

**The Effect of a 10-Week Training Regimen on Lumbo-pelvic Stability, Balance,
Agility and Leg Power in College and University-level Female Athletes**

by

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We accept this ~~thesis~~ as conforming to the required ~~standard~~

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ABSTRACT

This study investigated the capacity of female athletes to improve stability within the lumbo-pelvic region, and quantified a relationship between lumbo-pelvic stability and athletic performance. Thirty participants were selected from university and college female volleyball and basketball teams and randomly assigned to either a treatment, pseudo-treatment, or no-treatment control group. The treatment and pseudo-treatment groups participated in distinct 10-week training regimens emphasizing recruitment of either the transversus abdominus and lumbar multifidus muscles of the lumbar spine or the rectus abdominis and external obliques of the abdomen. Lumbo-pelvic stability (Stabilizer pressure biofeedback unit), balance (static and dynamic Bass tests), agility (T-test), and leg power (Sargent's vertical jump test) were measured before and immediately after the 10-week study period. A combination of repeated measures ANOVA and non-parametric Friedman and Wilcoxon analyses identified significant differences between the improvements in lumbo-pelvic stability for both the treatment and pseudo-treatment groups relative to the control group.

The agility and leg power of the treatment group improved relative to both the pseudo-treatment and the control groups. There were, however, no significant differences between the improvements of any of the groups on the static and dynamic balance measures. Pearson's product-moment correlation coefficient identified significant relationships between the measures of lumbo-pelvic stability and athletic performance, but, there were no significant correlations between the

improvements in lumbo-pelvic stability and the improvements in athletic performance.

The results of this study demonstrate that lumbo-pelvic stability can be improved through training, although the focus of training (local stability vs. global mobility) seems to account for little difference in the extent of this improvement. While athletes with the most stable lumbo-pelvic regions demonstrated the best scores for both agility and leg power, there was no correlation found between improvements in lumbo-pelvic stability and improvements in athletic performance. The findings of this study indicate that athletes can improve stability of the lumbo-pelvic region by participating in training regimens which focus on the recruitment of either local stability or global mobility muscles. However, improvements in athletic performance are not likely to occur as a result of improvements in lumbo-pelvic stability alone.

TABLE OF CONTENTS

Abstract	ii
Table of Contents	iv
List of Tables	vi
List of Figures	viii
Acknowledgements	x
Chapter 1 Introduction	1
Chapter 2 Review of the Literature	4
2.1 Lumbo-pelvic stability (LPS)	4
2.1.1 Measurement of intersegmental motion	8
2.1.2 LPS as pelvic motion and orientation	10
2.1.3 Measurement of pelvic motion	11
2.2 Abdominal anatomy	13
2.3 Contributions of the local muscle system to Lumbo-pelvic stability	15
2.3.1. Intra-abdominal pressure and the thoracolumbar fascia	17
2.3.2. The lumbar multifidi	21
2.4 Contributions of the global muscle system to lumbo-pelvic stability	23
2.5 LPS and athletic performance	26
2.6 Training to enhance LPS	27
2.6.1 Can the local stability muscles be selectively recruited?	27
2.6.2 Can the local stability muscles be trained?	29
2.7 Conclusion	31
Chapter 3 Methodology	33
3.1 Experimental Design	33
3.2 Subjects	33
3.3 Procedure	34
3.4 Measures	35
3.4.1 Lumbo-pelvic stability	35
3.4.2 Athletic Performance	37
3.5 Training Regimen	41

3.6 Hypotheses	42
3.7 Statistical Analyses	43
Chapter 4 Results	45
Chapter 5 Discussion	63
Chapter 6 Summary and Recommendations	74
6.1 Summary	74
6.2 Recommendations	74
References	76
Appendix	
Appendix A – Consent Form	82
Appendix B – Weekly Activity Log	87
Appendix C – Treatment Exercises	89
Appendix D – Pseudo-treatment Exercises	100
Appendix E – Reliability Study	106

LIST OF TABLES

Table #	List of Tables	Page #
Table 1	Physical signs of instability	12
Table 2	Local and Global Musculature	14
Table 3	Classification of muscle systems	16
Table 4	Dynamic abdominal strength and lumbo-pelvic stability before and after training	26
Table 5	Descriptive data for subjects by group	45
Table 6	Mean physical activity of the groups throughout the 10-week study	46
Table 7	Stability scores collected using the Sahrman protocol	47
Table 8	Stability scores collected using the anticipated leg lift	48
Table 9	Stability scores collected using short lever spontaneous leg loading	50
Table 10	Stability scores collected using long lever spontaneous leg loading	51
Table 11	Time to complete an agility T-test before and after a 10 week training program	53
Table 12	Vertical jump heights attained before and after a 10 week training program	54
Table 13	Static balance times attained before and after a 10-week training program	56
Table 14	Dynamic balance scores attained before and after a 10-week training program	57
Table 15	Correlation matrix for the measures of lumbo-pelvic stability	59
Table 16	Correlation matrix for the measures of athletic performance	60

Table 17	Correlation matrix for stability and athletic performance measures	60
Table 18	Correlation matrix for the changes in stability and in athletic performance	62

LIST OF FIGURES

Figure #	List of Figures	Page #
Figure 1	Motion occurring at the spinal segment	5
Figure 2	The load-deformation curve of a soft tissue or a body joint	6
Figure 3	Geometry used in biplanar or stereo-radiography	9
Figure 4	Neutral position of the pelvis	11
Figure 5	Recordings of intra-abdominal pressure (IAP), abdominal (RA, OE, OI, and TrA) and erector spinae (ES) myoelectric activity	19
Figure 6	Lateral tension created by TrA contraction results in craniocaudal tension along the spinal column	20
Figure 7	Anatomy of the Lumbar Multifidus	21
Figure 8	Bass's modified test of dynamic balance	39
Figure 9	Mean Sahrman Protocol score for the measurement of LPS in the treatment, pseudo-treatment and control groups	47
Figure 10.	Mean anticipated leg lift score for the assessment of LPS in the treatment, pseudo-treatment and control groups	49
Figure 11	Mean short lever spontaneous leg loading score for the assessment of LPS in the treatment, pseudo-treatment and control groups	50
Figure 12	Mean long lever spontaneous leg loading score for the assessment of LPS in the treatment, pseudo-treatment and control groups	52
Figure 13	Mean time to complete a T-test of agility for the treatment, pseudo-treatment and control groups	53
Figure 14	Mean vertical jump heights for the treatment, pseudo-treatment and control groups	55

Figure 15	Mean balance times for Bass' stick test of static balance for the treatment, pseudo-treatment and control groups	56
Figure 16	Mean balance scores for Bass' modified test of dynamic balance for the treatment, pseudo-treatment and control groups	58
Figure 17	The Lumbo-pelvic Stability/Athletic Ability model to describe the relationship between LPS and athletic performance	71
Figure 18	The Athletic Ability model to describe the Relationship between LPS and athletic performance	72

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CHAPTER 1: INTRODUCTION

A relatively recent phenomenon has captured the attention of many coaches, trainers and athletes endeavouring to push back the limitations of human performance. A new form of training, synonymously referred to as core training, stability training, or inner unit activation, is based upon the premise that athletic performance is closely tied to an athlete's ability to control pelvic motion and position during competition. Coaches and trainers who prescribe this method of training believe that lumbo-pelvic stability (LPS) can be improved and that such improvements will elicit subsequent improvements in athletic performance. In the words of one such trainer, "it is almost indisputable that possessing a strong core, [the ability to stabilize the lumbo-pelvic region,] is of importance to just about every athlete" (Baker, 2000, p.5).

Conceptually, a high degree of LPS may contribute to athletic performance by aiding in the "efficient transmission of force generated by the lower body through the trunk to the upper body" (Baker, 1999, p.5). During running, if LPS becomes compromised "rotation of the pelvis will occur to counteract shoulder rotation, resulting in poor technique and inefficient force application, therefore a slower athlete will be the result" (Faccioni, 1994, p.7). However, as in any field, investigative efforts must be employed to establish relationships between the variables of interest—in this case, LPS and athletic performance--and to validate these conceptual models.

As with many new training methods, the opinions of many coaches and trainers in regards to LPS and its contribution to athletic performance have been formed

far in advance of the findings from investigative study. In fact, perhaps due to the limitations of present assessment techniques, few investigators have even attempted to assess whether LPS can be improved with training let alone correlated with improvements in athletic performance. For coaches to continue encouraging their athletes' participation in LPS training regimens, the merit of these regimens must be demonstrated. If such merit cannot be demonstrated, then perhaps the limited training time of athletes should be directed towards training techniques with known and reliable outcomes.

The purpose of the present study was to evaluate whether a 10-week training regimen would result in;

1. Improved lumbo-pelvic stability
2. Improved static and dynamic balance abilities, agility, and leg power.
3. A measurable correlation between improvements in LPS and improvements in athletic performance.

Assumptions

The following assumptions were made when designing the study:

1. All participants will provide a maximal effort during the pre-and post-assessments of both lumbo-pelvic stability and athletic performance.
2. All participants will comply with the training regimens.
3. All participants will respond honestly, to the best of their knowledge, regarding the amount of activity that they perform on a weekly basis.

Limitations

The study at the present time, was limited by the following:

1. The Stabilizer pressure biofeedback unit is designed to measure pelvic motion in the sagittal plane alone.

Delimitations

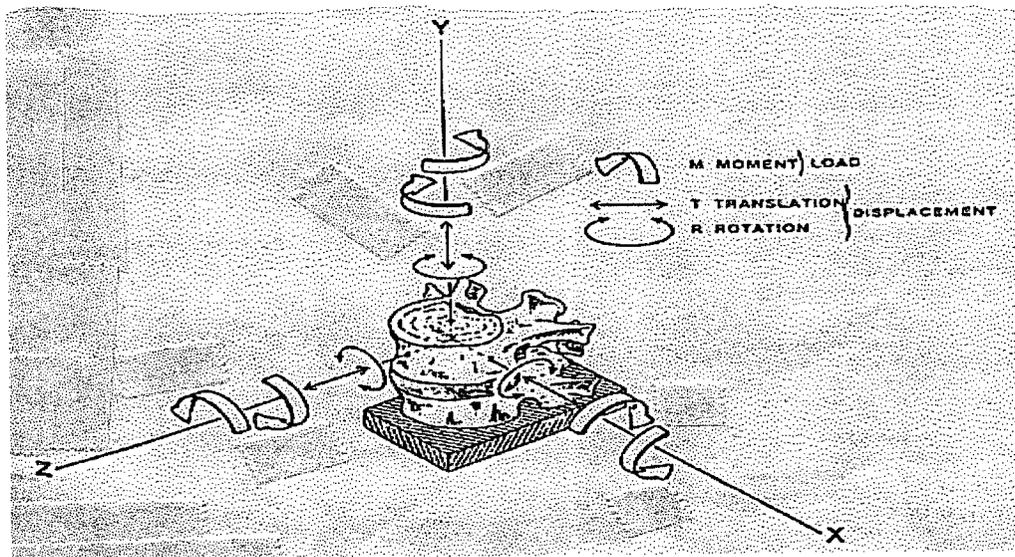
1. Sample selection; highly trained athletes were selected in order to test the hypothesis that LPS training had some benefit in the sport performance of athletes as opposed to that of sedentary or non-trained individuals.

CHAPTER 2: REVIEW OF THE LITERATURE

2.1 Lumbo-pelvic stability (LPS).

Viewing the spine as a series of spinal segments--the junction of one vertebra with the vertebrae directly above and below--stability can be defined in relation to the amount of movement occurring at each segment. Due to vertebral orientation and restraints imposed by the bony articulations of vertebrae, intersegmental motion is limited to either translation or rotation in any of three anatomical planes (sagittal, frontal, and coronal) for a total of six directions of motion (Figure 1). The ability of each segment to resist displacement along these six ranges of possible motion determines the stability of that segment of the spine.

Figure 1: Motion occurring at the spinal segment. Coronal, frontal and sagittal translations are indicated by motions along the Y, Z and X-axes, respectively while rotations in the same planes are represented by the arrows $\pm MY$, MZ and MX .

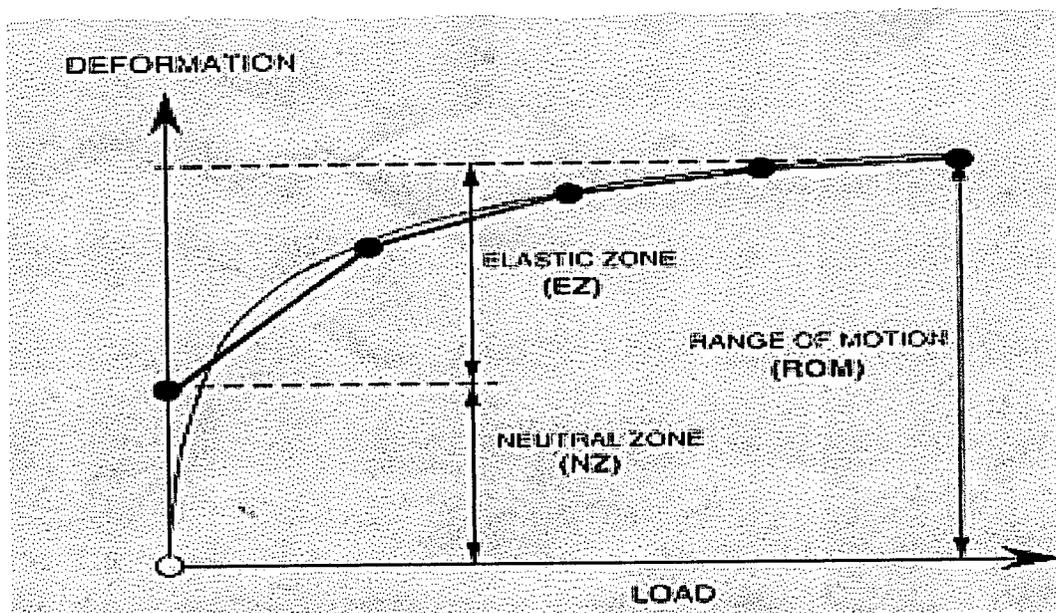


From: Panjabi, M., Kuniyoshi, A., Duranceau, J., & Oxland, T. (1989). Spinal stability and intersegmental muscle forces: A biomechanical model. *Spine*, 14, (2), 194-199.

The nature of intersegmental motion has been investigated with the use of load-deformation curves. Using these curves, relationships between forces imposed upon a joint and the motions occurring within the joint as a consequence of applied force have been explored. In early kinematic studies of the spine, load-deformation curves have often appeared as nearly straight lines indicating that intersegmental motion increases proportionally with imposed loads (Panjabi, Brand, & White, 1976; Tencer, Ahmen, & Burke, 1982). However, such a relationship between applied loads and vertebral displacement has recently been criticized on the grounds that the methodology of these earlier studies may have

influenced their findings. In studies which have corrected these suspected methodological errors, a non-linear relationship between applied force and intersegmental motion is found (Figure 2). Panjabi (1992) has suggested that intersegmental motion of the spine be considered as comprising two distinct zones of motion: the neutral zone (NZ), which allows for a high degree of flexibility in the beginnings of movement, and the elastic zone (EZ), which provides a stiffening effect towards the end of the range of motion.

Figure 2. The load-deformation curve of a soft tissue or a body joint.



From: Panjabi, M. (1992). The stabilizing system of the spine, part 1: Function, dysfunction, adaptation, and enhancement. *Journal of Spinal Disorders*, 5, (4), 383-389.

The importance of a distinction between these two zones of intersegmental motion is apparent when considering the functional role of muscles in and adjacent to the spine. Using normal and injured models of the lumbar spine,

Panjabi et al. (1989) investigated changes in overall intersegmental range of motion (ROM) and the size of the neutral zone (NZ) in response to simulated muscular forces approximating the actions of the lumbar multifidus (LM), rotatores, and interspinales. As vertebral injuries progressed from division of the supraspinous and interspinous ligaments, to left medial facetectomy, and to bilateral medial facetectomies, the spinal units were subjected to a series of flexion, extension and axial rotation movements at increasing levels of simulated muscle forces. While ROM increased with the severity of injury, the NZ was found to decrease in size as the force of simulated muscle contractions increased. Panjabi and colleagues (1989) suggest that the neutral zone may be a better indicator of spinal stability than the overall ROM since it seems to be the most affected by simulated muscle force.

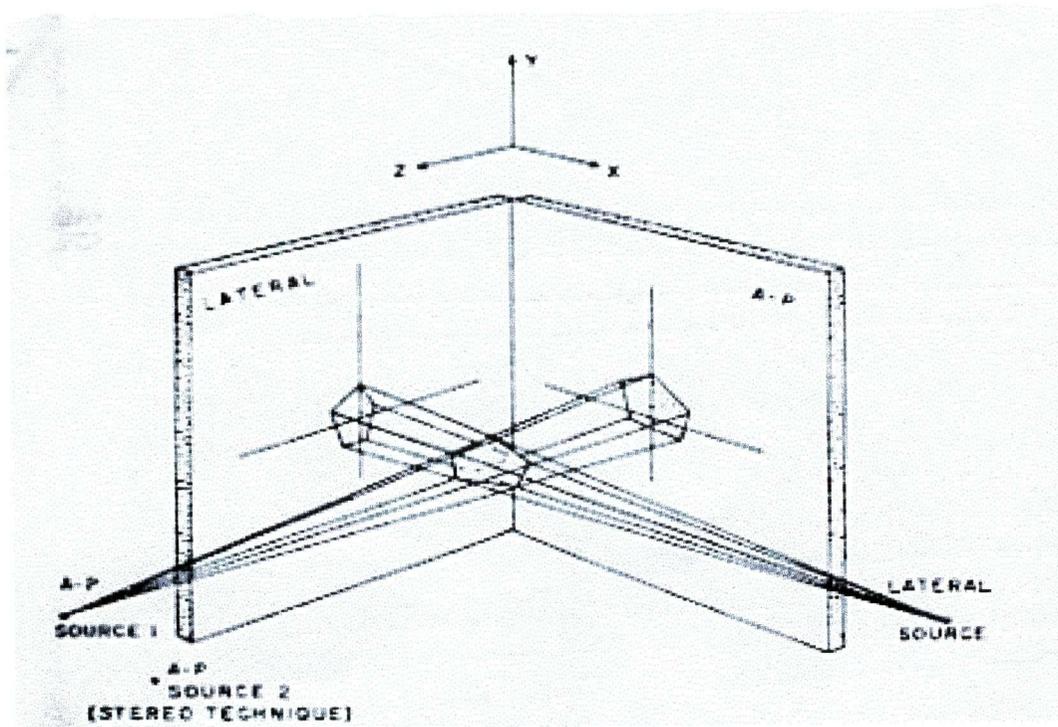
Increases in the size of the neutral zone have been observed in patients with chronic low back pain and are considered to represent a deficit in the stabilizing capacity of muscles like the LM, rotatores and interspinales which surround the spine. For individuals where deficits in the activity of stabilizing musculature are present yet asymptomatic, a greater risk of injury is believed to exist (Panjabi, 1992).

2.1.1 Measurement of intersegmental motion

Definitions of LPS in terms of intersegmental motion are limited by a present lack of a gold standard with which to quantify this motion. Radiography is frequently used to assess intersegmental motion by tracking the positions and orientations of prominent spinal and pelvic landmarks as the spine moves through specific ranges of motion. The simplicity, low expense, and availability, of the two dimensional view provided by uni-planar, or non-stereographic, flexion-extension radiography makes this the most commonly used radiographic technique (Pitkanen, Manninen, Lindgren, Turunen, & Airaksinen, 1997). However, the measurements obtained by this method are spurious at best.

Stokes and colleagues (1981) have emphasized that vertebral motions are complex, three-dimensional, and coupled such that the primary or intentional movements of the vertebrae are accompanied by motion in more than just one plane. For this reason, a three-dimensional, bi-planar view is believed to capture a more valid picture of vertebral motion (Figure 3). However, despite greater accuracy, bi-planar radiographic techniques suffer from a complexity of measurement requiring computers and a sophisticated knowledge of mathematics that limits their immediate usefulness to the clinician (Shaffer, Spratt, Weinstein, Lehmann, & Goel, 1990).

Figure 3. Geometry used in biplanar or stereo-radiography.



From: Stokes, I.A.F., Wilder, D.G., Frymoyer, J.W., & Pope, M.H. (1981). Assessment of patients with low back pain by radiographic measurement of intervertebral motion. *Spine*, 6, (3), 233-240.

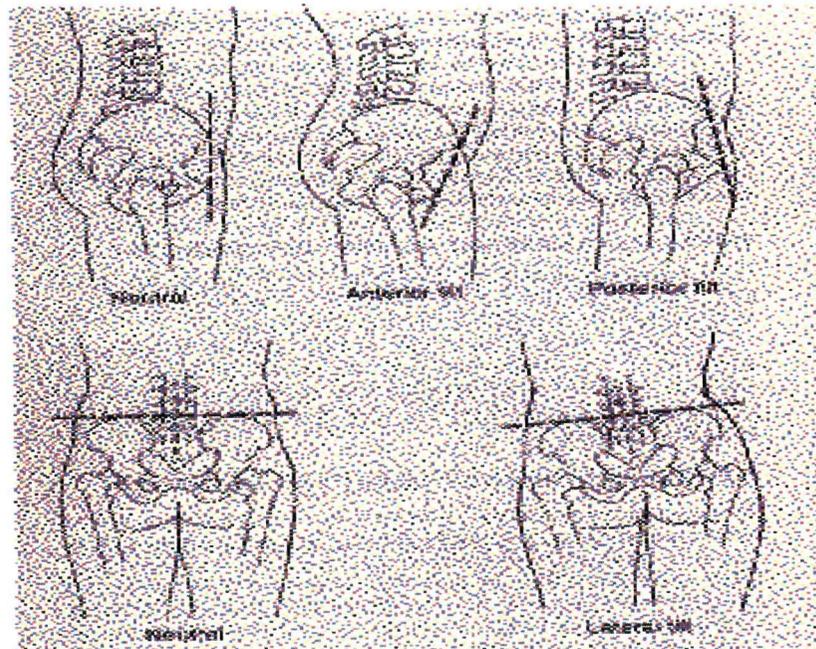
In addition, the reliance of clinicians on this technique is challenging and debatable for a number of other reasons. First, reproduction of functional radiographs is extremely difficult since a slight variation in-patient positioning may result in a 10% to 15% variation in the range of vertebral displacement (Nizard, Wybier, & Laredo, 2001). Second, the manner in which functional radiographs are performed and the methods used to measure displacement, including the landmarks chosen, are not yet standardized. Third, because of the lack of a gold standard with which to compare measurements obtained radiographically, the diagnostic value of functional radiographs cannot be determined (Nizard et al., 2001).

2.1.2 LPS as pelvic motion and orientation

Viewing the lumbar spine and pelvis together as one functional unit, lumbo-pelvic stability can also be defined as the motion of the lumbar spine and pelvis relative to an arbitrarily defined neutral position. While a view of the spine and pelvis comprising one functional unit may be criticized as oversimplifying the lumbo-pelvic region, such a view lends itself to clinical application as motion of the spine becomes more easily observed in clinical assessment when it is coupled with motion of the pelvis. To assess LPS, the clinician observes the ability of the patient to maintain a neutral position of the pelvis in the presence of external loads applied to the upper or lower limbs.

Neutral position can be identified with reference to the positions and orientations of both the anterior and posterior superior iliac spines and the pubic symphysis (Kendall, McCreary, & Provance, 1993). For the pelvis to be in the neutral position, the anterior superior iliac spine (ASIS) and the anterior inferior iliac spine (AIIS) must lie in the same sagittal plane while the left and right ASIS must lie in the same transverse plane (Figure 4). Inability to actively maintain the orientations of these landmarks during loading of the upper or lower limbs represents a deficit in lumbo-pelvic stability.

Figure 4. Neutral position of the pelvis



From: Kendall, F.P., McCraery, E.K., & Provance, P.G. (1993). *Muscles, Testing and Function* (4th ed.). Baltimore: Williams and Walkins.

2.1.3 Measurement of pelvic motion

Pelvic motion and orientation can be assessed by palpating prominent pelvic and spinal landmarks while noting the patient's ability to control movements of the lumbo-pelvic region. In addition to palpation, many clinicians rely on the stabilizer pressure bio-feedback unit (Chattanooga, Australia), an assessment tool developed by Jull and colleagues (1993). This device provides an indication of the ability of abdominal musculature to actively control lumbo-pelvic motion.

Palpation as an assessment technique may hold a greater and more immediate clinical application than intersegmental motion inferred through the use of radiography. In order to diagnose spinal stability, palpation should include the assessment of vertebral position, condition, and mobility through a range of active

movements including flexion, extension, and lateral bending (Paris, 1985). Physical signs indicative of excessive vertebral motion include muscle spasm and palpable step deformities (Table 1). Despite the greater applicability of palpation in a clinical setting, assessment by this means is limited in that direct comparisons between manual palpation techniques and objective methods such as radiography have yet to be reported (Pope, Frymoyer, & Krah, 1992).

Table 1. Physical signs of instability

- | |
|--|
| <ol style="list-style-type: none"> 1. Step deformity (spondylolisthesis) or rotation deformity (spondylolysis) on standing which reduces on lying. 2. Transverse band of muscle spasm which reduces on lying. 3. Localised muscle twitching while shifting weight from one leg to the other. 4. Juddering or shaking during forward bending. 5. Alteration to passive intervertebral motion testing, suggesting excessive mobility in the sagittal plane. |
|--|

Adapted from: Paris, S.V. (1985). Physical signs of instability, *Spine*, 10, 3, 277-279.

Frustrated by the lack of a technique to measure the ability of abdominal muscles to stabilize the lumbar spine, Jull and colleagues developed and tested the stabilizer pressure biofeedback unit (1993). Beginning from the premise that excessive lumbar spine movement would indicate an inability of stabilizing muscles to co-ordinate appropriate muscle force to support the spine under load, Jull and colleagues developed a model of measurement that assesses sagittal plane control of lumbar motion under an imposed sagittal load. A pressure cuff is attached to a gauge and inserted under the small of the back with the patient lying supine. Inflated to an initial pressure reading of 40mmHg, deviations from this

baseline pressure during a series of leg lifting tasks are indications of lumbo-pelvic motion in the sagittal plane. This instrumentation has been adopted by a number of investigators as an indicator of lumbo-pelvic stability (Cusi, Juska-Butel, Garlick, & Argyrous, 2001; Baker, 1999; Young, McLaren, & McDowell, 1998; Wohlfahrt, Jull, & Richardson, 1993).

2.2 Abdominal Anatomy

On the basis of functional and anatomical differences in muscle origins and insertions, Bergmark (1989) divided abdominal muscles into two systems; local and global (Table 2). The local muscle system is comprised of muscles (with the exception of the psoas major) originating from or inserting upon the vertebrae, thereby controlling spinal curvature and providing lateral and sagittal stiffness to maintain mechanical stability of the spine. The transversus abdominus (TrA), lumbar multifidus (LM), rotatores, interspinales, and intertransversarii are all members of the local muscle system. The global muscles are comprised of the erector spinae muscles, internal and external obliques, rectus abdominis, psoas major, and lateral parts of the quadratus lumborum and are responsible for transferring load directly between the thoracic cage and the pelvis.

Table 2. Local and Global Musculature

	Muscle	Origin	Insertion	Action
Local Muscle System	Multifidus	mammilar process	spinous proces	extends the lumbar spine
	Transversus abdominus	Linea alba	Posterior TLF	Cranio-caudal tension along vertebrae
	Interspinal	spinous process	spinous process	increases spinal stiffness
	Intertransversarii	transverse process	transverse process	increases spinal stiffness
Global Muscle System	Erector spinae	erector spinae aponeurosis	transverse processes of vertebrae and ribs	extends / laterally bends the lumbar spine
	Internal obliques	lateral raphe of TLF, iliac crest, inguinal ligament	Costal cartilage of the lower 3 or 4 ribs, rectus sheah	flex / laterally bend the thoracic cage
	External obliques	lower 8 ribs	lower 3 or 4 ribs, rectus sheath	flex / rotate the thoracic cage
	Rectus abdominis	Superior surface of pubic symphysis	Costal cartilage of ribs (5-7) and xyphoid process	flexes the thorax
	Psoas Major	femoral head	vertebral bodies of lumbar vertebrae	flexes the lumbar spine
	Quadratus lumborum	iliac crest	transverse processes and lowest ribs	laterally bends the spine

Adapted from: Bergmark, A. (1989). Stability of the lumbar spine: A study in mechanical engineering, *Acta Orthopaedica Scandinavica, suppl.230,(60)*, 19-24.

Commerford and Mottram (2000) have created an additional classification scheme which suggests a further distinction within the global muscle system and

expands upon the functional differences between the local and global systems (Table 3). The activity of the local system is described as continuous, independent of the direction of movement and resulting in minimal change in muscle length. Activity of the global muscle system, which Commerford and Mottram (2000) suggest be further divided into global stability and global mobility, is continuous, dependent upon movement direction and productive of either eccentric or concentric range of motion.

2.3 Contributions of the local muscle system to lumbo-pelvic stability

As contraction of the local stability muscles does not produce motion of either the spine or pelvis, the role of these muscles in stabilizing the lumbo-pelvic region seems counterintuitive (Commerford & Mottram, 2000). However, convincing evidence for a contribution from these muscles has arisen both from direct observation of the ability of TrA and LM contractions to lend stability to the spine, and from investigations of muscle recruitment patterns during specific tasks.

When a movement is initiated (i.e., shoulder flexion), reactive forces act upon the centre of mass causing the spine to flex and the centre of mass to be displaced (Hodges, & Richardson, 1997b; Bouisset & Zattara, 1987). The CNS prepares for these predictable challenges to posture by activating compensatory muscles prior to the muscle initiating the limb movement (Bouisset & Zattara, 1987; Hodges & Richardson, 1997b).

Table 3. Classification of muscle systems

Local Stability	Global Stability	Global Mobility
i.e. transversus abdominus lumbar multifidus	i.e. oblique abdominals spinalis gluteus medius	i.e. rectus abdominus iliocostalis piriformis
Monoarticular	Mono/Biarticular	Mono/Biarticular
Increase muscle stiffness to control intersegmental motion	Generate force to control ROM	Generate force to produce ROM
Contraction controls the neutral joint position / contraction does not produce ROM	Contraction produces an eccentric length change: low load deceleration of momentum	Contraction produces concentric length changes: concentric acceleration of movement and shock absorption of load
Activity is independent of the direction of motion	Activity is dependent on the direction of movement	Activity is dependent on the direction of movement
Activity is continuous throughout the movement	Activity is non-continuous	Activity is non-continuous

Adapted from: Comerford, M.J., & Mottram, S.L. (2000). Functional stability retraining: principles and strategies for managing mechanical dysfunction. *Manual Therapy*, 6, (1), 3-14.

The activation of abdominal muscles to resist postural changes has been investigated by Hodges and Richardson (1997a; 1997b) who compared the time of onset of EMG activity within TrA, to the onset of activity within the external obliques (EO), internal obliques (IO), rectus abdominis (RA), and deltoid during rapid shoulder flexion, extension, and abduction movements. Subjects were

instructed to produce these movements as quickly as possible following a visual stimulus. The onset of TrA EMG activity was consistently found to precede deltoid activity irrespective of the movement direction. Results from these studies suggest that the CNS controls spinal stability in anticipation of predictable disturbances. While Hodges and Richardson (1997a; 1997b) were able to conclude that the muscular force exerted by TrA activity must contribute to the control of spinal perturbations regardless of movement direction, the mechanism by which TrA activity controls these perturbations was not the focus of their studies.

2.3.1 Intra-abdominal pressure and the thoracolumbar fascia

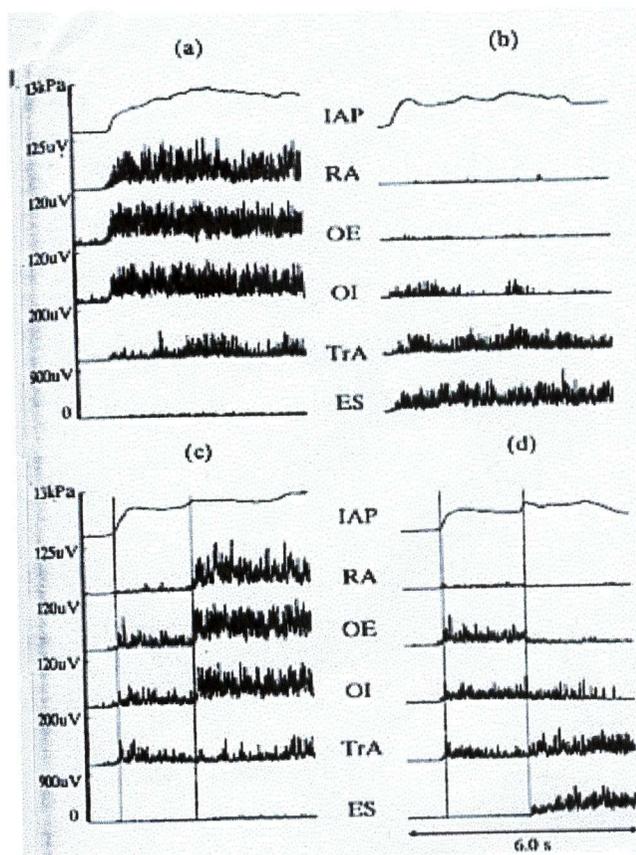
Pressure acting within the abdomen is believed to provide an additional extensor moment to the spine by effectively making the trunk a more solid cylinder and thereby reducing both axial compression and shear loads while at the same time transmitting these loads over a wider area (Twomey & Taylor, 1987). This pressure is referred to as intra-abdominal pressure (IAP) and was the focus of some of the first studies to investigate TrA as a potential contributor to spinal stability (Cresswell, Grundstrom, & Thorstensson, 1992; Goldman, Lehr, Millar, & Silver, 1987). Using fine wire electrodes inserted intramuscularly under the guidance of real-time ultrasound imaging, Cresswell and colleagues (1992) recorded EMG activity of the abdominal muscles (RA, OE, OI, TrA) and the erector spinae (ES) during maximal isometric trunk flexion and extension with and without maximal voluntary Valsalva manoeuvres. At the same time, IAP was

measured during all tasks intra-gastrically using a micro-tip pressure transducer. During trunk flexion all muscles were active and IAP levels were high, however, during extension all abdominals, with the exception of TrA, showed a marked reduction in activity while IAP levels remained consistent (Figure 5). Cresswell and colleagues (1992) concluded that transversus abdominis, and to a lesser extent OI, were the abdominal muscles that appeared most consistently to govern the development of IAP (Cresswell et al., 1992).

A number of important criticisms have been raised against the IAP mechanism as the primary stabilizing mechanism of the spine (Norris, 1993). For example, for the spine to be stabilized by IAP alone, it is speculated that the pressure generated would exceed the systolic pressure within the aorta and occlude blood flow to the lower extremities (Bogduk & Twomey, 1997). From the current body of evidence it seems that the raising of IAP may provide for a portion of the stabilizing mechanisms of the spine, yet it cannot be considered the only, or primary mechanism for stabilization.

The search for the mechanism behind stabilization of the spine has also focussed on the interaction of the local stability muscles, specifically TrA, with the thoracolumbar fascia (TLF). Fibres of TrA insert upon the middle layer of the TLF which itself, inserts upon the spinous processes of the lumbar vertebrae (Bogduk & Macintosh, 1984). Tension generated by TrA contraction is transmitted through this middle layer to its points of insertion upon the spinous and transverse processes of the lumbar vertebrae (Bogduk & Macintosh, 1984).

Figure 5. Recordings of intra-abdominal pressure (IAP), abdominal (RA, OE, OI, and TrA) and erector spinae (ES) myoelectric activity during: (a) maximal isometric trunk flexion, (b) maximal isometric trunk extension, (c) combination of maximal voluntary Valsalva plus maximal isometric trunk flexion and (d) combination of maximal voluntary Valsalva plus maximal isometric trunk extension.

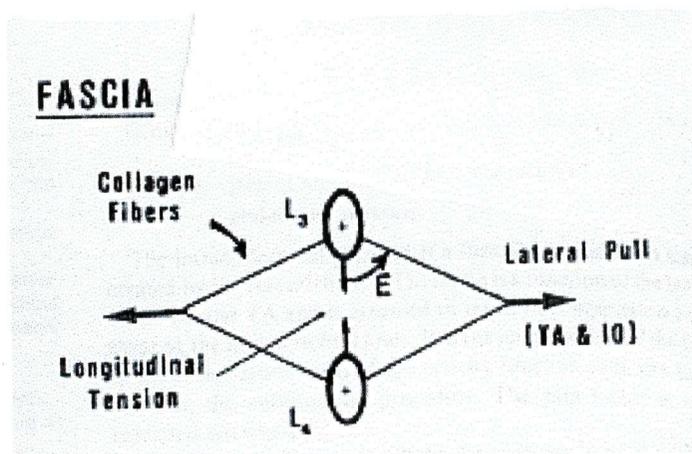


From: Cresswell, A.G., Grundstrom, H., & Thorstensson, A. (1992). Observations on intra-abdominal pressure and patterns of abdominal intra-muscular activity in man. *Acta Physiologica Scandinavica*, 144, 409-418.

Due to the orientation of these fibrous insertions, lateral tension within the TLF is translated to a craniocaudal tension (Figure 6) along the length of the lumbar

spine (Gracovetsky, Farfan, & Helleur, 1985). Craniocaudal tension provides a compressive force which limits intervertebral motion and creates an antiflexion / extension force to counteract the flexing force of the abdominal muscles and gravity during heavy lifting.

Figure 6. Lateral tension created by TrA contraction results in craniocaudal tension along the spinal column.



From: Gracovetsky, S., Farfan, H., & Helleur, C. (1985). The abdominal mechanism. *Spine*, 10, (4), 317-324.

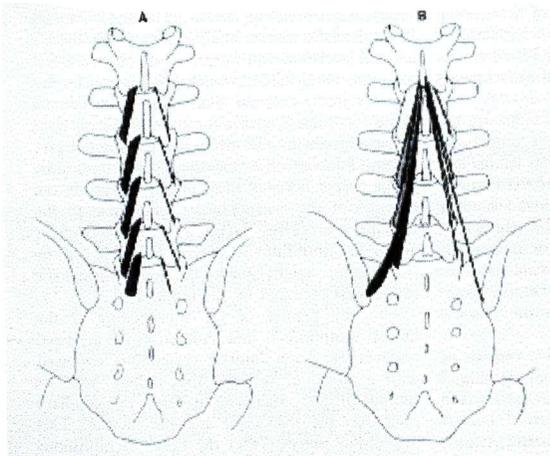
As was the case for the IAP mechanism, the action of TrA through its insertions with the TLF has not been unanimously accepted as the primary stabilizing mechanism of the spine. According to an anatomical and biomechanical analysis of this mechanism by Macintosh, Bogduk, and Gracovetsky (1987), the actual anti-flexion moment generated in this way may be very small in relation to the forces imposed upon the spine during heavy-lifting tasks. It seems that compressive force imposed upon the spine by TrA contraction may lend a portion

of stability to the spine but cannot be considered the primary mechanism of spinal stability.

2.3.2 The lumbar multifidi

The lumbar multifidi (LM) are the largest and most medial of the lumbar muscles, and at each vertebral segment (L1 through L5) are divided into five distinct bands of muscle (Macintosh & Bogduk, 1987; Bogduk & Twomey, 1997). LM arise from the spinous processes of each lumbar vertebrae as a common tendon, comprised of 5 fascicles diverging caudally and attaching separately to mammillary processes, the iliac crest, and the sacrum below (Macintosh & Bogduk, 1986). With this arrangement, the multifidi are believed to provide individual control of each spinal segment (Figure 7).

Figure 7. Anatomy of the Lumbar Multifidus



From: Bogduk, N., & Twomey, L.T. (1997). *Clinical anatomy of the lumbar spine and sacrum* (3rd ed.). Toronto: Churchill Livingstone.

Our present understanding of the functional role of the LM has been inferred from three avenues of investigation: descriptive study of the muscles' origins and

insertions, in vitro demonstrations and analyses of the effect of LM contraction on vertebral motion, and recordings of muscle activity during specific movement patterns and tasks. Macintosh and Bogduk (1986) dissected 5 cadavers to assess the vertebral attachment sites of LM. From the consistent insertion of the LM fascicles at 90° angles to the vertebral spinous processes, Macintosh and Bogduk (1986) concluded that the pull of LM must primarily produce posterior sagittal rotation with a virtually insignificant amount of posterior translation. This conclusion has also been supported by the findings of more recent studies (Macintosh and Bogduk, 1987; Kalimo, Rantanen, Vilgarnen, & Einola, 1989).

In an in vitro study, Wilke and colleagues. (1995) measured range of motion (ROM) and the size of the neutral zone (NZ) at the junction of L₄ and L₅ with and without the simulated actions of five different muscle groups; multifidus & rotatores, iliocostalis and longissimus, psoas major at the vertebral body, psoas major at the transverse process, and multifidus and rotatores in a cranial direction. ROM and NZ were measured in the absence of any muscular force, with the actions of each muscle group individually, and with the actions of all muscle groups corporately. The strongest influence was noted during the simulated action of the multifidus and rotatores muscles where ROM was decreased for all movements, and NZ was decreased for all movements except axial rotation.

With the use of fine-wire indwelling electrodes, investigators have been able to make direct recordings of LM activity during trunk movement. Morris and colleagues (1962) recorded muscle activity during flexion, extension and rotation movements from erect standing, full flexion, and full extension positions. The

authors attributed LM with functions of both a primary mover and a stabilizer depending upon the movement and the starting posture. Donisch and Basmajian (1971) monitored LM activity in 25 healthy adults during flexion and rotation in sitting and standing postures and recommended that LM be considered a dynamic ligament which adjusts small movements between vertebrae while muscles with better leverage and mechanical advantage perform movements of the vertebral column. In a more recent EMG study, Ng and Richardson (1994) assessed activity in the erector spinae and LM in response to prone arching, trunk holding, and leg holding tasks. The authors found the two muscle groups to act as a single functional unit in these scenarios.

Muscles of the local stability system, specifically the transverses abdominis (TrA) and the lumbar multifidi (LM), play an important role in providing stability to the spine. Contraction of TrA produces intra-abdominal pressure and interacts with the thoracolumbar fascia to produce an antiflexion force on the spine while evidence for the provision of stability via LM contraction can be inferred from descriptive anatomical studies, EMG analyses, and in vitro studies which have simulated these muscle forces. However, movements of the pelvis are also affected by muscles of the global system and it is to this system which we will now focus our attention.

2.4 Contributions of the global muscle system to lumbo-pelvic stability

The movements of the pelvis affected by activation of the global muscle system (rectus abdominis (RA), erector spinae, iliopsoas, and hamstrings muscles) have

been compared to the motions of a marionette in response to the pull of attached guide strings (Baker, 2000). Synergistic recruitment of the erector spinae and iliopsoas muscles produces anterior tilting of the pelvis by pulling the sacrum cranially and the lumbar spine caudally. Similarly, the combined actions of rectus abdominis and the hamstrings muscles produce a posterior pelvic tilt by generating cranially and caudally-directed forces on the symphysis pubis and ischial tuberosities, respectively. A lack of muscular balance in these opposing muscle groups is believed to result in inefficient posture and compromised lumbo-pelvic stability (Baker, 2000).

Conditioning programs for athletes as well as the general population often include exercises intended to train the abdominal muscles. However, it has been suggested that athletes participating in abdominal-type exercise regimens do not always possess the ability to control pelvic position (Norris, 1993), and that abdominal strength obtained by sit-up exercise does not automatically transfer to lumbo-pelvic stabilization under conditions of rapid limb movements such as sprint running (Faccioni, 1994). The precise role of the global muscle system in spinal stability remains unclear.

Wohlfahrt and colleagues (1993) measured the relationship between dynamic and static function of abdominal muscles in 38 highly-trained members of the Australian Army. Subjects performed a repetitive curl-up test at a cadence of 1 repetition every 3 seconds to assess the dynamic function of the abdominals. Static function was determined by recording the subjects' ability to maintain a neutral position of the pelvis while the lower limbs were progressively loaded.

Subjects were divided into two groups: a higher fitness group whose members were able to perform more than 51 repetitions of the dynamic curl-up exercise at a specified cadence, and a lower fitness group whose members completed less than 51 repetitions. The higher fitness group achieved a significantly better stabilizing performance on the static function than did the lower fitness group, which suggested that dynamic abdominal endurance capacity was able to carry over to lumbo-pelvic stabilization function.

More recently, Young et al (1998) compared dynamic trunk flexion training with lumbo-pelvic stabilization training by measuring dynamic and stability-oriented abdominal function before and after training. Dynamic abdominal function was assessed by the ability to perform curl-up movements against a progressively increased resistance. Upon failure, the subject was assigned a score corresponding to the level of resistance they were able to achieve. Lumbo-pelvic stability was assessed with a static holding test whereby the lower limbs were progressively loaded while subjects attempted to maintain a neutral position of the pelvis. Similar to the dynamic assessment of abdominal function, subjects were assigned a score based on the level of resistance at which failure occurred. Following pre-testing, subjects were randomly assigned to either a 4-week dynamic or a 4-week stabilization training group. A Pearson correlation using the pre-test results indicated a statistically insignificant association ($r=0.41$) between the dynamic and stabilizing muscle functions. Following training, improvements in abdominal function were specific to the type of training which subjects completed (Table 4). The investigators concluded that traditional abdominal

strengthening exercises are inadequate for the development of lumbo-pelvic stability.

Table 4. Dynamic abdominal strength and lumbo-pelvic stability before and after training.

A d a p p a r t g r o u p	Dynamic abdominal strength		Lumbo-pelvic stability	
	pre	post	pre	post
Dynamic group	2.33 ± 1.51	4.83 ± 1.17	4.67 ± 1.97	3.50 ± 1.90
Stability group	3.50 ± 1.22	4.67 ± 1.86	3.50 ± 1.38	6.00 ± 1.26

From: Young, W., McLaren, J., & McDowell, M. (1998). Specificity of abdominal muscle function. *Strength and Conditioning Coach*, 6, (2), 2-9.

2.5 LPS and athletic performance

In the athletic realm, coaches and trainers recognize functional distinctions between the global and local muscles of the abdomen (Norris, 1993; Faccioni, 1994). Many coaches and trainers have begun to include stability training within the regimens of their athletes in spite of a lack of evidence supporting the merits of this type of training. In studies attempting to assess the benefit of LPS training toward athletic performance, differences in training methods and exercises make comparisons and conclusions difficult (Cusi et al., 2000; Young, McLaren, & McDowell, 1998; Wolfhart, et al., 1993). While there may be some support for the contribution of LPS toward athletic performance, a relationship between these two constructs has yet to be quantified.

Baker (2000) assessed the ability of rugby players within state and national level leagues to maintain a neutral position of the pelvis during the application of an external force to their lower limbs. With subjects lying supine, Baker recorded

the angle to which subjects could lower their straightened legs while maintaining a pelvic neutral position. Athletes competing at the national level were able to lower their legs to a position which placed a significantly greater external load upon the pelvis. In the conclusion of this article Baker claims "it is almost indisputable that possessing a strong core is of utmost importance to just about every athlete" (Baker, 2000, p.5).

While Baker may consider these findings as support for his conclusion that LPS is a vital component of sport performance, as with many other descriptive studies, the findings have very little insight to offer toward a possible connection between LPS and athletic performance. For instance, whether the observed difference in LPS is an integral component of athleticism, enabling players to compete at the national level, or whether differences are merely a result of the more rigorous training schedule of national-level athletes, cannot be inferred from the findings of this study alone.

2.6 Training to enhance LPS

2.6.1 Can the local stability muscles be selectively recruited?

As a necessary first step towards demonstrating that lumbo-pelvic stability can be enhanced with training, investigators have used EMG analysis to ensure that the local stability muscles can be preferentially activated during specific exercises. Richardson et al. (1990) recorded muscle activity during eight abdominal exercises including curl-ups, isometric trunk flexion in sitting, pelvic tilt with a single leg lower, pelvic tilt with a double leg lower, pelvic-lumbar

flexion, crook lying with pelvic rotation, sitting with trunk rotation, and bridging with pelvic rotation. The pattern of muscle activity believed to be most optimal in providing stability to the lumbo-pelvic region was obtained by means of a computational formula emphasizing activity within TrA, IO, and the low back extensors. RA activity was considered a negative contribution to spinal stability and was subtracted from the stability score of each exercise. Exercises with large, positive stability scores were considered to possess greater stabilizing capacities. Of the 8 exercises included in the study, crook lying with pelvic rotation, sitting with trunk rotation, and bridging with pelvic rotation were deemed most applicable to a training regimen to improve lumbo-pelvic stability.

Richardson et al. (1992) used this same formula to compare the stabilizing capacity of three commonly prescribed exercises for low back pain; abdominal hollowing and back flattening, abdominal bracing, and posterior pelvic tilting, in both sitting and standing positions. Abdominal hollowing in either position demonstrated an activity pattern that primarily activated TrA, IO, and the low back extensors and was concluded to be the most suitable for improving lumbo-pelvic stability. Results obtained by Beith and colleagues (2001) during hollowing manoeuvres in both quadruped and prone positions confirmed Richardson et al's conclusion that the abdominal hollowing manoeuvre does preferentially recruit IO over RA.

O'Sullivan et al. (1997) also examined the efficacy of the abdominal hollowing manoeuvre in preferentially recruiting parts of the local stability system (IO) rather than the global mobility system (RA). From recordings of EMG activity

during the hollowing manoeuvre, O'Sullivan and colleagues compared the ratio of IO activity to RA activity. While the manoeuvre activated the IO to a greater extent than RA in both asymptomatic subjects and subjects with chronic low back pain (CLBP), the ratio of IO / RA was significantly larger in subjects with no history of back pain. O'Sullivan and colleagues inferred from these findings that factors associated with CLBP may interfere with the extent to which the local stability system can be activated.

2.6.2 Can the local stability muscles be trained?

By combining the results of investigations such as these and their own clinical experience, Richardson and Jull (1995) have developed a training regimen to specifically address deficits in the functions of the local stability muscles. Richardson and Jull (1995) recommend the local stability muscles to be co-contracted isometrically at a low level of voluntary contraction in order to simulate their normal functions. Exercise positions such as prone lying or quadruped kneeling are recommended as these positions reduce external loading which, in turn, will decrease the activity of the global muscle system. Exercises can be progressed by increasing the holding time of contractions, increasing the number of repetitions, adding resistance, and by incorporating activities into functional body positions.

Despite the frequency of its clinical use as a treatment for lumbo-pelvic instability, there are few available studies which have evaluated its efficacy in improving LPS. Lindgren et al. (1993) evaluated the effect of an exercise program

on lumbar segmental movements in patients with CLBP. Nine subjects were included in the study and outcome measures included functional EMG analysis of paraspinal muscle activity, and segmental motion viewed with flexion-extension and traction-compression radiography. While the exact details of the training program are unclear, subjects were trained approximately 4 to 7 months with stretching, coordination, and strengthening exercises. Before training, functional EMG recordings showed a decreased activity at the level of the unstable segments, however, following training this activity had normalized. In addition, 8 of the 9 subjects reported a decrease in painful symptoms. However, radiographic findings showed a resolution of instability in only one of these subjects.

Young and colleagues (1998) assessed the specificity of abdominal muscle training by comparing the effects of two distinct methods of abdominal training on two distinct functions of the abdominal musculature—the ability to produce flexion of the vertebral column versus the ability to stabilize the lumbo-pelvic region. The investigators found greater improvements in lumbo-pelvic stability for those who had trained the local stability muscle system when compared with those who had trained muscles of the global mobility system.

In an attempt to observe the effectiveness of a specific lumbo-pelvic stability programme in the training regimens of rugby players, Cusi and colleagues (2001) randomly assigned players to one of two groups: a treatment group which performed three stability-oriented exercises twice a week for 10 weeks, and a control group which performed no training in addition to their team practices and games. LPS, injury rate and flexibility in the knee and hip of each subject were

measured before and after the ten-week study period. Upon completion of the study, both groups demonstrated improvement in LPS with no significant difference between these improvements. The authors concluded the lack of statistical significance to be due to an insufficiently large sample size ($n=39$) and emphasized the need for further research to investigate a connection between local stability training regimens and improved lumbo-pelvic stability. While this study offers virtually no insight into the relationship between local stability muscle function and lumbo-pelvic stability, its mention is justified simply because such little investigative effort has been directed to the nature of abdominal muscle function and lumbo-pelvic stability.

Finally, in an unpublished study, Brovender (2001) recruited 25 participants from a swim club and randomly assigned these participants to one of two groups: a group that trained the local stability muscles on a stable surface, and a second group which performed these same exercises on an unstable surface. LPS was assessed using the Stabilizer biofeedback pressure unit (Chatanooga) before and after six weeks of training. The results of this study indicate that LPS can be improved through training, and that instability in the surface upon which training is conducted may augment this training effect.

2.7 Conclusion

Among many trainers and coaches, LPS is considered an important factor in athletic performance. However, the relationship between LPS and athletic performance has not been defined within the present body of research. For LPS

training to continue to be included in the regimens of athletes, a pressing need exists for evidence which demonstrates its efficacy. First, it must be demonstrated that LPS can be improved with training. If improvement can be shown through training, effort must then be taken to quantify a possible relationship between improved LPS and improved athletic performance. If such a relationship does exist, then the use of LPS training can be justified. However, if a relationship cannot be shown to exist, athletes' may be encouraged to devote training time to regimens of demonstrated value.

CHAPTER THREE: METHODOLOGY

3.1 Experimental Design

This study examined the effect of 10 weeks of local stability vs 10 weeks of global mobility muscle training on LPS, balance, agility and leg power in a group of college and university-level female athletes. Outcome variables were assessed and compared between treatment, pseudo-treatment, and control groups prior to and immediately following a 10-week training program. Treatment and pseudo-treatment groups participated in distinct 10-week programs, emphasizing recruitment of either the local stability or global mobility muscles of the abdomen. The control group performed no specific abdominal muscle training in addition to their regular sport training.

3.2. Subjects

Subjects between the ages of 18 and 23 years were selected from university and college-level basketball and volleyball teams within the immediate vicinity of Vancouver, British Columbia. Subjects were excluded if they presented with exaggerated sway-back or flat-back --assessed with the aid of a plumb-bob (Kendall, 1993)—postures, if they had received treatment for back pain within the last year, or if they had any existing injury that limited their present athletic ability. In all, thirty healthy subjects were selected and randomly assigned to one of three groups, a treatment, a pseudo-treatment, or a control group. After recruitment to the study, participants who had met the above criteria were then required to carefully read and sign a consent form and fill out a questionnaire that

was approved by the University of British Columbia Clinical Ethics Committee for research involving human subjects (Appendix A).

3.3 Procedure

Following assessment of subjects' lumbo-pelvic stability and athletic performance, random assignment to groups was stratified on the basis of the participant's sport (volleyball vs. basketball) and their level of competition (college vs. university). Subjects in the treatment and pseudo-treatment groups met with the co-investigator once per week to ensure that exercises were being performed accurately. In addition, three 20 to 30-minute training sessions were completed each week by subjects in the treatment and pseudo-treatment groups without the co-investigator present. Subjects in the treatment and pseudo-treatment groups were asked to complete weekly exercise logs detailing their compliance with the assigned exercise regimen, any subject who failed to complete three or more exercise sessions, was dropped from the study. Subjects in the control group performed no additional abdominal training in addition to their team practices and games. All subjects were retested on the outcome variables at the end of the 10th week of training. The co-investigator with the aid of a research assistant collected scores on the outcome measures.

3.4 Measures

Objective outcome measures can be discussed in two groups: those that assess lumbo-pelvic stability and those that assess athletic performance. Each of these two groups and the measures comprising them will be discussed separately.

3.4.1 Lumbopelvic stability

The ability of the abdominal muscles to actively stabilize the lumbar spine was assessed using the Stabilizer pressure biofeedback unit (Chattanooga, Australia). This unit consists of an inflatable cuff and a pressure gauge connected to the cuff by a flexible plastic tube. In previous validation studies a linear relationship has been observed between the forces applied to the cuff and the pressure recorded by the gauge. Variation between the recorded and expected pressure changes was only 7% over a range of 40-60 mmHg (Jull, Richardson, Toppenburg, Commerford, & Bui, 1993).

In order to assess movement of the lumbo-pelvic region, the weight of the subjects' legs was used to apply a sagittal-plane load upon the lumbo-pelvic region (Jull et al., 1993). This was done according to four methods observed in the literature. While these methods were distinct in the manner of application of load to the lumbo-pelvic region, all required the subject to lie supine on a plinth with the Stabilizer cuff inflated to an initial pressure reading of 40 mmHg and placed between the lumbar spine above, and the plinth below.

Sahrmann Protocol

This assessment of lumbo-pelvic stability consisted of a series of lower limb movements of increasing levels of difficulty (Wohlfahrt et al., 1993; Brovender, 2001). The subjects' scores were of an ordinal nature and represent the highest level they were able to successfully complete. Once TrA was recruited, the Stabilizer cuff was inflated to 40 mmHg and the movement pattern begun. Levels were deemed complete if the movement was carried out with a positive or negative pressure change no greater than 10 mmHg as indicated on the Stabilizer pressure gauge. The highest level attained across three trials was used in subsequent statistical analyses.

Anticipated Leg Loading,

Subjects were instructed to engage the transversus abdominus (TrA) by performing an abdominal hollowing manoeuvre. Once TrA was recruited, the cuff was inflated to 40 mmHg and, beginning from a hip angle of 70°, participants flexed the right hip in order to lift the right foot slightly off the plinth and attain a new hip angle of 90° (Jull et al., 1993). The maximal pressure change in either a positive or negative direction was recorded from the Stabilizer pressure gauge. The mean pressure change across three trials was used for statistical analyses.

Spontaneous leg-loading (short and long-lever).

During the short lever spontaneous leg-loading test, the right leg was supported from just behind the knee by the examiner with the hip and knee flexed to 70° and 90°, respectively. Once the subject was steadied in this position, the Stabilizer cuff was inflated to 40 mmHg and neutral positioning of the pelvis was ensured.

Subjects were instructed to maintain this neutral position of the pelvis while continuing to hold the hip and knee in the starting position once leg support was released. Without warning, support of the leg was released and the maximal pressure change indicated on the Stabilizer gauge was recorded. The mean pressure change across three trials was used for statistical analyses.

During the long-lever spontaneous leg loading test this same procedure was conducted with the hip and knee flexed to 50° and 35° flexion, respectively. Again, the mean pressure change across three trials was used in subsequent statistical analyses.

3.4.2 Athletic performance

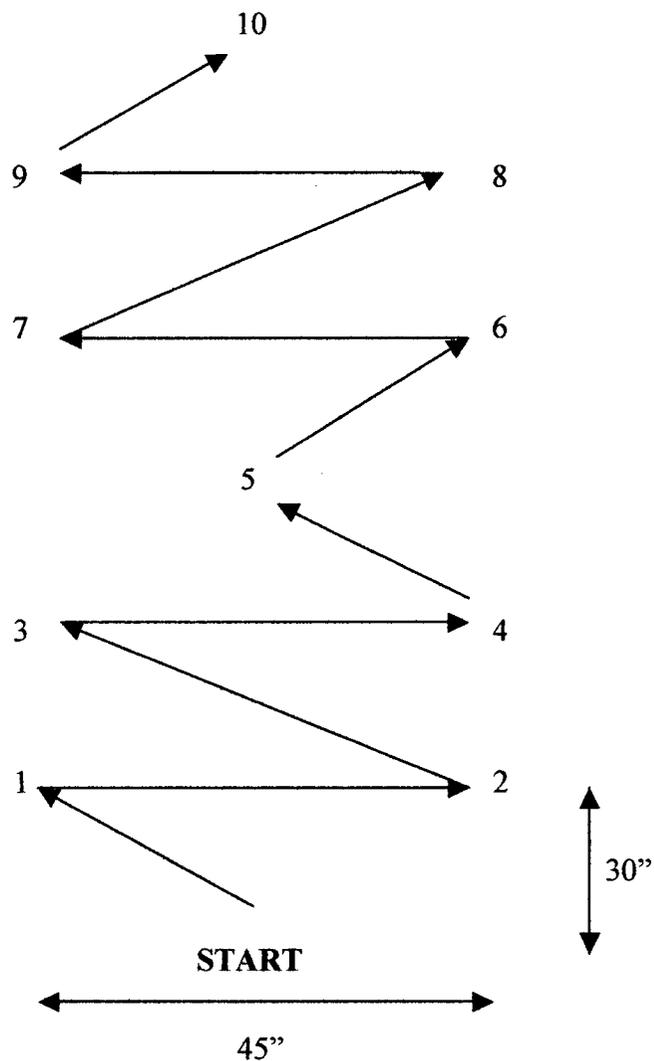
Athletic performance was defined as subjects' scores on four measures. Each of these measures will be discussed separately.

Balance

Static balance was assessed using the Bass stick test. Subjects were required to balance on the ball of one foot on a narrow 1" stick. The time the participant was able to maintain this balance position, up to a maximum of 60 seconds, was recorded. If the non-balancing foot or either the heel or toes of the balancing foot touched the ground, the trial was terminated and the elapsed time recorded. Three trials were given on each foot and the times from all six trials were summed to give the static balance score. This testing protocol has been assessed with a test-retest reliability of 0.90 (Johnson & Nelson, 1986).

In order to assess dynamic balance the modified Bass test of dynamic balance was used. Subjects began on the right foot and hopped diagonally to and from a series of markings measuring 1" by $\frac{3}{4}$ " (Figure 9). Subjects were required to land and maintain balance on the ball of their foot for 5 seconds at each marking. Five points were awarded for each mark successfully landed on, and one point was awarded for each second, up to a maximum of five seconds, that balance was maintained at that mark. A total of ten points of contact made 100 the maximum score attainable. Participants lost 5 points for committing any of the following landing errors; failure to stop at the marker, touching the heel or any other body part to the floor, failure to completely cover the marker with the ball of the foot. During the maintenance of balance, subjects had one point deducted for each second remaining from the required 5 second maintenance of balance if they touched any other part of their body to the floor besides the balancing foot or pivoted the balancing foot while attempting to maintain balance. This test has been associated with a reliability coefficient of 0.75 when subjects were tested on separated days and validity coefficient of 0.46 when correlated with the Bass test of dynamic balance. (Johnson & Nelson, 1986).

Figure 8. Bass's modified test of dynamic balance.



Agility

Agility was assessed using the T-test, a measure of 4-directional agility and body control that evaluates the ability to change directions rapidly while maintaining balance without loss of speed. Upon a starting signal, subjects sprinted forward 9.14 m., rang a bell at the base of a cone, shuffled in a defensive position 4.57 m. to their left, rang another bell, shuffled 9.14 m. to their right, rang a bell, shuffle stepped 4.57 m. back to their left, rang a bell, and then

sprinted backwards 9.14 m. to cross the original starting line. Time was recorded to the nearest one-hundredth of a second for three test trials. Individual trials were repeated if the subjects failed to ring a bell, crossed their feet during the defensive shuffle step, or failed to face forward at all times. The fastest trial was used for statistical analyses. Using college-aged participants Pauole et al. (2000) found a reliability coefficient of 0.98 across three trials of this T-test. In the same study, the T-test was found to have a multiple correlation of 0.69 to measures of vertical jump, hexagon test, and 40-yd. dash.

Leg Power

Measurements of vertical jump ability are a common means of assessing lower extremity power. One of the most frequently used methods is Sargent's test of vertical jumping ability (Sargent, 1921). Prior to jumping, the subjects' maximal reach was measured against the wall with each participant on the balls of their feet. Subjects stood with feet shoulder-width apart, one arm on the hip, and the reaching hand at shoulder level. After flexing the knees to 70°, the subjects paused for a brief moment and then jumped as high as they could. Subjects were closely monitored so that neither a counter-movement nor arm swing contributed to the jumping height. At the highest point of each jump subjects made a mark on the wall with their reaching hand. Three trials were performed with the average of these three trials used for statistical analyses. This method of assessing vertical jump demonstrated excellent test-retest reliability ($r=0.93$) and a validity coefficient of ($r=0.78$) when correlated with other measures of lower extremity power (Johnson & Nelson, 1986).

3.5 Training Regimen

Treatment Group

The training regimen for the treatment group is provided in detail in Appendix C. Training was divided into three stages, each with a different goal and focus of training. Stage one was four weeks in length and focused on voluntary activation of the local stability muscles. Instructional methods included visualization techniques such as the abdominal hollowing manoeuvre to isolate contraction of TrA, and swelling of the area on either side of the lumbar spinous processes in order to facilitate contraction of LM. These local muscles were activated in supine, quadruped, side-lying, and prone positions. Compensatory movements such as posterior tilting of the pelvis, expansion or compression of the rib cage, or contraction of the gluteal muscles was discouraged.

The following four weeks comprised the second stage of training. In this stage participants began to train the local stability muscles by applying loads to the trunk. During the application of these loads, failure of the local stability muscles was indicated by an inability of the participants to maintain a neutral position of the pelvis. Loads were applied by flexing and rotating the hip while in a supine position, rotating the hip while in a side-lying position, or by flexing and extending the legs and arms while in the quadruped position.

In the final two weeks of training, stage 3, subjects were challenged to maintain co-contraction of the local stability muscles while stability was further decreased by the inclusion of an exercise ball. The exercises performed were similar to those in stage 2, but were conducted while maintaining balance on a Swiss ball.

Pseudo-treatment Group

The training regimen for the pseudo-treatment group is provided in detail in Appendix D. Subjects in the pseudo-treatment group performed trunk flexion, rotation and lateral bending exercises in order to primarily recruit fibres of the rectus abdominis and external obliques. The volume of training between the treatment and pseudo-treatment groups was matched by ensuring equal training time between the two groups.

3.6 Hypotheses

H1. Following the 10-week training program, LPS will be significantly improved in the treatment group relative to both the pseudo-treatment and control groups for each of the four LPS assessment techniques.

H2. Following the 10-week training program, agility will be significantly improved in the treatment group relative to both the pseudo-treatment and control groups

H3. Following the 10-week training program, vertical jump will be significantly improved in the treatment group relative to both the pseudo-treatment and control groups

H4. Following the 10-week training program, static balance will be significantly improved in the treatment group relative to both the pseudo-treatment and control groups

H5. Following the 10-week training program, dynamic balance will be significantly improved in the treatment group relative to both the pseudo-treatment and control groups

H6. A correlation will be observed between the measures of LPS and agility.

H7. A correlation will be observed between the measures of LPS and vertical jump.

H8. A correlation will be observed between the measures of LPS and static balance.

H9. A correlation will be observed between the measures of LPS and dynamic balance.

3.7 Statistical Analyses

The majority of data were collected at a ratio scale of measurement and for these data, a 3x2 ANOVA with repeated measures on the second factor was used to assess differences between or within groups as well as any interactions which may have occurred. For these same data, Pearson's product-moment correlation coefficient was used to assess correlations and relationships between variables.

Data collected using the Sahrman protocol assessment of LPS were of an ordinal nature and therefore required analysis using non-parametric statistical tests. Analysis of these data was carried out with a combination of Friedman, Wilcoxon and Mann-Whitney U tests. Associations between the Sahrman protocol and other variables were assessed using Spearman's rho. An alpha level

of 0.05 was set as a cut-off point for statistical significance in both parametric and non-parametric analyses.

CHAPTER FOUR: RESULTS

Anthropometric Data

The mean physical characteristics and sport of the 30 subjects who completed the study are listed in Table 5. No significant differences were detected between groups in height, weight, or age of the subjects.

Table 5. Descriptive data for subjects by group. Values reported as Mean \pm SD.

	Age (yrs)	Height (cm)	Weight (kg)	Sport
Treatment (n=10)	20.3 \pm 2.0	176.7 \pm 6.0	73.2 \pm 5.8	Volleyball - 9 Basketball - 1
Pseudo-treatment (n=10)	18.9 \pm 1.1	177.5 \pm 5.4	73.8 \pm 5.9	Volleyball - 7 Basketball - 3
Control (n=10)	19.4 \pm 1.7	176.8 \pm 6.8	73.3 \pm 4.5	Volleyball - 8 Basketball - 2

Note: no significant differences between groups on any of these variables

Activity Level

The activity level of subjects throughout the ten-week study period is summarized in Table 6. Activity is differentiated into cardiovascular, weight training and team practice and games, and is reported as the number of hours completed per week of any of these types of activity. No significant differences were detected between the activity levels of the three groups for any of the different activity types.

Table 6. Mean physical activity of the groups throughout the 10-week study.

Values are reported as hours per week.

	Cardio	Weights	Team practice/games
Treatment Mean \pm SD	2.2 \pm 0.5	1.5 \pm 0.1	10 \pm 1.7
Pseudo-treatment Mean \pm SD	2.5 \pm 0.1	2.0 \pm 0.6	10.5 \pm 1.4
Control Mean \pm SD	2.5 \pm 0.4	1.8 \pm 0.2	12.0 \pm 0.7

Note: no significant differences between the activity levels of the three groups.

LUMBO-PELVIC STABILITY

Sahrmann Protocol

Results for the measurement of lumbo-pelvic stability by means of the Sahrmann protocol are presented as a function of group in Table 7 and are illustrated in Figure 9. Improvement in LPS is indicated by an increased in the level of completion.

Table 7. Stability scores collected using the Sahrmann protocol. Values are reported as the level attained (0-5) on the Sahrmann testing protocol.

	Treatment	Pseudo-treatment	Control
Pre-test (mean \pm SD)	1.30 \pm 1.25	0.60 \pm 0.70	1.80 \pm 1.40
Post-test (mean \pm SD)	2.80* \pm 1.48	2.30* \pm 1.42	2.40 \pm 1.26

Note: * represents a significant improvement in stability following a 10-week training program ($p < 0.01$).

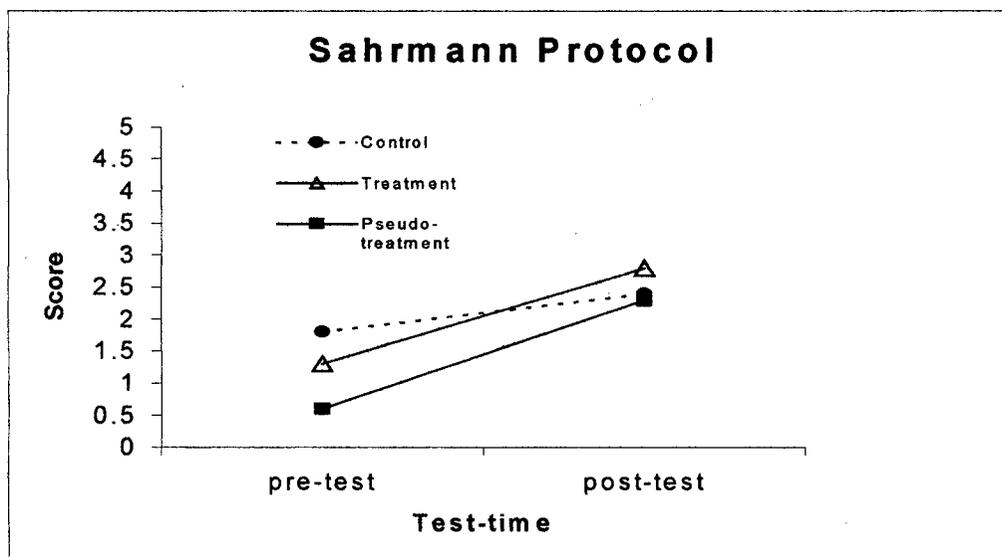


Figure 9. Mean Sahrman Protocol score for the measurement of LPS in the treatment, pseudo-treatment and control groups.

A non-parametric Friedman analysis of variance by ranks revealed a significant increase (Chi Square (2) = 22.43, $p < 0.01$) in stability following the 10-week training period. Subsequent Wilcoxon tests localized this improvement over time to the treatment ($z = -2.75$, $p < 0.01$) and pseudo-treatment ($z = -2.86$, $p < 0.01$) groups. There was no statistical difference between the control group's pre- and post-test scores ($z = -1.29$, NS). A Mann-Whitney U comparison found no significant difference between the stability scores of the treatment and pseudo-treatment groups at the pre-test ($z = 1.26$, NS) or post-test measurements ($z = -0.78$, NS).

Anticipated leg lift

Results for the measurement of LPS employing the anticipated leg lift are presented as a function of group in Table 8 and are illustrated in Figure 10. Improvement in LPS is indicated by a decrease in recorded pressure.

Table 8. Stability scores collected using the anticipated leg lift.
Scores are reported in mmHg.

	Treatment	Pseudo-treatment	Control
Pre-test (mean \pm SD)	5.0 ^a \pm 2.8	4.7 \pm 1.8	5.1 \pm 3.8
Post-test (mean \pm SD)	3.4 ^{*a} \pm 1.7	4.4 \pm 2.0	5.6 [*] \pm 1.7

Note: * indicates a significant difference between these scores ($p < 0.01$).

^a indicates a marginally significant improvement in stability following a 10-week training program ($p < 0.1$).

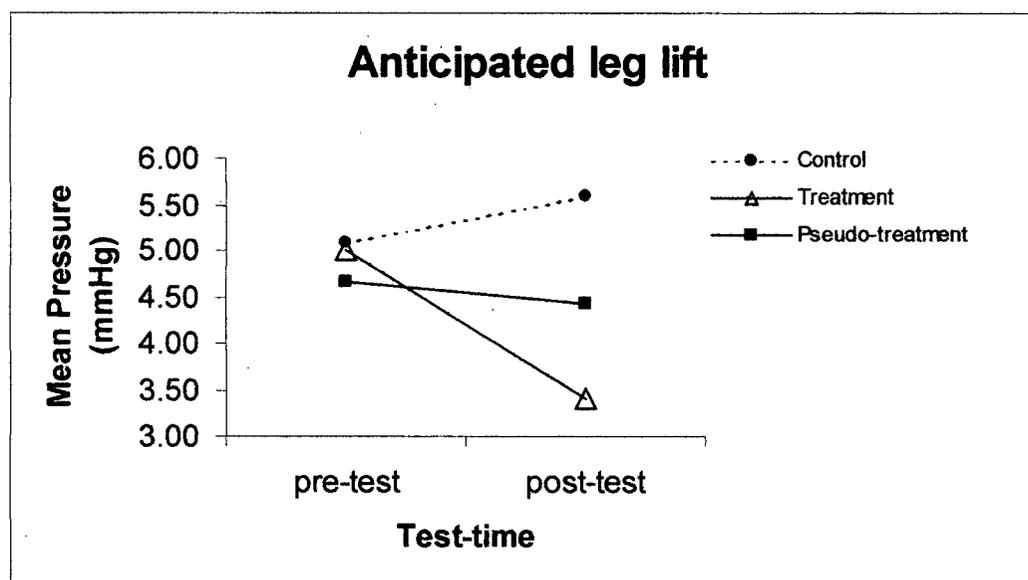


Figure 10. Mean anticipated leg lift score for the assessment of LPS in the treatment, pseudo treatment and control groups.

A repeated measures ANOVA of the stability scores for the anticipated leg lift revealed no significant effect of time of testing ($F(1, 27) = 0.55$, NS) or group ($F(2, 27) = 1.04$, NS). There was also no indication of a significant test-time by group interaction ($F(2, 27) = 1.19$, NS).

A priori comparisons revealed a significant difference ($t(27) = 2.71$, $p < 0.01$) between the stability of the treatment and control groups upon completion of the 10-week training program. This difference was not present at the pre-test ($t(27) = 0.10$, NS). There was no difference detected between the stability scores of the pseudo-treatment and control groups ($t(27) = -1.44$, NS) at the post-test measurement. A priori comparisons also revealed a marginally significant difference between the pre-test and post-test scores of the treatment group ($t(27) = 1.58$, $p < 0.1$)

Spontaneous leg loading

i) Short Lever

Results for the assessment of LPS by means of short lever spontaneous leg loading are presented as a function of group in Table 9 and are illustrated in Figure 11. Improvement in LPS is indicated by a decrease in recorded pressure.

Table 9. Stability scores collected using short lever spontaneous leg loading
Scores are reported in mmHg.

	Treatment	Pseudo-treatment	Control
Pre-test (mean \pm SD)	9.5 \pm 3.8	11.6* \pm 4.1	8.7 \pm 4.5
Post-test (mean \pm SD)	8.6 \pm 4.1	7.5* \pm 3.6	7.8 \pm 3.4

Note: * represents a significant improvement in stability following a 10 week training program ($p < 0.05$).

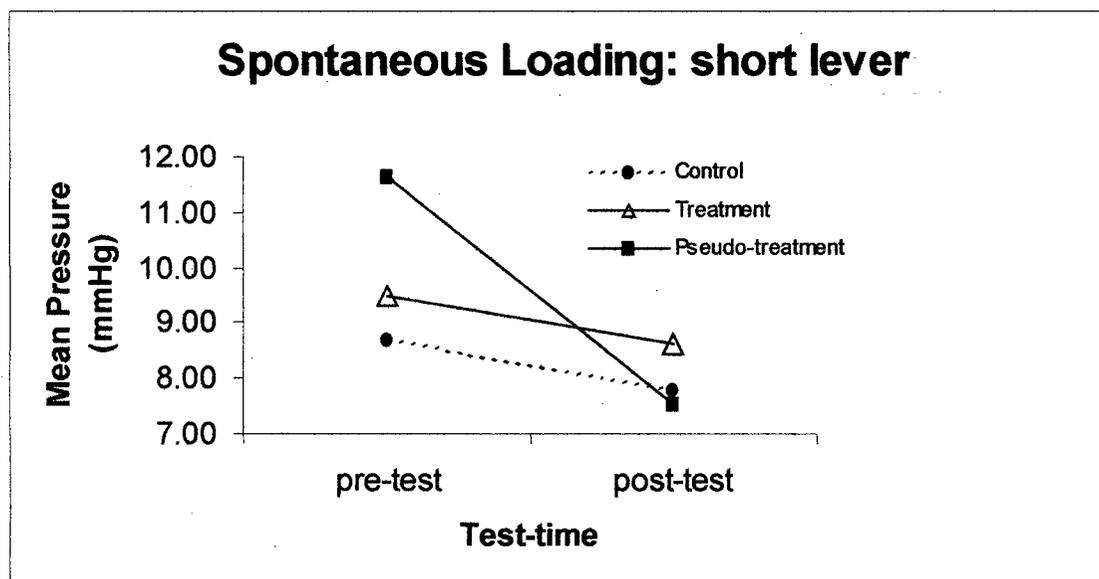


Figure 11. Mean short lever spontaneous leg loading score for the assessment of LPS in the treatment, pseudo-treatment and control groups.

A repeated measures ANOVA revealed a significant effect of time of testing ($F(1, 27) = 7.45, p < 0.05$) but did not reveal a significant group effect ($F(2, 27) = 0.39, NS$). The test-time by group interaction was marginally significant ($F(2, 27) = 2.19, p = 0.07$). Post-hoc comparisons indicated a significant improvement ($t(27) = 3.29, p < 0.01$) in the stability of the pseudo-treatment group between pre- and post-tests. There was no improvement in stability noted between the pre- and post-tests of either the treatment ($t(27) = 0.72, NS$) or control ($t(27) = 0.72, NS$) groups.

ii) Long Lever

Results for the assessment of LPS by means of long lever spontaneous leg loading are presented as a function of group in Table 10 and are illustrated in Figure 12. Improvement in LPS is indicated by a decrease in recorded pressure.

Table 10. Stability scores collected using long lever spontaneous leg loading. Scores are reported in mmHg.

	Treatment	Pseudo-treatment	Control
Pre-test Mean \pm SD	8.6 \pm 3.6	11.6 \pm 5.1	9.2 \pm 5.3
Post-test Mean \pm SD	8.2 \pm 3.2	8.9 \pm 4.6	8.0 \pm 1.9

Note: no significant differences detected.

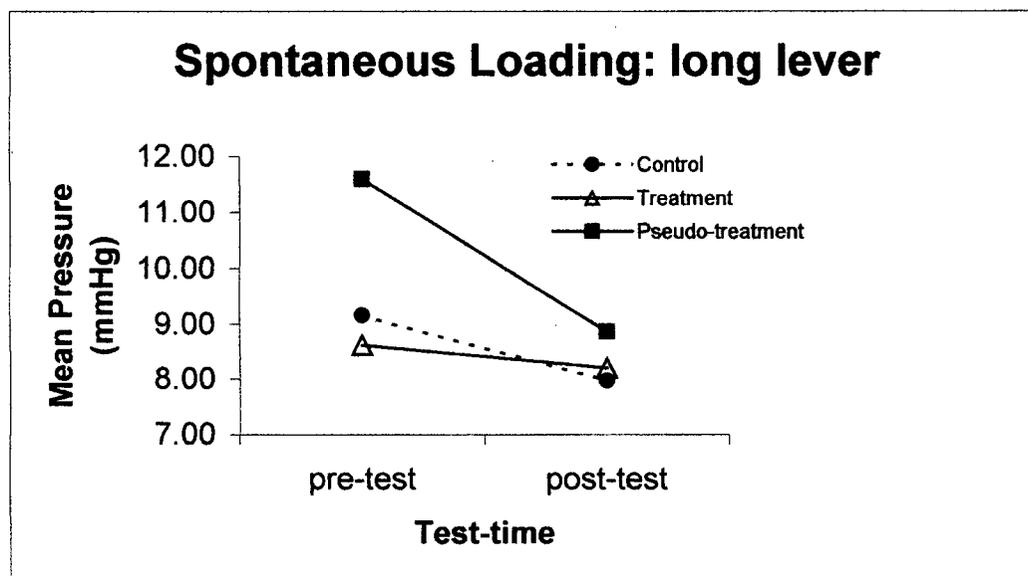


Figure 12. Mean long lever spontaneous leg loading score for the assessment of LPS in the treatment, pseudo-treatment and control groups.

A repeated measures ANOVA revealed a marginally significant effect of time of testing ($F(1, 27) = 2.07, p=0.08$), however, there was no group effect ($F(2,27) = 1.09, NS$). There was no indication of a significant test-time by group interaction ($F(2, 27) = 0.45, NS$).

ATHLETIC PERFORMANCE

Agility

Results for the assessment of agility using the T-test are reported as a function of group in Table 11 and are illustrated in Figure 13. Improvement in agility is indicated by a decrease in time to complete the agility task.

Table 11. Time to complete an agility T-test before and after a 10-week training program. Times are reported in seconds.

	Treatment	Pseudo-treatment	Control
Pre-test (mean \pm SD)	8.8* \pm 0.7	8.8 \pm 0.3	9.0 \pm 0.3
Post-test (mean \pm SD)	8.5* \pm 0.6	8.8 \pm 0.4	9.0 \pm 0.4

Note: * represents a significant improvement in agility following a 10-week training program ($p < 0.05$).

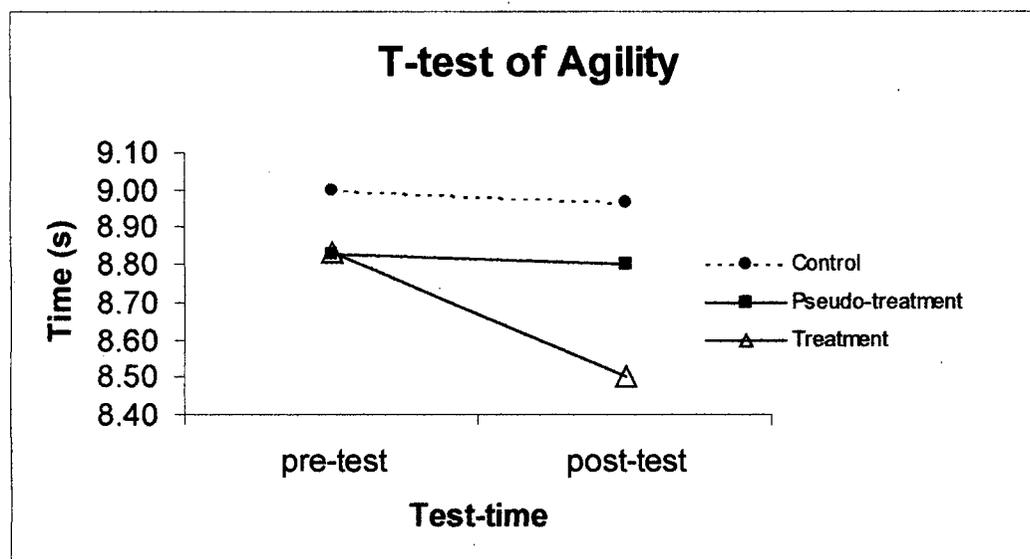


Figure 13. Mean time to complete a T-test of agility for the treatment, pseudo-treatment and control groups.

A repeated measures ANOVA revealed a significant effect of time of testing ($F(1, 27) = 6.19, p < 0.01$) but did not reveal a significant group effect ($F(2, 27) = 1.32, NS$). The ANOVA also revealed a significant test-time by group interaction ($F(2, 27) = 3.81, p < 0.05$). A priori comparisons demonstrated a significant difference between the treatment group's pre- and post-test agility scores ($t(27) = 3.75, p < 0.0005$). No differences were found between either the pseudo-treatment ($t(27) = 0.33, NS$) or control ($t(27) = 0.33, NS$) groups' pre- and post-test scores.

Leg Power

Results for the assessment of leg power using Sargent's vertical jump test are reported as a function of group in Table 12 and are illustrated in Figure 14. Improvement in vertical jump is indicated by an increase in jumping height.

Table 12. Vertical jump heights attained before and after a 10-week training program.

Jump heights are reported in cm.

	Treatment	Pseudo-treatment	Control
Pre-test (mean \pm SD)	29.1* \pm 6.0	30.1 \pm 7.2	29.0 \pm 4.0
Post-test (mean \pm SD)	32.3* \pm 4.5	30.2 \pm 6.8	29.5 \pm 6.3

Note: * represents a significant improvement in vertical jump following a 10-week training program ($p < 0.05$).

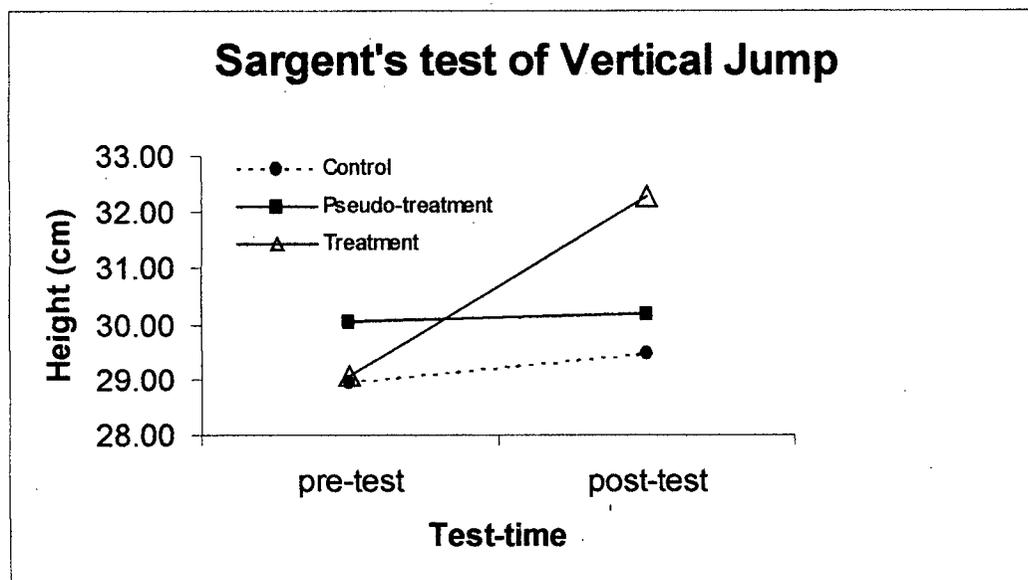


Figure 14. Mean vertical jump heights for the treatment, pseudo-treatment and control groups.

A repeated measures ANOVA revealed a significant effect of time of testing ($F(1,27) = 3.07, p < 0.05$) but no significant group effect ($F(2, 27) = 0.18, NS$). ANOVA also revealed a marginally significant test-time by group interaction ($F(2, 27) = 1.76, p < 0.1$). Post-hoc comparisons of the within groups effect demonstrated a significant difference ($t(27) = 2.53, p < 0.05$) between the treatment group's pre- and post-test vertical jump heights. No difference was found between the pre- and post-test vertical jump heights of either the pseudo-treatment ($t(27) = 0.09, NS$) or the control ($t(27) = 0.40, NS$) groups.

Static Balance

Results for the assessment of static balance using Bass' stick test are reported as a function of group in Table 13 and are illustrated in Figure 15. Improvement in static balance is indicated by an increase in balancing time.

Table 13. Static balance times attained before and after a 10-week training program.

Score are reported in seconds.

	Treatment	Pseudo-treatment	Control
Pre-test (mean \pm SD)	88.4 ^a \pm 69.5	78.6 ^b \pm 63.6	54.8 ^c \pm 35.2
Post-test (mean \pm SD)	116.8 ^a \pm 79.6	116.6 ^b \pm 86.2	85.2 ^c \pm 89.4

Note: ^a ^b ^c represent significant improvements in static balance following a 10-week training program ($p < 0.05$).

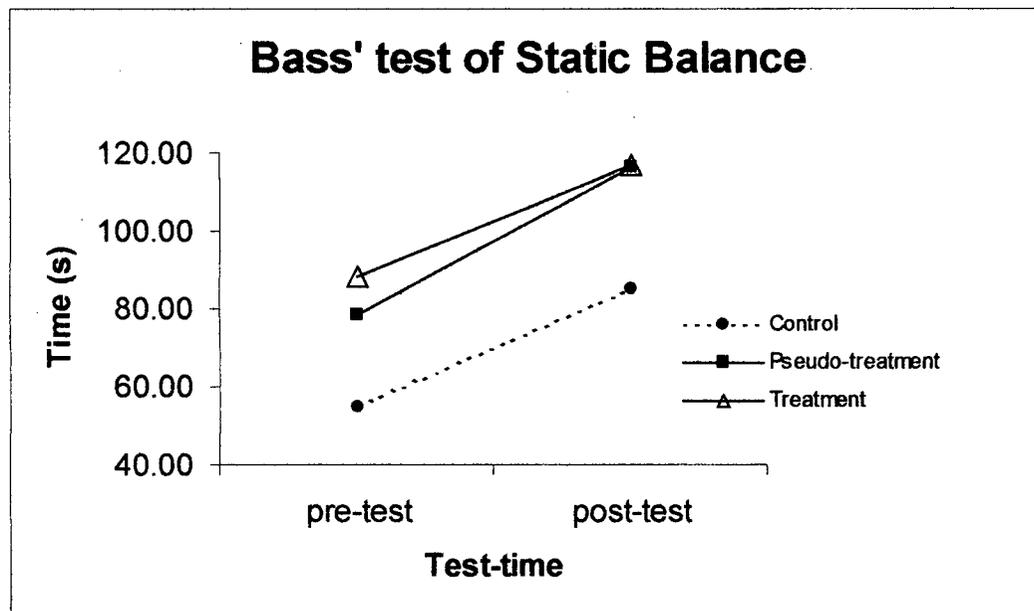


Figure 15. Mean balance times for Bass' stick test of static balance for the treatment, pseudo-treatment and control groups.

A repeated measures ANOVA revealed a significant effect of time of testing ($F(1, 27) = 10.62, p < 0.01$) but did not indicate a significant group effect ($F(2, 27) = 0.67, NS$). There was no indication of a significant test-time by group interaction ($F(2, 27) = 0.09, NS$). Post-hoc comparisons demonstrated significant improvements in static balance from pre- to post-tests for the treatment ($t(27) = 2.21, p < 0.025$), pseudo-treatment ($t(27) = 2.96, p < 0.005$) and control ($t(27) = 2.37, p < 0.05$) groups.

Dynamic Balance

Results for the assessment of dynamic balance using Bass' modified test of dynamic balance are presented as a function of group in Table 14 and are illustrated in Figure 16. Improvement in dynamic balance is indicated by an increase in score out of 100.

Table 14. Dynamic balance scores attained before and after a 10-week training program. Values represent a score out of 100.

	Treatment	Pseudo-treatment	Control
Pre-test (mean \pm SD)	61.2 ^a \pm 17.2	63.0 ^b \pm 12.1	46.7 ^c \pm 21.8
Post-test (mean \pm SD)	73.5 ^a \pm 12.6	73.5 ^b \pm 17.0	67.2 ^c \pm 10.7

Note: ^a ^c represent a significant improvement in dynamic balance following a 10-week training program ($p < 0.025$).

^b represents a marginally significant improvement in dynamic balance following a 10-week training program ($p < 0.10$).

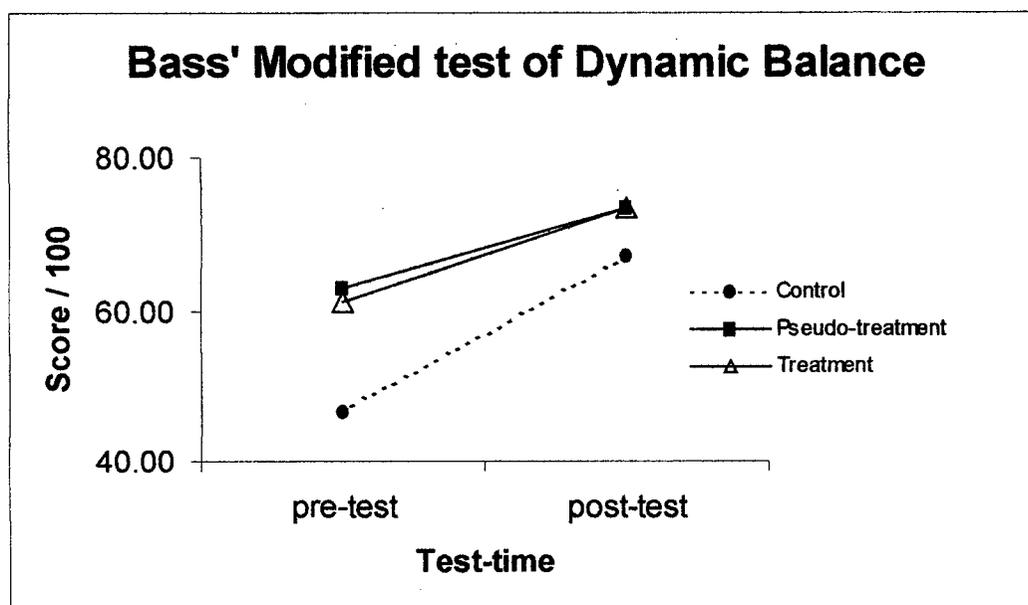


Figure 16. Mean balance scores for Bass' modified test of dynamic balance for the treatment, pseudo-treatment and control groups.

A repeated measures ANOVA revealed a significant effect of time of testing ($F(1, 27) = 20.20, p < 0.01$) but did not demonstrate a group effect ($F(2, 27) = 2.34, NS$). There was no indication of a significant test-time by group interaction ($F(2, 27) = 0.92, NS$). Post-hoc comparisons demonstrated significant improvements in dynamic balance from pre- to post-tests for the treatment ($t(27) = 2.22, p < 0.025$) and control ($t(27) = 3.70, p < 0.001$) groups, and a marginally significant improvement in the scores of the pseudo-treatment group ($t(27) = 1.90, p < 0.10$).

CORRELATIONS

Correlations between the four measures of lumbo-pelvic stability are presented in Table 15.

Table 15. Correlation matrix for the measures of lumbo-pelvic stability.

	Sahrmann Protocol	Anticipated Leg Lift	Spontaneous Leg Loading – short lever	Spontaneous Leg Loading – long lever
Sahrmann Protocol	1.00	0.092	-0.155	-0.256
Anticipated Leg Lift	-----	1.00	0.063	0.152
Spontaneous Leg Loading – short lever	-----	-----	1.00	0.707*
Spontaneous Leg Loading – long lever	-----	-----	-----	1.00

Note: stability assessment with the short-lever test could be used to predict the score on the long-lever test with significantly greater accuracy than the mean ($p < 0.01$).

Regression using Spearman's rho (r_s) revealed no significant correlations between LPS scores attained via the Sahrmann protocol and the LPS scores attained on any of the other assessment techniques. Pearson's product-moment correlation coefficient (r) showed a significant association between the short-lever and long-lever spontaneous leg loading assessments of LPS ($p < 0.01$). There were no other significant associations detected among the measures lumbo-pelvic stability.

Correlation between the four measures of athletic performance and injury susceptibility are presented in Table 16.

Table 16. Correlation matrix for the measures of athletic performance.

	Agility	Leg Power	Static Balance	Dynamic Balance
Agility	1.00	0.742*	0.537*	0.379*
Leg Power	-----	1.00	0.358*	0.243
Static Balance	-----	-----	1.00	0.563*
Dynamic Balance	-----	-----	-----	1.00

the score from one athletic performance test can be used to predict the score on the corresponding test with significantly greater accuracy than the mean ($p < 0.05$).

Pearson's product-moment correlation coefficient (r) showed a significant association between the scores obtained on the agility and leg power tests ($p < 0.01$), the agility and static balance tests ($p < 0.01$), the agility and dynamic balance tests ($p < 0.05$), the leg power and static balance tests ($p < 0.05$) and between the static balance and dynamic balance tests ($p < 0.01$). There was no significant correlation found between scores obtained on the leg power and dynamic balance tests.

Correlations between athletic performance measures and lumbo-pelvic stability measures are presented in Table 17.

Table 17. Correlation matrix for stability and athletic performance measures.

	Agility	Leg Power	Static Balance	Dynamic Balance
Sahrmann Protocol	0.06	0.07	0.29	-0.07
Anticipated Leg Lift	0.454*	0.515*	0.299	0.041
Spontaneous Leg Loading – short lever	0.325*	0.169	0.163	0.048
Spontaneous Leg Loading – long lever	0.179	0.212	0.095	0.016

stability assessment could be used to predict the appropriate athletic performance score with significantly greater accuracy than the mean ($p < 0.05$).

Regression using Spearman's rho (r_s) revealed no significant correlations between LPS scores attained via the Sahrmann protocol and any of the four measures of athletic performance. With the Pearson product-moment correlation coefficient (r) significant relationships were found between LPS scores attained via the anticipated leg lift and both agility ($p < 0.05$) and vertical jump ($p < 0.01$). A significant correlation was also detected between LPS scores from the short lever spontaneous leg loading test and agility ($p < 0.05$). No other significant correlations were found.

Correlations between the changes in LPS and the changes in athletic performance are presented in Table 18.

Table 18. Correlation matrix for the changes in stability and in athletic performance.

	Agility	Leg Power	Static Balance	Dynamic Balance
Sahrmann Protocol	0.095	0.082	0.287	-0.168
Anticipated Leg Lift	0.064	0.162	0.320*	0.086
Spontaneous Leg Loading – short lever	0.096	0.123	0.251	0.320*
Spontaneous Leg Loading – long lever	0.171	0.093	0.210	0.264

Regression using Spearman's rho (r_s) revealed no significant correlations between the pre- to post- changes in LPS scores attained via the Sahrmann protocol and the pre- to post- changes in any of the four measures of athletic performance. With the Pearson product-moment correlation coefficient (r) marginally significant relationships were demonstrated between the changes in LPS scores attained via the anticipated leg lift and the changes in static balance ($p=0.085$). A marginally significant correlation was also demonstrated between the changes in LPS scores attained via the short lever spontaneous leg loading test and the changes in dynamic balance scores ($p=0.085$).

CHAPTER FIVE: DISCUSSION

The use of lumbo-pelvic stability training as a potential aid to athletic performance is increasing among athletes, trainers, coaches and other fitness and conditioning professionals. However, there is a paucity of scientific evidence to support the effectiveness of such a training regimen. Previous studies have not convincingly proven that LPS can be improved with training, or that such improvement, if it does occur, can in any way contribute to improvements in athletic performance. The aim of the present study was to determine whether LPS could be improved through training, to evaluate whether changes in LPS are dependent upon the specific muscles groups trained, and to quantify a possible correlation between LPS and the changes in LPS with athletic performance and the changes in athletic performance over a 10-week training program.

Lumbo-pelvic Stability

It was hypothesized that, upon completion of the 10-week training program, each of the tests employed to assess LPS, i.e. the Sahrman protocol, the anticipated leg lift test, and the short- and long-lever spontaneous leg loading tests, would reveal an improvement in the treatment group's LPS. Two of the four test methods provided some support for this hypothesis while two did not. The treatment group demonstrated significant improvement from pre-test to post-test when assessed via the Sahrman protocol. While the treatment group evidenced only marginally significant improvement as assessed by the anticipated leg lift test, the improvement was large enough to produce a significant difference

between the post-test stability scores of the treatment and control groups. LPS assessed via the short-lever and long-lever spontaneous leg loading methods showed no significant improvement within the treatment group.

With two measures of LPS showing improvement with training and two measures showing no significant change, questions arise concerning the nature of LPS and our present ability to measure this construct. The four methods of assessing LPS in this study have been used in isolation throughout the literature but have not previously been used in conjunction with one another (Baker, 2000; Jull et al., 1993; Wohlfahrt, et al., 1993). While the reliability of these measures has been established (Appendix C), their validity is presently unmeasured and may remain so until a gold standard emerges with which all measures of LPS can be compared. However, in the absence of such a gold standard, one would expect to observe some level of convergent validity among the measures presently used to assess LPS. In this study convergent validity was not demonstrated between the measures of LPS as two of the four assessment methods showed improvements from the pre- to post-tests, while two did not. Furthermore, as demonstrated in Table 15, evidence for convergent validity of these test measures is scarce as a significant association was observed between the scores of only two LPS assessment techniques, the short- and long-lever spontaneous leg loading tests.

If it is assumed that the measures showing significant change as a result of training are valid indicators of LPS, the treatment group's improvement on the Sahrman protocol and anticipated leg lift measures of LPS provides support for presently accepted theories concerning spinal function. Stability of the spine is

believed to be a result of the integrated functioning of the active, passive and control subsystems (Panjabi, 1992). It is believed that the function of each subsystem can be attenuated through injury or disuse and that the active subsystem can be enhanced through specific muscular training. A number of similar training regimens have been introduced and through controlled, clinical trials these training programs have been shown to result in decreased pain scores and increased ROM in patients with chronic low back pain (Liebenson, 1998; O'Sullivan, Twomey, & Allison, 1997). While it has been assumed that these results occurred because training increased LPS, the ability of training to increase LPS has yet to receive direct experimental support (Lindgren, et al. 1993). In the present study, the treatment group's improvement in LPS demonstrates that LPS can be improved within an athletic population through specific training of abdominal musculature.

Precisely which of the abdominal muscle systems (local stability vs global mobility) plays a greater role in the stability of the lumbo-pelvic region has been previously investigated with conflicting results (Young et al., 1998; Wohlfahrt et al., 1993). Young and colleagues (1998) concluded that dynamic and stabilizing functions are independent of one another and, therefore, recommend stabilizing exercises over dynamic sit-up type exercises for improving stability within the lumbo-pelvic region. However, rather than finding support for this distinction between the roles of the local stability and global mobility systems, Wohlfahrt et al. (1998) found just the opposite, i.e. a significant relationship between the roles of the two muscle systems.

The results of the present study do not support Young et al.'s (1998) strong distinction between the roles of the local stability and the global mobility muscles but are more consistent with the findings of Wohlfart and colleagues (1993). Although the treatment group's LPS via the Sahrman protocol demonstrated improvement from pre- to post-test measurement, significant improvement was also observed in the pseudo-treatment group's scores. Moreover, no significant difference was found between these two groups' Sahrman protocol scores at the post-test measurement. Finally, although the treatment group demonstrated improved stability on the post-test relative to the control group as measured by their anticipated leg lift scores, no significant difference was found between the post-test anticipated leg-lift scores of the treatment and pseudo-treatment groups. From these results it appears that training of either the local stability or global mobility muscles affects lumbo-pelvic stability to an equal extent.

The present conclusion equating training of the local stability and global mobility muscles rests on the assumption that the training conducted by the treatment and pseudo-treatment groups did, in fact, succeed in recruiting the two muscle systems independently of one another. Since the present treatment group's stability training program (Appendix C; Richardson & Jull, 1995) was based on an abdominal hollowing manoeuvre which has been demonstrated to preferentially activate the local stability muscles (Beith, Synnott, & Newman, 2001; O'Sullivan et al., 1997; Richardson et al., 1992; Richardson et al., 1990), and since the pseudo-treatment group's exercises (Appendix D) were selected from those shown to predominantly activate the global muscle system (McGill,

1998; Vezina & Hubley-Kozey, 2000; Arokoski, Valta, Airaksinen, & Kankaanpää, 2001)), this assumption seems justified.

Athletic Performance

Four measures were chosen to represent subjects' athletic ability. These measures include the T-test (agility), Sargent's squat jump (leg power), Bass's stick test (static balance) and Bass's modified test of dynamic balance. In light of findings by Hoffman et al. (1996) of a significant correlation between improved athletic performance—indicated by increased playing time—and scores on both the T-test and Sargent's squat jump in female volleyball players, it was believed that improvements in these indirect measures of athletic performance would provide a valid indication that actual sport performance had improved.

In the present study significant improvements were detected in the treatment group's agility and leg power scores following the 10-week training period. The treatment group demonstrated improvement in the time required to complete the agility test and in the height of vertical jump recorded by Sargent's squat jump test. Similar improvements were not detected in the pseudo-treatment or the control groups' agility and leg power scores. One can conclude, therefore, that training the local stability muscles brought about these improvements in the treatment group's agility and leg power scores.

Popularly accepted theory suggests that the ability of peripheral musculature to produce torque efficiently is improved as the spine becomes more stable (Baker, 2000; Faccioni, 1994). With less movement at the origin of peripheral muscles, these muscles are able to generate movement more efficiently or with greater

power at their insertions. As movement at the origin of peripheral muscles was not directly measured in this study, it is left up to future investigators to determine whether or not enhanced torque efficiency is the mechanism through which the beneficial effects of local stability muscle training on agility and jumping ability are mediated. Answers to these types of question extend beyond the scope of the present study.

McGuine et al. (2000) demonstrated an association between ankle injury and low balance scores among basketball players while Bahr et al. (1997) noted a decreased number of ankle sprains among volleyball players following improvements in balance. While improvement was noted in the present study in both the static and dynamic balance tests, this improvement was present across all groups and therefore cannot be attributed to a training effect. Rather, improvement is most likely an indication of a learning effect for the test measures themselves. In fact, a lack of correlation among tests thought to measure the same kind of balance has led many researchers to suggest that balance is not a general motor ability but rather is specific to the task performed (Baumgartner & Jackson, 1995; Tsigilis, Zachopoulou, & Mavridis, 2001). The improvement in both static and dynamic balance in the present study was observed independent of group assignment and therefore may reflect a learning effect relative to the test procedure rather than an actual improvement in balancing ability.

Correlations

Correlation coefficients were calculated between each measure of LPS and athletic performance in order to investigate any possible relationship between subjects' ability to stabilize the lumbo-pelvic region and their scores in agility, leg power and balance tests (Table 17). A significant correlation was found between LPS as measured with the anticipated leg lift and both leg power ($r=0.52$) and agility ($r=0.45$) scores. According to the strength of these correlations, the subjects' anticipated leg lift scores could account for 27% of the variability in leg power scores and 20% of the variability in agility scores. A significant correlation was also found between LPS as measured by short lever spontaneous leg loading and agility ($r=0.33$) scores. This correlation accounted for 11% of the variability in subjects' agility scores. According to Howell (1999) these correlations can be considered moderate ($r>0.7$ =high, $0.69<r>0.3$ =moderate, $0.29<r>0$ =low). There were no significant correlations found between either the Sahrmann protocol or the long lever spontaneous leg loading tests and any of the measures of athletic performance or injury susceptibility.

A second group of correlation coefficients were calculated in order to assess possible associations between changes observed in LPS scores, whether or not those changes were produced by LPS training, and the changes observed in athletic performance. With the exception of marginally significant correlations between changes in anticipated leg lift scores and changes in static balance ability ($r=0.32$, $p=0.085$) and between changes in short-lever spontaneous leg loading

scores and changes in dynamic balance ability ($r=0.32$, $p<0.085$), no significant correlations were found.

The lack of correlation between improvements in LPS and improvements in athletic performance implies that improvements observed following training of the local stability muscles did not result from improvements attained in LPS. Rather, there is likely to be another mechanism through which these improvements are mediated. For instance, it is possible that training of the local stability muscles resulted in improvements in kinaesthetic awareness of the lumbo-pelvic region which may, in turn, have influenced athletic performance. However, as kinaesthetic ability was not measured in the present study, its influence is speculative.

There are at least two possible views of lumbo-pelvic stability and its relationship to athletic performance. In both views, a hypothetical construct, "athleticism", or "general athletic ability", underlies all athletic performance. Athletic performance as measured in such specific tests as agility, leg power, static balance and dynamic balance is regarded as being a function of general athletic ability and, therefore, performance on the specific tests can be expected to be highly correlated with one another. In the present study a high degree of correlation was demonstrated between nearly all the measures of athletic performance (Table 16).

The first theoretical view (Figure 17) to be considered here poses a second hypothetical construct, "lumbo-pelvic stability", that is assumed to underlie general athletic ability. Lumbo-pelvic stability is deemed to be measurable by

such tests as the Sahrman protocol (SP), the anticipated leg lift test (ALL), and the short (SL) and long lever (LL) tests. Lumbo-pelvic stability is also regarded as being trainable. This view, the Lumbo-pelvic Stability/Athletic Ability view might be represented diagrammatically as follows:

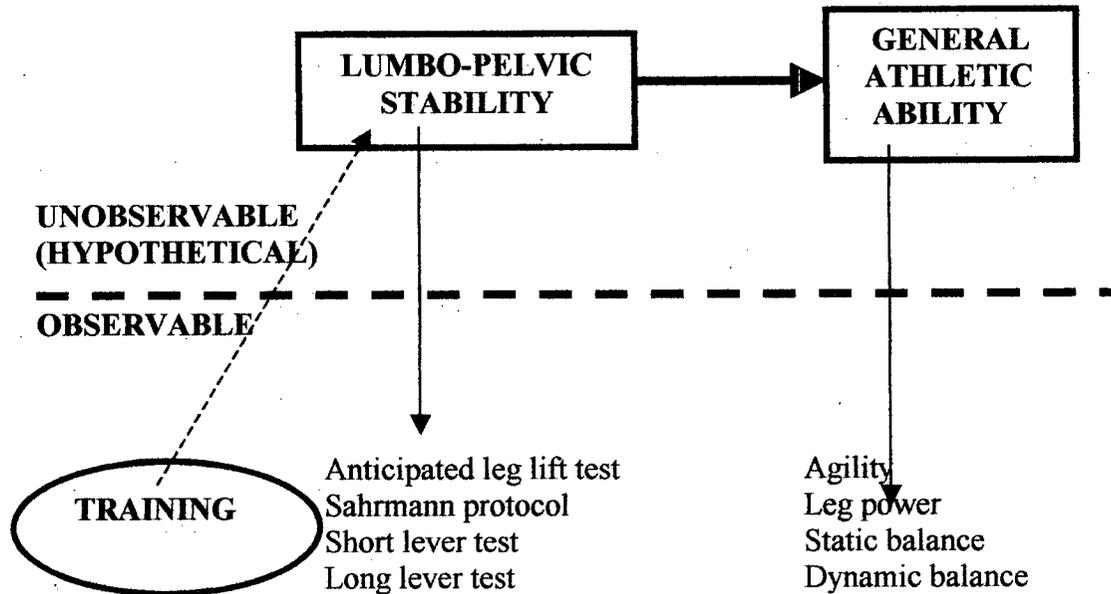


Figure 17. The Lumbo-pelvic Stability/Athletic Ability model to describe the relationship between LPS and athletic performance.

The Lumbo-pelvic Stability/Athletic Ability model can be understood to predict that, since ALL, SP, SL and LL are all measures of lumbo-pelvic stability, performance on these tests ought to be highly correlated. Moreover, since LPS is regarded as underlying athletic performance, scores on the tests used to measure LPS ought to correlate strongly with scores on tests of athletic performance. In addition, training designed to increase LPS is predicted to produce changes on the scores of stability tests that correlate strongly with one another and, since LPS

underlies athletic performance, changes in LPS test scores ought to correlate strongly with changes of athletic performance.

The second view can be diagrammed as follows:

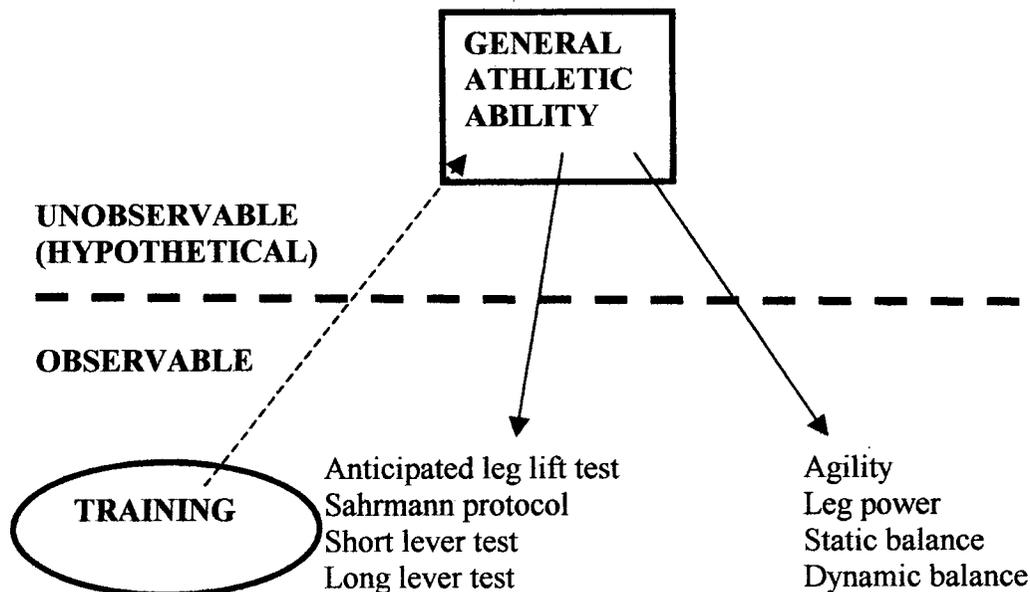


Figure 18. The Athletic Ability model to describe the relationship between LPS and athletic performance.

In the Athletic Ability model, no hypothetical construct such as lumbo-pelvic stability is posited. All the test scores are determined by and are simply specific measures of the more general construct of general athletic ability. Since general athletic ability determines all of the scores, on both “stability” and “athletic” tests, correlations among all of the test scores would be expected. However, since the treatment group’s training did not target the specific tests of athletic ability employed, changes in those measures would only be expected to the extent that the training influenced general athletic ability. The same conclusion applies to the

training received by the pseudo-treatment group. Changes in the specific tests employed would also be expected for that group to the extent that the pseudo-treatment's training affected general athletic ability. Moreover, while the specific test scores would be expected to show inter-test correlations since all are determined by general athletic ability, there is no reason to expect that changes in any of the specific test scores (e.g. "stability test" scores) would be correlated with changes in any of the other specific test scores (e.g. "athletic test" scores) beyond those correlations brought about because the two tests share common elements.

CHAPTER SIX: SUMMARY AND RECOMMENDATIONS

6.1 Summary

- 1) The present results provide some evidence that LPS training does indeed enhance lumbo-pelvic stability. However, since global muscle training produced a comparable enhancement of LPS, there is no evidence that the muscle group exercised (local stability vs global mobility) differentially results in improved LPS.
- 2) The present findings provide support for a relationship between LPS scores and athletic performance as three of these measures showed a moderate level of association.
- 3) The moderate correlations between LPS scores and tests of athleticism, but non-existent correlations between changes in LPS scores and changes in athleticism, suggest that the relationship between LPS and athleticism may need to be reconceptualized. In the revised conceptual model, LPS tests would be seen as additional measures of athleticism, not as measures of a hypothetical construct upon which athleticism is contingent.

6.2 Recommendations

Based on the information gathered during this study, the following recommendations are proposed:

1. The lack of a gold standard for the measurement of LPS makes it impossible to validate measures obtained via the Stabilizer pressure biofeedback unit. Until a

gold standard is developed, perhaps convergent validity between existing indirect measures of LPS can be established. While convergent validity was not demonstrated in this study between the LPS assessment techniques provided by the Stabilizer unit, it may be possible to demonstrate such a validity between the Stabilizer unit and other methods of measuring LPS such as radiography or palpation.

2. This study showed a weak improvement in LPS following training. This was shown in a population of elite athletes. For individuals with chronic low back pain, where dysfunction of the local stability system has been shown, improvements gained in LPS through training may be much greater. However, such improvements have not been shown. Investigative study supporting the use of LPS training within a chronic low back population would be of great value to therapists who frequently prescribe this form of training as a treatment for low back pain.

3. The treatment program used in this study is based on a program developed by Jull and Richardson (1995), which itself rests upon the assumption that the local stability muscles can be voluntarily activated independently of the global mobility system. This has been shown in a number of sEMG studies. An EMG study showing activation of the local stability muscles obtained from indwelling electrodes would bolster the conclusion that these muscles can be voluntarily activated, would enable further development of strengthening exercises for these muscles, and improve the quality of instructions given to patients attempting to recruit these muscles.

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APPENDIX A
CONSENT FORM

my static balancing ability. The test used to assess dynamic balance will be Bass' modified test of dynamic balance. In this test I will hop diagonally from one foot to the other. I will earn balance points by landing on a target and maintaining balance upon this target for five seconds. However, balance points will be deducted for failing to balance on the target for five seconds. Upon completion of the hopping course my balance score will be used as an indication of my dynamic balance ability.

Following the initial testing I will be assigned to either of two treatment groups, or a control group. The likelihood of my being assigned to any of these groups is equal and will be determined by random assignment. If I am assigned to either of the two treatment groups I will participate in ten weeks of core stability training. I will be required to meet with the investigator once per week for one half hour and will be asked to complete three additional 20-30 minute unsupervised training sessions per week. I will be given weekly activity logs to record these additional training sessions as well as my activity level during the week.

If I am assigned to the control group I will be asked to keep a record of my activity level over the ten week period but will not participate in the training sessions. I will be tested once more for vertical jump, agility, and balance abilities in ten week's time.

Participation in this study will require three hours for the measurement of performance variables; one hour each testing day and a total of two testing days. In addition to this time, the treatment groups will also be asked to participate in training sessions four days a week for 20 minutes each day. Both groups will also be asked to keep weekly activity journals which should take no longer than five minutes each week to fill out.

Exclusions:

I will be excluded as a participant in this study if I have had a significant incident of back pain within the last year, if I have any injury which presently limits my athletic performance, or if I have already participated in core stability training as a treatment for previous injury. Failure to attend the weekly training sessions or non-compliance in keeping the weekly activity journal will also be grounds for my exclusion from this study.

Risks:

It is possible that I may experience some shortness of breath and muscle fatigue as a result of the test measures. Some short-term muscle discomfort may be felt in the legs after this testing, much like the discomfort I might feel following an exercise workout. If I am assigned to the exercise group I recognize that some of the exercises may be frustrating due to the specific and unfamiliar nature of the exercises and may also be physically challenging.

Participant Consent:

I understand that participation in this study is entirely voluntary and that I may refuse to participate or I may withdraw from the study at any time without any consequence.

I have received a copy of this consent form for my own records.

I consent to participate in this study.

Participant Signature

Date

E-mail

Phone

Investigator Signature

Date

APPENDIX B

WEEKLY ACTIVITY LOG

Activity	Hours
Weight training:	
upper body	_____
lower body	_____
Aerobic training:	_____
Team Practice:	_____
<hr/>	
Total:	_____

APPENDIX C

TREATMENT EXERCISES

Introduction

Spinal stabilization training involved a number of different stages, each with a distinct goal and focus. In total, athletes completed 40 training sessions (4/week x 10 weeks). One session per week was supervised by the co-investigator while the remaining three were completed independently by the athletes. The first 16 training sessions comprised the first stage of training. During this stage, exercises educated athletes to voluntarily isolate and recruit each of the local stability muscles both independently and corporately. A high level of awareness was demanded of athletes in order to isolate the co-contraction of the transversus abdominus (TA) with lumbar multifidus and muscles of the pelvic floor, with controlled respiration and at low levels of MVC. In this stage, it was important to eliminate any compensatory movement patterns or global muscle substitutions.

Once the participants were able to selectively isolate the local stability muscles, the 16 training sessions of stage two focussed on the application of loads to the trunk while a static position of the pelvis was maintained. Each training session in this stage began with exercises to practice co-contracting the local stability muscles and continued with movements to place loads upon these co-contracting muscles. Athletes were taken through these specific movement patterns in supine, side-lying, prone, and quadruped positions while maintaining co-contraction of the local muscle system so long as the neutral pelvic position was not lost.

The third stage of training consisted in 8 training sessions incorporating exercises involving controlled trunk and limb movements. Stability was further challenged in this stage with the inclusion of an exercise ball. Loads were

gradually increased according to the athletes' ability to maintain co-contraction of the local stability muscles during these movements.

Stage 1: Isolation and Recruitment of the Local Stability Muscles.

Week 1.

Transversus abdominus (TrA)

Supine.

Lying with knees at 90° and feet dorsi-flexed, the athletes were instructed to continue breathing normally and, during exhalation, draw the navel towards the spine. The navel was held in this position while breathing continued. Palpating medially to the iliac crest, TrA. contraction was distinguished from contraction of rectus abdominus by the absence of bulging across the lower abdomen. Trunk flexion, pelvic tilt, depression of rib cage, and breathing were all monitored in order to ensure proper recruitment of TrA.

Quadruped.

The athletes assumed a four-point stance with the hands directly under the shoulders and the knees directly under the hips. Abdominal muscles were released allowing the stomach to sag while the spine remained in a neutral position. The athletes were instructed to draw the navel towards the spine during exhalation and to continue breathing in a relaxed manner while the navel was held in this position. The lower abdomen rising prior to the upper abdomen helped distinguish TrA. contraction from that of rectus abdominus. Pelvic tilt and trunk flexion were discouraged while relaxed, continuous breathing was encouraged.

Multifidus.

Prone.

First, contraction of the erector spinae during back extension was explained and demonstrated. The trainer then palpated on either side of the spinous process and applied pressure with the index finger and thumb at the levels of the lumbosacral junction and the L4–L5 interspace. The athletes were then instructed to cause the muscle at the site of palpation to swell beneath the trainer's fingers. Another useful method of verbal cueing involved having the athletes visualise a string being pulled from the inner thigh through the abdomen and out through the lumbosacral junction. Contraction was monitored for any sign of trunk extension, anterior pelvic tilting, contraction of the gluteal muscles, and to ensure symmetrical contraction of the multifidus.

Pelvic Floor.

Supine.

The athletes were instructed to tighten the muscles which stop urine flow and were told they would should feel an increase in periurethral, vaginal, and rectal tension. The trainer monitored the exercise to ensure that substitution methods were avoided. Possible substitutions included tightening of the gluteal muscles, rectus abdominus, or external obliques.

2 sets of 10 repetitions were performed for each muscle (TrA., multifidus, and pelvic floor) in each position (supine, quadruped, and prone). Contractions were isometric and sustained for 10 seconds. Throughout these exercises a 1:1 work to rest ratio was recommended.

Week 2.

Transversus abdominus Isolation and Recruitment

Supine.

As above, 1 set of 10 repetitions, held for 15 seconds.

Quadruped.

As above, 1 set of 10 repetitions, held for 15 seconds.

Seated on ball or chair.

While the athletes were seated on the exercise ball both feet were kept in contact with the ground and TrA. was recruited and held just as in previous exercises, 1 set of 10 repetitions, held for 10 seconds.

Standing

The athletes stood with feet shoulder width apart and performed the abdominal hollowing movement with the same breathing technique as described above. 1 set of 10 repetitions, held for 10 seconds.

Multifidus Isolation and Recruitment

Prone. As above, 1 set of ten repetitions, held for 15 seconds.

Side-lying.

In side-lying the athletes' hips and knees were flexed to 90°. The athletes were instructed to draw navel towards the spine. Palpating medially to the iliac crest, TrA. contraction was distinguished from contraction of rectus abdominus by the absence of bulging across the lower abdomen.

Pelvic Floor Isolation and Recruitment

Supine. As above. 1 set of ten repetitions, held for 15 seconds.

Standing. With feet spaced shoulder width apart, the athletes contracted the pelvic floor muscles to subjectively feel the development of periurethral, vaginal, and rectal tension. 1 set of ten repetitions, held for 10 seconds.

Throughout these exercises a 1:1 work to rest ratio is recommended.

Week 3.

Transversus abdominus Isolation and Recruitment

Supine.

As above. 1 set of 10 repetitions, held for 20 seconds.

Multifidus Isolation and Recruitment

Side-lying.

As above. 1 set of 10 repetitions, held for 20 seconds.

Transversus abdominus, Multifidus, and Pelvic Floor Co-contraction

Supine.

Lying with knees at 90° and feet dorsi-flexed, the athletes were instructed to continue breathing normally and, during exhalation, contract the three inner unit muscle groups simultaneously. Again, the trainer monitored the athletes during this co-contraction for possible substitution patterns which may have included tightening of the gluteal muscles, pelvic tilting, depression of the rib cage, contraction of rectus abdominus, or an altered breathing pattern. 1 set of ten repetitions, held for 20 seconds.

Week 4.

Transversus abdominus Isolation and Recruitment

Supine.

As above. 1 set of 10 repetitions, held for 20 seconds.

Multifidus Isolation and Recruitment

Side-lying.

As above, 1 set of 10 repetitions, held for 20 seconds.

Transversus abdominus, Multifidus, and Pelvic Floor Co-contractionSupine.

As above.

Quadruped.

The athletes assumed a four-point stance with the hands directly under the shoulders and the knees directly under the hips. In this position the three stability muscles were recruited.

1 set of 10 repetitions were performed for each of these exercises that incorporate simultaneous recruitment of the three muscle groups (TrA., multifidus, and pelvic floor). Contractions were isometric and sustained for 10 seconds. Throughout these exercises a 1:1 work to rest ratio was recommended.

Stage 2: Maintaining Control of the Inner Unit While Training the Outer unit.

Week 5.**Transversus abdominus, Multifidus, and Pelvic Floor Co-contraction**Quadruped.

As above. 1 set of 10 repetitions, held for 15 seconds.

Side-lying.

In side-lying the athletes' hips and knees were flexed to 90°. In this position the three stability muscles were recruited. 1 set of 10 repetitions held for 10 seconds.

Transversus abdominus, Multifidus, and Pelvic Floor LoadingSupine leg lifts.

Lying with knees at 90° and feet dorsi-flexed, the athletes were instructed to continue breathing normally and, during exhalation, draw the navel towards the spine. With TrA recruited in such a manner, the athletes now shifted their weight so that one foot was non-weight bearing and the leg was able to flex until the hip reached 90°. After a brief pause, the leg was extended to lower the foot back to the ground. Weight was shifted again, and the opposite leg was flexed, and so on. By palpating medially to the iliac crest the trainer was able to ensure that rectus abdominus was not recruited, particularly during the initial flexion of the leg.

Loss of control of the inner unit was indicated by recruitment of rectus abdominis, an altered breathing pattern, or loss of the neutral spine position.

Supine bent knee fall-outs.

Lying with knees at 90° and feet dorsi-flexed, the athletes were instructed to continue breathing normally and, during exhalation, draw the navel in, towards the spine. During TrA contraction, multifidus was co-contracted. With the co-contraction of these muscles maintained, one leg was slowly externally rotated at the hip and then brought back to the starting position.

For each of these supine exercises 2 sets of 5 repetitions were completed working at a slow and controlled pace.

Week 6.

Transversus abdominus, Multifidus, and Pelvic Floor Co-contraction

Quadruped.

A above. 1 set of 5 repetitions, held for 15 seconds.

Side-lying.

In side-lying the athletes' hips and knees were flexed to 90°. In this position the three stability muscles were recruited. 1 set of 10 repetitions held for 10 seconds.

Transversus abdominis, Multifidus, and Pelvic Floor Loading

Supine alternating leg lifts.

As above. 2 sets of 10 repetitions.

Quadruped leg extension.

The athletes assumed a four point stance with the hands directly under the shoulders and the knees directly under the hips. Abdominal muscles were released allowing the stomach to sag while the spine remained in a neutral position. The athletes were instructed to draw the navel towards the spine during exhalation and to continue breathing in a relaxed manner while the navel was held in this position. Once TrA had been recruited, the athletes shifted weight to allow extension of one leg. The toe of the extended leg was held 3" from the ground and, after a short pause, the leg was returned to the starting position. From this position, the contra-lateral leg repeated the same manoeuvre. Loss of control was indicated by failure to maintain the neutral spine position, or alterations in the breathing pattern. 2 sets of 5 repetitions.

Side-lying clamshell.

In side-lying, the athletes' hips were flexed to 50° and knees were flexed to 90°. In this position, the three stability muscles were recruited and the superior leg was abducted at the hip with the knee remaining flexed at 90° and the hip remaining in 50° flexion. The hip was abducted to the highest point before which the hips began to rotate, lowered to the start position, and repeated. 2 sets of 5 repetitions.

Week 7.

Transversus abdominus, Multifidus, and Pelvic Floor Co-contraction

Quadruped.

As above. 1 set of 5 repetitions, held for 15 seconds.

Side-lying.

In side-lying the athletes' hips and knees were flexed to 90°. In this position the three stability muscles were recruited. 1 set of 5 repetitions held for 15 seconds.

Supine.

Lying with knees at 90° and feet dorsi-flexed, the athlete is instructed to continue breathing normally and, during exhalation, contract the three inner unit muscle groups simultaneously. Again, the trainer monitors the athlete during this co-contraction for possible substitution patterns which may include tightening of the gluteal muscles, pelvic tilting, depression of the rib cage, contraction of rectus abdominus, or an altered breathing pattern. 1 set of 5 repetitions, held for 15 seconds.

Transversus abdominis, Multifidus, and Pelvic Floor Loading

Supine leg lifts and extensions.

Lying with knees at 90° and feet dorsi-flexed, the athletes were instructed to continue breathing normally and, during exhalation, contract TrA and LM. With these muscles engaged, the athletes flexed one leg at the hip to lift the thigh until the hip reached 90° flexion. From here, the leg was extended with the heel 3" from the floor. The leg was flexed again at the hip and the knee to bring the leg into the starting position. Movement was slow and controlled to ensure that TrA was engaged throughout the entire movement. The athlete was encouraged to be vigilant concerning extraneous pelvic motion including anterior/posterior tilting, or any rotational changes in position. 2 sets of 10 repetitions.

Quadruped Leg Extension with Contralateral Arm Flexion (Superman).

Similar muscle recruitment and leg movement was followed as in week 6 for the leg extension exercise. However, during extension of the leg the contra-lateral arm was flexed at the shoulder until the hand was pointing straight ahead. After a

brief pause, the arm and leg were returned to their starting positions and the same movement was performed by the opposite arm and leg. 2 sets of 10 repetitions.

Sidelying Clamshell

In side-lying the athletes' hips and knees were flexed to 90°. In this position the three stability muscles were recruited and the superior foot was lifted slightly from the inferior foot. The superior leg was abducted at the hip with the knee remaining flexed at 90° and the hip remaining in 50° flexion. The hip was abducted to the highest point before which the hips began to rotate. 2 sets of 5 repetitions.

Week 8.

Transversus abdominis, Multifidus, and Pelvic Floor Co-contraction

Standing

The athletes stood with feet shoulder width apart and performed the abdominal hollowing movement with the same breathing technique as described above. 1 set of 10 repetitions, held for 10 seconds.

Transversus abdominis Loading

Supine alternating leg extensions.

The athletes began by contracting the local stability muscles and lifting first one leg, and then the other to a starting position of 90° hip and knee flexion. Keeping the local stability muscles engaged the legs were alternately extended one at a time, keeping the heel 12" from the ground, and not permitting the pelvis to be either posteriorly or anteriorly tilted. Athletes paused to re-establish co-contraction of the local stability muscles every 10 repetitions. 2 sets of 30 repetitions.

Transversus abdominis and Multifidus Loading

Prone bilateral leg extensions.

Lying prone, the athletes flexed the knees to 90°, contracted LM, and extended the thighs to lift the knees approximately 2" from the ground. Pausing for three seconds, the legs were lowered to the ground, and the exercise repeated. 2 sets of 10 repetitions.

Transversus abdominis, Multifidus, and Pelvic Floor Loading

Supine Bridging with leg lifts.

Athletes lied supine with the knees at 70° flexion, co-contracted the local stability muscles, and extended the legs at the thigh to create a bridge with the lower body. Weight was shifted, and one foot was lifted slightly from the floor and held for three seconds. Athletes were careful to control pelvic rotation and tilting during the maintenance of this balancing posture. The foot was then returned to the floor and the procedure repeated with the contra-lateral leg. 2 sets of 10 repetitions.

Stage 3: Controlled trunk and limb movements while maintaining contraction of the TrA, LM, and pelvic floor musculature.

Week 9.

Transversus abdominis, Multifidus, and Pelvic floor Loading

Supine alternating leg extensions.

The athletes began by contracting the local stability muscles and lifting first one leg, and then the other to a starting position of 90° hip and knee flexion. Keeping the local stability muscles engaged, the legs were alternately extended, keeping the heel 12" from the ground, and not permitting the pelvis to be either posteriorly or anteriorly tilted. The athletes paused to re-establish contraction of the local stability muscles between the 20th and 21st repetition. 3 sets of 40 repetitions.

Supine bridge on ball with alternating leg lifts.

Athletes assumed a supine position over an exercise ball keeping the knees at 90° flexion, the upper legs and back parallel to the ground, and the hands on the iliac crests to monitor pelvic motion. One leg at a time was lifted 3-4" from the ground and held for a 3-second count while the rest of the body remained motionless. Alternating legs, the athletes completed the required number of repetitions. 3 sets of 10 repetitions.

Quadruped arm flexion on ball.

The athletes assumed a quadruped position on an exercise ball. TrA, LM, and pelvic floor musculature were recruited and one arm at a time was flexed forward and held for a 3-second count. 3 sets of 10 repetitions.

Week 10.

Transversus abdominis, multifidus, pelvic floor

Supine alternating leg extensions.

The athletes began by contracting the local stability muscles and lifting first one leg, and then the other to a starting position of 90° hip and knee flexion. Keeping the local stability muscles engaged, the legs were alternately extended one at a time, keeping the heel 12" from the ground, and not permitting the pelvis to be either posteriorly or anteriorly tilted. 3 sets of 40 repetitions.

Supine bridge on ball with alternating leg lifts.

Athletes assumed a supine position over an exercise ball keeping the knees at 90° flexion, the upper legs and back parallel to the ground, and the hands over the iliac crests. One leg at a time was lifted 3-4" from the ground and held for a 3-second count while the rest of the body remained motionless. Alternating legs, the athlete completed the required number of repetitions. 3 sets of 10 repetitions.

Quadruped arm and leg extensions on ball.

The athletes maintained the same balance as in week 9. The arm was flexed and held in position for a 3-second count. 3 sets of 10 repetitions.

APPENDIX D

PSEUDO-TREATMENT EXERCISES

Introduction

In the realm of athletics the core takes on a very different definition than in clinical settings. In contrast to the clinical distinction between local stability and global mobility musculature, many athletic trainers think of the core as consisting in any muscle between the shoulders and hips. The exercises in this program targeted the strengthening of the core as it is defined athletically and therefore included exercises for what would be clinically labelled as the global mobility muscles of the trunk. Muscle groups targeted included the rectus abdominus, external and internal obliques, latissimus dorsi, and erector spinae.

Week 1Crunches.

Lying with knees at 90° and feet dorsi-flexed, athletes were instructed to curl the shoulders up towards the knees, lifting the shoulder blades off of the floor until the palm of the hand rests over the knee. 2 sets of 20 repetitions.

Side-lying Crunches.

Athletes lied supine with the knees bent to 90°. Both legs were lowered towards the ground on one side until the bottom knee came in contact with the ground. From this starting position, the athletes curled the trunk upwards. 2 sets of 20 repetitions.

Side Bridging

Athletes supported themselves upon one elbow while preventing any side bending from occurring at the waist or hips. 2 sets of 30 seconds.

Week 2.Crunches.

As above. 2 sets of 25 repetitions.

Side-lying Crunches.

As above. 2 sets of 25 repetitions.

Side-bridging.

As above. 2 sets of 45 repetitions.

Week 3.Crunches.

As above. 2 sets of 30 repetitions.

Supine Straight leg raise and rotations

Lying supine with the knees bent to 70° and the arms abducted to 90°, the athletes lifted their legs upward to a position of 90° hip flexion. Once in this position the feet were lowered to the floor while posterior tilting of the pelvis was resisted. The legs were brought back up to centre, lowered to the one side and then the other, returned once again to centre, lowered to ground, and so on. 2 sets of 10 repetitions.

Side-bridging.

As above. 2 sets of 60 repetitions.

Week 4.Crunches.

As above. 2 sets of 30 repetitions.

Supine Straight leg raise and rotations

As above. 2 sets of 10 repetitions.

Pelvic Lifts

Lying supine, the legs were flexed at the hip to point vertically up to the ceiling. With head remaining on the ground the trunk was curled until the sacrum and lumbar vertebrae were elevated off the floor. Motion was done with minimal leg swing. 2 sets of 15 repetitions.

Week 5.Twist Curl-up

Athletes lied supine and curls up as in previous sessions, only the right hand was directed toward the left knee while curling the trunk forward, and the left hand was directed to the right knee in the follwoing repetition. 2 sets of 30 repetitions.

Side-lying Crunch

As above. 2 sets of 30 repetitions.

Pelvic Lifts

As above. 2 sets of 20 repetitions.

Week 6.Twist Curl-up

As above. 2 sets of 30 repetitions.

Supine Straight leg raise and rotations.

2 sets of 12 repetitions.

Pelvic Lifts

As above. 2 sets of 20 repetitions.

Week 7.Crunches.

As above. 2 sets of 35 repetitions.

Bicycle kicks.

Lying supine, the athletes curled upwards elevating the shoulder blades from the floor. With hips at 90° and feet off the floor, the athletes performed alternating leg extension and flexion movements simulating a pedalling motion. As the leg was flexed and the knee brought towards the chest, the trunk was twisted to bring the contra-lateral elbow toward the knee. 2 sets of 30 repetitions.

Leg extensions.

Lying supine, knees were flexed towards the chest and extended outwards until the hips reached a 45° angle with the feet kept off the floor. 2 sets of 12 repetitions.

Week 8.Crunches.

As above. 2 sets of 35 / 1 set of 30 repetitions.

Bicycle kicks.

As above. 3 sets of 40 repetitions.

Leg extensions.

Lying supine, knees were flexed towards the chest and extended outwards until the hips reached a 30° angle with the feet kept off the floor. 3 sets of 12 repetitions.

Week 9.Twist Curl-up.

As above. 3 sets of 35 repetitions.

Bicycle kicks.

As above. 3 sets of 40 repetitions.

Bridging leg extension Curl-ups.

Lying supine, the athletes bridged until upper legs and torso formed a straight line. With one hand supporting the back of the head, one leg was flexed and extended as in the bicycle kick. As the leg flexed and the knees was brought towards the chest, the trunk was curled and the opposite elbow brought across the body to touch the knee. At contact, the trunk was curled with the shoulder blades no longer in contact with the ground. 3 sets of 30 repetitions.

Week 10.Crunches.

As above. 3 sets of 38 repetitions.

Bicycle kicks.

As above. 3 sets of 40 repetitions.

Bridging leg extension curl-ups.

As above. 3 sets of 40 repetitions.

APPENDIX E

Stabilizer Pressure Biofeedback Unit Reliability Study

Introduction

This study is a first attempt to measure the test-retest reliability of the Stabilizer pressure biofeedback unit (Chatanooga). No previous study has evaluated the reliability of its measures despite frequent reference to this instrument as a measure of the abdominal muscles' ability to actively maintain the pelvis in a neutral position. It was hypothesized that a high correlation would be demonstrated between LPS scores attained on two separate testing days.

Participants

Four participants were recruited from the University of British Columbia women's basketball and volleyball teams. After obtaining informed consent from each participant, testing times were booked at the University of British Columbia Respiratory Physiology lab. Participants reported for an initial familiarization session and for two subsequent testing sessions separated by a weeks' time.

Measures

For a discussion of the measurement apparatus and protocol refer to section 3.4 of the main thesis.

Hypotheses

H1. A high correlation will be demonstrated between the scores attained on the two testing days for each of the Sahrman protocol measurement of LPS

H2. A high correlation will be demonstrated between the scores attained on the two testing days for each of the anticipated leg lift measurement of LPS.

H3. A high correlation will be demonstrated between the scores attained on the two testing days for each of the short lever spontaneous leg loading measurement of LPS.

H4. A high correlation will be demonstrated between the scores attained on the two testing days for each of the long lever spontaneous leg loading measurement of LPS

Results

Results of the analysis of correlations between testing days 1 and 2 for the four measurements of LPS are presented in Table A1.

Table A1. Correlations between testing days for the four methods of testing LPS.

Sahrman Protocol	Anticipated Leg Lift	Short Lever	Long Lever
0.83 ^b	0.98 ^a	0.95 ^a	0.38

^a represents a significant correlation between the scores obtained on test days 1 and 2 ($p < 0.05$).

^b represents a marginally significant correlation between the scores obtained on test days 1 and 2 ($p < 0.1$).

Pearson's product moment correlation coefficients (r) were used to evaluate the relationships between the scores from the same tests conducted on two distinct test days. Significant correlations were found for the anticipated lift ($F(1,2) = 37.99$, $p < 0.025$) and the short lever spontaneous leg loading ($F(1,2) = 19.62$, $p < 0.05$). Spearman's rho was used to evaluate the relationship between scores on

the two distinct test days for the Sahrman protocol. A marginally significant correlation was detected ($p < 0.1$). There was no significant correlation demonstrated for the long lever spontaneous leg loading.

Discussion

The Stabilizer pressure biofeedback unit has frequently been employed in the present body of literature as a means of assessing lumbo-pelvic stability (Brovender, 2001; Cusi et al., 2001; Baker, 2000; Young et al., 1998; Wolfhart, Jull, Richardson, 1993). Four common methods of measure LPS with this measurement tool are found within the literature, these are the Sahmann protocol, anticipated leg lift, short-lever spontaneous leg loading and long-lever spontaneous leg-loading.

Measurement of LPS by means of the Sahrman protocol gave an ordinal score between 0 and 5 representing the highest level in a series of lower body movements that subjects were able to attain without shifting their pelvis from its neutral position. Spearman' rho indicated a moderately significant ($p < 0.1$) test-retest reliability between scores attained on the two test days.

Pearson's product-moment correlation coefficient indicated highly significant test-retest reliabilities for both the anticipated leg lift ($r = 0.98$, $p < 0.05$) and the short-lever spontaneous leg loading ($r = 0.95$, $p < 0.05$) tests. However, test-retest reliability for the long-lever spontaneous leg-load assessment was not significant.