taken place. Because trunk stability is largely an issue of control of position and movement, early learning effects would likely contribute more to this control than they would to a purely physiological muscular change. Further study into the biomechanical and motor control changes that occur due to trunk stability training is needed before conclusions can be reached in this area.

If the initial gains in vertical take off velocity were due to the trunk stability training program, it would also be expected that the trunk stability and leg strength training group would also have increased in vertical take off velocity. Although there appears to be a trend that the TL group seemed to score better on the vertical jump than the CO group after the three week training period, this effect was not statistically significant. One explanation for this is that the group

sizes may not have been large enough to detect a difference. A larger sample size would have been preferable and may have detected a significant difference.

Another possible explanation is that there is a true difference between the effect of the trunk stability training program alone and the trunk stability and leg strength program. This difference could be due to a number of factors. One factor may be an interference effect. The trunk stability program was to be completed after the leg strength program on the same day of training. There is the possibility that the leg strength training somehow decreased the subject's ability to perform the trunk stability exercises. This decrease may be due to the onset of fatigue after completing the leg strength training.

A second factor that may have contributed to a true difference in the response of the training programs is derived from the theory of stability training. Because trunk stability training merely optimizes the ability of the prime movers to produce force, it does not directly contribute to the production of that force. If available leg strength is not improved, there is a theoretical end point to the amount of enhancement of performance that can be achieved with trunk stability training alone. This performance is limited by the strength of the appropriate leg muscles. However, if the strength of the leg muscles increases, it is possible that the gains in trunk stability are not enough to maintain stability for that increased leg strength. Therefore, a greater period of trunk stability training may be required to catch up to the increase in available leg strength in order to optimize force output. The results of the present study support this theory in that there were no significant increases in vertical take off velocity for the LS and TL

groups over the first three weeks of training; however, both groups significantly increased their leg strength. In order to see a significant increase in vertical take off velocity, after only three weeks of leg strength training, it is possible that an extra period of trunk stability training may be required. Further study is required before conclusions can be reached regarding this possibility.

There is evidence to support the theoretical endpoint to the gains in force output achieved by trunk stability training. Although the TS group increased in vertical take off velocity so to be significantly greater than the CO group in the first three weeks of training, there was no change in vertical take off velocity over the remaining six weeks. There was, however, a significant change in trunk stability score over the remaining period for the TS group. If the subjects had achieved optimal trunk stability for the available leg strength in the first three weeks, and the leg strength did not change over the remaining period, then further gains in performance would not occur. Indeed, for the TS group, leg strength did not change over the entire nine week training period.

The second hypothesis of this study was that trunk stability training combined with leg strength training would produce gains in vertical take off velocity that are greater than those produced by either group alone. This hypothesis was rejected because the gains in vertical take off velocity achieved by the TL group were not statistically greater than those achieved by the LS or TS groups. There was, however, a significantly greater slope in the gains of the TL group compared with the LS group between the third and ninth week testing periods because only the TL group significantly increased in vertical take off

velocity over this time period. Because both the TL and LS groups had significant increases in leg strength and the TL group increased in trunk stability while the LS group did not, the greater improvement in vertical take off velocity for the TL group is likely due to the enhanced trunk stability. A longer training period may reveal significant group differences at the end of training.

The secondary analysis examined the effects of the training programs on fatigue index as measured by a repeated vertical jump. This test was used to add a more sport specific element to the testing procedures. The results indicated that no significant relationships were evident for any of the groups at any time period. Because the repeated vertical jump is a measure of anaerobic power, any change in anaerobic power in the subjects would likely lead to changes in fatigue index that would not necessarily be related to the present training protocol. Subjects were not prohibited from completing any outside cardiovascular training or from participating in their sport during the duration of the study. Results of the pre-testing questionnaire reveal that forty-two out of fifty-five subjects were in their inseason during the study. It is quite possible that changes in anaerobic power due to gains made during inseason training would mask any possible effect of the training program. Further study that better controlled for activity is necessary to examine this relationship.

Another factor that might have contributed to the fact that there were no significant differences in fatigue index is specificity of training. The trunk stability and leg strength training protocols were designed to achieve maximum strength and control. In order to achieve this goal, training must be slow and

relatively static (Bompa, 1999). Following this guideline, the subjects in this study completed slow and controlled strength and stability exercises. Because the repeated vertical jump is a dynamic, repetitive skill, a more dynamic training protocol for both trunk stability and leg strength may have resulted in a greater carry over to the skill of repetitive jumping, and therefore, may have shown a significant difference due to the training protocol.

There are several limitations to the interpretation and generalization of the results of this study. Although all athletes in the Saskatoon area between the ages of 18 and 30 were eligible for participation of this study, time and feasibility factors limited recruitment. As such, there are a high proportion of athletes from rugby and a high proportion of female athletes. As well, forty-two of the total fifty-five athletes were in their inseason. These factors may have contributed to a bias in either the testing results or the training programs. A high proportion of subjects in a certain demographic may have an effect on the training or the testing protocols or results. For example, if the high proportion of female rugby players (all in their inseason) were all training similarly, there may be an effect on the testing or training protocols that is due to their rugby training. The resulting effect on the testing results may not be due to the effect of the trunk stability or leg strength training programs, but to the rugby training. This effect over a large number of subjects may result in a decreased ability to generalize these results to populations other than female inseason rugby players.

This study examined the effect that a trunk stability training program using mat exercises, and a leg strength program using machines, had on vertical

jump performance. There are many training methods available that claim to enhance trunk stability. Other methods such as Pilates exercises, Swiss Ball or Theraball exercises and conventional dynamic abdominal exercises have been used to enhance stability (Liggett, 1999). There is no known literature that compares different types of stability training methods. The results of the present study apply only to the mat exercises used within the study, and further study is required to attempt to determine differences in training methods.

Leg strength training is commonly used to enhance sport performance. In training for increased ability to jump vertically, most training programs would incorporate high velocity training as well as training using exercises that are more specific to the mechanics of jumping. Comparison of these training methods shows that for functional strength gains, free weights using a movement pattern that is similar to the movement that is desired to be improved are superior to machine training (Augustsson, Esko, Thomee and Svantesson, 1998; Blackburn and Morrissey, 1998). The movement pattern most specific to vertical jump is the squat (Bompa, 1999). A free weight squat exercise was not used in this study to avoid excessive trunk activity and to help control for training technique. The comparison of results obtained using trunk stability exercises to that of a more functional strengthening exercise program may yield different results.

A final limitation to the generalization of the results of this study is the lack of supervision during training. Decreased availability of time and space limited the ability to supervise the subjects. Subjects trained on their own and training logs (Appendix C) were used to assess compliance. If the subjects had

been supervised, there would have been less of a need for subject self reporting of training frequencies and the accuracy of the reported frequencies would be ensured. Inaccurate reporting of training frequencies may lead to a decreased ability to generalize the results to other training programs that would follow the guidelines of this study.

The results of this study have wide implications for athletes, coaches, sport scientists and trainers looking to enhance an athlete's jumping ability. It is possible to increase an athlete's vertical jump by performing a short program of basic trunk stability exercises. This effect appears to be more relevant after three weeks of training than after nine weeks of training. Further study is required to determine ongoing effects related to combining trunk stability training and leg strength training, however; this study is the first known to show a positive effect of trunk stability training on athletic performance enhancement.

The results of this study should help to guide training programs that are designed to enhance performance in athletes. As well, the results should provide some insight into the importance of examining subtle changes in training and skill techniques from the point of view of the body's alignment and posture. The results should spark further interest and research in biomechanics and motor control to determine the exact effects and mechanisms of trunk stability training for performance enhancement.

Chapter Four

CONCLUSIONS

4.1 SUMMARY

Athletes and coaches are constantly endeavoring to achieve the best possible performance in their chosen sport. Part of achieving that optimal performance is preparing the athlete physically. There are many methods of training that will help prepare the athlete for competition. Abdominal and trunk muscle training have been a staple of modern day physical preparation (Norris, 1993). Yet, the contribution of the abdominal and back musculature to performance of sporting skills is poorly understood.

In order to achieve optimal performance, the muscles used in the skills performed must be able to produce force both maximally and efficiently. For this function to occur, the prime movers of a particular movement or skill must have a stable base from which they can contract (Kisner and Colby, 1990). This base allows the muscle contraction to produce movement in the desired body segment only and not in the proximal segment. Undesired movements of the proximal segment will result in less overall force production (Kisner and Colby, 1990).

Trunk stability training has been used in the treatment of low back pain and injury (O'Sullivan, Twomey, and Allison, 1998) and is often assumed to be useful in enhancing athletic performance. Positive results have been found in a recent

unpublished study at the University of Saskatchewan (B.R. Craven, personal communication, September, 1999) that determined that a significant correlation exists between trunk stability and vertical jump.

The results of the present study reveal that trunk stability training can enhance vertical jump ability in athletes after three weeks of training using mat exercises. This effect does not result in significant gains beyond the initial three week training period, but may supplement leg strength training in the later stages of training. A trend exists for the group that trained trunk stability and leg strength to increase in vertical take off velocity to a higher degree than the group that trained leg strength alone. This increase is not statistically significant.

Trunk stability training should include exercises that provide local stability through co-contraction of transversus abdominis and multifidus and expand to include global stability through the directional control of the larger trunk muscles. This combination of muscle activity will increase the intra-abdominal pressure and the overall stiffness of the spine in order to help maintain a stable spine and pelvis while performing various limb tasks (Richardson and Jull, 1990).

There is no accurate measure of trunk stability. This study attempted to modify the most appropriate measure so that it better meets the requirements of trunk stability. The double straight leg lowering test was modified to allow the subject to maintain a neutral spine position, and to maintain appropriate co-contraction throughout the test. As well, the scores were converted to a score that more accurately reflects the torque that is being produced at the hip joint, and the corresponding forces at the pelvis.

4.2 CONCLUSIONS

- 4.2.1 Within the limitations and assumptions previously stated, hypothesis 1.3.2.1 was supported by the experimental evidence.
- 4.2.2 Within the limitations and assumptions previously stated, hypotheses 1.3.2.2 and 1.3.2.3 were not supported by the experimental evidence.

4.3 RECOMMENDATIONS FOR FUTURE RESEARCH

Research should be completed to further define and describe the effects of trunk stability training in order to:

- 4.3.1 Compare the effects of different methods of trunk stability training on improvements in stability and performance.
- 4.3.2 Compare the present methods of training for improvements in leg strength with methods that incorporate the use of the trunk muscles as stabilizers, such as the squat.
- 4.3.3 Determine the effect of trunk stability training on other performance measures.
- 4.3.4 Examine the biomechanical and motor control changes that occur with trunk stability training.
- 4.3.5 Determine the effect of a longer training period using combined trunk stability and leg strength training on vertical take off velocity.

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APPENDICES

APPENDIX A
CONSENT FORM AND COVER LETTER

**THE EFFECT OF TRUNK STABILITY TRAINING ON VERTICAL TAKE
OFF VELOCITY IN ATHLETES**

COVER LETTER

Dear Athlete,

We are conducting a study to determine the role that trunk stability and leg strength training have on vertical takeoff velocity and repeated vertical jump. We would like you to participate in this study. It involves three testing periods that includes 4 physical tests and a nine-week training period. You will be asked to perform a trunk stability test, a leg press test a vertical jump test and a repeated vertical jump test. During the nine week training period you will be placed into one of four training groups: Group One will be a control group that will not be doing any form of training, Group Two will be undergoing trunk stability exercises, Group Three will be undergoing leg strengthening exercises and Group Four will be undergoing both trunk stability and leg strength exercises.

The proposed study provides insight into the proper way of developing training programs for athletes competing in a variety of sports. Many athletes simply develop limb strength utilizing machines that stabilize the trunk. The most recent research seems to indicate that athletic function is dependent not only on leg strength but also on trunk stability. With the proposed study, the researchers aim to clarify the need for proper trunk stability in conjunction with leg strengthening exercises to maximize athletic performance.

All strength testing and training is accompanied with injury risk. You may experience back pain and you could suffer a strained muscle or other injury.

However, these risks are remote due to the properly designed training and testing methods and by supervision by qualified professionals.

All of your results will remain confidential. That is, no person outside of the research team will be able to acquire your data. Copies of the trunk stability training program and the findings of this project will be made available to you at your request upon the completion of the project.

Procedures

1. Double Straight Leg Lowering Test:

In this test, the stability of the trunk is measured by the ability of the trunk muscles to keep the pelvis stable and unmoving. The participant will lie on their back with their legs hanging off the edge of a hard table. Forearms are folded across the chest with fingers touching the opposite shoulders. A blood pressure cuff is inflated to 40 mmHg and is used to determine when the participant is raising the lumbar spine off of the table. The examiner places the cuff under the participant's back. The participant will be instructed as to the proper method of muscle contraction and will be asked to perform this contraction and hold the spine and pelvis stable through the course of the test. The examiner assists the participant in raising the legs to a 70 degree angle above horizontal. An electric goniometer (angle measure) measures the angle between the subject's legs and the table. The subject then lowers their straight legs down towards horizontal. To grade the test, the angle between the extended legs and the table is noted on the goniometer at the moment the pressure on the cuff raises above 50mmHg or drops below 30mmHg. The test is measured in degrees from horizontal and converted to a relative torque value. A perfect score is 0 degrees from horizontal, which converts to a relative torque of 100%.

2. Vertical Jump:

The participant stands on a force plate with their feet placed approximately shoulder width apart with toes pointing forward. A bar is placed behind the participant's neck and will be held at a comfortable width. The body weight should be equally distributed between both feet. Participants will lower their body weight quickly and explode upward to attempt to gain as much height as possible. The bar should remain across the participant's shoulders throughout the test so that the arm's contribution to the jump is minimal. The participant will perform three jumps with a one-minute rest between each jump. Specialized software will determine vertical take off velocity.

3. Leg Press:

The leg press machine attempts to isolate the leg muscles and avoid any muscle action in the trunk region. The participant is required to sit down on the leg press machine so that the back is flush against the back support when the knees are bent to approximately 70 degrees. The athlete's pelvis is secured to the machine by straps to ensure stability. Both feet are placed on the foot platform shoulder width apart. The movement is to be performed under control and the feet should remain flat on the platform throughout the movement. The first set is a light warm-up. The second set is 12 repetitions at a weight that the athlete feels comfortable with. The third set is a weight that the athlete believes that would only be able to be lifted only once. If the athlete is able to complete more than one lift, the weight is increased in the fourth set to a level that the athlete would likely be able to complete only once. This process will be repeated until a weight is reached that can be lifted only once. A rest of 2 minutes is given between each trail to allow for recovery. The final weight will be recorded as the participant's one repetition maximum.

4. Repeated Vertical Jump:

The participant will stand on a jump mat in a comfortable stance. The body weight should be equally distributed between both feet. A bar will be placed behind the participant's neck and will be held at a comfortable width. The bar should remain across the participant's shoulders throughout the test so that the arm's contribution to the jump is minimal. The participant will perform repeated maximal vertical jumps for a period of 30 seconds. Jumps will be performed without pause between jumps. Specialized software will determine flight time and power.

THE EFFECT OF TRUNK STABILITY TRAINING ON VERTICAL TAKE OFF VELOCITY IN ATHLETES

CONSENT FORM

My signature on this sheet indicates that I, _____, will participate in a study by Scott Butcher and Bruce Craven investigating the effect of trunk stability training on vertical take off velocity in athletes.

I understand the following:

1. I am a volunteer and am free to withdraw at any time from the study without fear of penalty.
2. I have received explanations about the nature of the study, its purposes, and procedures.
3. There is minimal risk of physical harm and I have completed the injury questionnaire.
4. My individual data will remain confidential from sources outside of the study.
5. I will receive a summary of the project and a copy of the trunk stability training program, upon request, following the completion of the project.

Statement:

I voluntarily consent to participate in this project. I understand that at any time during the study, I am free to withdraw from the study without fear of penalty. The procedures have been explained to me and I fully understand the contents of the cover letter, testing procedures and test restrictions, possible injury risks and the injury questionnaire and consent form. I have had the opportunity to ask questions and have received satisfactory answers to all inquiries regarding this study.

Subject Signature: _____ Date: _____

Investigator Signature: _____ Date: _____

Scott J. Butcher, B.Sc. (P.T.)
College of Kinesiology
University of Saskatchewan

APPENDIX B

**TABLE OF FREQUENCY OF PARTICIPATION BY
SPORT, GROUP, AND GENDER**

Frequency by Group and Gender

Sport	TS		TL		LS		CO		Total
	M	F	M	F	M	F	M	F	
Basketball							1	2	3
Dance		1							1
Distance running		1				1	1	1	4
Football	1								1
Hockey				1		1			2
Kayaking	1								1
Martial Arts			1			1			2
Rowing				1		1			2
Rugby	1	5		2	2	5	2	2	19
Slow Pitch	1			2				1	4
Soccer	1		1	1			1	1	5
Swimming			2	1		1			4
Touch Football								1	1
Track and Field			1		1				2
Volleyball	1	1	1					1	4
In-season	4	6	4	7	3	8	3	7	42
Off-season	2	2	2	1	0	2	2	2	13
Total Males	6		6		3		5		20
Total Females		8		8		10		9	35
Total in Group	14		14		13		14		55

APPENDIX C
TRAINING LOG

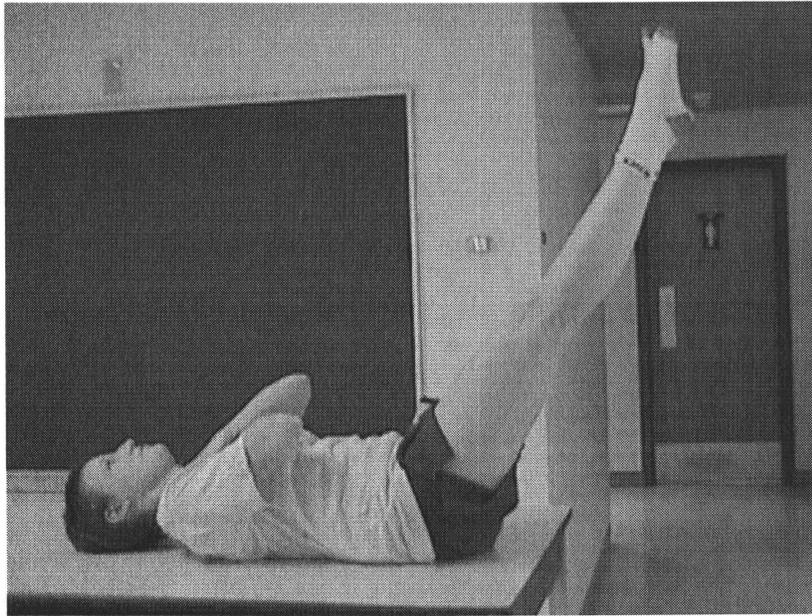
Training Log

Week 1	Monday	Tuesday	Wed.	Thursday	Friday	Saturday	Sunday
Time of day, exercises done, Comments							
Week 2	Monday	Tuesday	Wed.	Thursday	Friday	Saturday	Sunday
Time of day, exercises done, Comments							
Week 3	Monday	Tuesday	Wed.	Thursday	Friday	Saturday	Sunday
Time of day, exercises done, Comments							

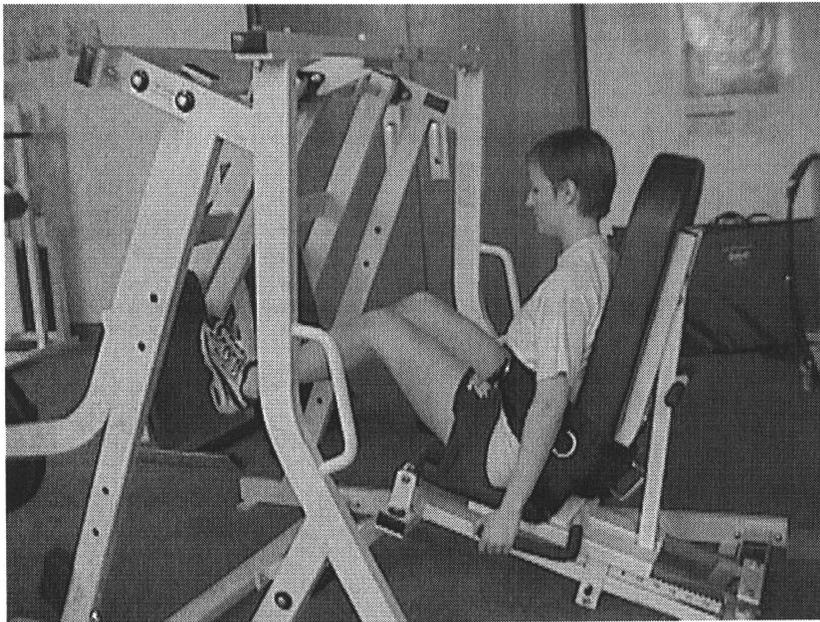
Note: Please return this Training Log at Follow up testing.

APPENDIX D
PHOTOGRAPHS OF TESTING PROCEDURES AND EQUIPMENT

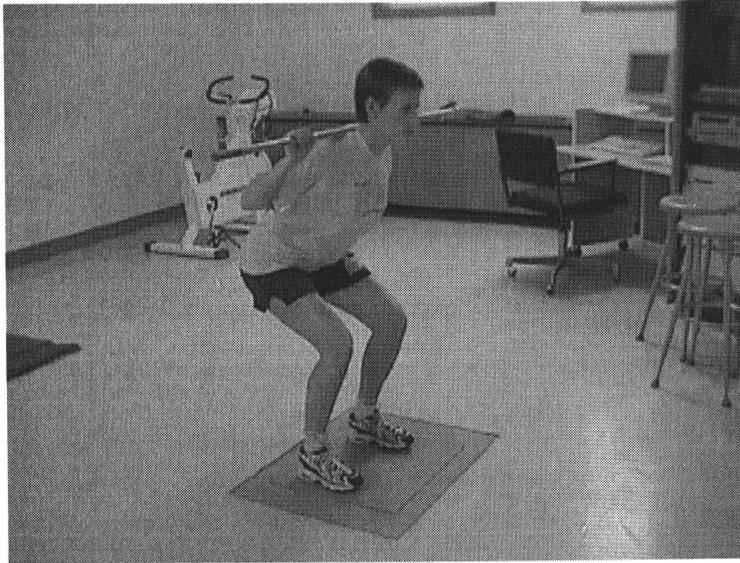
Subject performing the double straight leg lowering test



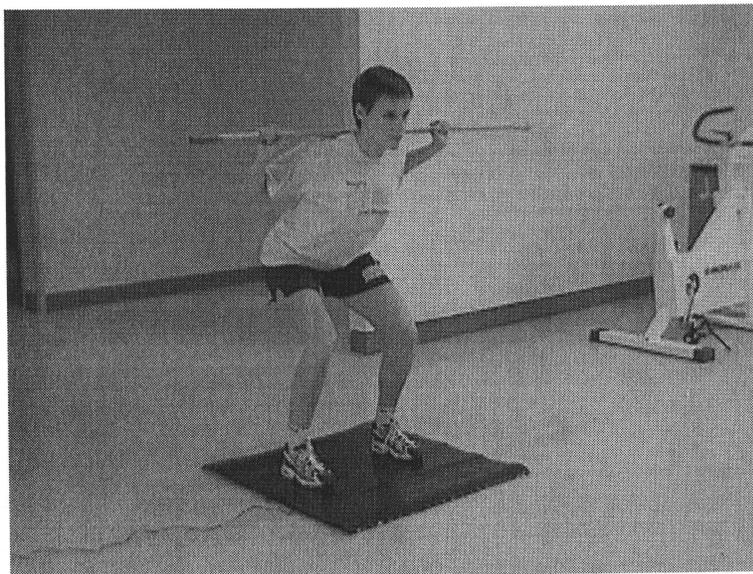
Subject performing the leg press test



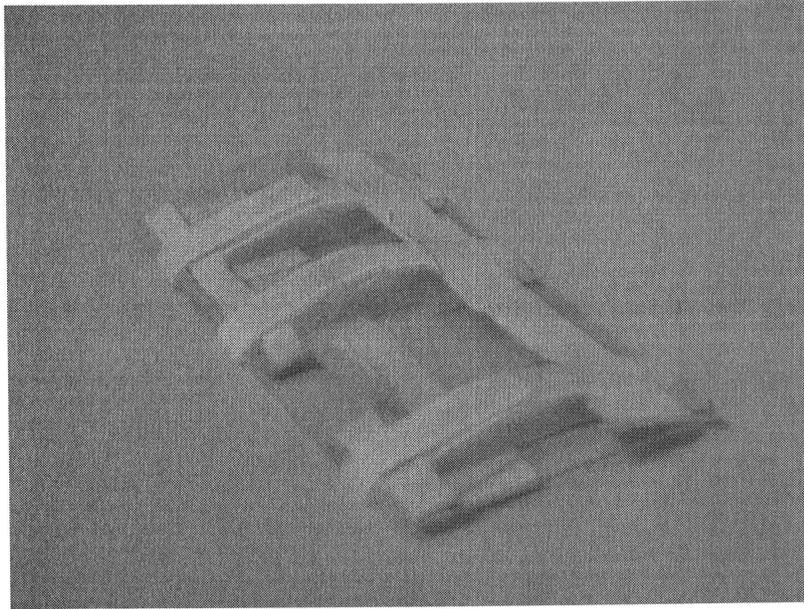
Subject performing the vertical jump test



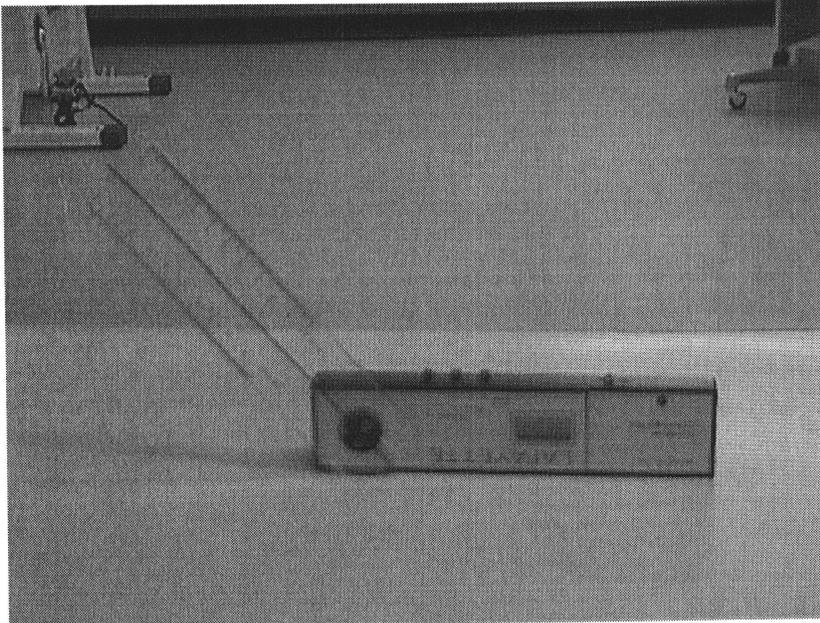
Subject performing the repeated vertical jump test



The Plexiglas support to house the sphygmomanometer cuff



The Lafayette goniometer used to measure leg lowering angle



APPENDIX E
PRE-TESTING QUESTIONNAIRE AND RESTRICTIONS

PRETESTING QUESTIONNAIRE

Name:

Email:

Phone:

Fax:

Address:

DOB:

Gender M / F

Age:

Occupation:

Sport:

years played:

Length of season:

times per week:

Is this your:

hours per week:

Inseason

Offseason

PRE TEST RESTRICTIONS

Please follow these restrictions in order to help obtain the most accurate measurements possible. Your cooperation will help provide the best scientific results possible and is appreciated.

1. Do not lift weights closer than 24 hours prior to your testing time.
2. Do not eat for 4 hours prior to testing time.
3. Do not consume caffeine and do not smoke the day of testing.
4. Do not drink alcohol closer than 24 hours prior to your testing time.
5. Be prepared to give full effort during testing.

Thank you for volunteering.

Signature: _____ Date: _____

INJURY QUESTIONNAIRE

Please circle the appropriate response.

YES NO 1. Do you have low back pain when you perform physical activity?

YES NO 2. Have you injured your back in the past 12 months?
YES NO If yes, are you currently being treated for the injury?

YES NO 3. Do you have any injury that could be made worse by testing?
If yes, please describe:

YES NO 4. Do you have a bone or joint problem that could be made worse
by testing? If yes, please describe:

YES NO 5. Do you know of any other reason why you should not participate
in the study?

Signature: _____ Date: _____

APPENDIX F
EXERCISE PROGRAM GUIDES

Exercise Guide

Trunk Group Phase I

Instructions:

1. Complete each of the five exercises in turn.
2. Your tempo should be such that it takes one second to attain the position, five seconds to hold the position and one second to return to the starting position.
3. Follow the audio cassette instructions for the timing of each exercise.
4. Complete five (5) repetitions with a 5 second rest in between each repetition.
5. Complete two (2) sets of these five (5) repetitions with a one (1) minute rest in between each set.
6. Rest one minute then move on to the next exercise.
7. Complete the entire program three times per week on non consecutive days for the entire three week period of Phase I.
8. Return for follow up testing on your specified day and receive the program for Phase II.

Exercises:

(1) Heel Slides

Lie on back, contract stomach muscles so that belly button is brought closer to your spine and upwards towards rib cage.

Lower back should be in neutral (slight inward arch).

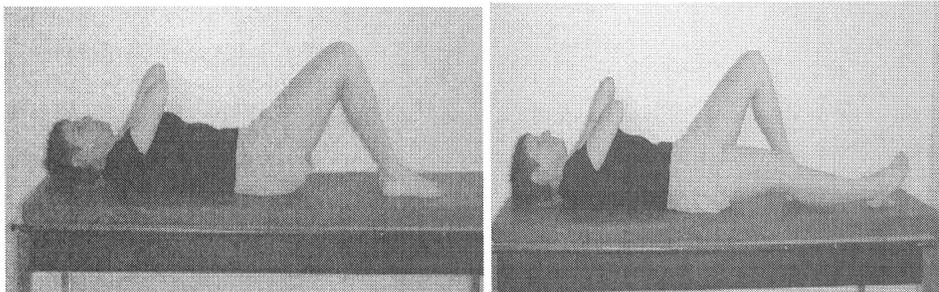
With knees bent, slide one leg straight out.

Back and pelvis **MUST NOT** move during the leg movements.

Slide one leg at a time

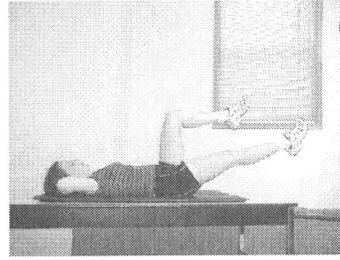
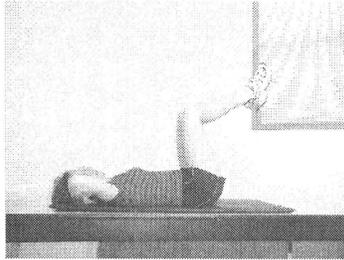
Stop moving your leg when your back and pelvis begin to move. Hold position for 5 seconds and return to the start position.

One repetition is counted after you have lowered both of your legs once.



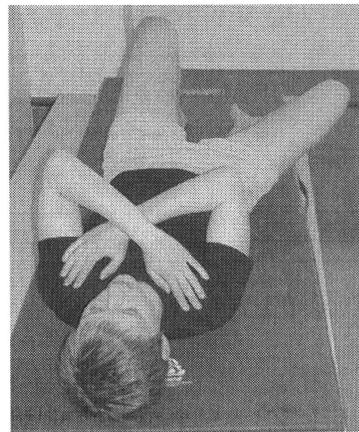
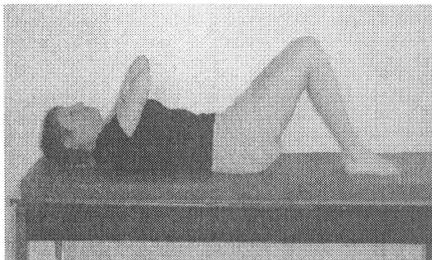
(2) Single Leg Lowering

- Lie on back, contract stomach muscles so that belly button is brought closer to your spine and upwards towards rib cage.
- Lower back should be in neutral (slight inward arch).
- With knees bent, raise both legs into a vertical position.
- Back and pelvis **MUST NOT** move during the leg movements.
- Lower one leg at a time
- Stop moving your leg when your back and pelvis begin to move. Hold position for 5 seconds and return to the start position.
- *One repetition is counted after you have lowered both of your legs once.*



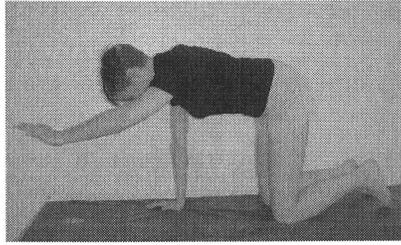
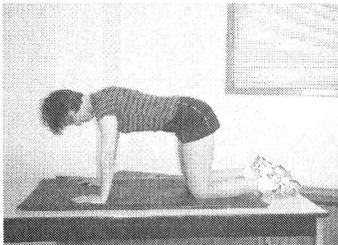
(3) Knee Outs

- Lie on back, contract stomach muscles so that belly button is brought closer to your spine and upwards towards rib cage.
- Lower back should be in neutral (slight inward arch).
- With knees bent, drop one knee out to the side.
- Back and pelvis **MUST NOT** move during the leg movements.
- Drop one knee at a time
- Stop moving your leg when your back and pelvis begin to move. Hold position for 5 seconds and return to the start position.
- *One repetition is counted after you have lowered both of your knees once*



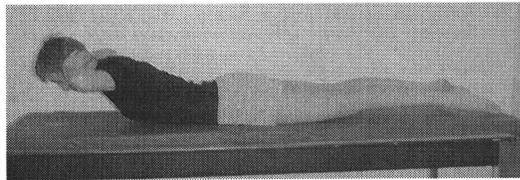
(4) Quadruped

- Move onto your hands and knees.
- Ensure that your back is straight. The use of a mirror will help you make sure it is in-line. Another way to check is to put a shoe or book on your back to help give you more feedback.
- Contract stomach muscles so that belly button is brought closer to your spine and upwards towards rib cage.
- Raise one arm. Hold for five seconds and lower.
- Raise the other arm. Hold for five seconds and lower.
- One repetition is counted after you have raised both arms once.
- Remember not to move your back or hips while moving arms.



(5) Back Extensions

- Lie on your stomach with your hands behind your head.
- Ensure that your back is straight. Contract stomach muscles so that belly button is brought closer to your spine and upwards towards rib cage.
- Slowly raise your shoulders keeping your stomach muscles tight.
- Hold for five seconds and lower.



Exercise Guide

Trunk Group Phase II

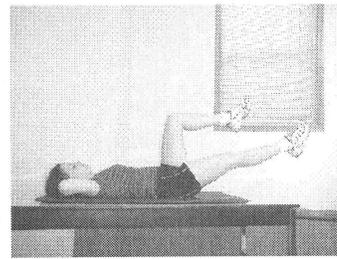
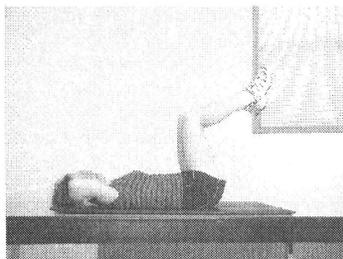
Instructions:

9. Complete each of the five exercises in turn.
10. Your tempo should be such that it takes one second to attain the position, five seconds to hold the position and one second to return to the starting position.
11. Follow the audio cassette instructions for the timing of each exercise.
12. **Complete five (5) repetitions with a 5 second rest in between each repetition.**
13. **Complete two (2) sets of these five (5) repetitions with a one (1) minute rest in between each set.**
14. Rest one minute then move on to the next exercise.
15. Complete the entire program three times per week on non consecutive days for the entire three week period of Phase II.
16. Return to receive the program for Phase III at the specified time.

Exercises:

(1) Single Leg Lowering

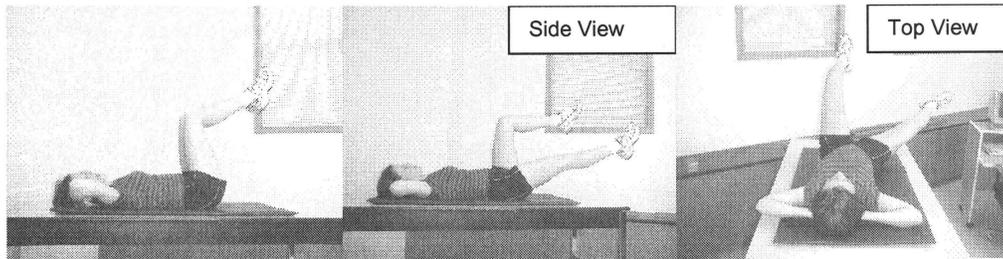
- Lie on back, contract stomach muscles so that belly button is brought closer to your spine and upwards towards rib cage.
- Lower back should be in neutral (slight inward arch).
- With knees bent, raise both legs into a vertical position.
- Back and pelvis **MUST NOT** move during the leg movements.
- Lower one leg at a time
- Stop moving your leg when your back and pelvis begin to move. Hold position for 5 seconds and return to the start position.
- *One repetition is counted after you have lowered both of your legs once.*



(2) Diagonal Leg Lowering

- Lie on back, contract stomach muscles so that belly button is brought closer to your spine and upwards towards rib cage.
- Lower back should be in neutral (slight inward arch).
- With knees bent, raise both legs into a vertical position.
- Back and pelvis **MUST NOT** move during the leg movements.
- Lower one leg at a time diagonally down and out.
- Stop moving your leg when your back and pelvis begin to move. Hold position for 5 seconds and return to the start position

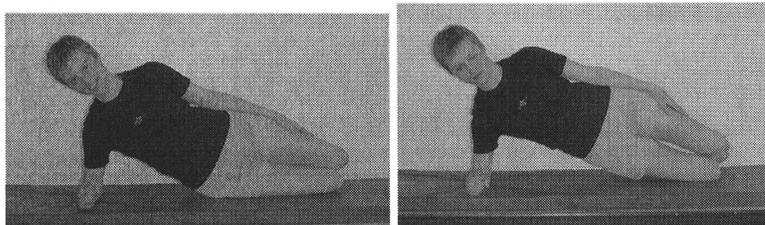
One repetition is counted after you have lowered both of your knees once



(3) Side Supports (knees)

- Lie on your side with your elbow directly under your shoulder supporting your body, with your hips straight and your knees bent to 90°.
- Contract your stomach muscles so that your belly button is brought closer to your spine and upwards towards rib cage.
- Lower back should be in neutral (slight inward arch).
- Lift your hips so that so that your body is in a straight line from your shoulders to your knees.
- Do not allow your hips to bend forward or backward.
- Hold position for 5 seconds and return to start.
- Repeat for all 5 repetitions on one side then turn and repeat for the other side.

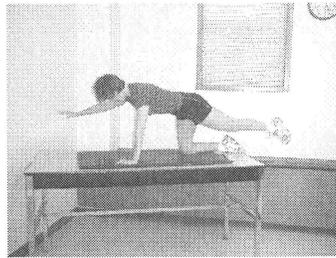
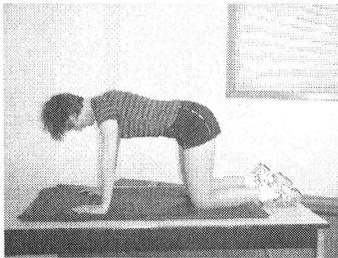
One set is counted after you have performed 5 reps on each side.



(4) Quadruped

- Move onto your hands and knees.
- Ensure that your back is straight. The use of a mirror will help you make sure it is in-line. Another way to check is to put a shoe or book on your back to help give you more feedback.
- Contract stomach muscles so that belly button is brought closer to your spine and upwards towards rib cage.
- Raise one arm and the opposite leg. Hold for five seconds and lower.
- Raise the other arm and the other leg. Hold for five seconds and lower.
- Remember not to move your back or hips while moving limbs.

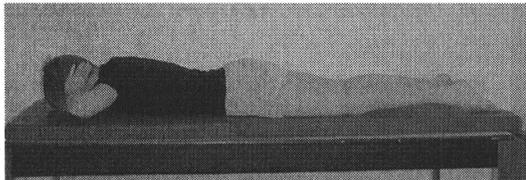
One repetition is counted after you have raised all four limbs once.



(5) Back Extensions

- Lie on your stomach with your hands behind your head.
- Ensure that your back is straight. Contract stomach muscles so that belly button is brought closer to your spine and upwards towards rib cage.
- Slowly raise one arm and the opposite leg keeping your stomach muscles tight. Hold for five seconds and lower.
- Raise the other arm and leg. Hold for five seconds and lower.

One repetition is counted after you have raised all four limbs once.



Exercise Guide

Trunk Group Phase III

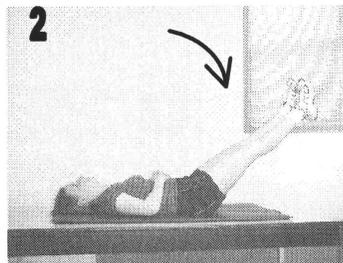
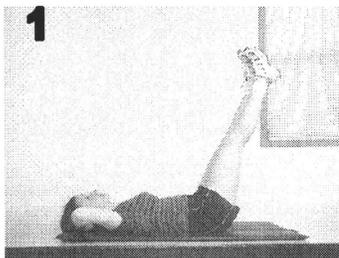
Instructions:

17. Complete each of the five exercises in turn.
18. Your tempo should be such that it takes one second to attain the position, five seconds to hold the position and one second to return to the starting position.
19. **Complete five (5) repetitions with a 12 second rest in between each repetition.**
20. **Complete two (2) sets of these five (5) repetitions with a one (1) minute rest in between each set.**
21. Rest one minute then move on to the next exercise.
22. Complete the entire program three times per week on non consecutive days for the entire three week period of Phase III.
23. Return for final testing at the specified time.

Exercises:

(1) Double Leg Lowering

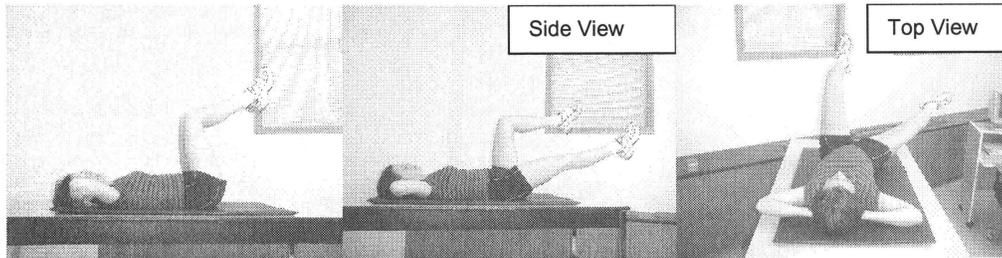
- Lie on back, contract stomach muscles so that belly button is brought closer to your spine and upwards towards rib cage.
- Lower back should be in neutral (slight inward arch).
- With knees straight, raise both legs into a vertical position.
- Back and pelvis **MUST NOT** move during the leg movements.
- Lower both legs together.
- Stop moving your leg when your back and pelvis begin to move. Hold position for **8 seconds** and return to the start position.



(2) Diagonal Leg Lowering

- Lie on back, contract stomach muscles so that belly button is brought closer to your spine and upwards towards rib cage.
- Lower back should be in neutral (slight inward arch).
- With knees bent, raise both legs into a vertical position.
- Back and pelvis **MUST NOT** move during the leg movements.
- Lower one leg at a time diagonally down and out.
- Stop moving your leg when your back and pelvis begin to move. Hold position for **8 seconds** and return to the start position

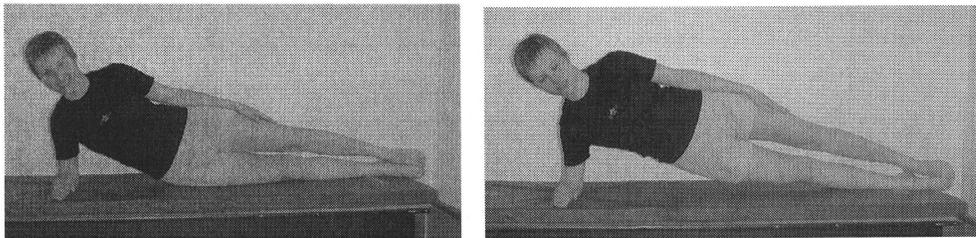
One repetition is counted after you have lowered both of your knees once



(3) Side Supports (feet)

- Lie on your side with your elbow directly under your shoulder supporting your body, with your hips straight and your knees straight.
- Contract your stomach muscles so that your belly button is brought closer to your spine and upwards towards rib cage.
- Lower back should be in neutral (slight inward arch).
- Lift your hips so that so that your body is in a straight line from your shoulders to your feet.
- Do not allow your hips to bend forward or backward.
- Hold position for **8 seconds** and return to start.
- Repeat for all 5 repetitions on one side then turn and repeat for the other side.

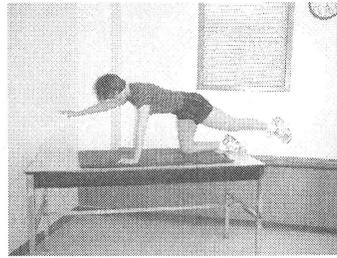
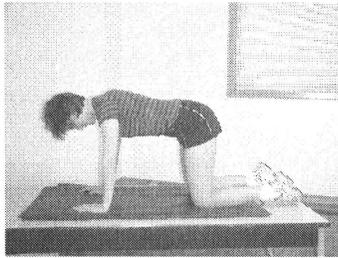
One set is counted after you have performed 5 reps on each side.



(4) Quadruped

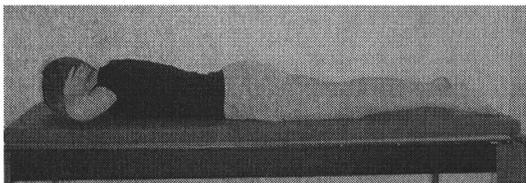
- Move onto your hands and knees.
- Ensure that your back is straight. The use of a mirror will help you make sure it is in-line. Another way to check is to put a shoe or book on your back to help give you more feedback.
- Contract stomach muscles so that belly button is brought closer to your spine and upwards towards rib cage.
- Raise one arm and the opposite leg. Hold for **8 seconds** and lower.
- Raise the other arm and the other leg. Hold for **8 seconds** and lower.
- Remember not to move your back or hips while moving limbs.

One repetition is counted after you have raised all four limbs once.



(5) Back Extensions

- Lie on your stomach with your hands in front of you.
- Ensure that your back is straight. Contract stomach muscles so that belly button is brought closer to your spine and upwards towards rib cage.
- Slowly raise both arms and legs keeping your stomach muscles tight. Hold for **8 seconds** and lower.



Exercise Guide

Leg Group

Phase I

Instructions:

- Complete this program three times per week on non-consecutive days.
- Return at the specified time to receive the program for Phase II.

(1) Leg Press

Repetitions: 10
Sets: 3
Rest: 1 minute
Tempo: 3:0:1
Frequency: three times a week
Intensity: work at 80% of your maximum weight

(2) Leg Curl

Repetitions: 10
Sets: 3
Rest: 1 minute
Tempo: 3:0:1
Frequency: three times a week
Intensity: work at 80% of your maximum weight

(3) Leg Extension

Repetitions: 10
Sets: 3
Rest: 1 minute
Tempo: 3:0:1
Frequency: three times a week
Intensity: work at 80% of your maximum weight

Exercise Guide

Leg Group

Phase II

Instructions:

- Complete this program three times per week on non-consecutive days.
- Return at the specified time to receive the program for Phase III.

(1) Leg Press

Repetitions: 6
Sets: 4
Rest: 3 minutes
Tempo: 3:0:1
Frequency: three times a week
Intensity: work at 85-90% of your maximum weight

(2) Leg Curl

Repetitions: 6
Sets: 4
Rest: 3 minutes
Tempo: 3:0:1
Frequency: three times a week
Intensity: work at 85-90% of your maximum weight

(3) Leg Extension

Repetitions: 6
Sets: 4
Rest: 3 minutes
Tempo: 3:0:1
Frequency: three times a week
Intensity: work at 85-90% of your maximum weight

Exercise Guide

Leg Group

Phase III

Instructions:

- Complete this program three times per week on non-consecutive days.
- Return at the specified time to complete final testing.

(1) Leg Press

Repetitions: 4
Sets: 4
Rest: 3 minutes
Tempo: 3:0:1
Frequency: three times a week
Intensity: work at 90% of your maximum weight

(2) Leg Curl

Repetitions: 4
Sets: 4
Rest: 3 minutes
Tempo: 3:0:1
Frequency: three times a week
Intensity: work at 90% of your maximum weight

(3) Leg Extension

Repetitions: 4
Sets: 4
Rest: 3 minutes
Tempo: 3:0:1
Frequency: three times a week
Intensity: work at 90% of your maximum weight

APPENDIX G
DATA SHEETS

APPENDIX H

DESCRIPTION OF MODIFICATION OF SPSS OUTPUT TO CALCULATE SIMPLE MAIN EFFECTS

To change the SPSS output of repeated measure ANOVA to add calculation of simple main effects, perform the following steps (using SPSS 10.0.5):

- Double click on *Notes* in the output window after you have run the analysis of repeated measures.
- Double click on *Code*.
- Click on *Code* once to select it.
- Copy the contents using Edit.
- Go to File – New – Syntax.
- Paste from clipboard into the Syntax window.
- Add the following to the code syntax:

```
/EMMEANS = TABLES(factor 1*factor 2)COMPARE(factor 1)  
/EMMEANS = TABLES(factor 1*factor 2)COMPARE(factor 2)
```

where factor 1 is a factor such as group and factor 2 is a factor such as time. You have to use the factor names as used in the analysis.

- Go to Run – Current.

APPENDIX I
POST HOC ANALYSES USING SIMPLE MAIN EFFECTS

**Simple Main Effects for Trunk Stability Measure (Relative Leg
Gravitational Torque) for Group and Time.**

Time 1	Group CO	Group LS	Significance 0.756
		TL	0.006
		TS	0.005
<hr/>			
	LS	Group CO	0.756
		TL	0.003
		TS	0.002
<hr/>			
	TL	Group CO	0.006
		LS	0.003
		TS	0.916
<hr/>			
	TS	Group CO	0.005
		LS	0.002
		TL	0.916
<hr/>			
2	CO	Group LS	0.537
		TL	0.000
		TS	0.000
<hr/>			
	LS	Group CO	0.537
		TL	0.000
		TS	0.000
<hr/>			
	TL	Group CO	0.000
		LS	0.000
		TS	0.561
<hr/>			
	TS	Group CO	0.000
		LS	0.000
		TL	0.561
<hr/>			
Group CO	Time 1	Time 2	Significance 0.057
LS	1	2	0.184
TL	1	2	0.000
TS	1	2	0.000

Simple Main Effects for Leg Strength Measure (Predicted 1RM) for Group and Time.

Time	Group	Group	Significance
1	CO	LS	0.034
		TL	0.171
		TS	0.078
	LS	CO	0.034
		TL	0.400
		TS	0.656
	TL	CO	0.171
		LS	0.400
		TS	0.683
	TS	CO	0.078
		LS	0.656
		TL	0.683
2	CO	LS	0.003
		TL	0.006
		TS	0.433
	LS	CO	0.003
		TL	0.767
		TS	0.021
	TL	CO	0.006
		LS	0.767
		TS	0.037
	TS	CO	0.433
		LS	0.021
		TL	0.037
Group	Time	Time	Significance
CO	1	2	0.699
LS	1	2	0.021
TL	1	2	0.002
TS	1	2	0.392

**Simple Main Effects for Vertical Jump Measure (Vertical Take off Velocity)
for Group and Time.**

Time	Group	Group	Significance
1	CO	LS	0.297
		TL	0.144
		TS	0.028
	LS	CO	0.297
		TL	0.708
		TS	0.254
	TL	CO	0.144
		LS	0.708
		TS	0.443
	TS	CO	0.028
		LS	0.254
		TL	0.443
2	CO	LS	0.028
		TL	0.001
		TS	0.022
	LS	CO	0.028
		TL	0.199
		TS	0.974
	TL	CO	0.001
		LS	0.199
		TS	0.197
	TS	CO	0.022
		LS	0.974
		TL	0.197
Group	Time	Time	Significance
CO	1	2	0.621
LS	1	2	0.060
TL	1	2	0.000
TS	1	2	0.809